NFI Forecasts Methodology Overview

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Introduction

The National Forest Inventory (NFI)* measures and monitors the nature and condition of forests, woodlands and trees within Great Britain (GB). As part of this process a series of 25-year forecasts are made of the volumes of timber that may be harvested in the United Kingdom (UK).

Associated with these forecasts of harvested timber, procedures have been developed to estimate the amount of current and future material in standing trees in the forest. This is measured in alternative ways:

1. As the volume of timber in the standing tree stock, taking account of future removals.
2. As biomass (expressed in oven-dried tonnes). Assessments are made of biomass contained in the stemwood, stumps, roots, branches, tip and leaves of standing trees.
3. The carbon content of standing biomass, expressed in tonnes.

This document provides an overview of the processes of data generation for the forecast and of how these quantities are estimated and forecast from the data.

The 2011 forecast has taken a new approach to forecasting Private sector estate timber and forest volumes in GB compared to the previous (2005) softwood forecast, using information and data generated by the NFI mapping and field survey operations.

Rationale behind the new approach to the GB Private sector production forecast

Traditionally, the Forestry Commission supplied a production forecast of conifer timber broken down into size classes (e.g. 7–14, 14–18, 18+ cm) that was predicted to come to market over a 20-year period. These forecasts separately covered the Forestry Commission (FC) and Private sector estates. The Forestry Commission also supplied a broadleaved forecast for the FC estate, but no Private sector broadleaved forecast was supplied.

Over the last three decades or so, fluctuations in predicted levels of ‘available timber’ from successive historical production forecasts raised concerns about the production forecast and awareness of its deficiencies. This led the Forestry Commission to review the production forecasting process. From this review, the following broad observations were made:

* The sense in which technical and other terms are used are defined in the Glossary at the end of the report.

- In the past, field measurements of Private sector estate growing stock were limited and often decades out of date, precluding an accurate assessment of the growing stock.
- Assumptions made about the timing of future felling in the Private sector estate were built in consultation with the sector, but often failed to reflect actual practice, or to keep pace with changing practice.

When retrospectively looking at previously forecast volumes, it could be observed that forecast volumes were close to actual production in the Private sector. It was concluded that there were three possible reasons for this:

1. That the forecasts were very accurate.
2. That the sector responded to the published forecast by adjusting its overall harvesting capacity to match the forecast.
3. That the forecast itself was being adjusted to reflect known future harvesting capacity.

The review also noted that there were new requirements for the production forecast:

- to take account of biomass, full-tree assortments and carbon dioxide (CO_2) sequestration potential;
- to estimate and track current and future standing volume and increment resulting from the forecast removals in order to generate a more holistic view of the sustainability of different management options.

Additionally, the review noted that the historical approach would become increasingly problematic and less fit for purpose over time because:

- The FC estate dominated production from 1970 to 2000, but has since been overtaken by the Private sector estate.
- The above-mentioned trend, with the Private sector estate becoming the principal supplier of timber, further exposed the production forecast to the risks associated with:
    - the previously weak growing stock assessment for the Private sector;
    - the assumptions used for determining future felling and thinning practice in the Private sector.
- The historical planting profile of GB, where most planting took place in the 1960s, 1970s and 1980s, meant that there was a potential peak of conifer timber available for harvesting around 2022, and it was important to test that expectation.
- Initial work by the sector between 2000 and 2009 pointed to supply of conifer timber potentially meeting or exceeding demand.
- New consumers (full-tree assortments, biomass etc) were increasingly entering the market.

Against this background of ongoing substantive changes in the supply/demand balance, the Forestry Commission has implemented a new approach to production forecasts to deal with these issues and to meet future industry requirements. This approach has entailed:

- Establishment of the new National Forest Inventory (NFI), which has involved the production of a map of British forests and a programme of ground surveying of areas of the map according to a statistically designed sample. This has enabled estimates and forecasts to be produced to a calculated level of statistical accuracy, with consequent enhancement of the confidence that can be attached to the outputs.
- Distinguishing information on current standing timber volume and other characteristics of the forest resource (which can now be estimated with a measurable degree of precision) from future levels and patterns of harvesting (which are largely unpredictable).
- Creating a realistically estimated maximum and minimum of what could be produced from the GB timber resource under specified sets of assumptions about future harvesting practice. This gives the sector a well-defined window or 'broad path' of opportunity within which to make decisions – avoiding the pitfalls in the historical approach of making one prediction of the future and ignoring the wide range of alternative scenarios.
- Expanding the outputs of the forecast to include carbon weights, biomass oven-dried weights, stem straightness scores, standing volume and increment.

Volume estimates and forecasts

Basic approaches to volume estimation

To estimate any of the above parameters (timber volume, raw biomass, tonnes of carbon, or specific elements of the trees such as stemwood, stumps, roots, branches or leaves) within woodlands, the following underlying factors need to be assessed:

- area of woodland;
- woodland state;
- rate of woodland growth;
- the timing and rate of future removals from the forest.

These four factors are discussed in more detail in the following sections.

The UK coniferous timber production forecast is composed of four separate forecasts corresponding to four distinct sectors of UK woodland:

- the FC estate in GB;
- the Private sector estate in GB;
- the Forest Service (FS) managed estate in Northern Ireland;
- the Private sector estate in Northern Ireland.

The FC/FS estate is often referred to as the 'national forest estate' or 'public forest estate' but as these terms are also used in other senses they are avoided here. All remaining forests are referred to as Private sector estate, but will include land owned by other public bodies, government departments and NGOs, such as charities and local authorities. All previous forecasts followed the same overall approach but each component forecast was derived in different ways, dependent upon ownership (Forestry Commission, FS or Private), which determined the nature of the data available for generating the forecasts.

In 2005, for example, the FC estate forecast was derived from the Commission's sub-compartment database (SCDB), an inventory with full coverage of the FC estate, which includes woodland area, woodland type and growth rates recorded on a stand-by-stand basis. This was used in combination with Forestry Commission felling and thinning plans (held as individual felling and thinning coupes across the entire estate) and these were used as inputs to the Forestry Commission's Production Forecast system, which uses Forestry Commission growth and yield models to project future stand characteristics. This resulted in a prediction based on approved plans, which was used to produce a commitment of production over the first five years of the forecast period and a broad prediction for the following 15 years. The Northern Ireland public forest forecast was derived in a similar fashion.

The 2005 GB Private sector estate forecast was based upon a woodland area derived from fieldwork conducted by the National Inventory of Woodland and Trees (NIWT) between 1995 and 1999, woodland type taken from the same source and future growth assumptions based upon industry opinion. It also used generic assumptions about trends in felling and thinning based upon the view of industry, as opposed to actual plans. The Private sector estate forecast in Northern Ireland was based upon records of woodland and forests established in line with the requirements of the UK Forestry Standard.

Area of woodland

A key parameter that determines the total volume in any volume estimation is the total area of woodland that exists within the estimation target area. For example, in the UK there are 24.3 million hectares of land, but only 2.9 million hectares of woodland, which represents 13% of total land area. National woodland areas are generally estimated through two main methods:

- Mapping all areas of woodland using aerial photography, remote sensing and administrative data.
- Taking a systematic field sample of all land to identify which land is woodland and which is not.

In the UK the mapping technique is used, as this is more efficient in areas with a relatively low woodland density.

Woodland state

Woodland state encompasses a number of different features that characterise a particular stand of woodland at a given point in time. This would include the broad type of woodland (broadleaved or coniferous), the habitat type and the particular tree species present. Within such categorisations, the age, size and stocking rates of the trees in a stand, and other relevant features such as the incidence of diseases, determine the overall state of the woodland.

The two main methods for assessing woodland state are by full census and by sampling:

- A full census generally involves the mapping and recording of woodland characteristics across all woodland, stand by stand. It is by nature comprehensive, but also intrinsically costly.
- Sampling involves examining a small proportion of the whole woodland area in such a way that the area sampled is expected to be representative of the whole.

In the information used for the 2011 UK production forecast, the state of woodlands has been assessed in the following ways:

- GB FC estate – full census;
- GB Private sector estate – sampling.

Woodland growth

The rate at which trees grow is central to the estimation of how woodlands will change over time. This rate is determined by their genetic makeup, the environmental conditions within which they are growing, and the interaction between these two factors.

Certain species of trees will always grow faster than others, due to their physiology, and certain strains within species will grow faster than others, due to genetic variation. The tree's environment affects its rate of growth too. Factors such as rainfall, temperature, light levels, exposure, elevation, latitude and longitude, and soil type, depth and moisture regime have a significant impact on tree growth.

The combination of all these factors means that there is a wide range of tree growth rates within the UK, even within the same species. Therefore, particular attention needs to be paid to the estimation of tree growth rates, which are specific to their particular geographic location and the individual genetic makeup of the trees concerned. In the UK, the index of tree growth rates used is referred to as 'yield class', which reflects the average volume of timber that a hectare of woodland of defined composition gains per annum at that site. Much attention is paid to yield class in volume estimation in the UK. It generally involves observing the species, age and height of the trees in the field and relating this information to growth curves derived from empirical measurement. Data used for establishing these yield curves have been collected over many years within the Forestry Commission's permanent sample plot (PSP) programme, which is a continuing exercise.

In the generation of a forecast, these growth rates are generally applied at the scale of the available data, which for all four sectors is at the individual stand or stand component level in the 2011 production forecast.

Rate of future removals from the forest

The assessment of the current state of the forest and how it is likely to grow over time can be ascertained or estimated from direct measurements of form and growth to date. However, predicting future rates and timings of removals is more problematic, since there is no equivalent evidence base on which to make such predictions. In addition to the supply side of the equation (i.e. the availability of timber in the forest), the rate of removals are also driven on the demand side by government policies and market conditions. In the case of the latter factor, rate of future removals will be influenced by the future price of cut timber or other forest products. Clearly, when constructing forecasts for 25 years and beyond, predicting such factors is not straightforward. Projections in this area are much more prone to change and error. Underlying factors influencing future timber prices include currency exchange rates, import and export demands, and developments within the UK economy as they relate to, for example, the use of timber in the construction industry. No attempt is made in the forecasts to predict the effects of these demand-side factors, apart from the likely implications of current official policies on stands that may or may not be harvested in the future. Instead, a number of alternative assumptions are made according to knowledge or inferences about future harvesting activity:

- harvesting according to known and currently set felling and thinning plans;
- basing cut upon historical levels;
- using industry expertise to predict future harvesting strategies;
- using scenarios to estimate a range of possibilities for future harvesting.

In the four sectors of the 2011 UK production forecast, future removals are projected by:

- GB FC estate – known felling and thinning plans;
- GB Private sector estate – scenarios and industry expertise;
- Northern Ireland FS estate – known felling and thinning plans;
- Northern Ireland Private sector estate – scenarios and industry expertise.

Steps involved in deriving a volume forecast

This section describes the sequence of tasks that have been performed in the preparation of the 2011 Production Forecast. The initial steps include the preparatory work that is multi-purpose in nature and is, or will be, utilised for past, present and future outputs other than the present forecast. This includes the preparation of woodland maps in step 1 below (the NFI woodland map and, for the FC estate, the geo-spatial information contained in the FC sub-compartment database (SCDB)). It also includes the design and execution of the NFI field survey and the collection, recording and organisation of relevant survey and other information in the SCDB. The steps are:

1. Map and sample the forest

A map is made of the whole forested area in GB. For the FC estate, the spatial records of every stand in the Forestry Commission's SCDB are used. For the Private sector estate, the part of the NFI Woodland Map outside the Forestry Commission ownership boundary is used. In the Private sector estate, samples of randomly located one hectare sample squares are selected for surveying in the NFI field survey programme.

2. Map the stand

Individual stands within the SCDB, and individual stands within the one-hectare sample squares, are mapped, from which the physical area occupied by the stand can be determined.

3. Specify the sample plot protocol

Usually a representative sample of trees are selected. In the NFI field survey this usually takes the form of a 0.01 (1/100th) hectare circular plot (radius of 5.64 m), within which all trees are measured. There are specific conventions to take account of 'exceptions' such as edge trees, forked trees, bent trees, leaning trees and slope. These can be found in the *NFI Survey Manual*. On the FC estate, previous surveys of individual stands may have been performed, and will largely have used protocols described in the Forestry Commission's *Survey Handbook*.

4. Set sampling level

In the NFI field survey and in Forestry Commission operations, trees within a stand are normally sampled using a number of sample plots. The number of sample plots chosen is determined by the variation within the stand and it size. UK conventions for this are set out in *Forest Mensuration: A Handbook for Practitioners* and the *NFI Field Manual*.

5. Measure trees and stands

The basic step common to all assessments is the measurement and categorisation of individual trees for height, diameter at breast height (DBH), species and live/dead status. Whole stands are also assessed for overall stand properties such as stocking rate. Estimates of age may also be made if this is not available in relevant records.

6. Calculate derived data

Calculations involving the use of empirical functions and relationships are required at the plot level to calculate derived data from the field measurements and assessments. An example of this would be the estimation of stem volumes of trees using functions that relate stem volume to DBH and tree heights.

7. Scale up to area of stand

Results for individual trees found in a sample plot are summed to give the overall result for the plot. These results then need to be aggregated across the sample plots, then scaled up to the whole area of the stand. The area of the stand will have been obtained in step 2. Further derivations are also made at this scale, an example of which would be yield class, where the height, species and age of the trees in a whole stand are referenced to growth and yield models to give a yield class for the stand.

8. Prescribe future harvesting plan

To prepare a production forecast for a particular stand, management prescriptions covering the type and timing of future thinning and felling operations need to be set for each component of the stand. If actual plans exist, as for the FC estate, these are used, but if they do not exist or are not known, as is the case for most of the Private sector estate, assumptions or generic prescriptions for future thinning and felling need to be applied to the stand. The NFI paper *Interpreting NFI Timber Volume Forecasts* covers in detail how these prescriptions are derived.

9. Apply growth models and calculate stand-level forecasts

Field assessments (from the field survey programme in NFI, or from operational surveys on the FC estate) provide information on the state of the stand at a particular point in time. This is projected forward using the Forestry Commission's growth and yield models to the present and to its state in the future. Management is applied to the stand at the

prescribed points in time, from which estimates and timing of harvested volumes are obtained for the stand.

10. Aggregate results for sample squares or sub-compartments

Components of individual stands are the smallest units for which individual production forecasts are derived. These need to be aggregated to provide a forecast for the whole stand, which in turn is added to the results from other stands to give an overall forecast for larger units. For the Private sector estate, using NFI sample data, these larger units are the one-hectare sample squares. For the FC estate, results from individual stands can be aggregated to give results for whole sub-compartments.

11. Aggregate or scale up to mapped forests

For the FC estate, the results of individual sub-compartments will then need to be accumulated across sub-compartments to provide overall forecasts for whole forests and regions. For the Private sector estate, since the information is in the form of a sample, the results found by the sample need to be scaled up to the whole area of Private sector forest in a region. This provides estimates of future production volumes that will be produced within regions. For a map of the NFI regions, see Appendix A.

12. Process into final forecasts

These aggregated or scaled-up results form the basis of the production forecasts. Final processing involves such things as summing results for individual regions to generate forecasts for whole countries and for GB as a whole. The forecasts from the NFI sample for the Private sector estate have associated sampling standard errors (SE), which also need to be taken account of in the scaling up and aggregating processes of generating overall production forecasts.

Quantifying errors and uncertainties in the forecast

Each stage of the construction of a forecast can introduce errors and uncertainties in the overall formulation and calculation of a production forecast. The types of error that may be introduced fall into the following categories:

1. Spatial mapping errors in the construction of the overall forest map.
2. Spatial mapping errors made while mapping individual stands.
3. Sampling error associated with sampling of whole stands. (This is controlled by the size and number of sample plots used.)
4. Measurement, observation and categorisation errors incurred during field surveying.
5. Modelling errors and biases resulting from the application of empirical models in the estimation of derived variables from field observations.
6. Uncertainties associated with predicting or prescribing the future management and harvesting of individual components and stands.

7. Errors and biases introduced from the application of stand growth and yield models to predict the future state of individual stands.
8. Errors arising from the selection of a particular growth and yield model to apply to a stand without sufficient inventory information to provide a reliable indication of a stand's yield class. (Such selections are made for young stands in NFI and SCDB, and for other stands in the SCDB for which operational survey results are not available.)
9. For Private sector estate forecasts using NFI data, sampling error arising from variation between NFI sample squares.

For NFI forecasts of the Private sector estate, category 6, resulting from the prediction of future management and harvesting operations on individual stands, introduces the greatest amount of uncertainty into the forecasts. Since it is difficult to quantify the error in a forecast that may result from this source, the approach taken in the 2011 production forecast has been to use alternative scenarios for management and harvesting in order to illustrate a range of outcomes resulting from these particular future harvesting assumptions. The choice of scenarios has been made with the purpose of providing information on the likely range of harvesting levels that may be realised in future years and periods. This approach is described elsewhere in this document, and the particular scenarios analysed are described and reported on in the NFI document *Interpreting NFI Timber Volume Forecasts*.

For NFI, therefore, the reported results from a forecast are contingent upon the particular form of the assumptions made on future harvesting activity. The other categories of error and uncertainties in an NFI forecast are either explicitly estimated or ignored. Among the other categories above, category 9 is expected to contribute the largest source of variation in the forecast results. The magnitude of the between sample square variation is estimable in the statistical analysis of the data, from which a sampling error can be calculated. These are quoted together with the estimates and forecasts themselves and provide a close indication of the amount of error attached to the value of a forecast, provisional upon the assumptions made about harvesting, described above.

Of the other categories of error and uncertainty contributing to an NFI forecast, random errors associated with categories 2, 3 and 4 are contained within overall sampling error and are therefore covered by the quoted standard errors of a forecast or estimate. Random errors from the application of empirical models, as in categories 5 and 7, are not covered by sampling error, but their accumulated effect on estimates and forecasts at GB, country and regional level are very small compared to sampling error and are ignored. Category 1 errors, deriving from the NFI map, are also thought to be small, given the degree of quality assurance and cross-checking of sources during the construction of the map, and are therefore also ignored. Category 8 errors in NFI apply to the forecasting of the growth of stands that were young at the time of survey. The

procedures put in place to assign assumed yield classes to these stands based on the averages of calculated yield classes of more mature stands is unlikely to introduce a large source of error in resultant estimates and forecasts.

The calculated sampling standard errors quoted with NFI forecasts and estimates are therefore expected to give a good indication of the accuracy of the result after taking account of all sources of random error in the derivation of the forecast. They do not, however, account for systematic biases that may be present in a number of the categories of error and uncertainties described. The quoted sampling standard errors are therefore conditional upon the underlying future harvesting assumptions made in the construction of the forecast, and also upon any systematic biases in other categories of error being small and able to be ignored.

With regard to systematic biases, a significant source of such bias could arise in the NFI field survey from field surveyors' assessments of the age of stands at the time of survey, which determines the estimated planting year of a stand. In most cases, the surveyor will not have access to administrative records of planting years and must therefore estimate crop age in the field. This is not always easy to do in an objective manner, so there is the potential for a level of subjectivity to be introduced in planting year assessments. Consequently, special data calibration measures have been taken to correct for this possible source of bias that can affect, through the top height–age relationship in Forestry Commission's growth models, the yield classes assigned to crops. These data calibration measures applied to assessed crop ages and planting years are described in the next section.

After application of these data calibration measures on crop age assessments, the assumption that overall systematic biases contributing to the forecasts and estimates of the 2011 production forecast are small is probably reasonable. There are also known biases, in particular in the current suite of Forestry Commission's growth and yield models used in the derivation of the forecasts, which will be contributing some inaccuracies to the forecast outputs. There is a strand of future work to further identify and account for these biases, at which point the contribution of these to current outputs (for both the FC estate and the Private sector estate) will be assessed.

Future development of forecasting techniques using NFI field sample data may attempt to incorporate uncertainties about future management and harvesting on the Private sector estate into an overall expression of error attached to forecasts for this sector. This could be achieved, for example, by expressing the likelihood and timing of future harvesting events in the form of probability distributions, rather than with the present use of fixed scenarios, which are fully prescriptive for all assessed stands.

Forecasts for the FC estate derived from the SCDB are subject to the categories of error and uncertainty listed in items 2 to 8 above. Since the SCDB is an inventory with full coverage of all stands on the FC estate, there is no sampling error (category 9) associated with forecasts derived from this source, and therefore no sampling standard errors are quoted with the forecasts and estimates for the FC estate.

However, this does not imply that such forecasts are 100% accurate. In the first instance they are also subject to the assumptions made about future harvesting plans. These assumptions are less speculative than those used for the Private sector estate because the SCDB holds details of existing management plans for each stand and these are used in the construction of the Forestry Commission 'management plans' forecast. Although these plans may or may not be strictly adhered to in the longer term, their use offers a more likely long-term scenario than the assumptions made about the Private sector estate.

In addition to the uncertainties about possible future changes to management plans and their eventual execution on the FC estate, the Forestry Commission forecasts themselves are subject to various other categories of error. Probably the largest among these are category 8 errors above, covering cases where stands have not been previously surveyed or assessed for their yield class, and the yield class assigned to the stand in the SCDB records may represent little more than an informed guess. Such cases may result in errors of 20%, and in some cases 40% or more, in both the estimate of current standing volume and in future volume growth of a stand. Combining errors from this particular source with other measurement and modelling errors and biases described in categories 2, 3, 4, 5 and 7 above, the overall error in a Forestry Commission forecast will be significant and could be approaching (in relative terms) the sampling errors quoted for equivalent Private sector forecasts.

NFI has built a volume estimation system that is fully automated throughout the process. First, the field surveyor is guided by bespoke software in the collection of data in the field at step 5. After entry of the field data into a central database, a series of automated calculations and procedures are run to derive a volume estimate with associated standard errors. As a result there is now a direct link between the data collected and the outputs derived, removing the capacity for human error or intervention, and all estimates are directly traceable back to the source data from which they are derived, providing a robust and auditable evidence trail of all estimates derived from the NFI.

In the 2005 production forecast for the Private sector, steps 1–8 were largely based upon industry expertise. This introduced a large potential source of error. Levels of error could not be assessed for this process and, consequently, statements could not be made

about the correctness or the accuracy of generated forecasts, as can be done with the 2011 production forecast.

As described above, the principal source of error in NFI forecasts for the Private sector estate is sampling error. However, this is quantified and, if the standard errors attached to estimates and forecasts are larger than desired, investment can be made in a higher level of sampling in order to achieve target levels for the standard error.

Calibration of NFI surveyors' stand age assessments

As noted above, the assessments made by NFI surveyors in the field that are used in the production forecast and have the greatest amount of uncertainty and potential inaccuracy are the assessment of crop age, and therefore of planting year. For conifer crops, it may be possible to count whorls up the trees in some cases, but this will not always provide reliable results, particularly for older stands.

This introduces a significant potential source of bias in the data, and consequently a special study has been undertaken to calibrate surveyor assessments of crop age against other information in a sample of NFI survey sites. The types of information used for this calibration were administrative records of planting years and, for a limited number of sites, independent tree borings from which age can be assessed by counting rings in the bore samples. On NFI sample squares so far surveyed on the FC estate, the surveyor assessment of age can be compared with the administrative records in the SCDB for the same stand. For some NFI sites on the Private sector estate, a variety of administrative sources were obtained for information on planting years.

With regard to planting years obtained from administrative sources, the administrative record of planting year could not always be matched with certainty to the particular stand assessed by the surveyor in the field. With this being the case, a pre-filtering exercise was performed on the data whereby the administrative record of planting year was discarded from the analysis if it was probable from the data on assessed planting year and other mensuration data collected for the same stand that the administrative record was not referring to the same stand.

Results of this calibration exercise are reported here only for conifer crops. (The exercise was also performed on broadleaved stands in order to provide a full assessment of individual surveyor performance, but these results are not reproduced here since they do not impact on the 2011 softwood production forecast.) Usable data for the calibrations, after the pre-filtering exercise, resulted in 414 individual planting records in NFI sample squares in England, 88 in Scotland and 68 in Wales.

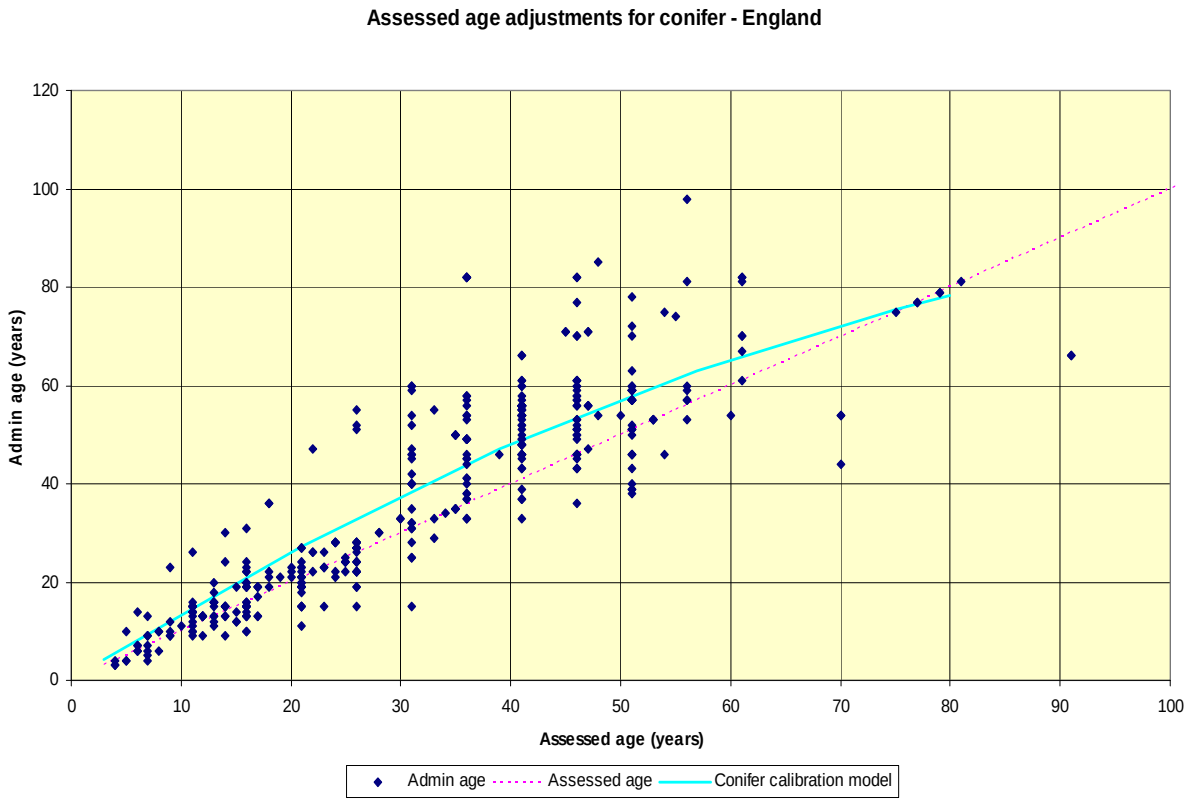
It was recognised that each individual NFI surveyor may exhibit different biases and abilities with respect to estimating stand ages, and the data were examined from this

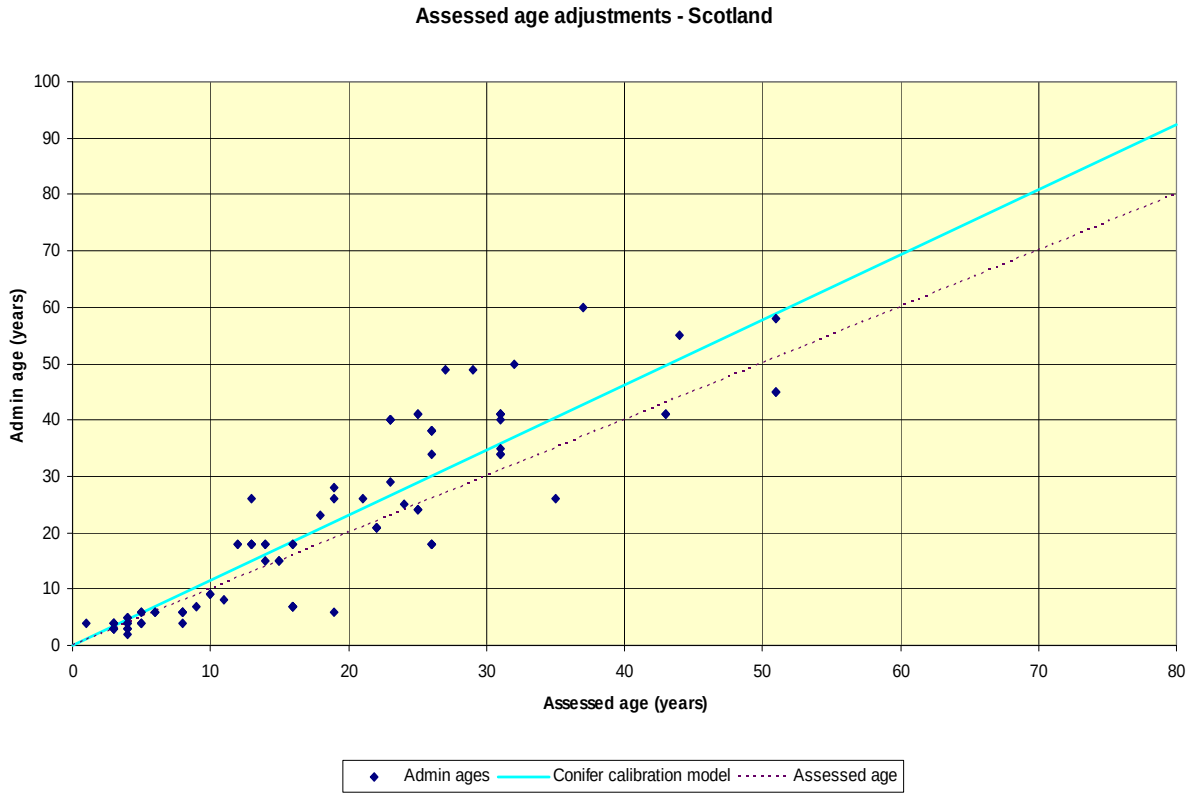
perspective. However, it appeared that, while there is bias in the surveyor assessments of age, these were fairly consistent in nature across different surveyors within countries, so it was thought sufficient to calculate calibrating relationships for each country but across all surveyors operating within each country.

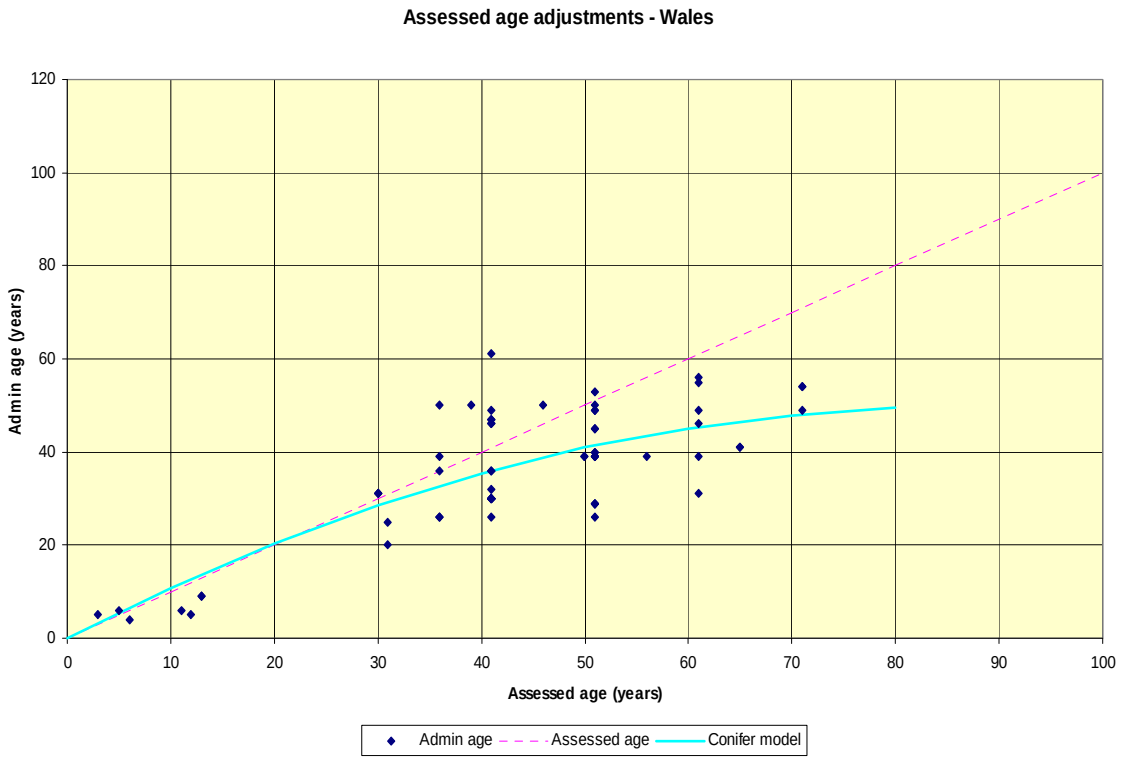
Not surprisingly, the data supported the contention that ages of younger crops can be more successfully assessed in the field (in absolute terms) than can older and more mature crops. In relating assessed age to 'Admin age' (as determined by the administrative record of planting year or by the results of tree borings) this effect was accommodated by fitting calibrating relationships that passed through the origin, so that, in any fitted model, at younger ages the assessed age would always be close to planting age. For each country, the calibrating relationship was estimated by fitting assessed age to 'Admin age' using a linear or quadratic function with zero intercept.

It was found that in England and Scotland the tendency is for the surveyors to underestimate age, whereas in Wales the evidence is that surveyors have been overestimating age (see Figure 1). In Scotland, a linear relationship between assessed age and 'Admin age' was found to be sufficient, whereby the surveyor assessment of age of a crop is too low by, on average, about 15% of its real age. In England and Wales, the relationships were found to be more complex, requiring quadratic functions to adequately describe the relationship between surveyors' assessments and actual ages. In England, the underestimate of age is largest on a middle range of ages, between approximately 25 and 50 years, but less so on older and younger crops. In Wales, ages were overestimated for most mature crops, and by greater amounts for older crops.

Figure 1. Calibration of NFI field assessments of ages of stands in England, Scotland and Wales







In NFI forecasts an 'assigned age' that determined the estimated planting year for each stand was allocated to each stand and component entering the production forecast. This was either the age and planting year indicated in confirmed administrative sources, or, where these do not exist or are not known, the surveyor's assessment of age adjusted by the calibrating function fitted in the above exercise. These adjustments equate to the distance and direction between the "assessed age" line and the "Conifer calibration model" line on the graphs shown in Figure 1, read at the relevant point on the assessed age scale.

These fitted calibrating relationships, taking account of the ranges in the data on which the calibrating regressions were fitted, are:

England

<assigned age> = 1.419 * <assessed age> * (1 – 0.00388 * <assessed age>)
when <assessed age> is less than 80 years; or
<assigned age> = <assessed age>
when <assessed age> is 80 years or more

Scotland

<assigned age> = 1.154 * <assessed age>
for all <assessed age>

Wales

<assigned age> = 1.152 * <assessed age> * (1 – 0.00668 * <assessed age>)
when <assessed age> is less than 80 years; or
<assigned age> = <assessed age>
when <assessed age> is 80 years or more

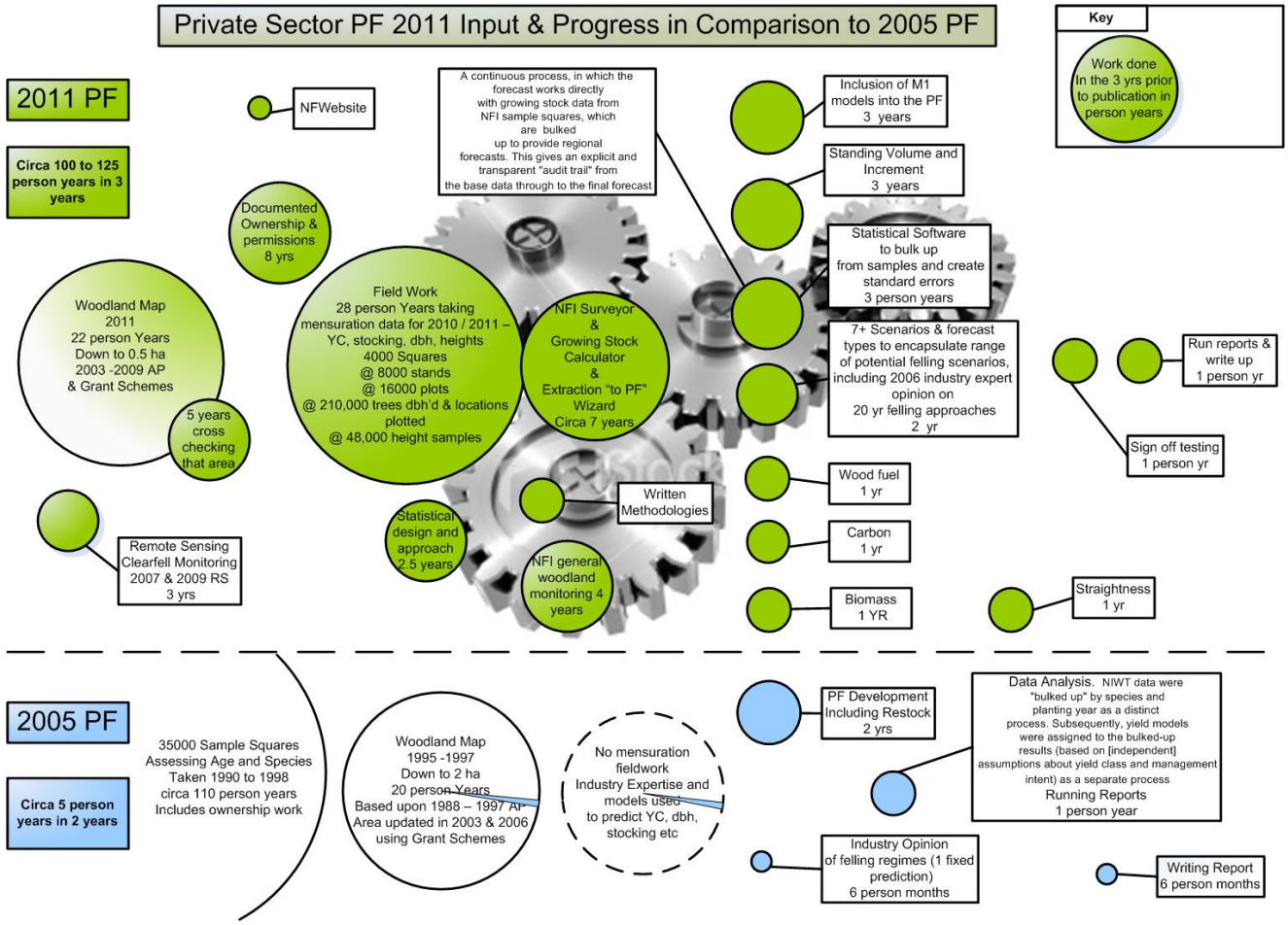
After applying these calibrations to surveyors' assessments of stand ages, there is still a degree of uncertainty and inaccuracy about the real age of individual stands; the standard deviations about the calibrating relationships are of the order of eight years, indicating the average inaccuracy of these calibrated age estimates in relation to actual ages. However, the result of the calibrating adjustments means that these inaccuracies are expected to contain little bias in so far as there is an equal chance of the estimated age being higher or lower than the actual age. This is important to the interpretation of forecast results. The random inaccuracies of these calibrated estimates of age of stands are, in effect, random observation errors and are therefore accounted for in the quoted sampling standard errors of estimates and forecasts. By eliminating, as far as possible, the inherent bias in the surveyors' estimates of ages of stands, it is ensured that this form of unaccounted error is not present in the forecast results.

This is especially important in the calculation of yield classes, which are directly estimated with the use of stand ages calculated from planting years. Use of calibrated estimates of age will largely remove bias in the assignment of yield classes due to this source, and ensures that mean yield classes calculated on mature stands and applied to young stands in NFI do not have large systematic biases in them.

Allocation of resources and the benefits of the new 2011 forecast approach

This new approach has involved a step change in the level of resources that have been allocated to deriving the production forecast and into woodland statistics in general. This has not involved additional resource, but the reallocation of existing resources allocated to inventory. Figure 2 illustrates this by comparing the relative resources of the 2005 and 2011 production forecasts. The circles represent different areas of work and they are sized by their respective input in person-years.

Figure 2. Comparison of resources for the 2005 and 2011 production forecasts.



Source: Forestry Commission

The biggest difference in approach to note is the amount of effort that has gone into the forecast in the years just prior to publication (in terms of person-years). Here to achieve up to date forecasts and estimates, the Forestry Commission has co-ordinated the cyclical woodlands survey / census, formerly known as NIWT, with the forecast, so that the data used for the forecast is current. The 2005 forecast was produced from five person-years of effort, in terms of work specific to that forecast (although it did take advantage of NIWT 1 data collected in the 1990s and the stand growth and yield models built up from the permanent sample plot programme over the preceding 100 years). The NFI and 2011 forecast have had 100 to 125 person-years of effort specifically put into their derivation. Much of this resource has been allocated to fieldwork to establish a body of mensuration data to provide a detailed assessment of the type of woodland. This data will be reused for other reporting requirements, such as the biodiversity and social value of forests. The main body of resource before the fieldwork was committed to the establishment of a new woodland map and, from this, improved estimates of woodland area. In contrast to NIWT, the NFI Woodland Map was triangulated and cross-compared with other sources (including the NIWT woodland map) to minimise errors and inconsistencies.

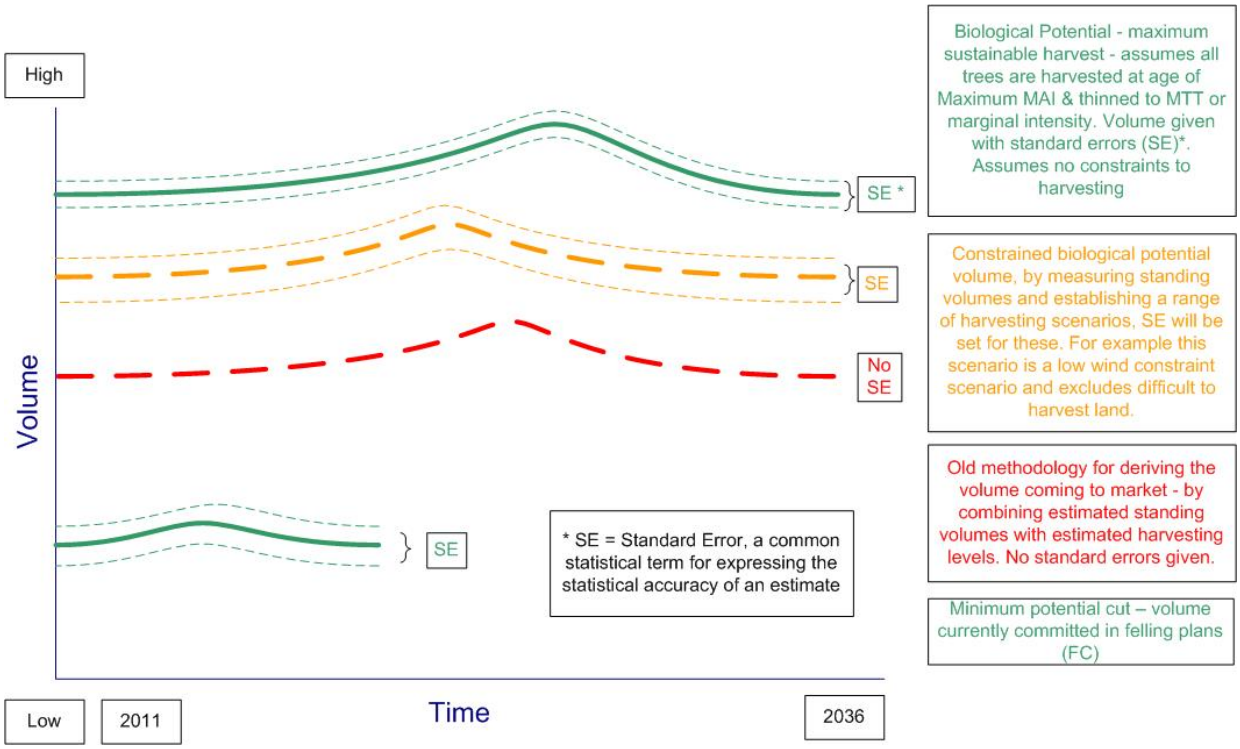
It should be noted that a large part of the resource expended in the preparation of the 2011 production forecast described above represents the initial development work involved in the establishment of the NFI programme. The full benefits of this investment will be realised in future with much deeper knowledge of the character and dynamics of the GB woodland resource, resulting in further outputs from the NFI of information on GB woodland, including future production forecasts. Such future production forecasts using the NFI resource will be able to be prepared with fewer immediate resources, but this will only be the case if the NFI mapping and field survey programmes (probably augmented with other developing technologies, such as LIDAR imagery and analysis) are sustained on a continuous rolling basis, as is currently planned.

The other area of increased input was in production forecast development. This development enabled:

- better basic growth and yield modelling;
- forecast scenarios (see Figure 4);
- biomass forecasts;
- full-tree assortments forecasts;
- carbon forecasts;
- straightness forecasts;
- the calculation of standard errors of NFI estimates and forecasts.

By producing a range of forecasts based on alternative felling and thinning scenarios, the breadth of potential future outcomes can be assessed. Figure 3 illustrates the principle of four separate scenarios for the timber forecast: unrestrained biological potential (top green line), an example of a restrained biological potential (yellow dashed line), 2005 felling and thinning assumptions (dashed red line), and volumes under management plans (bottom green line).

Figure 3. Forecast scenarios.



Source: Forestry Commission

Such scenario analysis provides the probable upper and lower limits of potential production. The forests cannot produce more than unrestrained biological potential (sustainably and over time) and harvesting levels are not likely to be less than the volume committed in management plans for the FC estate. Within this range of maxima and minima, assessments can be made about the likely levels of volume production, contingent upon the factors that affect levels of cut. The facility is now in place to generate a forecast based on any future harvesting scenario that can be formulated in rule-based strategic terms, differentiated by various types of spatial factors.

2011 GB Private sector forecast methodology

To produce a production forecast, four categories of information are required as inputs:

1. Estimates of total woodland area.
2. Information on the composition and nature of woodland (including mensuration data, such as heights, diameters, basal areas etc).
3. Estimates of how fast the trees grow (characterised by growth and yield models).
4. Knowledge of or assumptions about future harvesting plans.

This section gives more detail on the approaches used by NFI in the production of the 2011 GB Private sector production forecast. It covers how the derivation of the GB production forecast has been approached and describes how the Forestry Commission has built upon and improved this approach. As a result, the accuracy and amount of information available from the production forecast has been increased and an assessment of accuracy has been made and presented in the form of standard errors attached to the forecasts. Also in the new forecast the 'single answer' historical approach to the forecast has been distilled into several distinct products. These separate what can be measured and forecast with a high degree of confidence (e.g. standing timber growth and yield) from what can only be forecast with a moderate to low degree of confidence (e.g. levels of industry activity and harvest levels).

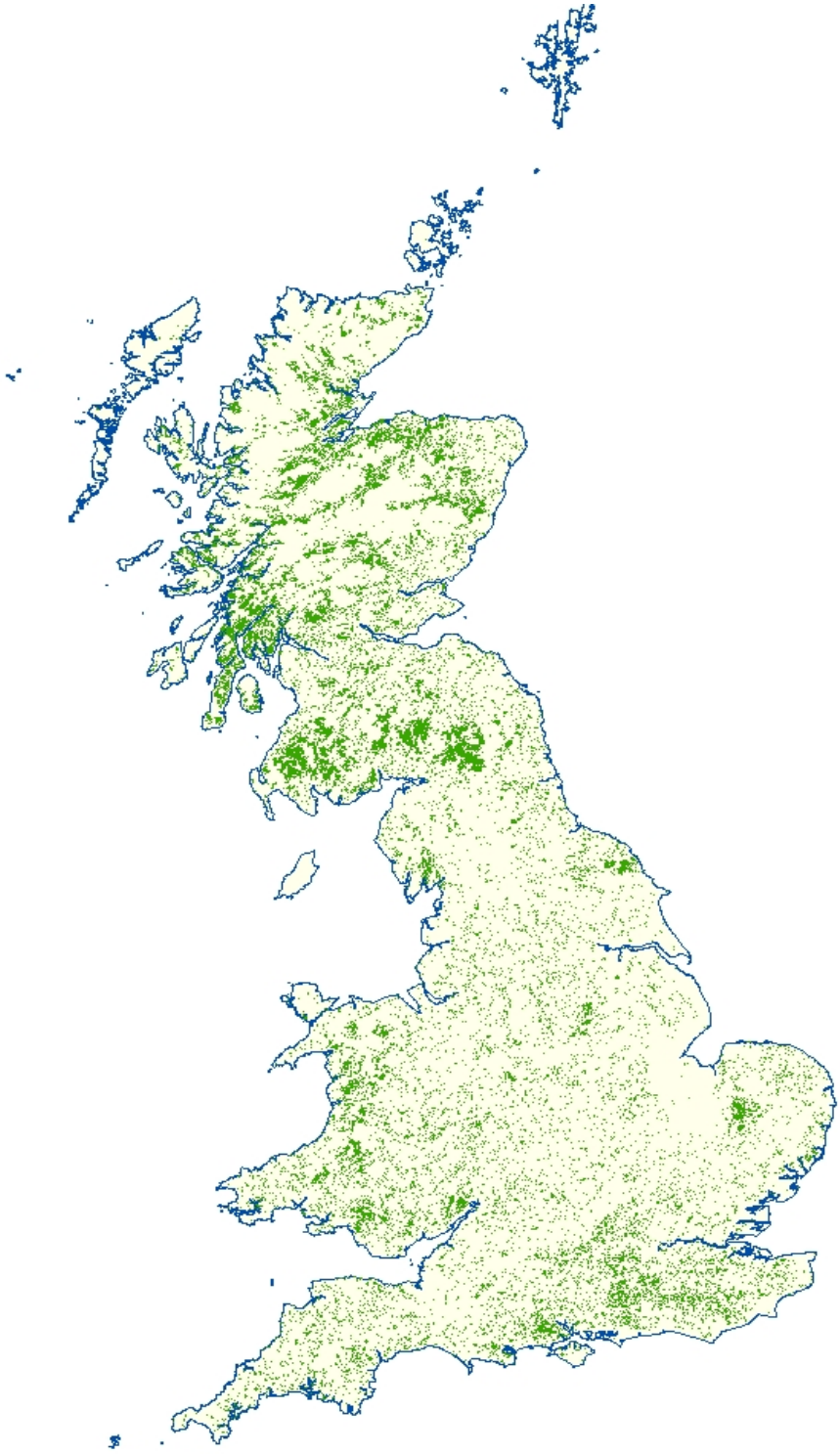
As levels of activity may vary under different market and policy scenarios over time, a forecast maximum and minimum is generated and presented, reflecting the full range of volumes of timber that could come to market. Within this range, a number of possible scenarios have been analysed, with results that fall between the two extremes. With such results, the sector will be in a better position to assess the opportunities and constraints it faces and decide on future harvesting strategies. This approach avoids the constraints inherent in a single interpretation or prediction of the future, as previously occurred, and the dangers in making such an assumption can be circumvented. This approach has been developed with input from the Confederation of Forest Industries (Confor), the Expert Group on Timber Trade Statistics (EGTTS) and the Private Sector Production Forecast Working Group.

Woodland area

Since 2007 the NFI has worked on the creation of a GB woodland map that is more accurate and up to date than previous versions. This is now complete and provides a sound evidence base for the production forecast. All woodlands defined as having over 20% canopy cover and over 0.5 hectare in area were mapped in GIS, using 1:10,000 colour aerial photography. Details of how the map was derived and is presently maintained are specified in the document *NFI Map Protocol*. Figure 4 shows the extent of GB woodlands in 2011 and Figure 5 shows a detail of the map set against the aerial photography that was used to derive it.

The woodland area derived from this map is a fundamental element of the production forecast and is used for scaling volumes and other attributes derived from the field survey to the total woodland area. This NFI Woodland Map will be annually updated using a combination of new aerial photography, remote sensing and administrative data, such as forest grant schemes.

Figure 4. The 2011 NFI Woodland Map.



Source: National Forest Inventory

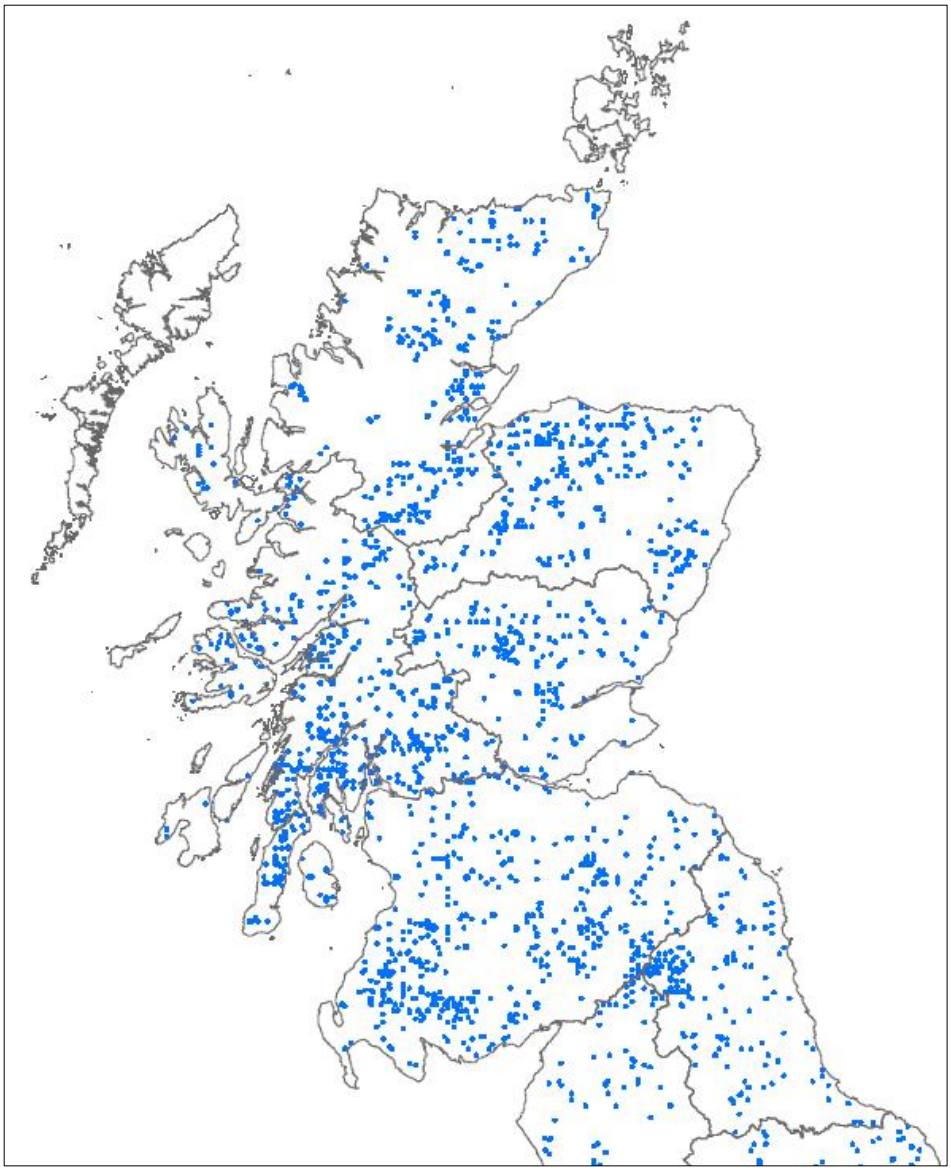
Figure 5 Detail of the NFI Woodland Map.

Assessment of woodland composition

The NFI Woodland Map differentiates woodland area into broadleaved woodland, conifer woodland and other categories of interpreted forest type (IFTs), but since this is achieved through the interpretation of aerial photography, this is only accurate to a certain level. This is suitable for some uses, but on its own it will not produce an accurate production forecast. To obtain more accurate estimates of woodland areas, type and composition, a ground survey is required of woodland areas. Such surveys are an integral part of the NFI programme and the results to date from this survey have been used to construct the 2011 production forecast of the Private sector estate in GB. The remainder of this section is devoted to describing the design and work of this survey in more detail, and notes how the results of the survey are used to construct the production forecast.

The first cycle of this programme involves ground surveys of about 15,000 one-hectare sample squares across GB within areas of the NFI map that are indicated to contain woodland. The survey has been designed such that all areas of woodland, including publicly and privately owned areas, and broadleaved and conifer woodland types, have a balanced representation in the sample. Figure 6 shows the distribution of currently selected sample squares in Scotland as an example of the geographic coverage of the NFI field sample.

Figure 6. Sample square locations in Scotland.



Source: National Forest Inventory

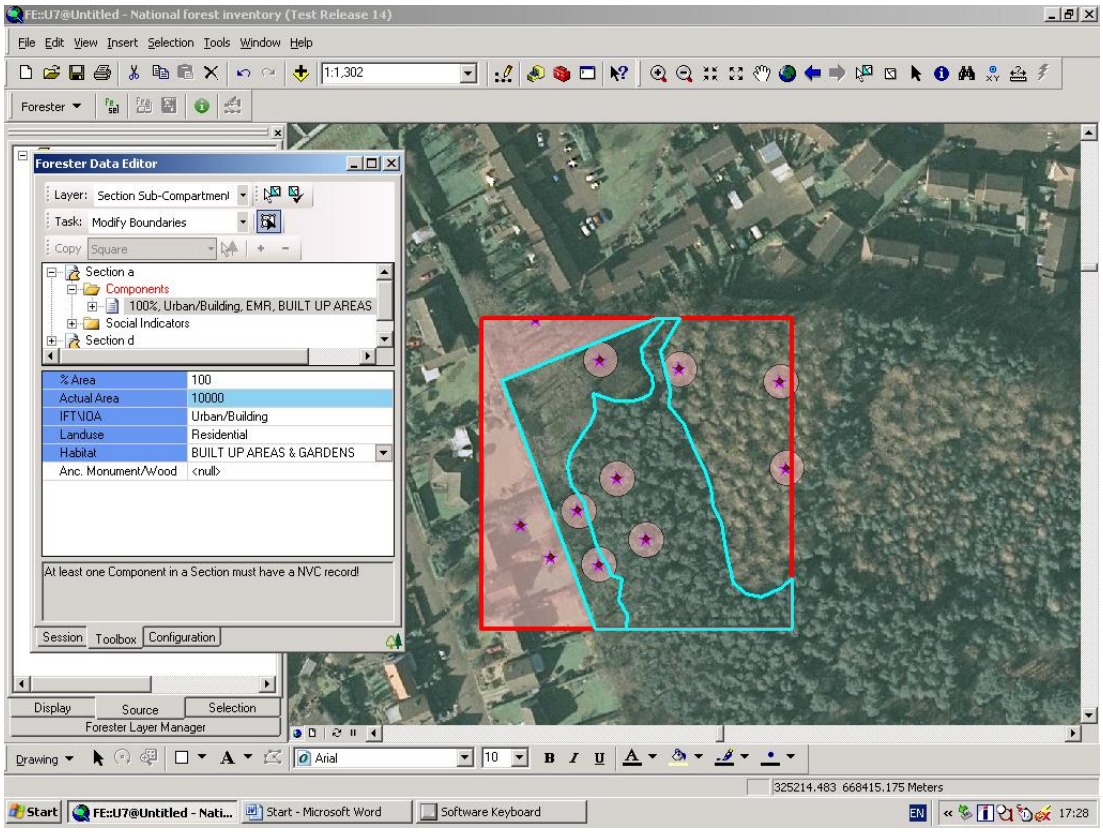
It is planned that about two-thirds of the sample (around 10,000 survey squares) are to be regarded as 'permanent' sites and will be revisited and resurveyed in subsequent five-year cycles of a continuously rolling NFI ground survey operation. Most of these permanent squares are sub-sampled from one-hectare squares containing woodland located at the southwest corners of a 1 km^2 grid. This part of the sample is therefore semi-systematic in design in order to ensure a representative geographic coverage of such sample squares across GB.

The remaining part of the field sample (about 5,000 sample squares) are planned to be 'temporary' sample squares that are replaced rather than revisited in subsequent cycles. These are selected from all one-hectare squares containing woodland according to the NFI map. The selections are being made in such a way that there is a balanced representation of different woodland types (IFTs on the NFI map) and areas of public and private ownership across the whole sample.

In addition to the NFI core sample of 15,000 squares, externally funded (top-up) samples may be added. The currently surveyed sub-sample used for the 2011 Private sector forecast includes an extra 700 sample squares within the Yorkshire and Humber region that have been externally funded by the Yorkshire Regional Development Agency. The results of the 2011 Private sector forecast for the Yorkshire and Humber region are therefore more accurate than for most other NFI regions, as can be seen in the quoted standard errors on estimates and forecasts for this region in comparison to other regions.

At each sample square the area is surveyed and differentiated into homogenous sections, noted in Figure 7 in turquoise. This stratification of a sample square into different sections is based upon broad-scale factors, such as land use and habitat, as well as differentiation of woodland areas into homogenous stands.

Figure 7. A single one-hectare sample square, sections and plots.



For each woodland section a series of assessments are made, including species, number of storeys, storey height, silvicultural system, presence of roads and rides, merchantability etc, much of which is used in the production of the forecast.

In each woodland section the surveyor's field computer automatically generates two to three circular 0.01 hectare plots with centres that are randomly located within the section (the small pink circles in Figure 7). The surveyor uses a rugged laptop with GIS, a GPS device and traditional survey techniques to locate the plot, as shown in Figure 8.

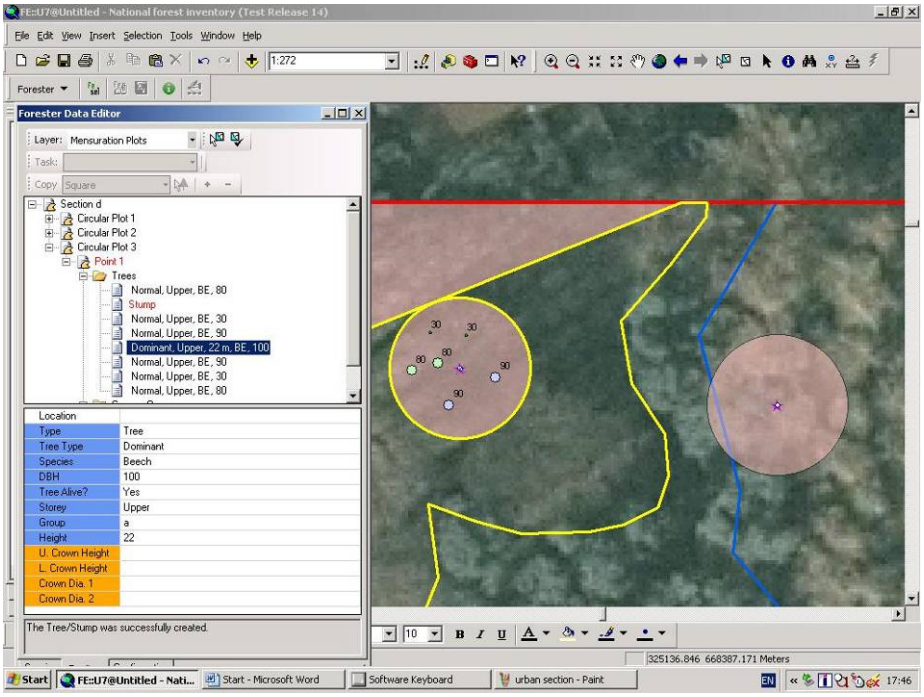
Figure 8. A surveyor uses a rugged laptop and GPS to locate a plot.

The plot centre is marked on the ground with a metal peg. This enables a sample of the plots to be relocated in the following weeks by an independent quality assurance team. The metal pegs will also help in finding the plots within permanent sample squares, when a surveyor returns to the square in subsequent five-year survey cycles.

The 15,000 sample squares of the core NFI field sample are planned to be visited over a five-year survey cycle ending in 2014. At the end of the cycle a full set of reports on NFI results will be run. During the cycle, interim reports will also be run, one of which is the 2011 softwood production forecast. In the next cycle of field surveys, the permanent sample squares will be resurveyed, allowing direct comparison over time and for real increment and change information to be derived between survey cycles.

At each 0.01 hectare plot a series of detailed mensuration measurements are recorded (see Figure 9). Each tree is located on the map (to an accuracy of 0.25 m) and its species, DBH, storey and live/dead status are recorded. Two 10-m transects are surveyed for young trees (less than 4 cm DBH) and three 5-m transects are also surveyed for lying deadwood. As of February 2012 the NFI had repeated this process 228,311 times for the 2011 production forecast. Figures 10, 11 and 12 show surveyors undertaking some of these measurements.

Figure 9. A survey plot.



On a sub-sample of trees in the plot, an additional set of height and crown measurements are taken. These sample height trees comprise, for each storey of the stand, the dominant tree (i.e. the tree with the largest DBH in the plot) and two other randomly selected sample trees. The extra measurements taken are selected from total height, upper crown height, lower crown height, crown diameter and height of lowest live branch. A vertex hypsometer is used for the height measurements. These measurements form the basis of the production forecast mensuration information and are specified in detail in the technical documentation *NFI Field Manual* and *NFI Mensuration Protocol*.

Figure 10. A surveyor checks whether a tree is within a plot.

Figure 11. Measuring DBH.

Figure 12. A surveyor measures a tree's height using an electronic vertex hypsometer.

Data collected

The NFI collected data from about 5,600 sample squares between January 2010 and December 2011, with about 4,000 of these situated in the Private sector estate and about 1,600 in the public sector estate. Of the 4,036 squares used for the Private sector production forecast, around 3,000 are sited in Private sector conifer woodland and around 1,000 in Private sector broadleaved woodland and other categories of woodland, such as clearfells, new planting and areas of low density woodland.

This has resulted in 8,052 stands being assessed (in part – see the earlier section on 'Assessment of woodland composition'). Within these, 20,000 circular plots of 0.01 hectare and 228,311 trees have been assessed, 59,334 for heights and crown dimensions. This has resulted in the largest mensuration dataset available to date in GB woodland and represents a solid basis for woodland and volume measurement. The

number of squares sampled per region and used in the production forecast is shown in Table 1.

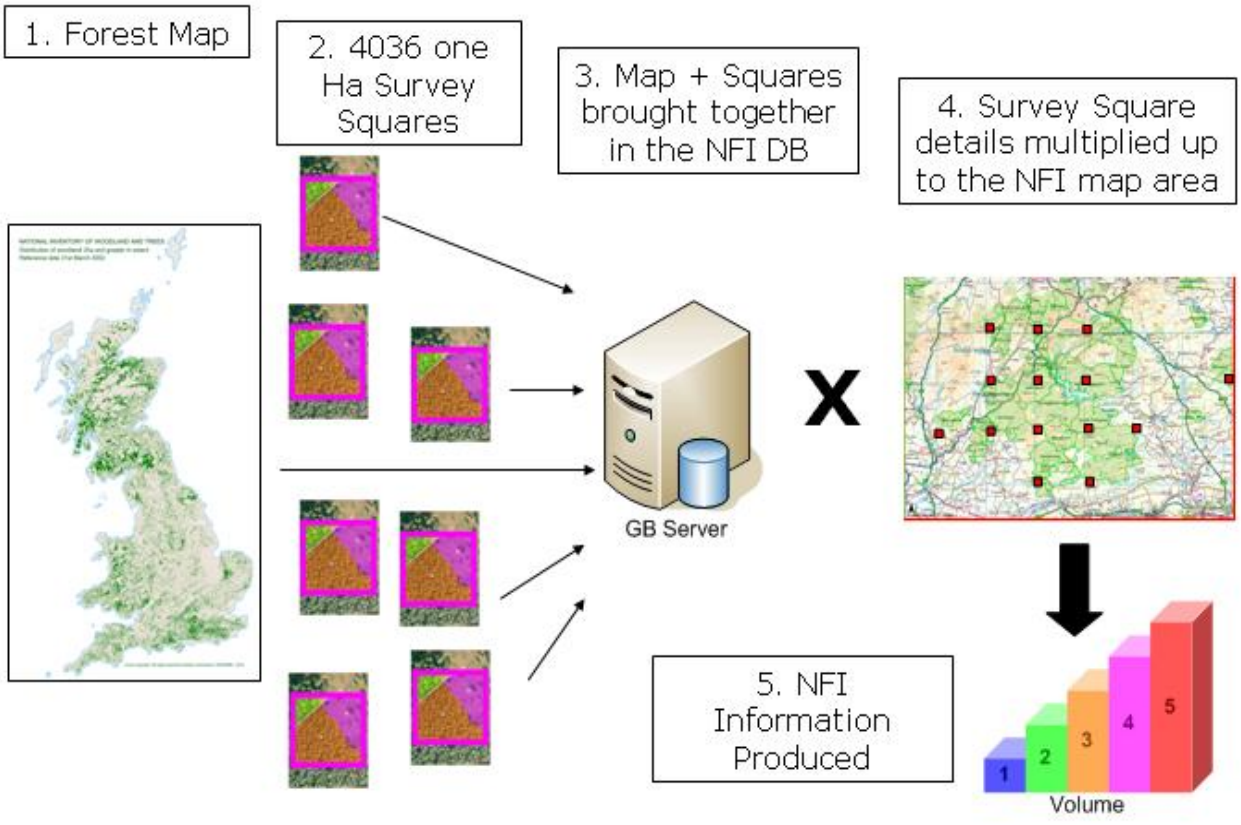
Table 1. Sample squares assessed per region.

Region	Number of squares	Number of Private sector squares	Number of Private sector squares with coniferous trees	Number of Private sector squares with broadleaved trees
North West England	258	219	152	193
North East England	150	95	77	77
Yorkshire & The Humber	509	365	226	332
East Midlands	173	149	75	147
East England	287	209	132	201
South East England & London	589	482	332	473
South West England	428	385	249	376
West Midlands	110	106	75	102
North Scotland	258	225	201	93
North East Scotland	337	324	306	204
East Scotland	335	272	223	192
South Scotland	671	542	497	252
West Scotland	474	352	298	158
Wales	343	311	207	261

Source: National Forest Inventory

The Private sector production forecast methodology is summarised in Figure 13.

Figure 13. Summary of Private sector production forecast methodology.



2011 FC estate forecast methodology

As previously noted, the FC estate is covered by a database (the SCDB) with spatial records and other information on every stand in the estate. This represents the cumulative inventory, efforts and knowledge of all the foresters who have managed the public estate since the inception of the Forestry Commission. In many ways it can be viewed as a historical document, as much of the information now used, such as planting years, was collected at the point of planting onwards, going back to 1919. A full description of how the FC estate inventory was derived and how it is currently managed can be found in the Forestry Commission publication *Survey Handbook*. This section gives a brief overview of that process.

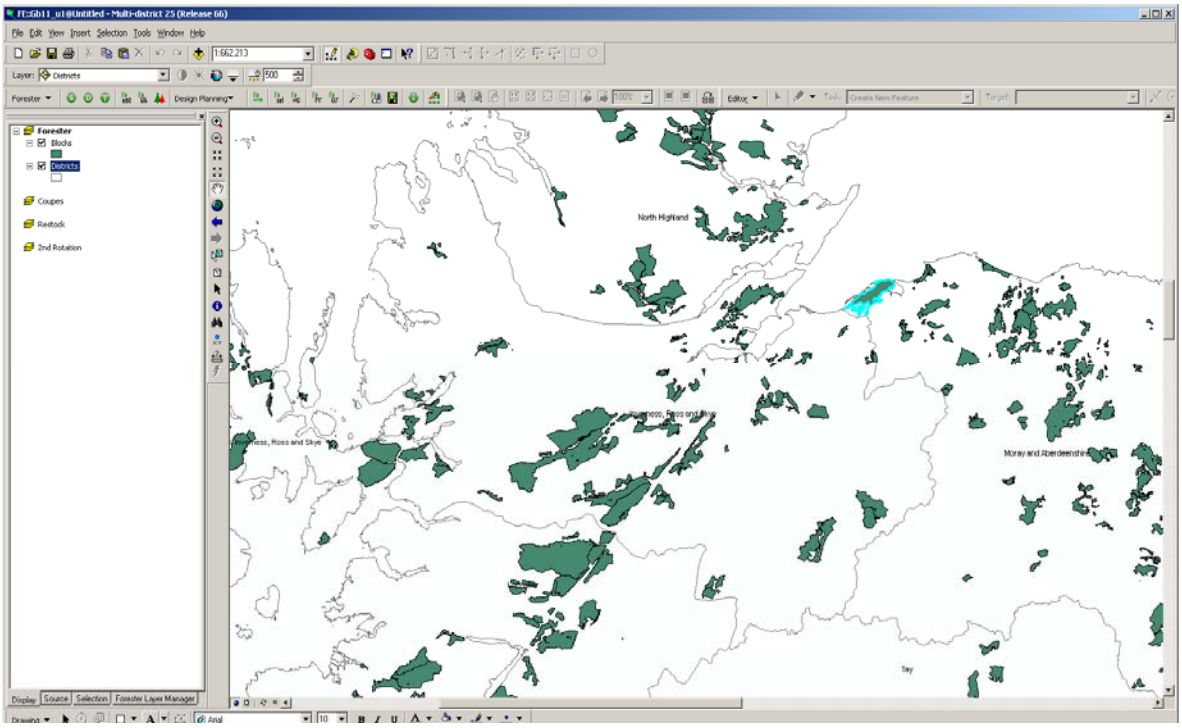
The FC estate inventory

The FC estate inventory has traditionally been called the sub-compartment database (SCDB). It maps all stands on the FC estate down to 0.1 hectare and contains a package of information about each stand, including species, planting years, estimated yield class and stocking. The SCDB has been in existence for 90 years and represents the Forestry Commission's cumulative knowledge of the growing stock on the FC estate. The data are now managed and updated with contributions from most field staff using a variety of survey techniques such as GPS, GIS and aerial photography. The data are managed within the Forestry Commission-built GIS Forester software system, a bespoke growing stock management system, which ensures the integrity of the data within the SCDB by enforcing a series of rules and procedures, which are set out in the *Survey Handbook*. The SCDB is now, therefore, in the form of a geo-spatial database.

Figure 14 shows a part of the inventory for northern Scotland, and in the upper right of the figure a single block, Culbin, can be seen highlighted.

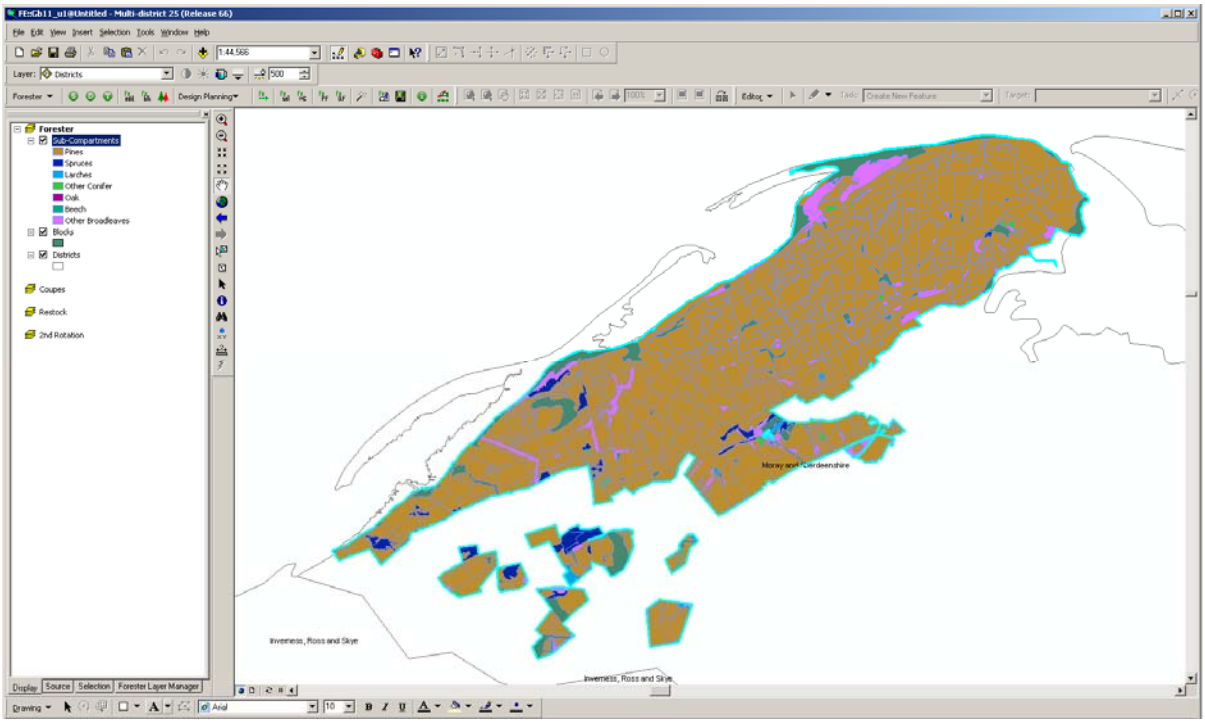
Figure 15 shows an extract from the SCDB and stock map, held within Forester. It is a thematic map showing the species held within individual stands in Culbin block. From the key it can be seen that most of the block is pine, with small stands of other species scattered throughout. For each of these stands, a reliable record of planting year, species and yield class is kept. The yield classes were assessed at different junctures in each crop's life cycle, sometimes by best estimate, at other times by direct measurement. As noted, this information has been built up over the Forestry Commission's history and has been quality assured. This level of detail and accuracy within the FC estate inventory allows for a detailed and representative production forecast to be produced on a stand-by-stand 'full census' basis.

Figure 14. The FC estate inventory Northern Scotland.



Source: Forestry Commission

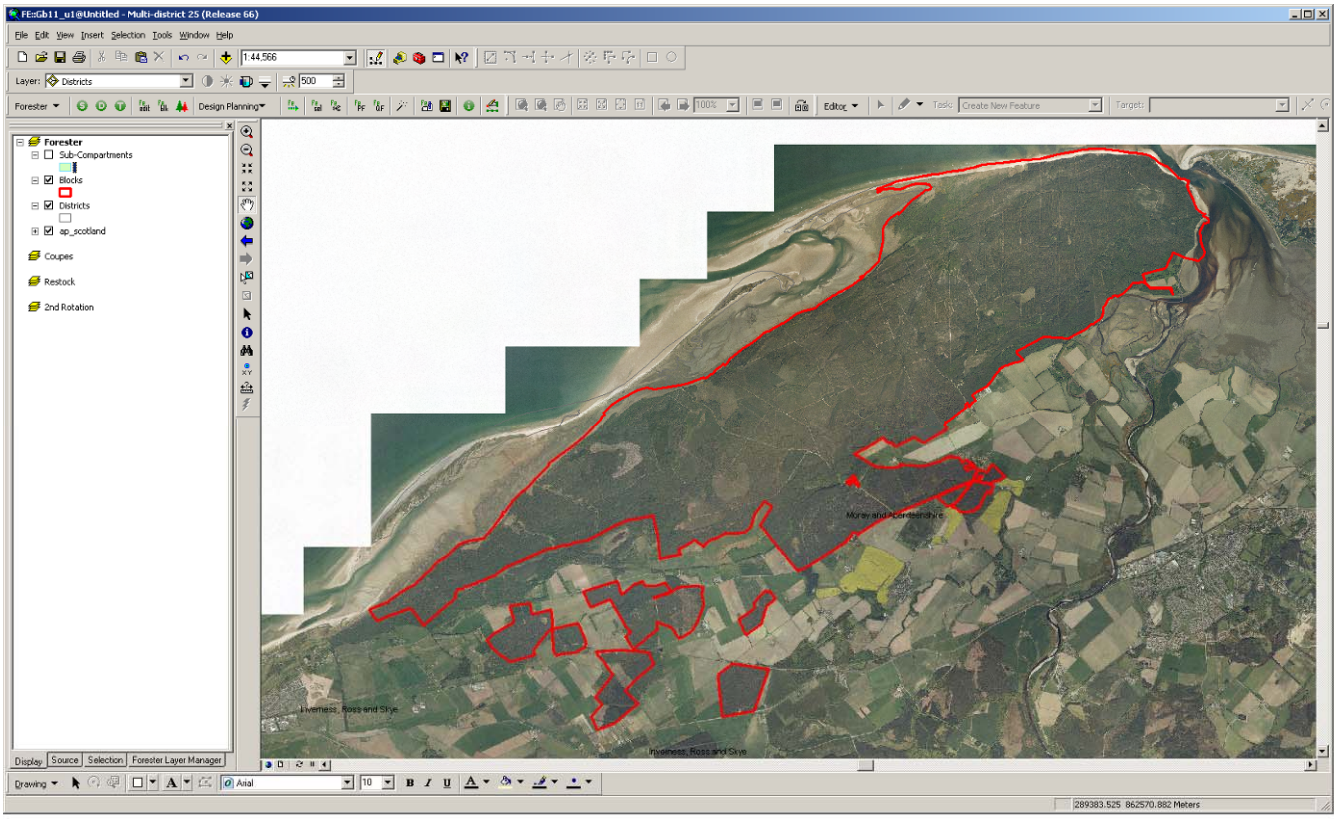
Figure 15. SCDB – Culbin.



Source: Forestry Commission

Part of the quality assurance of the SCDB is the use of aerial photography (Figure 16). Since 2004 the FC estate has had full aerial photography coverage held within the SCDB. This, combined with the bespoke editing and data protection tools in Forester, has allowed foresters and surveyors to tune, modify and update the inventory on a daily basis across the FC estate, resulting in a rich data source of the whole estate.

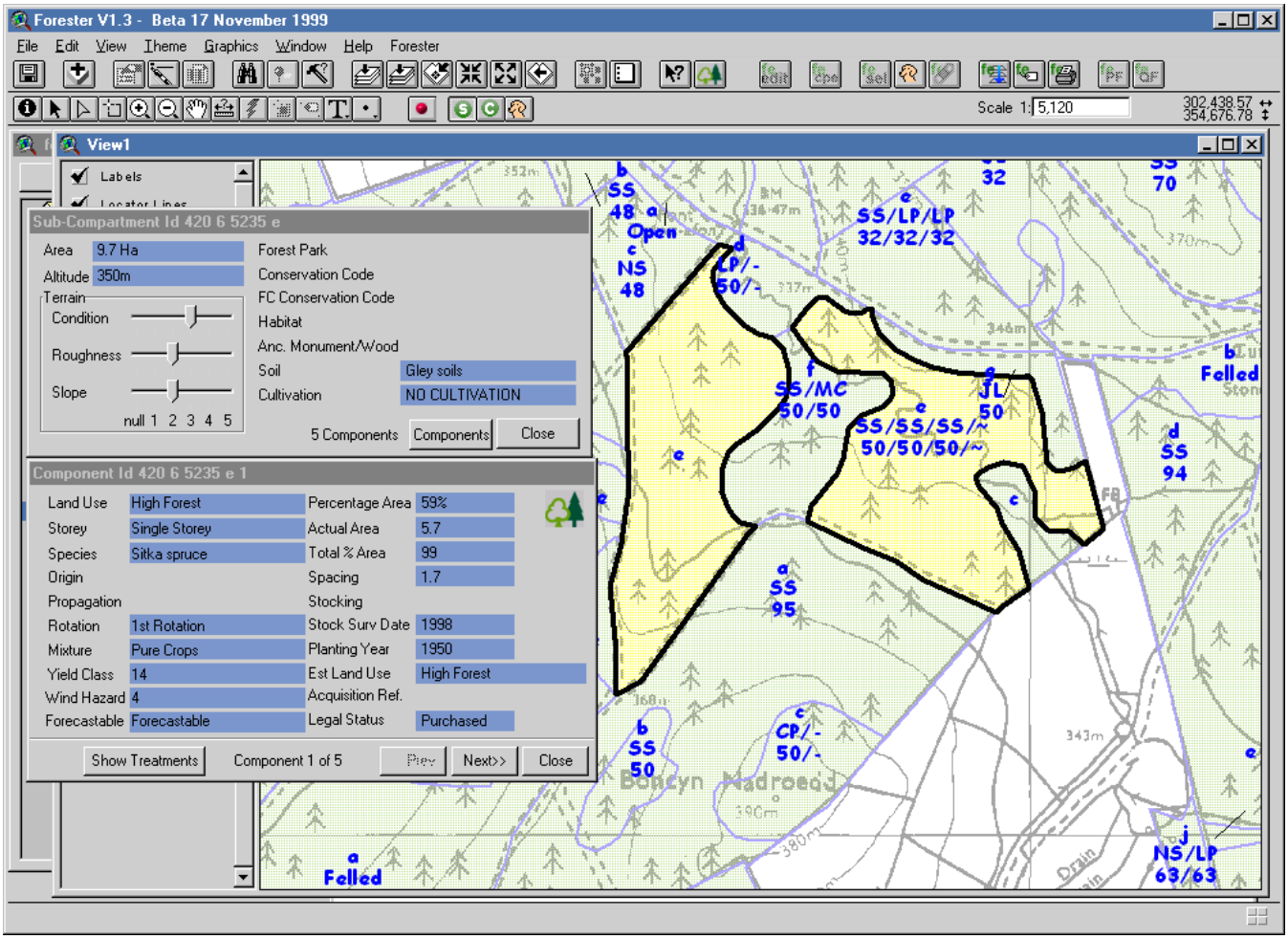
Figure 16. Culbin FC estate inventory in comparison to aerial photography.



Source: Forestry Commission

Figure 17 illustrates the SCDB records for a single stand. Data held include the area of the stand, the fact that there are five individual species or components within that stand, and the planting year, yield class and date of last survey for each species. This information is held for each stand across the FC estate and represents a very solid basis from which to run any volume forecast.

Figure 17. Stand-level information – the stock map and SCDB.



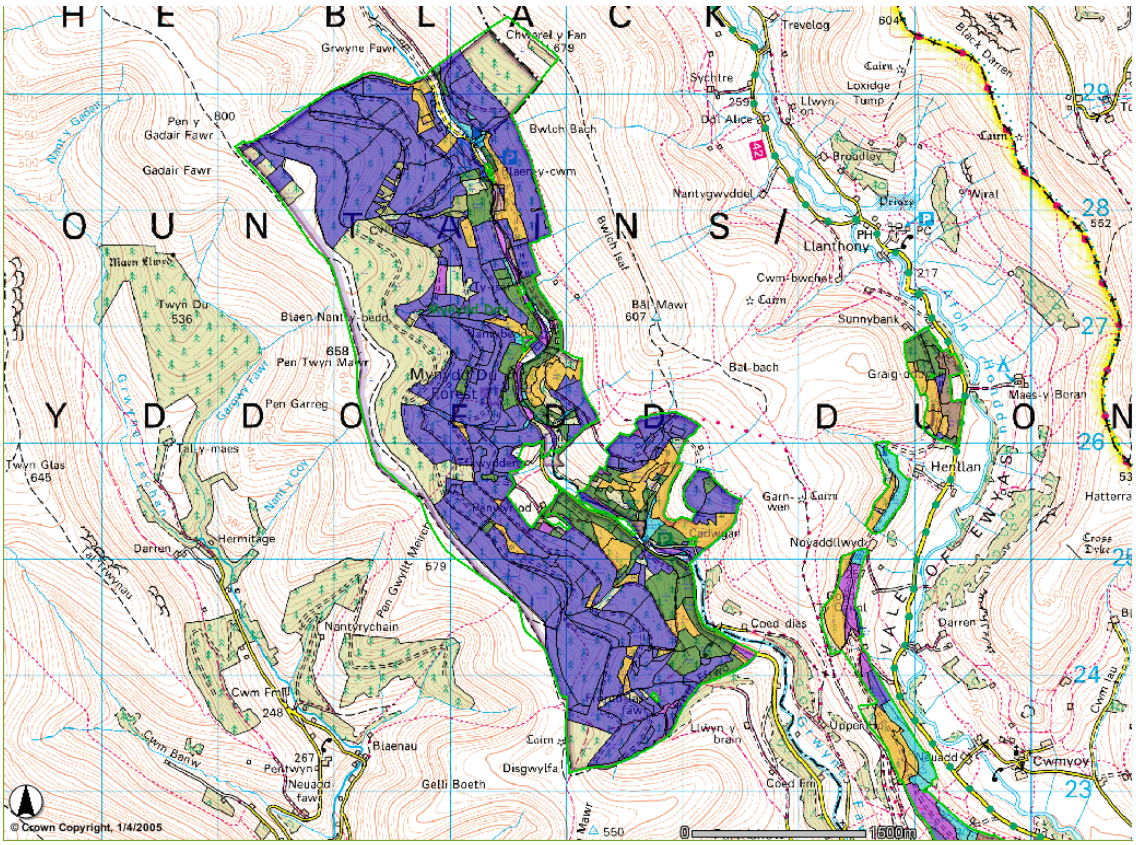
To ensure that the stand records are kept up to date, representing felling, planting, failures etc, Forestry Commission staff have been provided with leading edge technology such as GIS, Forester GIS, GPS and digital aerial photography. This has enabled them to update the inventory at their desks or in the field based upon their own observations, actions and measurements. Over 1,000 staff in the Forestry Commission have access to these tools and edit the data regularly. This will feed through directly into a reduced woodland area in the database, and in turn into the production forecast. The stock data is updated on an ongoing basis by staff across the country, culminating in all annual changes being consolidated in the SCDB as at 31 March of each year.

FC estate felling plans

As noted above, a detailed inventory for every stand is maintained by the Forestry Commission for its estate. Figure 19 shows a block in South Wales which holds a large number of stands and species.

The FC estate is managed according to sustainable forest management and multiple purpose forestry principles and to achieve this each block has a design plan (the felling part of the design plan for the block illustrated in Figure 18 is shown in Figure 19). The design plan is a plan of felling, thinning and planting, which aims to balance all the policy objectives required of the block in a single cohesive plan of action. The FC estate design planning process is specified in *Operational Guidance Booklet 36: Design Planning*.

Figure 18. Stock map for a block in South Wales.

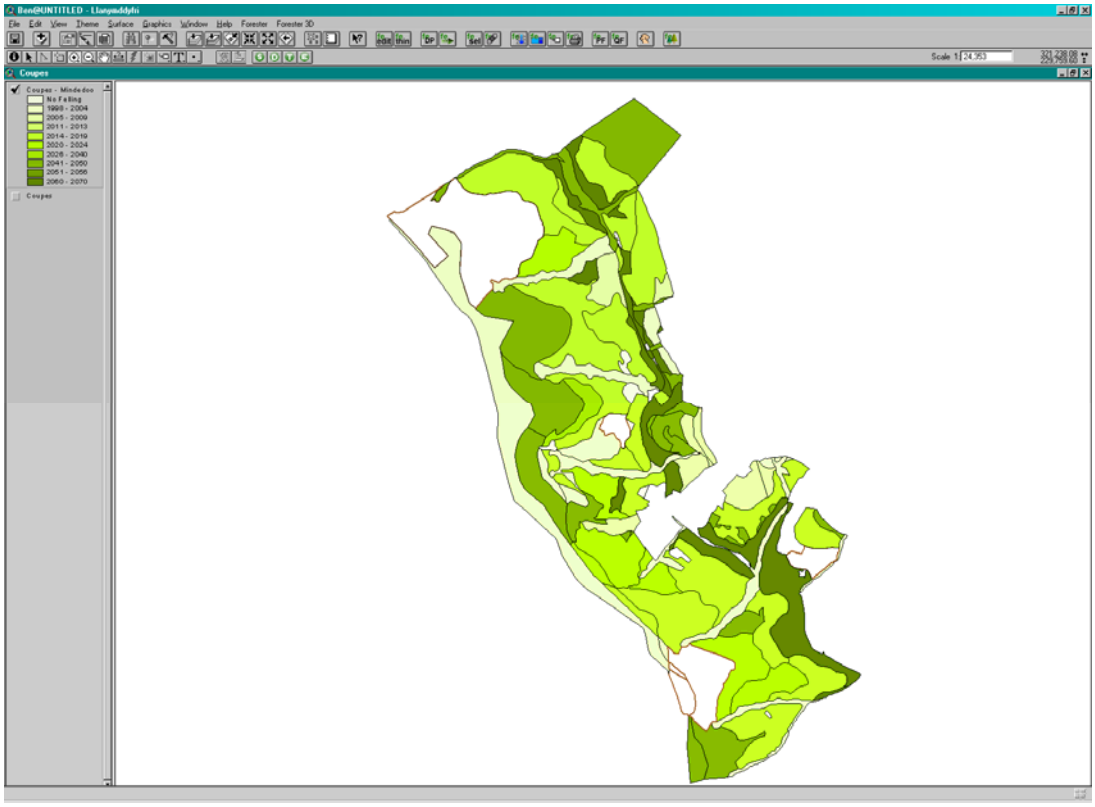


Source: Forestry Commission

These felling plans have been held for the whole FC estate for at least 12 years and in some areas for 20 years. The plans are under constant review on a 5 to 10-year cycle and directly reflect FC estate felling activity, sales plans and the production forecast. The plans project actions over a period of at least 20 years, and in some cases for over 100

years. The felling plans are the basis of the Forestry Commission five-year commitment to production, and although they do come under review on a five-year cycle, plans broadly follow the same predetermined path set by the nature of the growing stock and the implementation of the design plan for the last 10 to 20 years.

Figure 19. A FC estate felling plan.



Source: Forestry Commission

It is the combination of these felling plans together with the thinning plans and inventory data for the block that produces the production forecast for the FC estate. This process is specified in detail in the Operational Guidance Booklets 32 and 9 *Production Forecasting* and *Thinning*, respectively.

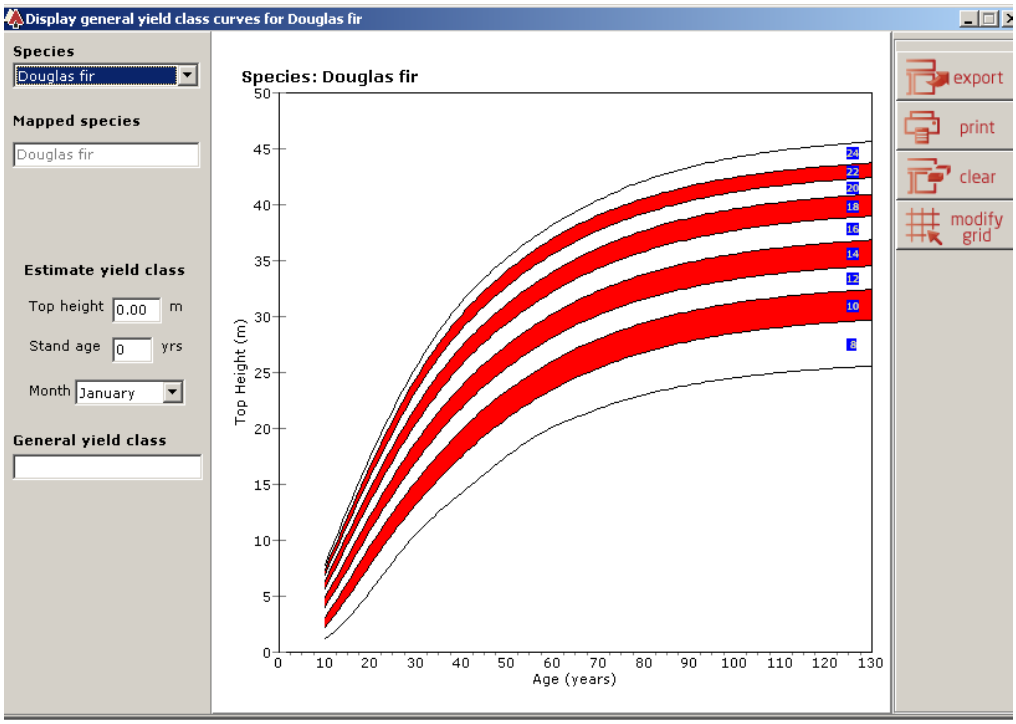
2011 Northern Ireland forecasts methodology summary

The Forest Service (FS) in Northern Ireland has compiled production estimates for forests it manages based on management plans and available yield data. These Northern Ireland volumes represent an estimate of availability but include areas where current management planning may defer harvesting while more information is gathered on future timber production. The FS has based Northern Ireland Private sector estate softwood availability upon planting records of woodlands and forests established in line with the requirements of the UK Forestry Standard.

Yield and growth models

The Forestry Commission's standard growth and yield models (see Figure 20) are applied to the inventory and management data by the Production Forecast system to produce a volume forecast. These models are based upon actual observations of tree growth, measured over the last 100 years in a series of permanent sample plots across GB, creating a series of general stand growth curves. This is a solid evidence base, giving reliable volume forecasts.

Figure 20. Growth and yield curves.



Source: *Yield Models for Forest Management* – Forestry Commission

The Production Forecast system

The Forestry Commission Production Forecast system is a timber forecasting tool developed by the Forestry Commission. It works by collating inventory, felling and thinning data and applying the growth and yield models derived by the Forestry Commission to these to build a volume forecast. The system has been developed on an incremental basis by the Forestry Commission since the 1970s and represents a significant body of work. The latest version of the Production Forecast software calculates, along with a timber production forecast, additional estimates and forecasts of standing volumes, volume increment, biomass and carbon weights. The following NFI Technical Documentation specifies in detail how the Production Forecast operates:

- *Specification of NFI Growing Stock Calculations*
- *Forecast Types*
- *Bulking Up Samples in the NFI*
- *Restocking in the Forecast*
- *NFI Survey Manual*
- *NFI Mensuration Protocol*
- *NFI Map Protocol*
- *Technical Glossary*
- *Felling and Removals Forecast*

Plans and assumptions about management intent

To forecast how forests will change over time and to estimate what proportion of their yield will come to market, a picture of future timber volume removals from forests needs to be built. The largest timber volume removals will be as a result of planned harvesting, with pathogens, fire, wind etc being other factors.

The most reliable data for building this picture are forest plans held by the Forestry Commission for its own estate, as by and large these come to fruition with some reliability and the Forestry Commission has full plan coverage held in the SCDB. However, the majority of coniferous woodlands in GB are now within the Private sector estate, for which the Forestry Commission does not in general have access to detailed management plans. An alternative approach is therefore needed for the construction of forecasts covering the Private sector estate.

In the case of the Private sector estate, assumptions need to be made. Work and consultations have been undertaken to establish how these assumptions should be formulated. The conclusions are that a range of likely options should be produced,

contained within a maximum and minimum of possible outcomes. The maximum production scenario is that of biological potential, whereby industry and owners harvest to maximise volume in a long-term sustainable manner. This is achieved by utilising maximum mean annual increment (MMAI) to set fell year. Management table thinning (MTT) ages and volumes are also used in this scenario. This scenario is unlikely to happen, but it is the maximum possible sustainable volume that can be achieved and, as such, sets the upper boundary of potential production. The minimum that should be produced is that committed under Forestry Commission plans. Again this is unlikely to be all that comes to market, but it sets a minimum to the forecast. In between these scenarios, the Forestry Commission and industry have consulted on establishing a set of possible scenarios, based upon physical, legislative and economic constraints, and assumptions about future market behaviour.

The following summarises the options for scenarios that have been formulated for investigation in the 2011 softwood production forecast:

- **Clearfelling to biological potential**. This assumes choosing a felling age which maximises long term productivity by harvesting at first year of maximum mean annual increment (maximum MAI)*. Within this overall approach to felling, several variants were defined:
    - **Biological potential felling and thinning all**. A scenario which maximises productivity by felling at age of maximum MAI in all stands irrespective of wind risk and to thin all stands to management table thinning (MTT), throughout the forecast period (from 2011 onwards).
    - **Modified biological potential, thinning and felling assuming moderate wind risk measures**. This scenario takes account of wind risk, but assumes a relatively risk-tolerant approach in applying wind-risk constraints to harvesting practice. This assumes felling to year of maximum MAI and thinning of all stands to management table (MTT) in all crops less than DAMS 16, and felling at an assumed terminal height of 25m (if this is attained before year of maximum MAI) and no thinning for stands at or above DAMS 16.
    - **Modified biological potential, thinning and felling assuming strong wind risk measures**. This scenario also takes account of wind risk, but applies a less risk-tolerant constraint to harvesting practice. This assumes felling to year of maximum MAI and thinning of all stands to management table (MTT) in all crops less than DAMS 16, and felling at an assumed terminal height of 21m (if this is attained before year of maximum MAI) and no thinning for stands at or above DAMS 16.
    - **Modified biological potential, assuming thinning based upon observed activity**. This scenario sets year of clearfell at first year of maximum MAI for all mature stands and thinning to MTT is only applied in those stands which were observed within the NFI field survey as having been thinned already. No

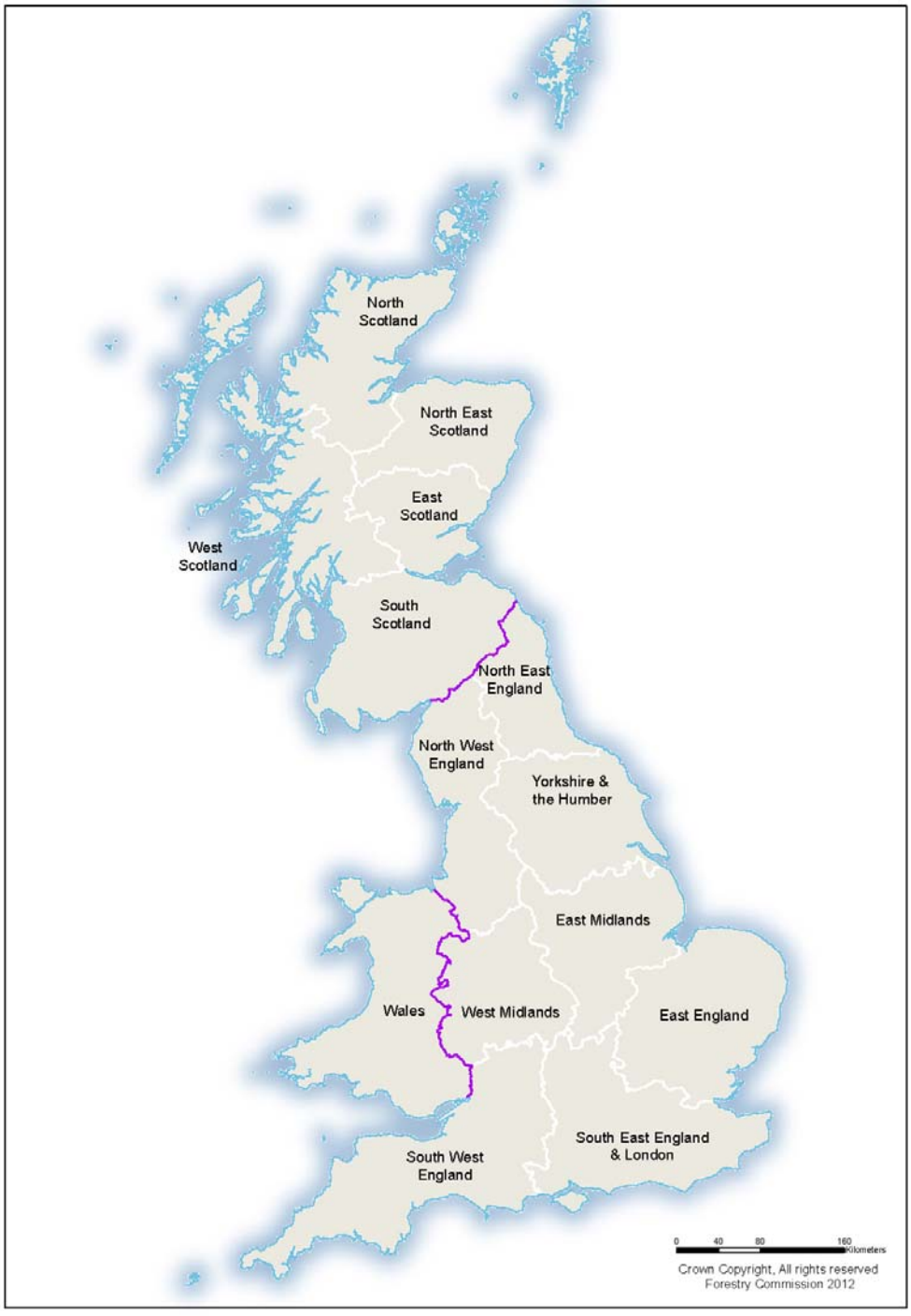
special wind-risk measures are assumed for mature stands. However, for stands that are too young to have yet been thinned according to management table prescription (taken to be younger than three years after prescribed age of first thin) the scenario assumes management according to the modified biological potential scenario with moderate wind risk measures, described above.

  - **Biological potential felling with no thinning.** Felling to maximise productivity by harvesting at first year of maximum MAI and undertaking no thinning.

- **Felling and thinning to the 2005 industry 'view'.** This scenario uses region-specific sets of harvesting prescriptions based upon what the sector thought would be future harvesting practice with regard to age of felling and amount and type of thinning. These were derived in consultation with private sector growers and processors and were the basis of the 2000 and 2005 forecasts.
- **Management felling and thinning plans.** A forecast based upon detailed, stand by stand plans prescribing age of felling and type and intensity of thinning. This applies to the Forestry Commission only.
- **No harvesting.** Known as zero intervention, this scenario assumes no felling or thinning of any stand.

Results and discussion of these and other scenarios run as part of the 2011 production forecast can be found in the NFI paper *Interpreting NFI Timber Volume Forecasts*.

Appendix A: Map of NFI reporting regions



Further information

This report is an NFI Methodology Paper, supporting the outputs of all of the themes in the 2011 production forecast. The individual themes are:

- GB 2011 Standing Coniferous Timber Volume
- GB 25-Year Forecast of Standing Coniferous Volume and Increment
- UK 25-Year Forecast of Softwood Availability
- GB 25-Year Forecast of Coniferous Carbon Stocks
- GB 25-Year Forecast of Coniferous Biomass Stocks

The NFI Technical Documentation papers listed below provide further information on specific aspects of the NFI methodology:

- *NFI Growing Stock Calculations*
- *Forecast Types*
- *Restocking in the Forecast*
- *NFI Survey Manual*
- *NFI Mensuration Protocol*
- *NFI Map Protocol*
- *Technical Glossary*
- *Felling and Removals Forecast*
- *Tree Species*
- *Volume Increment Forecasts*
- *Growing Stock Volume Forecasts*

The assumptions used in building the production forecast and how these should be interpreted are covered in the NFI Interpretation Paper *Interpreting NFI Timber Volume Forecasts*.

All these documents can be found on the NFI website (www.forestry.gov.uk/inventory).

Other Forestry Commission publications relevant to this methodology are:

Forest Mensuration: A Handbook for Practitioners
Operation Guidance Booklet 9: Thinning
Operational Guidance Booklet 32: Production Forecasting
Operational Guidance Booklet 36: Design Planning
The Forestry Commission's Survey handbook
Yield Models for Forest Management

These can be ordered via the Forestry Commission website (www.forestry.gov.uk).

Glossary

actual production	What was actually felled and removed from the forest. The Forestry Commission keeps records of actual production for its estates, while the Private sector estate production comes from what is reported to have been received by timber processors. These figures are available from Forestry Commission Statistics.
age class	A grouping of trees into specific age ranges, for classification purposes.
area (forest/woodland)	Forest and woodland area is divided into net forest area – the land actually covered by trees (in the NFI defined to the drip line of the canopy), and gross forest area – which includes both the area covered by trees and the open spaces (of less than 0.5 hectare) within the forest boundary (e.g. rides, glades, ponds).
availability	A term to describe what timber could potentially be available for harvesting within a forest area.
biological potential	A term applied to forecast scenarios with the objective of maximising timber production. It typically involves felling stands in the year of maximum MAI and Management table thinning. It may not take account of factors that constrain thinning and felling (e.g. wind risk or pest attack). The forecast results set out in this report involve constraints on thinning and times of felling to take account of wind risk.
biomass	In the sense used in this paper; the amount of live material held within the entire tree; roots, stumps, stem, branches and needles and is measured in over dried tonnes.
broadleaves	Trees and shrubs that belong to the angiosperm division of the plant kingdom (as distinct from the gymnosperm division that includes conifers). Most in the UK have laminar leaves and are deciduous. Sometimes referred to as 'hardwoods'.
carbon storage	The act of storing, for a finite period, in a component of the Earth system, or a carbon pool. Examples include trees as well as harvested wood products which retain biomass during their use
carbon sequestration (or capture or uptake)	The accumulation of biomass in the forest reservoir. Over the lifetime of a forest stand, there is a net accumulation of biomass in the forest up until the point where equilibrium is reached. Thus the quantity of biomass accumulated is finite. The process is also reversible and biomass can be returned to the atmosphere though dieback, decay, the burning of wood or disturbance to soil.
clearfelling	Cutting down of an area of woodland (if it is within a larger area of woodland it is typically a felling greater than 0.25 hectare). Sometimes a scatter or small clumps of trees may be left standing within the felled area.
conifers	Trees and shrubs that belong to the gymnosperm division of the plant kingdom (as distinct from the angiosperm division that includes broadleaves). Conifers mostly have needles or scale-like leaves and are usually evergreen. Sometimes referred to as 'softwoods'.
cumulative volume production	The total volume of timber that is forecast to be produced over the entire forecast period, including any overdue timber.
DAMS (Detailed Aspect Methodology	A measure of exposure at a particular location. Can be used as a proxy

Score)	indicator of the risk of catastrophic wind damage to a stand of trees. May be used to influence decisions on thinning and timing of clearfelling where wind is a risk factor
DBH (diameter at breast height)	The diameter on the stem of a tree at 'breast height', defined as 1.3 m from ground level.
design plan	A holistic spatial and temporal plan covering the main aspects of long-term woodland management such as felling and restocking.
FC estate (Forestry Commission estate)	Forests, woodlands, open land and other property managed by the Forestry Commission.
felling plan	A spatial and temporal plan of harvesting activity within a woodland.
forest	Land predominately covered in trees (defined as land under stands of trees with a canopy cover of at least 20%, or the ability to achieve this, and with a minimum area of 0.5 hectare and minimum width of 20 m), whether in large tracts (generally called forests) or smaller areas known by a variety of terms (including woods, copses, spinneys or shelterbelts).
Forestry Commission	The government department responsible for the regulation of forestry, implementing forestry policy and management of state forests in GB. Forestry policy is devolved, with the exception of common issues that are addressed on a GB or UK basis, such as international forestry, plant health and forestry standards.
FS (Forest Service) of Northern Ireland	An agency within the Department of Agriculture and Rural Development in Northern Ireland responsible for the regulation of forestry and the management of state forests in Northern Ireland.
full-tree assortment	A breakdown of a trees volume or weight into classes defined as stem, stump, roots, branches and needles.
Great Britain (GB)	England, Scotland and Wales.
growing stock	A term broadly referring to the standing resource of living trees at a point in time.
increment	The increase in volume of a tree or a stand over a year or annualised over a specified period measured either in m3 per year or in m3 per hectare per year. See also Mean annual increment (MAI).
interpreted forest type (IFT)	A classification system used by the Forestry commission to identify broad categories of woodland type than can be interpreted from aerial photography
management table thinning (MTT)	A sequence of thinnings prescribed by Forestry Commission yield tables over the life of a forest stand. Management table thinning refers to the pattern of thinning recommended in these yield tables. In standard yield tables the thinnings are set to an intensity which aims to maximise diameter increment whilst also maintaining maximum cumulative volume production. See thinning intensity.
maximising productivity	The management of woodland to maximise volume production by thinning at the MTI.
maximum MAI (Maximum MAI)	The maximum value of mean annual increment for a forest stand as observed directly or estimated from Forestry Commission yield tables. Under UK conditions, maximum MAI is usually achieved after a number of decades. See mean annual increment. When implemented within the forecast the year of maximum MAI is utilised.
mean annual increment (MAI)	The average rate of volume production up to a given year, expressed in m3 per hectare per year. In even-aged stands it is calculated by dividing cumulative volume production by age.
mensuration	The study of the measurement of lengths, areas, volumes and related

	quantities. Forest mensuration is concerned with the measurement of trees, woodlands and forests, including standing and felled timber.
MTI (marginal thinning intensity)	The maximum sustainable intensity of thinning defined as 70% of yield class per hectare per year (m3/ha/year).
National Forest Inventory (NFI)	An inventory run by the Forestry Commission, set up in 2009, to provide a record of key information about GB forests and woodlands.
National Inventory of Woodland and Trees (NIWT)	An inventory run by the Forestry Commission in the mid 1990's, to provide a record of key information about GB forests and woodlands.
overbark	Used as a definition when the volume of wood includes the bark.
planned production	The volumes and assortments published in the removals forecast, reflecting the cumulative impact of managing the FC estate (as of 31 March 2011) in accordance with approved forest design and thinning plans.
potential production	A forecast which will not necessarily transpire. As the Private sector estate forecast makes assumptions about future levels of harvest, and the assumptions may not transpire, this forecast is one of potential production.
Private sector estate	Forests and woodlands in the UK not owned or managed by the Forestry Commission (GB) or the Forest Service in Northern Ireland. In the context of the NFI, 'Private sector' is used for convenience although it includes land owned or managed by bodies such as local authorities and charities.
production forecast	A forecast of softwood availability from the Forestry Commission (GB), the Forest Service in Northern Ireland, and potential softwood availability from the Private sector (UK).
Production Forecast system	The software package built by the Forestry Commission which is used to produce forecasts of timber metrics such as production, standing volume and increment
restocking plan	A spatial and temporal plan covering replacement planting in harvested areas.
SCDB (sub-compartment database)	The SCDB is a record of all land managed by the Forestry Commission. Each stand of trees is represented spatially, together with information on individual stand characteristics (e.g. species, planting year, spacing and yield class) that is periodically updated. As new surveys of stands are conducted (e.g. for operational purposes), survey results are also recorded against the stands. In addition, the SCDB contains details of how the stands are being managed – in particular the planned frequency and type of thinning operations and a 'due date' for felling.
softwood	The wood of coniferous trees or the conifers themselves.
stand	A relatively uniform collection of trees (from either artificial or natural regeneration) composed, for example, of a single species or a single age class.
standard error (SE)	The measure of the margin of error associated with an estimate as a result of sampling from a population with statistical variability. Larger standard errors indicate less precision in the estimate. Standard errors in this report are quoted in relative terms (i.e. as percentages of the value of the estimate).
standing volume	the live stemwood and useable branchwood of trees (up to 7 cm top diameter). It excludes roots, below ground stump material, small branches, foliage and deadwood. For Private sector woodland only, it also excludes standing volume in trees in woodlands of less than 0.5 hectares.

	Usually expressed as m3 overbark standing (m3 obs). For Private sector woodland only, it also excludes standing volume in trees in woodlands of less than 0.5 hectare.
stemwood	The woody material forming the above ground main growing shoot(s) of a tree or stand of trees. The stem includes all woody volume above ground with a diameter greater than 7 cm overbark. Stemwood includes wood in major branches where there is at least 3 m of 'straight' length to 7 cm top diameter.
Sustainable (forest management)	The stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity and vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions at local, national and global levels, and that does not cause damage to other ecosystems.
terminal height	The top height of a stand at which wind damage is expected to reach a level necessitating clearfelling.
thinning	The removal of a proportion of trees in a forest after canopy closure, usually to promote growth and greater value in the remaining trees.
thinning intensity	A measure of the 'lightness' or 'heaviness' of a thinning, generally expressed in terms of the amount of timber volume per hectare removed relative to the growth rate of a forest stand.
timber	The woody product from felled trees, which is destined for construction material, pulp or paper industries.
top diameter	The diameter of the smaller (top) end of a log, often used to define different categories of wood products (e.g. sawlogs, roundwood, pulp) and merchantable timber.
top height	The mean total height of the 100 largest DBH trees per hectare.
UK (United Kingdom)	Great Britain plus Northern Ireland.
UK Forestry Standard	The UK government's approach to sustainable forest management
vertex hypsometer	A device that uses laser based technology to measure distance, height and angle in the forest
volume per hectare	The woody volume of trees (measured in m3/ha).
year of maximum MAI	The year or age at which a stand achieves, or is estimated to achieve, maximum MAI. Felling and re-establishing the stand at this age will achieve the highest average production per annum. See maximum MAI, mean annual increment.
yield class (YC)	An index used in the UK of the potential productivity of even-aged stands of trees based on maximum MAI. It reflects the potential productivity of the site for the tree species growing on it