National Forest Inventory

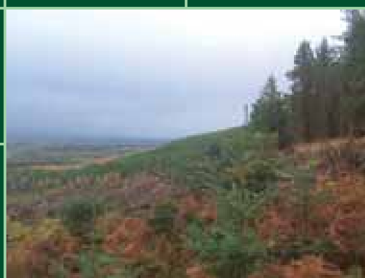
Republic of Ireland

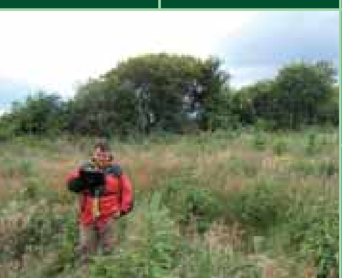
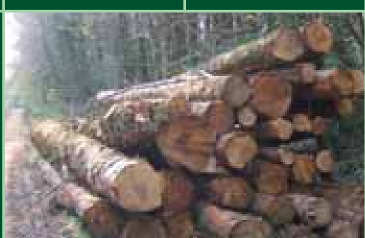
Proceedings of NFI Conference

Forest Service

THE DEPARTMENT OF AGRICULTURE, FISHERIES & FOOD
AN ROINN TALMHAÍOCHTA, IASCAIGH AGUS BIA



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Covering the National Forest Inventory, 2004 to 2006

The Forest Service of the Department of Agriculture, Fisheries and Food is Ireland's national forest authority. It is responsible for the forestry sector, the administration of forestry grant schemes, forest protection, the control of felling and the promotion and support of forest research. The Forest Service promotes Sustainable Forest Management as a central principle of Irish forest policy, whereby forests are managed to provide economic, social and environmental benefits on a sustainable basis for both current and future generations.

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TABLE OF CONTENTS

Introduction to Ireland's NFI

Christy O'Donovan

1. Introduction

Ireland's national forest cover has increased from 1.4 % of land cover at the start of the 20th century (Neeson, 1991) to 10% in recent times. Unlike most other European countries where large scale forests were indigenous, Irish landowners and farmers focused largely on agriculture and food production throughout the previous 150 years. From the early 1900s the state funded many afforestation programmes, the success of which varied due to the fiscal capacity of the programme and the availability of suitable land. By 1970, state forestry developed into a worthwhile resource of 300,000 hectares (ha) as a result of forestry expansion programmes and the refinement of forest establishment techniques. Complimentary to the increase in state forests, some private estate owners who possessed forest expertise and a land bank also pursued private forestry programmes. However, it is only in the last 25 years that significant expansion of the private forest estate has taken place, with approximately 200,000 ha having been afforested.

2. Previous Inventories

In tandem with the growth and development of the forest resource a number of forest inventories have been carried out over the years. The earlier inventories were all carried out by the state Forest Service and they examined specific parts of the forest resource. They varied in their extent, consistent with the economic and personnel resources that were available at the time.

The outbreak of the Second World War in 1939 hastened the first general survey of forests, both public and private (O'Muirgheasa, 1965). The purpose of this survey was to secure an estimate of timber resources, and it being war-time, the results were never published. From 1945 through to 1948 an ongoing survey of state forests was undertaken but this was abandoned after 1948. At that time the total area surveyed extended to 38,000 ha. In 1957 a stand level inventory of state forests was planned and this was undertaken in the years 1958 and 1959. It was called the "Census of Woodlands 1958/59". The emphasis was again on the available timber resource, excluding scrub and forest crops less than 11 years old. The census extended to 55,225 ha (O'Muirgheasa, 1965). Twelve staff were involved and the survey took one-and-a-half years. Planning for the 1968 "Inventory of State Forests" commenced in the latter half of 1965 (O'Flanagan, 1968). The survey period covered two and a half years and 29 people were involved including survey officers, office personnel and mapping draughtsmen. The inventory covered 102,446 ha and crops less than 11 years of age were excluded. Similar to the 1958/59 inventory, this was also a stand-level inventory with emphasis on forest maps and quantifying the timber resource.

After the completion of the 1968 Inventory of State Forests, it was considered an opportune time to secure a complete picture of the national forest estate by undertaking an Inventory of Private Woodlands (Purcell, 1979). The survey ran for two years and three months and was divided into two phases. Phase one included a complete stand-level inventory of all forests, 40 ha or more in extent. In phase two the country was divided into four regions and a 9% strip sample was taken. The strips were 2.88 km (1.8 miles) wide and 32 km (20 miles) apart. This strip sample accounted for the smaller scattered private forests not already included in phase one. The survey covered 81,963 ha and identified 58% of the private forest estate as high forest, 40% being classified as scrub and the remainder unstocked.

In 1978 the Forest and Wildlife Service (FWS) updated the 1968 Inventory of State Forests. After this there was a continuous updating of the inventory records, the intensity of which was dependent on forest age. GIS was first introduced, as an inventory tool, operationally to the FWS in 1982. The 1986 inventory update was published in 1989, which took the 1976 inventory as the base and included areas which were updated between 1977 and 1989. Since the establishment of Coillte in 1989 there has been a continuous GIS based stand inventory of all crops (Quinn, 1996).

3. Early Inventory Developments

With EU support programmes, the annual afforestation area progressively increased through the years 1980 to 1995. In 1995 afforestation reached a peak, at approximately 17,300 ha, which resulted in the total private forest estate area growing to ca. 195,000 ha. At this time the information on the private forest estate was 22 to 25 years old. The absence of a National Forest Inventory (NFI) was seen as an impediment to strategic planning. It was also a constraint to securing full benefit from the forest resource.

In 1995 after a number of studies and pilot projects (Mac Siurtain *et al.*, 1994) it was decided to carry out a national inventory using satellite imagery and GIS. The country was 'flown' in the summer of 1995 and the air photographs provided an additional dataset for enhancing satellite image classification accuracy. In 1996, the forests were classified into 21 broad species and development classes (Gallagher *et al.*, 1996).

In the publication "Growing for the Future" (Anon., 1996), a strategic plan for the development of the forestry sector, a strategic action for the setting up of a GIS based forest inventory and planning system was outlined. The Forest Service needed to have strategic information so as to guide policy and decision making. The policy statement in relation to inventory and planning was: **To develop a comprehensive inventory and planning system to provide forest resource, geographical and environmental data for management control and planning purposes**.

The needs of the Forest Service were closely examined and it was clear that the forest classification system on its own was not sufficient for planning needs. A forest inventory and planning system (FIPS) would be developed with more detailed objectives, one of which was the field sampling of forests to characterise the forest estate and generate production forecasts. The Forest Service had access to all the public forest information, but apart from small scale stand inventories by private estate managers, a comprehensive and standardised inventory of the entire private forest estate was not available.

4. Reasons for the NFI

Apart from the ever present need to supply up to date and reliable information on potential timber production to the forest industry, additional information needs had arisen by the year 2000. Furthermore, a number of national and international bodies, had requested information on Ireland's entire forest estate. The following sub-sections outline two such information needs.

4.1 Carbon Accounting

The United Nations Framework Convention on Climate Change (UNFCC) sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. Activities in the Land-Use and Land-Use Change and Forestry (LULUCF) sector can provide a relatively cost-effective way of offsetting emissions either by carbon assimilation, through planting and afforestation, or by reducing emissions e.g. reducing deforestation. Under the terms of the Kyoto protocol, Ireland had committed to restrict its green house gas emissions by 13% above the 1990 levels. The NFI was seen as a means to quantify the contribution of the forest estate in contributing to the above target.

4.2 Forest Resource Assessment

At the second Ministerial Conference on the Protection of Forests in Europe (MCPFE), held in Helsinki in 1993, six criteria and 27 indicators for sustainable management of forests had been agreed. At a further ministerial conference in Lisbon in 1998, Ireland committed itself to report, on a regular basis, SFM indicators as outlined in the National Forest Standard (Anon., 1998). One of the main tasks of the United Nations Economic Commission for Europe (UNECE) and the Food & Agricultural Organisation (FAO) Timber Section (Geneva) is to monitor all aspects of forest and forest resources in the region. The Timber Section plays an important role in the implementation of the Global Forest Resource Assessment (FRA) in Europe. The FRA examines the current status and recent trends for about 40 attributes of forest extent, condition and uses. Ireland was included in this assessment, but with changing scope and content of the global assessments, a national forest inventory was required.

5. NFI Commencement

The timeline for the development and initiation of the NFI is outlined below.

5.1 Initiation (2001)

In 2001, the Forest Service and the Council of Forest Research and Development (COFORD) organised a series of workshops, one of which was attended by representatives of the forest industry and addressed by an international expert in the field of national inventories, Mr. Gyde Lund (United States Department of Agriculture, retired). In addition, there were several internal Forest Service meetings to establish and determine the scope of the inventory. Having established what was required from the inventory, the next step was to select an appropriate sampling intensity.

5.2 Sampling Design (2002)

Deciding on the sampling intensity related directly to the precision of results required and also to the cost of the operation. In 2002 expert advice was sought regarding the sampling design. Various precision levels ranging from 10% down to 1% accuracy were outlined. Arising from this advice and rough estimates of cost, further discussion focussed on the "deliverables" from the inventory. The discussions considered what was essential and desirable. Ideally, the Forest Service would have liked to produce target precision of ±2% with 95% confidence for a whole range of parameters down to county levels. However, since this approach would have necessitated huge numbers of sample plots, the cost of the inventory would have rocketed. It was agreed that our ambitions had to be revised downwards to providing a national estimate of volume, with a precision of ±5% with 95% confidence levels.

The sampling strategy, dealing with sampling intensity, stratification of sampling, sample size and sampling locations, was agreed. Arising from these discussions a document "Invitation to Tender to Complete a Sample Ground Inventory of Ireland's Forests" was produced (Anon., 2002). Estimations by an independent body of the likely contract cost of the NFI put the figure above what was considered affordable at that time. Therefore it was decided to carry out the inventory in house. Arising from a recruitment programme, a Forest Service Inspector Grade 3 was recruited to the Forest Service in November 2002 with specific NFI duties.

5.3 Adopting NFI Methodology (2003)

The immediate task was to examine the methods outlined in the proposed tender document with a view to completing the inventory at a reduced cost. Before the NFI sampling design was decided, international advice was gained through Cost E43 and Institute of Forest Ecosystem Research (IFER Ltd.).

From contacts with other European countries, it was learned that most recent national forest inventories were carried out using a systematic grid sample design. Further contacts were made with other countries who had used inventory systems similar to the grid sample, and various data collection methods were explored. From these discussions it was learned that there were several pieces of equipment suitable for collecting and storing the data. However, the analysis of the data, the distillation of results and the reporting was a more complicated process.

5.3.1 Cost Action E43

Cost is an instrument, funded by the European Union, which supports co-operation among scientists and researchers across Europe in many disciplines. As Cost E43 relate directly to NFI, Irish delegates took part in this initiative and, as Ireland was beginning its first NFI, it was an opportune time to get advice from international experts involved in NFI. The main objectives of the Cost Action E43 are to:

- improve and harmonise the existing national forest resource inventories in Europe;
- support new inventories in such a way that inventories will meet national, European and global level requirements in supplying up-to-date, harmonised and transparent forest resource information for decision (policy) making;
- to promote the use of scientifically sound and validated methods in forest inventory designs, data collection and data analysis.

5.3.2 Institute of Forest Ecosystem Research

Discussion with another state agency led to Forest Service contact with IFER, a Czech Republic company. IFER developed advanced hardware and software for computer aided field data collection. The Field-Map™ system has been implemented for the entire inventory process starting from the preparation of the data collection project through the field data collection up to the comprehensive data processing.

Following introductory discussions with IFER, the Forest Service invited the company to Ireland to demonstrate their inventory system. This demonstration extended over two days and was held in Co. Wexford. The Forest Service outlined their national inventory plans and IFER displayed and explained their data collection hardware and software. All facets of the equipment were demonstrated in the field exercises. The analysis software programme was also used to analyse the plot data. Following this demonstration, the Forest Service inventory team agreed that Field-Map software would be very suitable for use in the impending NFI. The Forest Service agreed to lease the equipment and the software package from IFER for a short period, for the purposes of a pilot study.

6. Pilot Project

In early 2003, the Forest Service were part of the Department of Communications, Marine and Natural Resources (DCMNR) and provision was made in the Forest Service budget for the purchase of suitable hardware and software for the NFI.

A pilot project covering 28 plots was completed in Co. Wexford. It was assumed that the variation in forest stands encountered in Co. Wexford would be representative of the national estate. This project was undertaken using similar methods as were planned for the NFI. Information from the data collection process proved useful in planning the logistical aspects of the NFI.

The inventory data were analysed and the results indicated that the 2 km x 2 km plot distribution was sufficient to give a national estimate of volume with a precision of ± 5% at the 95% confidence level. The pilot project also yielded very valuable information regarding scheduling, time lines, approximate costs and the difficulties involved in accessing the inventory plots.

Arising from the experience and results of the pilot project a revised schedule of costs and timelines were drawn up. Firm recommendations could now be made as to an affordable inventory design that had a favourable cost-benefit ratio and that could be expected to deliver results with the agreed levels of accuracy.

7. Personnel and Training

At this point, everything had been put into place to carry out the NFI, with the exception of the required personnel, for the task of collecting the field data. Following on from the pilot study, it was possible to ascertain personnel requirements.

7.1 Personnel

In Autumn 2003, the Forest Service were still part of the DCMNR. It appeared there was a distinct possibility that a reduction in the afforestation programme was being planned. If this planned reduction became a reality, the Forest Service District Inspectors could be available for part-time inventory data collection. With this in mind, a schedule was drawn up, including the Forest Service District Inspectorate in the data collection process. As things turned out this schedule was never put in place.

In effect the Forest Service moved to the Department of Agriculture and Food (DAF), with budgetary responsibility from January 1st 2004. Having moved to a new department, the justification for completing the NFI project had to be made again. At this time, an embargo on the recruitment of permanent Forest Service staff was in place in the DAF. In meetings with the DAF Personnel Section, a case was made for the recruitment of contract data collection personnel.

Recruitment advertisements were prepared and interviews were held in August 2004. A panel was prepared and on October 4th 2004 six data collection persons were recruited on contract. These people were highly qualified professional foresters.

7.2 Training

A five week intensive training programme was delivered by IFER and the Forest Service in Co. Wexford (Figure 1). Training covered plot navigation, plot set up, data collection procedures, precision of measurements, care and maintenance of the equipment and data storage. Site safety and first-aid courses were also undertaken. Training also included a soils identification module (Radford, 2004) and a plant species identification module (Fahy, 2004).

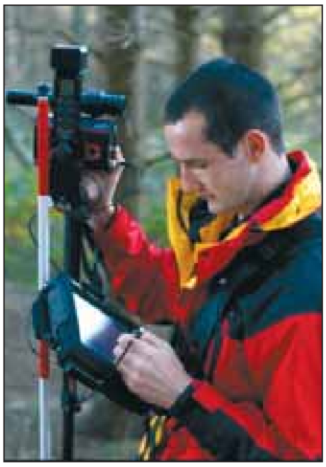

Figure 1. NFI training.

During the summer of 2004, further equipment had been purchased including differential GPS, laser and compass. At the culmination of training, a test was held and the group was divided into three two-person teams.

8. Data Collection

The period of data collection and quality control, staff substitution and the organisation of a public information day are outlined in this section.

8.1 Commence Data Collection

NFI sample plot measurement commenced with all three teams operating in Co Wicklow in November 2004. On-site advice and supervision was provided by the project co-ordinator.

Moving from a training situation into a working reality unearthed some equipment (e.g. spare parts) and procedural (e.g. data backup) deficiencies and these were resolved. As it was now mid winter, the shorter daylight did not help the progress of plot measurements.

A protocol for facilitating and securing entry to private forest lands had been developed and implemented. Advance notice of the project had been advertised in forestry related publications and regional newspapers. In addition, where possible, individual land owners were notified by the Forest Service of an impending NFI field-team visit. Coillte managers facilitated access by supplying keys to their forest properties. As work progressed, much more was learned about the durability of the equipment and it became obvious that an increased level of spare parts had to be carried to ensure continuity of work. There were regular update and discussion meetings between the three teams and project managers.

8.2 Continuing Data Collection

In January 2005 the teams dispersed to counties Mayo, Roscommon and Wexford. Work schedules took into account the home counties of the data collection persons, which meant that team members would complete the fieldwork in their home counties. The schedules were laid out in advance, and if changes had to be made team members were advised of the reasons for the changes.

The north-western team progressed through Mayo to Donegal and then to counties Clare and Galway. The team who had started in Wexford progressed to Cork. Since Cork is a very large county with many inventory plots, they were joined by the Roscommon team. During 2005 Munster was completed by these teams and then they moved to south Leinster.

Staff changes arose in September/October 2005 and a further four persons were recruited from the panel. The new recruits worked alongside the experienced people for some time and a further three-week training period with IFER personnel was completed. Further staff changes arose in early summer 2006 and two new staff were recruited. In addition, the Forest Service employed two forestry students for the 2006 summer period.

Mid Leinster was then completed, with only north Leinster, Sligo, Leitrim, Cavan and Monaghan remaining. These remaining counties were completed through the summer and autumn of 2006. The field data collection was completed on schedule by November 30th 2006, with the establishment of 1,742 permanent sample plots nationally (Figure 2).

8.3 Quality Control

As the project progressed, management staff made numerous site inspections of work procedures and the data collection protocol. In a further effort to implement and maintain quality control, re-calibration sessions were held regularly. These meetings were held on site with individual teams, and also included some group meetings to discuss methodology issues. A validation programme was conducted jointly by IFER and the Forest Service.

8.4 Staff Substitution

On occasion, regular data collection team members were absent for one reason or another. Almost all of the absences were planned and on these occasions substitute cover was provided by requesting the temporary assistance of local Forest Service District Inspectors. If possible, cover for unexpected absences of the regular staff was provided by a member of the NFI management team. On occasions when no cover was available, the remaining team member would visit check plots[1]. A "check plot" arose when the photo interpretation person could not decide if the particular plot qualified as forest or another land use type (LUT). If no work of this nature was available, the person was assigned to assist one of the other teams.

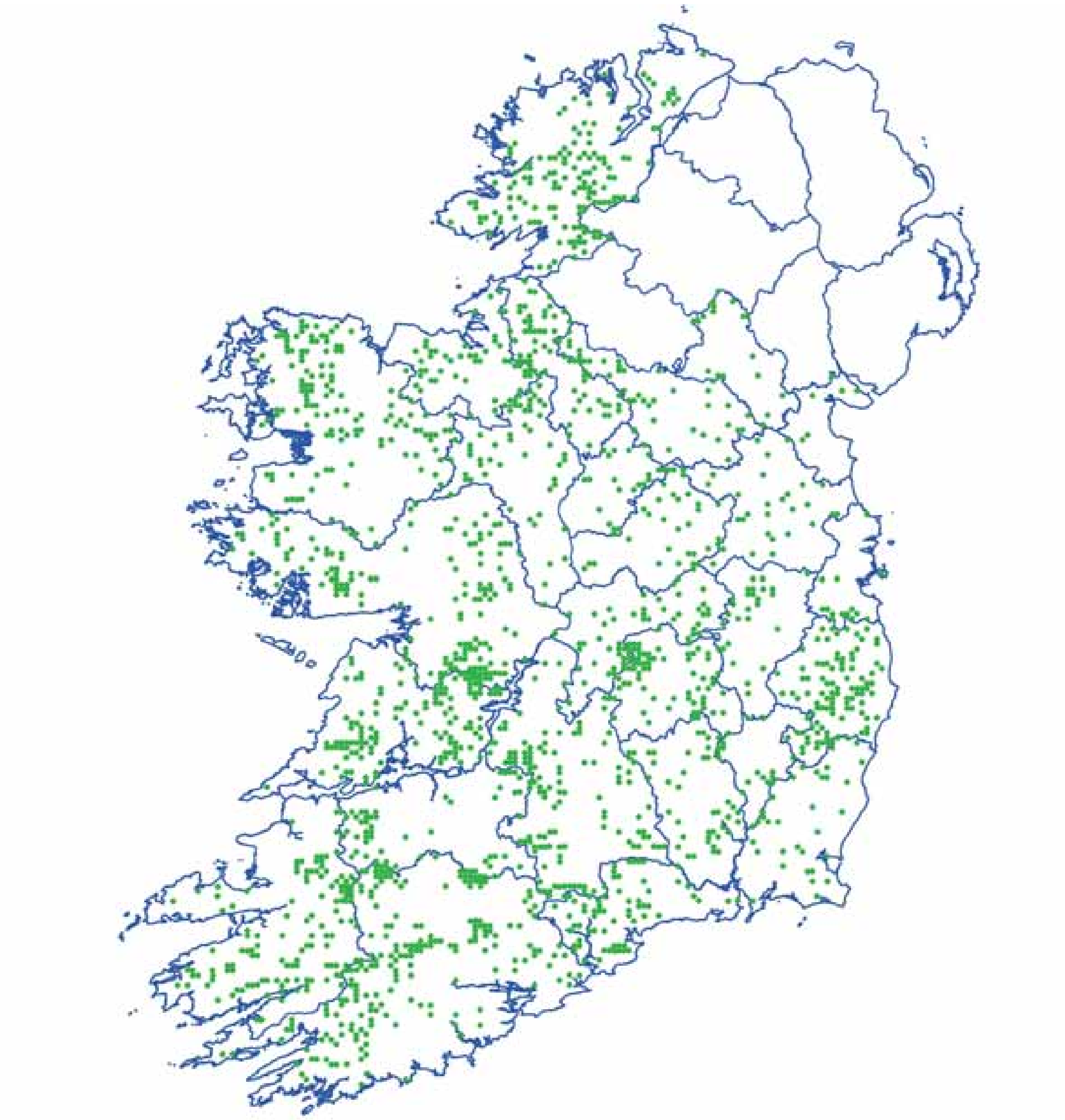

Figure 2. Distribution of the 1,742 NFI plots.
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[1] Check plots - It was not possible to definitively classify the land-use type prevailing on the inventory plot. Check plots were visited in the field for land-use type verification.

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8.5 Information Day

Throughout the data collection phase of the NFI, requests were received from interested parties who wished to see the data collection process at work in the field. Where possible, these people were accommodated with site visits provided such visits were anticipated not to be too disruptive to the work schedule. The management team also decided to hold a field demonstration of the hardware and the measurement systems for interested parties. This event took place on May 5th 2006 at Togher Wood, Portlaoise, courtesy of Coillte Teo.

The project management team also held an information meeting for an invited audience to outline the project and communicate general details of the expected results' format. This event was held on April 20th 2006 in Portlaoise. In the ensuing discussion, some suggestions were put forward which were later included in the reporting format.

9. NFI Results

Data checking and preliminary analysis began in December 2006 and continued until February 2007 with the production of some preliminary results. A results template was published in March 2007, initiating a one-month public consultation period. Submissions were received and these were taken into consideration in generating the final NFI results document.

9.1 Irish Interpretation

After the initial production of the NFI results it was decided that it was necessary to subject these results to an Irish interpretation. This task was undertaken by Dr. Gerhardt Gallagher and the NFI management team. The findings and results of the NFI were examined in detail, and appropriate explanatory comments were made where necessary. This interpretation, in turn, led to a refinement of outputs and expanded the NFI results to their present format.

9.2 Publication of Documents

Three main publications will arise from the NFI:

- NFI methodology
  This document describes the air photo interpretation exercise, navigation to the plot centre and defines all the attributes that were recorded in the field. The data analysis element describes the statistical procedures that were used to derive the estimates of the variables.
- Proceedings of the NFI results conference (this document)
  At the conference to describe and report the NFI results, five papers were delivered. These proceedings will summarise all stages of the NFI and will be a useful reference document for interested parties.
- NFI results
  This document contains ca. 150 statistical outputs (i.e. statistics) from the NFI.

9.3 Data Requests

It is anticipated that there will be numerous requests for specific data and result items arising from the NFI. All such requests will be honoured, if possible, conditional on the signing of a data release agreement form, and in the first instance should be directed to Mr. Paul Dunne at Johnstown Castle Estate, Co. Wexford or to his E-mail address: paul.dunne@agriculture.gov.ie.

10. Outstanding Tasks

The Forest Service intend to undertake additional analyses of the NFI data, specifically in relation to current annual increment (CAI). It is recognised that a truly accurate estimate of CAI can only be made after at least one subsequent NFI. However, it will be possible to provide a national estimate for CAI for the main species groups. This can be used to guide the estimation of allowable cut for those species assessed.

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The NFI management team wish to thank the field data collection teams for their work. Likewise all Forest Service personnel not directly involved in the project for their very welcome and valuable assistance with field data collection. In addition, the project team wish to acknowledge the administrative support, advice and assistance during the project.

The people who helped with the production of the NFI publications and who carried out the editorial work also deserve sincere thanks.

The advice and guidance of the NFI Advisory Committee is also acknowledged, as is the contribution of the NFI Management Board.

Finally, the NFI management team wish to acknowledge the immense contribution that IFER have made to this project, and wish to thank them sincerely for their professionalism in seeing it through to this stage.

METHODOLOGY OF IRELAND'S NATIONAL FOREST INVENTORY

Mark Twomey, Martin Černý, Radek Russ and John Redmond

1. BACKGROUND

The National Forest Inventory (NFI) was the first, purely statistical approach to forest inventory undertaken in both the public and private national forest estates. The field data collection element of the project began in November 2004 and was completed in November 2006. The primary purpose of this methodology paper is to summarise the methodology applied in Ireland's NFI.

2. OVERVIEW OF INVENTORY DESIGN

Ireland's NFI is based on a randomised systematic grid sample design. As a result of a pilot study in Co. Wexford, a grid density of 2 km x 2 km (Figure 1) was estimated to provide the frequency of plots needed to achieve a national estimate of volume with a precision of ±5%, at the 95% confidence level. This grid density equated to 17,423 points nationally, each representing approximately 400 ha.

The first element of the sample selection process involved placing a 2 km x 2 km grid over the total land base of Ireland (6,976,100 ha). Air photo interpretation was used to classify sample points into land-use types, primarily Forest and Non-Forest. This process identified plots that occur in forest or potentially in forest, and these became the focus of a detailed field survey.

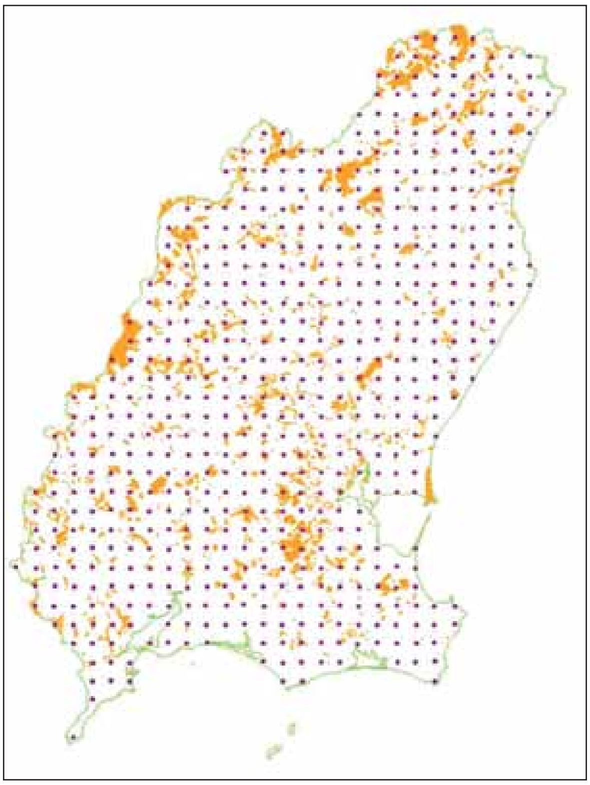
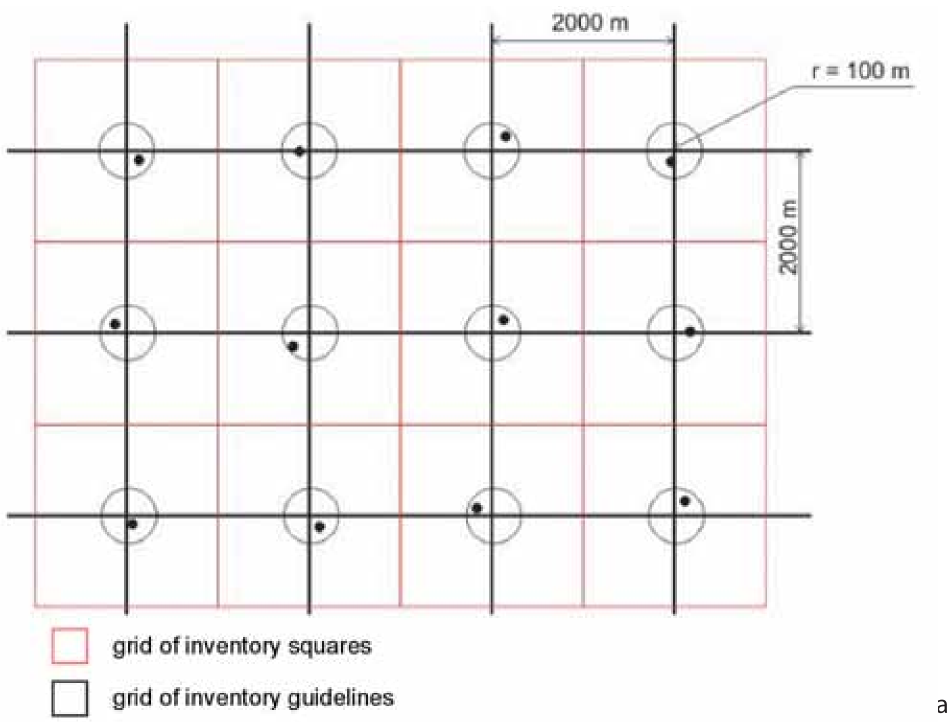


Figure 1. Primary sample grid for Co. Wexford.

3. SAMPLING DESIGN

A permanent inventory plot was established at a random location within 100 m of the 2 km by 2 km intersection (Figure 2). Thus the relationship between individual plots may be considered random. This displacement feature also ensures that plot locations are kept confidential, as knowledge of their locations could influence future management decisions.

As the grid was permanent, it allows for the re-assessment of the sample points at future dates, to monitor forest land-use change (i.e. afforestation and deforestation). The location of the sample plots was given by x and y grid co-ordinates, available as six digit Irish national grid co-ordinates.



are land-use type, land-use category and land-use class (Figure 3). They form the basis of the NFI, as the classification process dictates whether the sample points are included in the NFI or not, and the range of attributes to be collected at the individual sample points.

The initial stage classified the 2 km x 2 km grid (17,423 sample points) into Forest and Non-Forest **land-use types** (LUT) using air photo interpretation. This desk based exercise is detailed fully in the subsequent sub-section.

NFI plots with a land-use type of Forest and Check plot became the focus of the ground survey. The first attribute to be assessed after locating the plot centre was **land-use category**, which includes: Forest, Forest Open Area and Non-Forest (section 6.2). Plots classified as Forest and Forest Open Area were established as permanent sample points and became the focus of the NFI.

The final stage of classification involved the assignment of a **land-use class**, which gave a more detailed description of the sample point. This information was also used to update the air photo interpretation results.

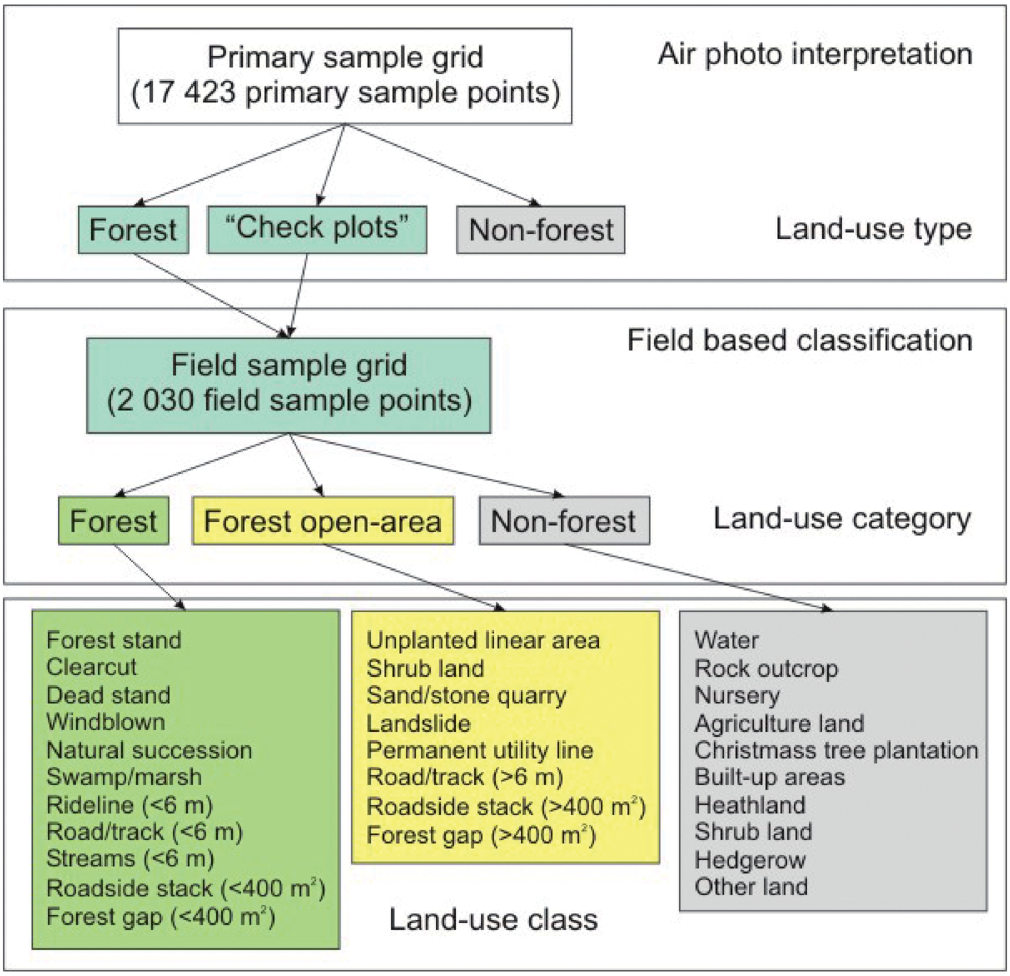


Figure 3. Overview of NFI land-use classification.

4.1 Air Photo Interpretation

Classification of LUT was carried out by five foresters who had considerable field experience in collecting NFI data, including the use of air photos during the navigation to plots.

In order to classify the sample points, it was necessary to view the air photos, using a GIS, at a scale of at least 1:15,000. In some cases it was necessary to zoom-in, beyond this scale, into each individual sample point to a scale of 1:5,000, in order to clearly identify the LUT. The provision of additional vector detail, in a GIS, also aided the identification process (Figure 4).

Interpretation was based on the criteria established in the forest definition. If it was unclear whether a sample point should be classified as Forest or another LUT, the sample point was classified as a Check plot. Sample points classified as either Forest or Check plot became the focus of the ground survey.

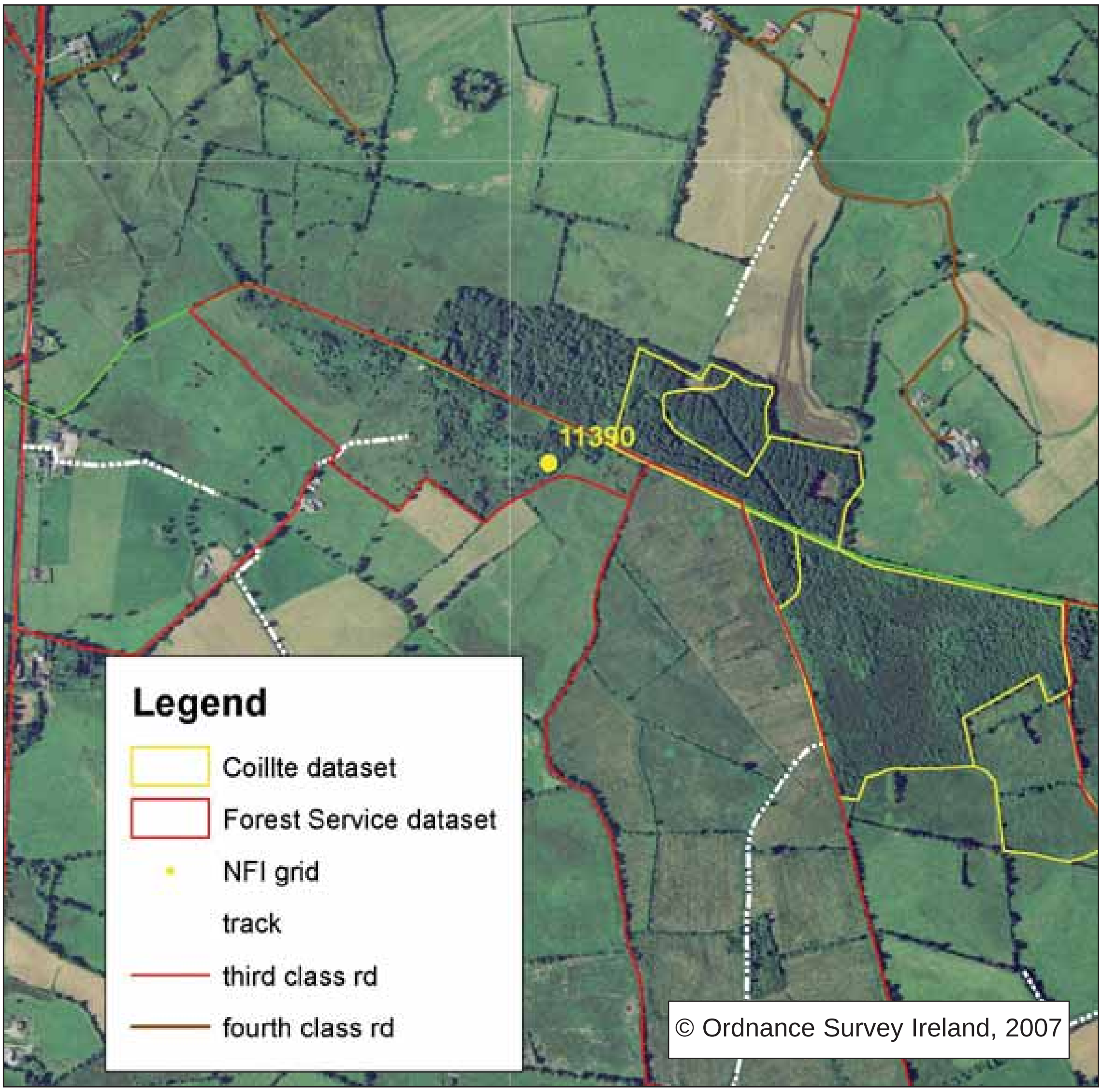


Figure 4. Air photo interpretation datasets.

4.1.1 Data sources

In this section, the datasets used in the air photo interpretation exercise are presented. All available digital information was consulted in the decision-making process.

Primary dataset

The primary dataset used in the NFI consisted of air photographs obtained from the Ordnance Survey of Ireland (OSi). Complete coverage was available for the 2000 air photos and 35% coverage for the 2004 air photos. The technical specifications of the air photos used are shown in Table 1. The first photo interpretation exercise was carried out in early 2005 using air photos made during 2000. This was reviewed in late 2006 using air photos made during 2004.

Table 1. Details of the air photos used in the NFI.

Details	Description
Scale	1:40,000
Data format	Tiff
Pixel size	1 m x 1 m
Year of flight	2000 + 2004
Specifications	2 km x 1.5 km
Number of photos	26,500 approximately
Individual file size	8 MB approximately

Secondary datasets

In order to capture forests that may not be apparent on the air photos, e.g. recently planted forests (planted 2000-2006), three forest datasets were used to aid the identification of Forest and Non-Forest areas. These forest maps were draped over the sample points in 'wire-frame' format and used as an indicative guide as to where forests were located. These secondary datasets are listed as follows:

- A database map containing all **Forest Service** grant and premium aided plantations, 1990-2006.
- Forest maps from the **Forest Inventory and Planning System (FIPS)** survey, identifying the distribution of the national forest estate in Ireland in 1998.
- **Coillte Teoranta** provided its comprehensive forest inventory dataset for all the forest land they manage. This database provides crop information such as age and species.

4.1.2 Land-use types

The LUTs used in the air photo interpretation exercise (Table 2) are based on land cover maps developed by Teagasc (Irish Agriculture and Food Development Authority) (Fealy *et al.*, 2006). The LUTs also have sufficient scope to enable re-classification into broader land-use categories, such as those which are consistent with IPCC guidelines and with the requirements of LULUCF, as specified under article 3.4 of the Kyoto protocol (IPCC, 2001).

Table 2. Land-use types used in the NFI.

Land-use type	Land-use type
Forest	Green space (urban)
Bareland within forest ownership boundary	Green space (rural)
Check plots	Coastal complex
Other woodland	Cropland
Individual tree	Grassland/forage/pasture
Hedgerow	Water bodies
Stonewall	Sea
Bare rock	Quarry
Bare soil	Paved road
Bog and heath	Sand
Cutover peat (industrial)	Shrub
Cutover peat (domestic)	Deforestation
Built land (urban)	Other
Built land (rural)	

5. Preparation for Ground Survey

Plots classified as Forest or Check in the primary sample are referred to as the ground survey plots. These ground survey plots became permanent sample plots if they were classed as Forest or Forest Open Area when visited in the field.

5.1 Preparation of Background Maps and Information

The preparation phase for the NFI field assessment includes the collation of background information and the preparation of maps. The collection of background information on each of the ground survey plots aided in locating the plot and provided background details, such as tree age. Stand details were provided by Coillte and extracted from internal Forest Service datasets. Where possible, ownership details were used to contact private owners whose land contained ground survey plots. Private landowners were notified by letter of the impending visit of field teams to their area. In order to aid efficient navigation to plot centres and efficient work planning, field teams used the following:

1. 1:50,000 OSi Discovery Series map to aid general plot location and work planning (Figure 5).
2. Colour air photos at 1:10,000 scale, to aid this process.
3. Digital maps, such as forest boundaries and road infrastructure, are pre-loaded into the field-computer. This helps to complete the navigation to the plot centre.

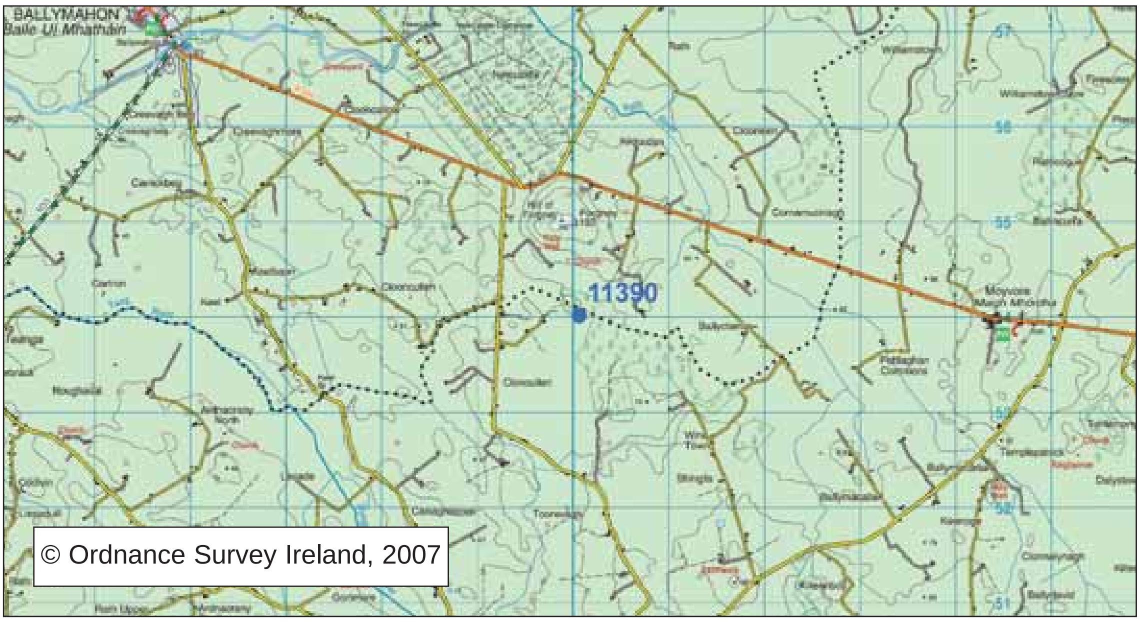


Figure 5. Example of general plot location on OSi discovery series.

6. Establishment of the Plot Centre

Navigation to the plot centre, land-use categories and forest boundaries are described in this section.

6.1 Navigation to the Plot Centre

Being able to precisely locate the plot centre was essential in the assignment of a definitive land-use categories. In the field, the exact location of the centre of NFI plots was found by navigating to a six-figure national grid co-ordinate, using a combination of GPS and compass/laser technology.

Field teams navigate as close as possible to the plot centre using a GPS and mark the position on the ground. Due to the variation in the individual GPS readings around the true position, navigation to the plot centre was completed with the compass/laser. The use of the compass/laser to complete navigation also overcomes any issues with dense canopy cover, which restricts GPS use.

The laser provides range-finding functionality (i.e. distance), while the electronic compass indicates the direction of travel (i.e. azimuth). Magnetic declination (i.e. angular offset of the magnetic north from true north) was calculated prior to navigation in the area where measurements would take place. This declination was incorporated into the electronic compass prior to locating the plot centre. An azimuth precision test was performed to ensure that no local magnetic field was affecting compass readings. Precision of plot centre location was between one and five metres, and was dependent on the achieved precision of the GPS position measurement and on the distance of navigation with the compass/laser. The plot centre was marked with a pole and referred to as the Generated Origin. High specification GPS and compass/laser equipment enables highly accurate plot location, which ultimately determines the land-use class. The plot centre becomes the permanent origin of the local cartesian[1] coordinate system to which all the measured entities (i.e. trees) are referenced. If the plot centre does not provide an ideal location for measurement, due to the obstruction of line(s) of sight, an out-of-centre measurement procedure was used enabling measurement to take place from any point inside or outside of the plot, which has been referenced to the plot centre.

6.2 Land-use Categories

The point on the ground where the plot centre was located was classified into one of three land-use categories: Forest, Forest Open Area, or Non-Forest. The total forest area includes both Forest and Forest Open Area. The NFI definitions reflect the high resolution of both the datasets and the field technology used to survey Ireland's forests.

6.2.1 Forest

Land with a minimum area of 0.1 hectare, a minimum width of 20 m, trees higher than 5 m and a canopy cover of more than 20% within the forest boundary, or trees able to reach these thresholds *in situ*.

Explanatory notes on Forest definition:

1. A tree is a woody perennial of a species forming a single main stem or several stems, and having a definitive crown.
2. It Includes windbreaks, shelterbelts and corridors of trees with an area of more than 0.1 ha and a minimum width of 20 m.

[1] A cartesian coordinate system was used to determine each point uniquely in a plane through two numbers, usually called the x-coordinate and the y-coordinate of the point.

3. Forest was determined both by the presence of trees/stumps and the absence of other predominant land-uses. Areas under reforestation that have not yet reached but are expected to reach a canopy cover of 20% and a minimum tree height of 5 m are included, as are temporarily unstocked areas, resulting from human intervention or natural causes, which are expected to be restocked.
4. The forest area was determined by the forest boundary. The term forest boundary was defined by any man-made boundary enclosing the forest area or, in the absence of such boundary feature, the boundary of the forest was determined by extending out 1 m from the position of the pith-line[2] of the outermost trees.
5. The forest area includes forest roads, firebreaks and other small open areas on forest land; forest in national parks, nature reserves and other protected areas such as those of specific scientific, historical, cultural or spiritual interest.
6. The forest area excludes tree stands in agricultural production systems, for example in fruit plantations and Christmas tree plantations.
7. The term also includes trees in urban parks and gardens, provided these areas satisfy the forest definition.

6.2.2 Forest Open Area

Forest Open Area is a non-stocked area (>400 m^2 and <2 ha) enclosed within the forest boundary.

Forest Open Area is an integral component of Irish forests (Figure 6). No other land-use should predominate on the site, such as grazing or peat harvesting. A 2 ha upper limit was adopted as open areas larger than this are deemed not to be integral to the forest. Areas greater than 2 ha and surrounded by trees are classified as Non-Forest. These areas occur mainly in the public estate and are usually deemed unplantable owing to climatic, fertility or legal constraints.

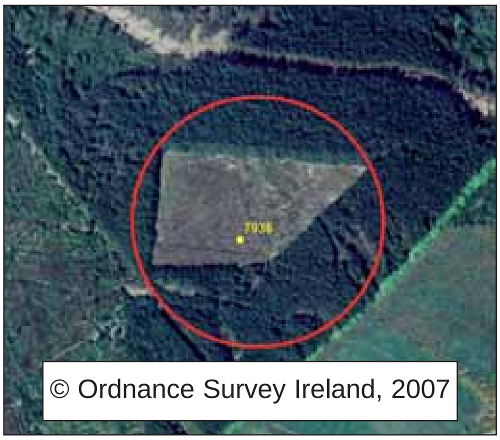


Figure 6. Forest Open Area, 1.8 ha in size.

6.2.3 Non-Forest

Areas that do not conform to the Forest or Forest Open Area definitions.

6.3 Forest Boundary

Being clearly able to identify the boundary between the land-use category was essential for the precise assignment of land-use category to the ground survey plot. The forest area was determined by using the forest boundary. The term forest boundary is defined by **any man-made boundary enclosing the forest area or, in the absence of such boundary feature, the boundary of the forest is determined by extending 1 m from the position of the pith-line of the outermost trees.**

[2] Pith-line is a national line connecting the ground-level tree piths/centres of the outermost trees. Where the trees have been planted this is commonly referred to as the planting line.

Explanatory notes of Forest Boundary:

1. The presence of man-made boundaries delineating parcels of land are a well-defined feature on the Irish landscape, i.e. hedgerow, sod-bank, stream, river, stonewall, drain, road centre and wire fence. The centres of boundary features and/or their positions relative to the pith-line of outermost trees will identify the Forest or Forest Open Area boundary.
2. In the absence of any boundary features, the edge of the Forest was determined by extending out 1 m from the position of the pith-line of the outermost tree (Figure 7).
3. All areas where the boundary feature was >5 m and <20 m from the pith-line are classified as Forest Open Area.
4. All areas where the boundary feature was <5 m from the pith-line are classified as forest.
5. Outlier trees more than 20 m from the nearest tree in the main body of trees will not be included in the forest (Figure 8). Examples of this usually occur in natural succession land.

It was also important to restate that Forest was defined both by the presence of trees/stumps and by the **absence of other predominant land-uses**. For example, a canopy of trees may be considered continuous from air photo interpretation. However, a feature on the ground (such as a fence) may dictate a change to another predominant land-use.

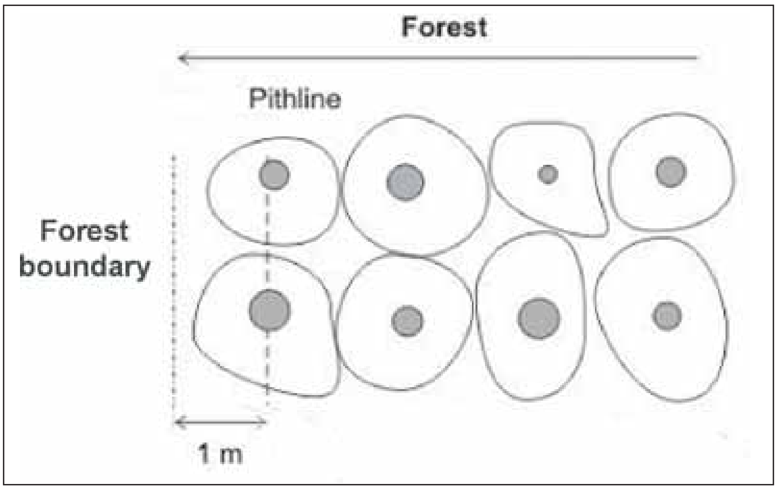


Figure 7. Establishing the Forest boundary where there is no boundary feature.

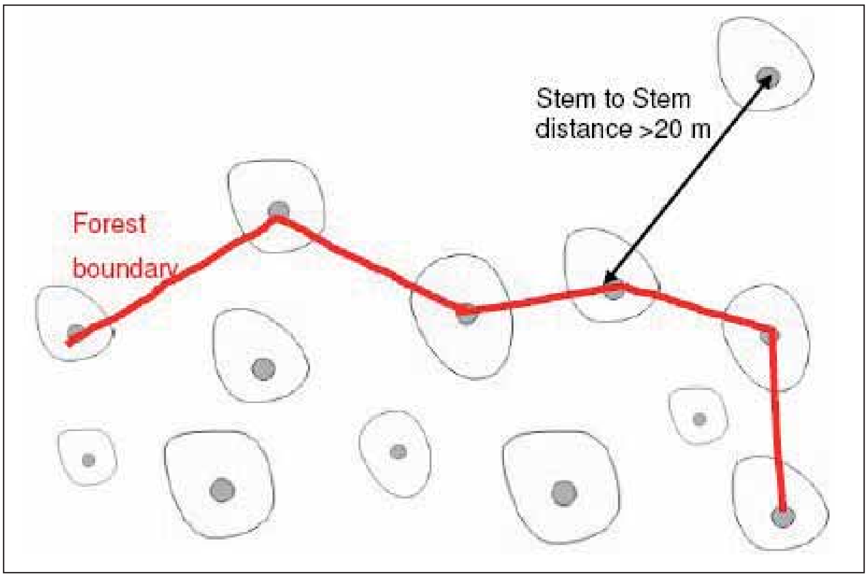


Figure 8. Identifying outlier trees.

7. Data Collection Overview

In this section the hardware and software used during field data collection is described and an overview of the attributes assessed is given.

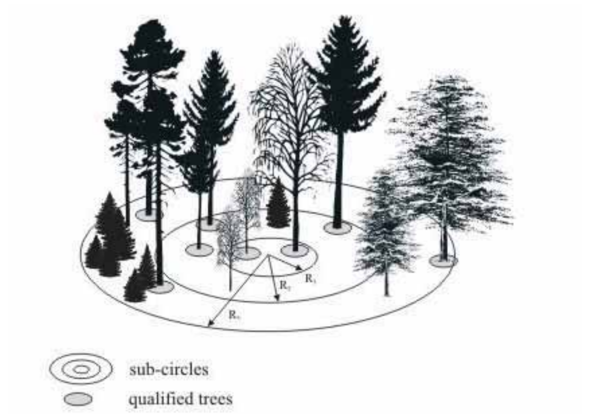
7.1 Hardware and Software

The underlying technology used in the NFI ground survey consisted of an integrated system of hardware and software developed by IFER. The specialised inventory software, Field-Map™, allows for the preparation of a NFI database and background maps, and plot generation. This in turn provides for the creation of projects for field teams, which facilitates the field data collection process. The data was stored directly into a computer database in the field. Inventory data were uploaded to a central database via USB memory sticks.

The NFI database is a fully relational database, containing 127 tables. The database also features a spatial map component, which is a layer containing the locations of field plots and ancillary background map data used for navigation to field plots. Selected layers (e.g. trees) have a spatial reference (i.e. position relative to the plot centre).

7.2 Plot Design

The concentric circle approach, comprising three concentric circles with different radii was used for tree assessment. Trees of different dimensions are mapped and described on each particular plot (Figure 9). The decision about which tree was considered to be qualified was based on its position on the plot and its dbh. These sub-plot radii and threshold dbh for these subplots are presented in Figure 9.



	R_1	R_2	R_3
Sub-circle radius (m)	3	7	12,62
Sub-circle area (m^2)	28,3	153,9	500
Treshold diameter (mm)	70	120	200

Figure 9. Concentric plot design.

7.3 Overview of Attributes Assessed

Ireland's NFI assessed the current state and development of the forest estate in relation to standing trees, forest structure, forest regeneration, deadwood, soil and other site characteristics. The primary attributes collected are displayed in Table 3.

Site characteristics, with reference to the entire plot, were described in detail, such as altitude, soil type, terrain. The presence/absence of tree lichens was also noted. Ground vegetation over the whole plot was identified and quantified as a percentage cover on the plot. The dimensions and quantities of deadwood were also assessed; this included stumps, lying and standing deadwood.

A description of the forest stand in the 12.62 m plot was undertaken using attributes similar to those collected in stand level inventories, such as forest type, growth stage and thin status. The total number of all trees with a minimum height of 20 cm was recorded on the 7 m plot.

Table 3. Main NFI attributes.

Plot	**Deadwood**
Plot id	Branch cover
Plot area	Stumps presence
Land-use category	Stump diameter, height and decay status
Geographic coordinates	Dead logs presence
Forest structure	Dead logs distribution
Stand layer type, canopy closure and composition	Dead log mid-diameter, length and decay status
Social status	Valuable site identification
Fork	Game accessibility and food
Dead tree	**Site**
Forest diversity	Altitude
Species composition	Relief form
Species composure	Aspect
Diameter and height diversity	Slope
Production	Erosion
Dbh	Anthropogenic factor
Upper diameter	Humus form
Upper diameter height	Soil condition
Tree height	Group soil
Live crown base	Parent material
Dead crown base	Principal soil
Stem quality (straightness, branchiness)	Peat texture
Damage	Soil texture
Negative factor limiting regeneration	Drainage
Type, intensity and age of regeneration tree damage	Moisture
Tree mechanical damage type, intensity and age	Soil depth
Peeling intensity and age	Peat depth
Stem rot	Litter description
Tree break	**Regeneration**
Tree root damage type, intensity and age	Presence
Other tree damage type	Origin
Defoliation	Protection
Defoliation of tree top	Regeneration distribution
Type and intensity of discoloration	Species mixture
Broadleaf damage	Species and age composition
Ecosystem	Height class
Lichens presence and type	Regeneration tree number
Plants species and cover	**Forest management**
Shrub species and cover	Ownership
Grass cover	Forest type
Herb cover	Forest subtype
Moss cover	Forest naturalness
Fern cover	Cultivation type
Brush cover	Growth stage
Shrub cover	Thin status
	Rotation type
	Stocking

Small planted trees with a maximum dbh of 69 mm were assessed on the 3 m plot. Naturally regenerated small trees with a maximum dbh of 69 mm and minimum height of 20 cm were also included.

Tree positions were mapped using a combination of electronic compass and laser. The dbh of each tree was recorded, along with other descriptive parameters such as species, age, social status, timber quality, branchiness and damage. A sub-sample of a maximum of seven trees per species were selected for height measurement, based on the distribution of dbh of the measured trees (Figure 10). An upper stem and base diameter were measured for a maximum of five trees (dbh $\geq$ 200 mm) for the primary species and three trees for each other species present. The upper diameter is measured using a remote diameter scope. For all height sample trees, a horizontal crown projection was measured. Vitality was assessed for all 'height trees' of *spruce, pine, oak* and *beech* species which were dominant or co-dominant (crown was in the upper level).

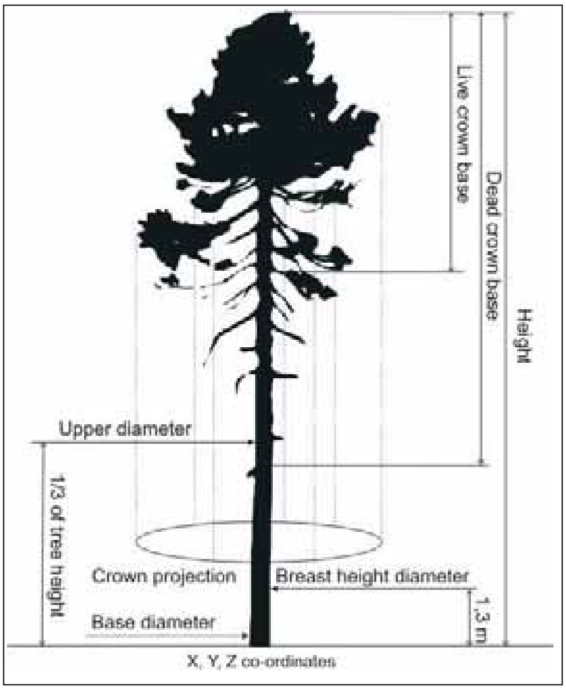


Figure 10. Visual representation of tree data collected.

7.4 Data Verification

Prior to leaving the plot the operator carries out comprehensive data checks, which are divided into three steps:

1. Missing data check – Field-Map searches for all missing data which are required and lists the missing items.
2. Data verification script – Field-Map checks defined logical relations and lists errors or possible errors. For example, slenderness ratio is used to check possible errors in dbh and height measurement.
3. Visual check – The operator checks the dbh distribution graph and also the height x dbh graph for possible

8. Validation Process

A total of 50 plots were included in the NFI validation exercise (Figure 11). The validation work was undertaken by one team, comprised of one Forest Service and one IFER staff member.

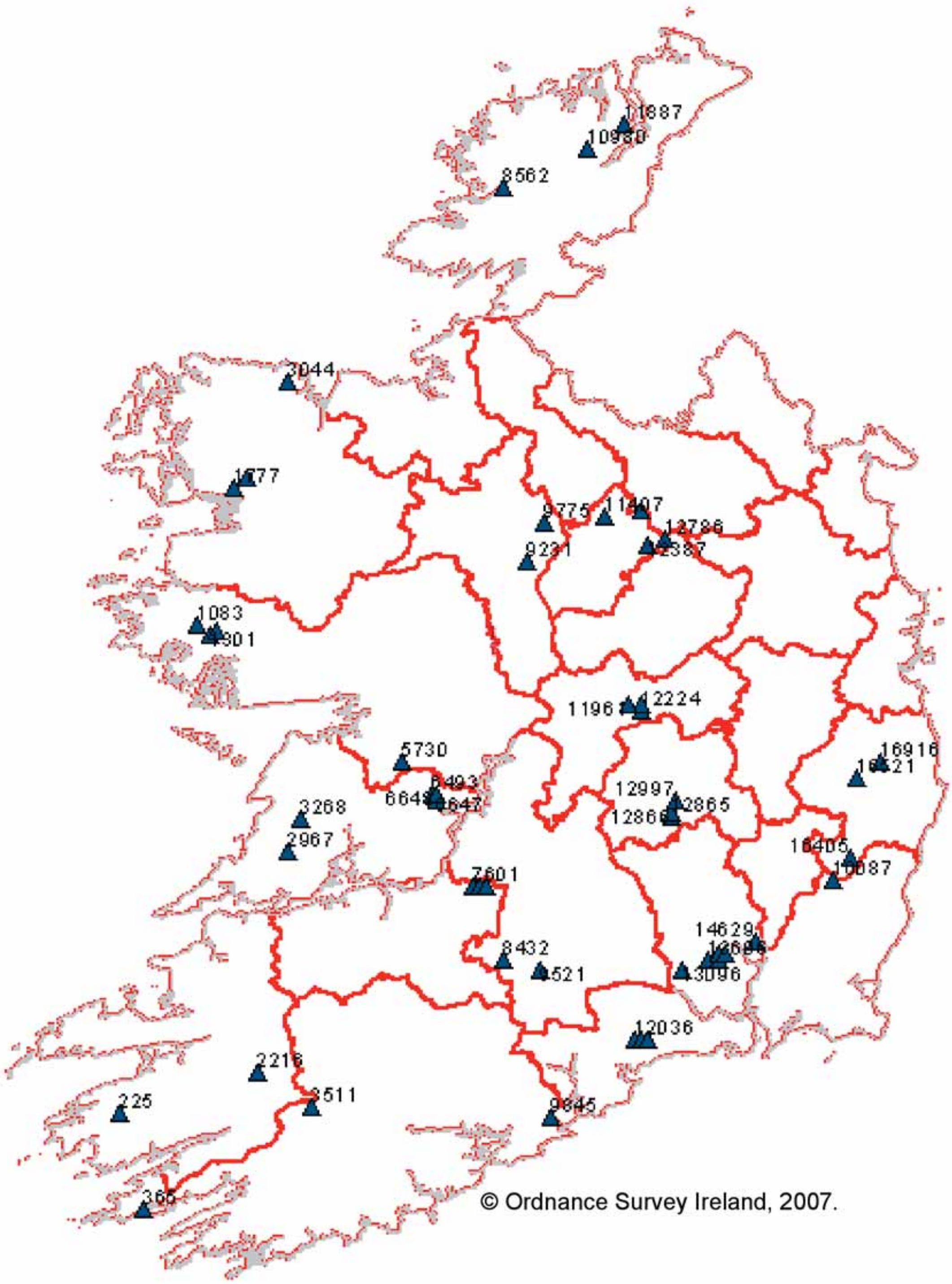


Figure 11. Location of validation plots.

8.1 Validation Methodology

The individual team make-up was subject to considerable and ongoing change over the course of the validation campaigns and thus validation plot selection had to be from across the range of the individual members and the team combinations. In order to select and achieve objective sampling of the validation plots, stratified random sampling was used. The sampling frame (i.e. grid of completed plots) was stratified by field team, with selection being proportional to the number of plots completed by each.

All validation plots were completely re-measured and described using the same technology and methodology as used by the NFI field teams. A direct, on-site comparison of the data collected by the field-team with the validation data was carried out at the end of each plot validation. The individual trees were identified from the field team data and all the tree attributes were compared using a customised Field-Map™ software extension. Important differences were discussed directly at the forest plot, and trees with a significant dbh or height difference were re-measured to verify the validation measurements.

8.1.2 Ranking system

Each plot was given an overall ranking as to the quality of the original data obtained by the field team when compared with the validation data. The overall ranking is a summation of general rankings and is divided into three categories for each plot, which are weighted according to the importance of the category:

1. **Dendrometric and equipment measurement:** this ranks the quality of all equipment-measured attributes on the plot and is mainly concerned with tree measurement. If plot has trees ≥ 70mm, then the mistake weight is 3, otherwise 1.
2. **Trees and forest layers description:** this ranks the descriptive attributes associated with the trees on the plot e.g. Species identification, stand layer, deadwood and small trees description. Mistake weight is 2.
3. **Site description:** describes all non-tree attributes e.g. soil, plants, lichens, etc. If plot has trees <70mm or no trees, then the mistake weight is 3, otherwise 1.

8.2 Validation Results

Out of 50 plots, the number to be re-measured was 5 (10%), the number categorised as 'acceptable' was 16 (32%) and those termed as 'good' was 29 (58 %). The validation results showed that, in general, data quality was good and that the data will form a reliable basis for the generation of results. Based on the validation results, a number of actions were taken with the view to maximising data quality.

8.2.1 Plot re-measurement

The validation process identified three counties where the plot data were not of sufficient quality. In the interest of maximising data quality, which ultimately increases the precision of the results, NFI plots in counties Longford, Roscommon and Wicklow were re-measured. Only those plots that had individual mapped trees with a dbh ≥70 mm were re-measured, as the validation showed that plots with trees with a dbh <70 mm were of good quality.

8.2.2 Field team update

To ensure the consistent classification of NFI attributes, field teams were brought together for briefing sessions following each stage of the validation exercises. During these sessions, all field team members would discuss the classification of attributes. This ensured consistency in the classification of NFI attributes across all field-teams.

8.2.3 Project management

The validation process also identified a plot on which assessment had begun but not completed. This was due to a project management oversight and led to the establishment of a tracking system for monitoring the completion of plots.

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National Forest Inventory of Ireland – Data Processing

Martin Černý, John Redmond, Radek Russ and Kevin Black

1. Introduction

The National Forest Inventory (NFI) of Ireland is based on a randomised systematic grid (2 km x 2 km) covering the land base of Ireland. A permanent inventory plot was established at a random location within 100 m around the 2 km by 2 km intersection. Thus the relationship between individual plots may be considered random. Inventory plots are of circular shape (500 m^2) with smaller concentric sub-circles used for the assessment of lower dimension trees.

The ground-based field survey included standing trees as well as forest regeneration, deadwood and site characteristics. Altogether, about 170 various primary attributes have been recorded in the field.

The total number of NFI plots was 17,423. The sampling intensity is 0.0125% i.e. each square metre of an inventory plot represents 8,010.7 square meters nationally. The number of plots classified as forest was 1,742 and trees were recorded at 1,562 plots. Total number of recorded trees, including regeneration, was 24,946 and the number of trees with diameter at breast height (dbh) over 7 cm was 22,477.

After multiple checks and validation of the field data, the data processing procedures were performed. The data processing consists of two major steps: ***i)*** calculation of the secondary attributes, i.e. attributes which values are calculated from the primary attributes, and ***ii)*** statistical data processing of NFI data.

2. Secondary Attributes

Prior to the statistical data processing it was necessary to add a number of attributes to the database, which were determined using various methods.

2.1 Tree Height

A sub-sample of trees were measured for tree height during the field survey, with a maximum of seven trees (dbh $\geq$ 70 mm) per species per plot measured. The sample trees were chosen regularly along the range of tree diameters within the plot. Based on this rule, 7,559 (i.e. 33.6%) of the 22,477 trees have been measured for height. For the height model calculations, only live and undamaged trees were used.

2.1.1 Modelling tree height

Based on the number of height sample trees per plot, a dbh-height model was calculated. Wherever the number of sampled height trees for a species within a plot was sufficient, greater than four, the local (i.e. plot) model was parameterised using linear or non-linear least squares methods. If the parameterisation of the local model was not carried out due to an insufficient number of measured trees or their unfavourable distribution then the global model (i.e. species model for all plots) was used.

Three dbh-height models were used (Table 1). Chapman-Richards exponential model, which is often used for growth modelling, is very flexible and accurately describes the dbh-height relationship. It is efficient, especially for global models where a large number of measurements are involved. The other two models were used if the model higher in hierarchy could not be parameterised. Model number 1 was used in 14.8% of cases, model number 1 with P_3 fixed to 0.7 was used in 78.9% of cases, model number 2 in 6.0% and model number 3 in 0.3% of cases.

Table 1. Models for dbh-height relationship

Model	Equation	Adjustment of global model
1 exponential (Chapman-Richards)	$h = 1.3 + P_1 \times \left(1 - e^{-P_2 \times dbh}\right)^{\frac{1}{P_3}}$	P_1
2 exponential	$h = 1.3 + e^{P_1 + \frac{P_2}{dbh}}$	P_1
3 logarithm	$h = 1.3 + P_1 + P_2 \times \ln(dbh)$	P_1

The overall model fit is demonstrated using the chart of predicted versus observed heights (Figure 1). The standard deviation of 1.0 m and correlation coefficient of 0.98 demonstrate good fit.

Examples of dbh-height models for particular species within individual inventory plots are presented in Figures 2 and 3. If the number of measured tree is sufficient then the local model is parameterised and used for the height calculation (Figure 2). If the local model could not be parameterised, then the global model for the respective species was used. However if at least one tree has been measured then the global model was adjusted using the available data (Figure 3). One of the parameters (Table 1) was adjusted using the least square method whereas the other parameters of the global model remained unchanged. Thus the global model was localised for a particular inventory plot. An example of the global model for Sitka spruce is presented in Figure 4. The global model has a characteristic curve, representing a mean height for a given diameter, for the whole country. Considering the method of localisation, the global model can be considered as a family of curves.

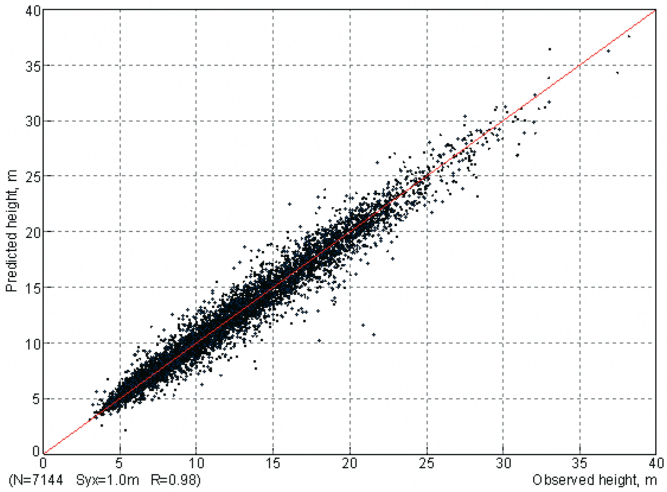


Figure 1. Predicted versus observed tree height.

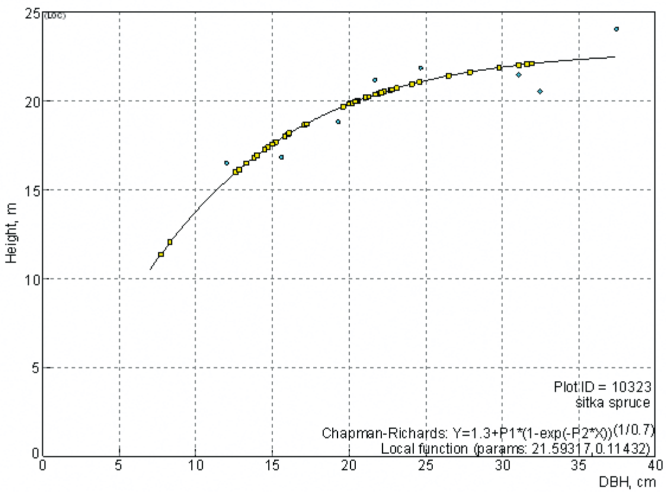


Figure 2. Example of local dbh-height model for an inventory plot (Plot No. 10323).

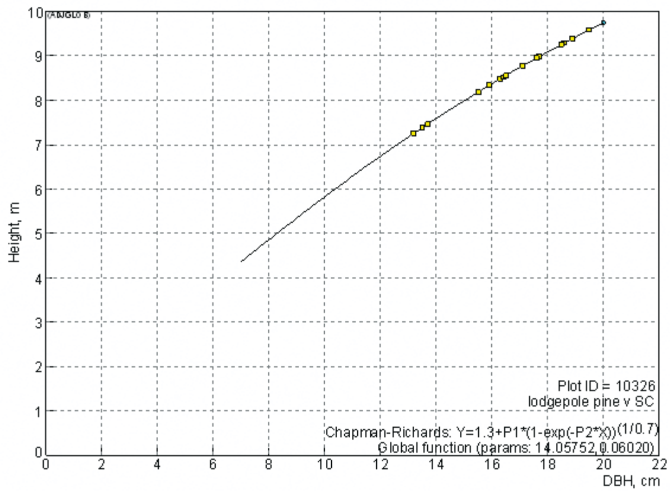


Figure 3. Example of the use of global dbh-height model for an inventory plot; adjusted using one measured tree (Plot No. 10326).

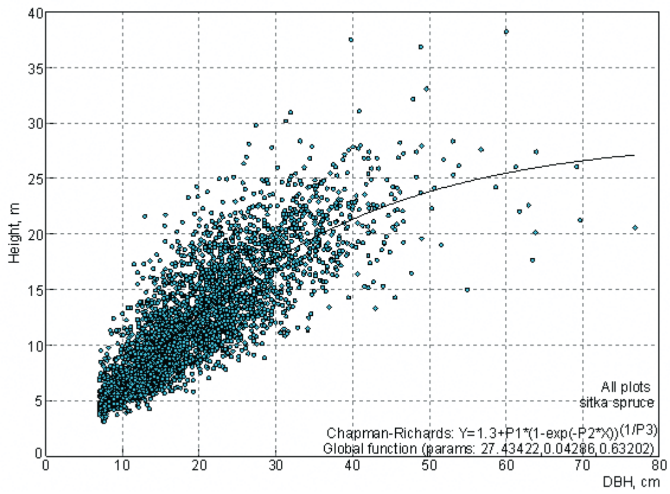


Figure 4. Example of the global dbh-height model (Sitka spruce).

The modelled tree heights were used for all further analysis involving tree height, even for those trees for which height was directly measured in the field. In fact, there was very little difference when measured or modelled height was used, because the dbh-height model has been parameterised using NFI data and the sum of residuals is minimised – the estimate is unbiased. Consideration was given for future surveys where the use of modelled values will be more appropriate. The height increment will be calculated as the difference of the consecutive modelled tree height values for every tree. Since there is no guarantee that the particular tree will be again measured for height in the field, the calculated difference might combine growth and deviation from the model for those trees which were measured only once. This will not happen if modelled heights are used in consecutive inventories.

2.1.2 Broadleaf timber height

Tree height is an important attribute for a number of subsequent calculations particularly for tree volume, biomass and carbon content. It was intended to use new national volume equations for Ireland which will be based on total tree height. This research project is currently underway and will provide an alternative to the Forestry Commission equations which were used in this NFI.

The Forestry Commission tariffs (Matthews and Mackie, 2006), which have been used for broadleaf species, require timber height as an input variable. Timber height concerns merchantable material only, and is the distance from the base to the highest point on the main stem where the diameter is not less than 7 cm top diameter overbark (Matthews and Mackie, 2006). The spring of the crown is frequently the timber point, but it may extend into the crown if there are merchantable lengths present. As the NFI collected total tree height, this had to be adjusted to timber height.

Three species were selected for sampling: oak, beech and ash. Thirty sites were sampled for each tree species across the land base of Ireland, with ten trees measured at each site. The dbh, total height and timber height was measured for each tree. The ratio between timber height and total height for oak, ash and beech was: 0.477, 0.470 and 0.449 respectively (Table 2). While this procedure may not represent the true situation at an individual tree level, it was deemed to be an acceptable procedure for the purposes of estimating broadleaf volume at a national level.

Table 2. The ratio between timber height and total height.

Species	Mean value	Confidence interval (a=0.05)	Sample size
Oak	0.477	±0.012	330
Ash	0.470	±0.023	311
Beech	0.449	±0.013	310

2.2 Tree Volume

The Forestry Commission single tree volume equations and tariffs (Matthews and Mackie, 2006) were used to estimate standing merchantable overbark volume for each tree on the plot with a minimum dbh of 70 mm. Conifer stem volume was measured from ground to 70 mm top diameter. Broadleaf stem volume was measured from ground to timber height.

The values of calculated timber volume are not fully compatible with the European standards which are gradually being established as a stump to tip volume of the stem overbark. It is expected that the volume or growing stock for Ireland will be re-calculated when the new national volume equations for Ireland become available.

2.2.1 Volume assortments

Tree volume was categorised by top diameter, on the basis of individual tree dbh (Matthews and Mackie, 2006). The percentage overbark volume to specified overbark top diameter (no minimum length) was calculated for three assortment categories:

- Pulp (7-13.9 cm top diameter)
- Pallet (14-19.9 cm top diameter)
- Sawlog (20cm+ top diameter).

Total volume stock by top diameter assortment assumes that there are no defects in the trees and all timber is merchantable. The reality in any forest stand is that there are factors, such as stem break or forking that will reduce the recoverable timber. Table 3 outlines how other NFI attributes (fork, tree break and stem straightness) were used to adjust the volume based on top diameter class to a more realistic potential end product volume.

Table 3. Volume assortment downgrading basis.

Variable	Category	Downgrade to
Fork	Up to 1.3m	Pulp
	1.3m to 3m	Pulp
Tree Break	Stem Break	Pulp
Stem Straightness	One 3m and one 2m log	Pulp
	One 2m log	Pulp
	Two 2m logs	Pulp
	No straight logs	Pulp

2.3 Tree Biomass and Carbon Content

Carbon (C) stock estimation for the forest estate was completed for five pools:

1. Tree above ground tree
2. Tree below ground tree
3. Deadwood (lying, standing and stump)
4. Soil
5. Litter

2.3.1 Tree

Traditionally biomass is derived from NFI sources using biomass expansion factors to convert timber volume to total biomass. However, previous analysis suggests that this approach can result in an under estimation of the national biomass stock due to the high proportion of young trees, with no appreciable volume (Black *et al.*, 2004). Dbh and height data from NFI plots were, therefore, used to derive above and below ground biomass using species specific and generalised biomass equations (Black *et al.*, 2004, 2007, Black and Farrell, 2006 and Cost E21 data sources). A carbon fraction of 50% was assumed for all species and biomass pools (Black and Farrell, 2006).

In the case of the less common species including all broadleaves, it should be noted that the use of generalised biomass equations, could lead to a systematic error in the estimation. This error is due to country/regional differences in allometric patterns of individual trees associated altered management and/or growth characteristics. This will, however, be improved as new information from national research becomes available.

2.3.2 Deadwood

The volume of decaying deadwood, including lying log, stump and standing deadwood, was calculated. The density and C fraction of different decay classes was obtained from a study on Sitka spruce by Tobin *et al.* (2007). The decay equation and C fraction was assumed to be the same for all species. These estimates will improve as new research information becomes available.

2.3.3 Litter

Litter carbon pools were calculated as a function of plot age based on the International Panel on Climate Change (IPCC) good guidance practice using net annual accumulation rates of 0.8 and 1.3 tonnes of C ha^{-1} yr^{-1} for broadleaves and conifers respectively, over a 20 year transition. This is the same methodology used to report C stock changes under EPA submissions to the EU and UNFCCC (Mc Gettigan *et al.*, 2006).

2.3.4 Soil

Small changes in C stocks in peat soils over the short to long term (5 to 50 years) are extremely difficult to measure because of the high background level of soil C. Soil C stocks are expected to decrease (i.e.

represent a C source) in peats following drainage and afforestation. This is due to the oxidation of previously non-decomposable organic matter following the creation of aerobic conditions. Alternatively, other studies suggest that most wet mineral soils are a sink of C (take up C) because of the accumulation of organic matter in these soils (Black *et al.*, 2007; Black and Farrell, 2006).

Soil types from the NFI were stratified into ten major soil groups and assigned a soils C stock reference value following a GIS overlay on a soil C stock database (Tomlinson, 2004, Figure 5).

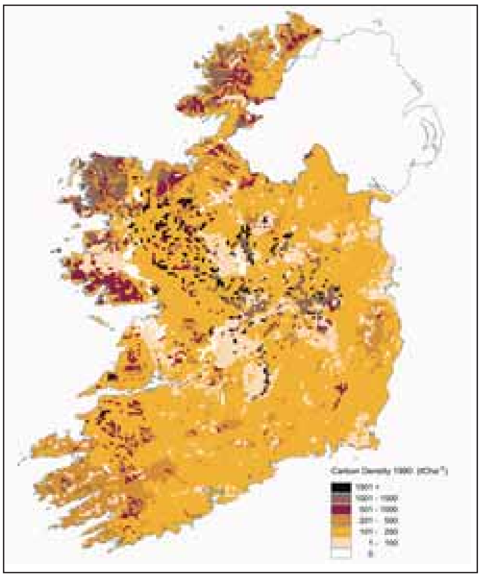


Figure 5. The 1990 baseline soil C reference stock values (Tomlinson, 2004).

This value provides a 1990 base line C stock (SOCREF). The soil sub-model component is based on the assumption that soil C reaches a steady state after 20-years following land-use transition into or out of forestry. Estimation of the area associated with the transition into or out of forestry was based on an overlay of the NFI sample points with the CORINE 1990 and 2006 datasets. This was further stratified to derive a land use transition and soil type matrix. The mineral soil organic C (SOC) stock change factors following land-use transitions were obtained from default IPCC equation:

$$SOC = \sum_{c,s,i} (SOCREF_{c,s,i} \times Flu_{c,s,i} \times FMG_{c,s,i} \times Fi_{c,s,i} \times A_{c,s,i})$$

Where SOC is soil organic carbon, SOCREF is the reference stock as described above, Flu is the accumulation or emission factor associated from land use change into forestry from grasslands, wetlands or agriculture specific to soils type (*s*), land use intensity (*i*) and transition time (*c*), FMG is the management specific factor which was assumed to be 1 (i.e. negligible), Fi is the management intensity (assumed to be 1) and A is the area. Flu was the most important factor.

The only soil which was assumed to accumulate C was wet mineral gleys following afforestation from grasslands based on national research (Black *et al.* 2007 and Black and Farrell, 2006). All other mineral soils were assumed to be C neutral.

All peat soils were assumed to loose C following afforestation for the 20 year transition based on the following equation:

$$\triangle C_{FForganic} = A_{drained} \times EF_{drainage}$$

$\triangle$C is the emission per year, $A_{drained}$ is the area of peat land afforested in the last 20 years and $EF_{drainage}$ is the emission factor taken from the IPCC guidelines 0.68 t C ha^{-1} yr^{-1}.

2.4 Virtual Trees from Regeneration

Trees with a minimum dbh of 70 mm were assessed on the inventory plot, including the mapping of their position. In addition, the small trees below 70 mm dbh were recorded in the regeneration circle (radius = 3 m). The total number of regeneration trees within regeneration circle is recorded by species and height classes.

For further data processing, the regeneration trees were transferred into the trees table, which contains the individual mapped trees. For small tree species a virtual tree was created and attributed with species, height and dbh information. Since every virtual tree may represent several trees the attribute TreeNumber is filled with the respective values.

Thus all tree data recorded on the inventory plot are stored in one data table for further processing. As a consequence, the results of statistical data processing include all trees, starting with seedlings, with a minimum height of 0.2 m.

2.5 Representative Area of a Tree

Statistical sample-based inventory usually does not relate tree attributes to area. In order to enable area related calculations, such as the determination of species composition, IFER has developed a procedure for the calculation of the so-called representative area of a tree.

The area of an inventory plot was distributed among the trees proportionately to their size. Larger trees got larger areas. Every tree got its own "piece of land". The sum of representative areas within the plot was equal to the area of the plot.

Since the NFI used concentric circles, it is necessary to weight trees by respective concentric circles, as there is no consistent tree data of all tree dimensions over the whole inventory plot. This meant that for area calculations it was assumed that the density of trees of smaller dimensions at the full inventory plot was the same as it was observed in the inner sub-plot.

If the landuse of the inventory plot was classified as Forest, and no trees (even no regeneration) were present, then the plot was classified as temporarily unstocked (e.g. clear-cut). A virtual tree with a representative area equal to the area of inventory plot was then created in the database.

2.6 Biodiversity Indicators

Some biodiversity indicators could be calculated for the NFI, but only those which do not consider spatial distribution. Spatial analysis of trees was not possible because of the concentric circle approach. Species and dimensional diversity of trees was quantified for each plot using entropy and the Simpson index:

$$H = \sum_{i=1}^{n} \frac{s_i}{S} \times \ln\left(\frac{s_i}{S}\right),$$

where:
H is entropy
s_i is representative area of class *i*
S is total plot area
n is number of classes

$$I = \sum_{i=1}^{n} \left(1 - \frac{s_i}{S}\right) \times \left(\frac{s_i}{S}\right),$$

where:
I is Simpson index

2.7 Classification

Classification is a common method for the conversion of continuous data into discrete classes, e.g. for the conversion of dbh into diameter classes, age into age classes, etc.

2.8 Aggregation

Some secondary attributes were calculated using aggregation. Statistics such as total, average, standard deviation or count are calculated for a group of data records. For example, the number of plant species occurring on an inventory plot, is calculated by counting the number of plant species recorded on the plot.

2.8 Stratification

Ireland's NFI has not been established as a stratified sample. However post-stratification is an efficient method of reducing variation. Stratification should be based on those inventory plot attributes which are not changing in time. The stratification of national estimates by county is a primary output of the NFI.

Considering possible future development of the NFI it seems to be wise to stratify data by counties. Since the forest cover differs between counties it might be useful in future NFI's to densify the sampling grid in the less forested counties. Stratified sampling techniques would then be applied to this variable sampling intensity approach for counties. For those reasons the post-stratification of variables by counties has been used in the processing of data for the first NFI.

2.10 Re-Classification (species groups)

Using re-classification, classes are re-grouped into different, usually broader classes. Re-classification has been used for grouping of species into species groups. For most NFI data processing tasks, it was more convenient to work with the species groups instead of individual species. The data would not have been sufficiently representative if they were processed by species. The species groups used in the NFI are presented in Table 4.

Table 4. Species groups used in the NFI.

Species	Species group
Sitka spruce	Sitka spruce
Norway spruce	Norway spruce
Scots pine	Scots pine
lodgepole pine v. inland	
lodgepole pine v. lulu	
lodgepole pine v. NC	other pine spp.
lodgepole pine v SC	
Austrian pine v. maritima	
Monterey pine	
Douglas fir	Douglas fir
European larch	
Japanese larch	larch spp.
other larches	
silver fir	
grand fir	
noble fir	
cedar of Lebanon	
Lawson cypress	other conifers
coast redwood	
yew	
western redcedar	
western hemlock	
sessile oak	sessile and
pedunculate oak	pedunculate oak
beech	beech
ash	ash
sycamore	sycamore

Species	Species group
silver birch	birch spp.
downy birch	
alder	alder spp.
field maple	
maple	
horse chestnut	
Strawberry tree	
hornbeam	
sweet chestnut	
holly	
notofagus sp.	other long living
white poplar	broadleaves
black poplar	
Turkey oak	
pin oak	
whitebeam	
small-leaved lime	
large-leaved lime	
wych elm	
crab apple	
aspen	
cherry	
blackthorn	other short living
goat willow	broadleaves
other willows	
mountain ash	
hazel	

3. Statistical Data Processing

Statistical sampling provides statistically representative data for the investigated area, i.e. the national forest estate. The NFI data processing was based on the quantification of the statistics of evaluated quantitative variables which were stratified and classified using qualitative or quasi qualitative variables. As a result, the value of main statistics, such as total or mean, was produced together with the estimate of sampling error.

3.1 Evaluated Variables

Evaluated variables (e.g. area) are represented by quantitative attributes of an investigated entity (e.g. ownership). In most cases the evaluated variable is represented by the area, volume or number of entities.

For instance the total volume stock by species is calculated from the vector of tree volume data where each element of the vector represents sum of the tree volumes of particular species in the inventory plot. From the vector the total as well as the confidence interval may be computed.

3.2 Classifiers

Most of the descriptive attributes collected during the field survey are used for classification of evaluated variables. Classifiers acquire distinct values from a list of predefined categories.

Classifiers are represented, for example, by species, damage classes, and many other attributes of trees, plots and other forest components investigated in the NFI. Some of the continuous variables, such as dbh, are classified to distinct classes and processed in the same way as predefined classifiers.

3.3 Stratifiers

The attributes which may be used for stratification of the sample are always related to the inventory plot and should be permanent in time. Altitude classes represent a typical example of a convenient stratifier. Use of the stratifiers and statistical methods relevant for stratified statistical sampling, can reduce variation and lead to more accurate estimates of NFI results. Currently, the NFI is using post-stratification based on counties.

3.4 Methods of Statistical Data Processing

The statistical methods used within NFI represent standard methods used for simple and stratified sampling design (e.g. Thomson, 1992).

3.4.1 Statistics

The following statistics (Table 5) were used in different data processing tasks: population total (for example, the total volume of a certain forested area) and sample mean (for example, mean volume per hectare). The confidence interval ($a = 0.05$) for each statistical variable was also estimated.

When calculating a sample mean, several alternative calculations can be applied in addition to the standard arithmetic mean:

(1) A **weighted mean** can be calculated if the contribution of samples should depend on a certain other variable (for example, mean tree defoliation weighted by tree diameter). Both, weighted and unweighted mean can be calculated for a tree (e.g., mean crown length) or plot (mean volume). In the second case, the mean can be expressed per plot or per unit area (hectare). There are two ways to calculate a mean value per unit area.

(2) **Arithmetic mean:** Mean value per hectare is calculated by dividing the arithmetic mean by the area of the inventory plot in hectares.

(3) **Normalized mean:** It is calculated in such a way that the calculated value of the variable under consideration for a plot is divided not by the whole plot area, but by the area of the part of the plot where the given variable is present. For example, the mean stand volume per tree species is calculated in such a way.

Table 5. Review of equations applied in the Inventory Analyst statistical calculations for individual inventory plots and for the whole dataset.

Variable	Calculation for plot	Plot weight	Calculation for the set of plots	*Example*
Total	$X_j = \sum_{i=1}^{m} x_i$	$w_j = 1$	$Y = \sum_{j=1}^{n} X_j$ $Y_{tot} = \frac{Y}{\sum_{j=1}^{n} s_j} S$	*Total volume for inventory plots;* *Total volume for the whole territory under study.*
Average sum	$X_j = \sum_{i=1}^{m} x_i$	$w_j = 1$	$\bar{y} = \frac{1}{n}\sum_{j=1}^{n} X_j$ $\bar{y}_{ha} = \frac{\bar{y}}{s}$	*Mean volume (mean volume per plot; divided by plot area it gives mean volume per hectare).*
Mean of means	$\bar{x}_j = \frac{1}{m}\sum_{i=1}^{m} x_i$	$w_j = 1$	$\bar{y} = \frac{1}{n}\sum_{j=1}^{n} \bar{x}_j$	*Concentration of carbon in the wood, mean wood density etc.*
Mean of weighted means	$\bar{x}_j = \frac{\sum_{i=1}^{m}(x_i v_i)}{\sum_{i=1}^{m} v_i}$	$w_j = 1$	$\bar{y} = \frac{1}{n}\sum_{j=1}^{n} \bar{x}_j$	*Mean tree defoliation (weighted by tree volume).*
Normalized mean of sums	$\bar{x}'_j = \frac{\sum_{i=1}^{m} x_i}{\sum_{i=1}^{m} v_i}$	$w_j = \sum_{i=1}^{m} v_i$	$\bar{y} = \frac{\sum_{j=1}^{n}(\bar{x}'_j w_j)}{\sum_{j=1}^{n} w_j}$	*Volume per hectare by species (tree volume of individual species is related to the representative area of this species).* *The plot weight can be, e.g., the sum of individual tree areas.*
Normalized mean of weighted means	$\bar{x}_j = \frac{\sum_{i=1}^{m}(x_i v_i)}{\sum_{i=1}^{m} v_i}$	$w_j = \sum_{i=1}^{m} v_i$	$\bar{y} = \frac{\sum_{j=1}^{n}(\bar{x}_j w_j)}{\sum_{j=1}^{n} w_j}$	*Mean defoliation by species.* *The plot weight can be, e.g., the sum of tree individual areas.* *This approach points out the different share of the given species within a plot; in contrast with mean of weighted means the weights of different plots are not the same.*

Where

x_i is the value of the variable under study for the *i*-th entity (e.g., tree) within the plot *j*
v_i is the weight of *i*-th entity within the plot *j*
m is the number of entities within the plot *j*
X_j is the sum of the variable under study for plot *j*
$\bar{x}_j$ is the mean value of the variable under study for plot *j*
$\bar{x}'_j$ is the mean value of the variable under study per unit *v* for plot *j*
w_j is the weight of the *j*-th plot from the set of inventory plots
Y is the total of the variable under study for the whole dataset of plots
Y_{tot} is the total of the variable under study for the whole territory of interest
$\bar{y}$ is the mean value of the variable under study for the dataset of plots
$\bar{y}_{ha}$ is the mean value of the variable under study for the dataset of plots per hectare

n is the total number of inventory plots in the dataset
S_j is the area of inventory plot j in hectares
S is the area of the total territory of interest in hectares
μ_h is the stratum mean
N is the total number of units in the population

3.4.2 Stratifying the population

A geographical region may be stratified into similar area by means of some known variable such as habitat type, elevation, or soil type. Even if a large geographic study area appears to be homogeneous, stratification into blocks (strata) can help ensure that the sample is spread out over the whole study area.

The variable of interest associated with *i*th unit (single plot) of stratum h will be denoted y_{hi}. Let N_h represent the number of units in stratum h and n_h the number of units in the sample from that stratum. L represents total number of strata. The total number of units in the population is

$$N = \sum_{h=1}^{L} N_h$$

and the total sample size is

$$n = \sum_{h=1}^{L} n_h$$

The total of the y-values in stratum h is

$$\tau_h = \sum_{i=1}^{N_h} y_{hi}$$

and the mean for the stratum is

$$\mu_h = \tau_h / N_h$$

The total for the whole population is

$$\tau = \sum_{h=1}^{L} \tau_h$$

The overall population mean is

$$\mu = \tau / N$$

All the calculations set forth below concern normally distributed variables. Often, in practice, the variables are not normally distributed, in particular they may have a significant skewness. In such a case special methods of calculation of a mean (or total) and its confidence interval can be applied. In particular, not the arithmetic mean, but another statistic (such as median, geometric mean, etc.) with its confidence interval can be the best estimator the population mean (e.g., Meloun *et al.*, 1992). In the case of stratified sampling, when applying the special methods for non-normal distributions, the sum of stratum totals or the mean of stratum means may differ from the population total or mean, calculated without stratification or using another stratification. Consequently, in order to avoid such a contradiction, only standard calculations supposing the normal distribution of variables were applied.

3.4.3 Estimating the population total

Suppose that within stratum h, any specified sampling design is used to select the sample s_h of n_h units, and one has an estimation $\hat{t}_h$, with respect to that design. Let $\mathrm{var}(\hat{t}_h)$ denote the variance of $\hat{t}_h$, and suppose that one has an unbiased estimator $\hat{\mathrm{var}}(\hat{t}_h)$ of that variance.

Then an unbiased estimator of the overall population total t is obtained by adding together the stratum estimators

$$\hat{\tau}_{st} = \sum_{h=1}^{L} \hat{\tau}_h$$

The variance of the stratified estimator, because of the independence of the selections in different strata, is the sum of the individual stratum variances

$$\mathrm{var}(\hat{\tau}_{st}) = \sum_{h=1}^{L} \mathrm{var}(\hat{\tau}_h)$$

An unbiased estimator of that variance is the sum of individual variance stratum estimators

$$\hat{\text{var}}(\hat{\tau}_{st}) = \sum_{h=1}^{L} \hat{\text{var}}(\hat{\tau}_h)$$

If the sample in each stratum is selected by a simple random sampling procedure without replacements, then $\hat{\tau}_h = N_h \bar{y}_h$

is an unbiased estimator of t_h, where $\bar{y}_h = \frac{1}{n_h}\sum_{i=1}^{n_h} y_{hi}$

is the sample mean for stratum *h*.

An unbiased estimator for the population total *t* is $\hat{\tau}_{st} = \sum_{h=1}^{L} N_h \bar{y}_h$

having variance $\text{var}(\hat{\tau}_{st}) = \sum_{h=1}^{L} N_h (N_h - n_h) \frac{\sigma_h^2}{n_h}$

where $\sigma_h^2 = \frac{1}{N_h - 1}\sum_{i=1}^{N_h} (y_{hi} - \mu_h)^2$

is the finite population variance from stratum *h*.

An unbiased estimator of the variance of $\hat{t}_{st}$ is $\hat{\text{var}}(\hat{\tau}_{st}) = \sum_{h=1}^{L} N_h (N_h - n_h) \frac{s_h^2}{n_h}$

where $s_h^2 = \frac{1}{n_h - 1}\sum_{i=1}^{n_h} (y_{hi} - \bar{y}_h)^2$

is the sample variance from stratum *h*.

3.4.4 Estimating the population mean

Since $\mu = t / N$, the stratified estimator for μ is $\hat{\mu}_{st} = \hat{\tau}_{st} / N$

Assuming that the selection in different strata has been made independently, the variance of the estimator is

$$\text{var}(\hat{\mu}_{st}) = \frac{1}{N^2}\text{var}(\hat{\tau}_{st})$$

with unbiased estimator of variance

$$\hat{\text{var}}(\hat{\mu}_{st}) = \frac{1}{N^2}\hat{\text{var}}(\hat{\tau}_{st})$$

With stratified random sampling, an unbiased estimator of the population mean μ is the stratified sample mean

$$\bar{y}_{st} = \frac{1}{N}\sum_{h=1}^{L} N_h \bar{y}_h$$

Its variance is

$$\text{var}(\bar{y}_{st}) = \sum_{h=1}^{L}\left(\frac{N_h}{N}\right)^2\left(\frac{N_h - n_h}{N_h}\right)\frac{\sigma_h^2}{n_h}$$

An unbiased estimator of this variance is

$$\hat{\text{var}}(\bar{y}_{st}) = \sum_{h=1}^{L}\left(\frac{N_h}{N}\right)^2\left(\frac{N_h - n_h}{N_h}\right)\frac{s_h^2}{n_h}$$

3.4.5 Confidence intervals

When all the stratum sample sizes are sufficiently large, an approximate 100(1-a)% confidence interval for the population total is provided by

$$\hat{\tau}_{st} \pm t\sqrt{\hat{\text{var}}(\hat{\tau}_{st})}$$

where *t* is the upper a/2 point of the normal distribution. For the mean, the confidence interval is

$$\hat{\mu}_{st} \pm t\sqrt{\hat{\text{var}}(\hat{\mu}_{st})}$$

Usually, the normal approximation may be used if all the sample sizes are at least 30. With small sample sizes, the *t*-distribution with an approximate degrees of freedom may be used. The Satterthwaite (1946) approximation for the degrees of freedom *d* to be used is

$$d = \left(\sum_{h=1}^{L} a_h s_h^2 \right)^2 \Big/ \left[\sum_{h=1}^{L} (a_h s_h^2)^2 / (n_h - 1) \right]$$

where

$$a_h = N_h (N_h - n_h) / n_h$$

3.4.6 Considering variable weights

Let us consider the variable x_i weighted by value w_i ($i = 1,\ldots,n$). In equations for *y* observations we should multiply any terms as y_i or $(y_i - \overline{y})^k$ by w_i and replace *n* by $W = \sum_{i=1}^{n} w_i$. Consequently we receive the following set of equations:

$$\overline{y} = \frac{1}{W} \sum_{i=1}^{n} y_i w_i \, , \qquad D(\overline{y}) = \frac{s^2}{W}$$

$$s^2 = \frac{1}{W-1} \sum_{i=1}^{n} (y_i - \overline{y})^2 w_i$$

where *D(.)* is the operator of variance.

In the current version of the statistical data processing, weights were standardised before their further application, in such a way as *W=N*, i.e. each w_i is replaced by $w_i . N/W$.

3.4.7 Using concentric circles at inventory plots

Data collected using the concentric circle approach were processed as having been collected from independent inventories within strata. Thus an unbiased estimator of the overall population total *t* was obtained by adding together the stratum and concentric circle estimators:

$$\hat{\tau}_{st} = \sum_{h=1}^{L} \sum_{c=1}^{M} \sum_{i=1}^{N_h} y_{hci}$$

where *M* is the total number of concentric circles used in the inventory design.

For the calculation of variance and, subsequently, of the confidence interval for stratified sampling, the variance related to individual concentric circles was summed, assuming that the data from individual circles were uncorrelated:

$$\mathrm{var}(\hat{\tau}_{st}) = \sum_{h=1}^{L} \sum_{c=1}^{M} \mathrm{var}(\hat{\tau}_{hc})$$

3.5 Formulation of Statistical Data Processing Tasks

More than 150 different outputs in the statistical data processing have been formulated using the described rules. The tasks were logically arranged in 12 groups:

1. Forest area
2. Species structure
3. Age structure
4. Tree size
5. Forest structure
6. Biodiversity
7. Growing stock
8. Carbon stock
9. Forest health
10. Deadwood
11. Forest regeneration
12. Vegetation and Lichens.

The full list of statistical data processing tasks together with the results, is presented in a separate NFI report. An example of a statistical data processing task, total growing stock by county and species group is presented in Table 6.

Table 6. Example of the formulation of the task of statistical data processing, total volume by county and species group.

Task name	Total volume by county and species group
Evaluated layer	Trees
Evaluated attribute	Growing stock (ground to 7cm)
Units of evaluated attribute	m^3
Multiplier	1000
Fixed decimal places	1
Stratifying attribute	County
Stratifier in output	Yes
Classifier(s)	Trees -> Species group
Calculated statistics	Total
Plot weight attribute	Repre. area, ha
Replace non zero weight with 1	Yes
Alpha	0.05
Include regeneration circle	No
Consider concentric circles	Yes
Output by circles	No
Forest land only	Yes
Skip dead trees	Yes

4. Technology for Data Processing

The NFI ground survey was based on the use of advanced technology for computer aided field data collection. The Field-Map™ system has been designed for the whole NFI process, starting with the preparation of the data collection database, through to the field data collection and on to the comprehensive data processing.

The data was stored directly into a computer database in the field. During the field data collection the data were automatically checked and verified. Without any intermediate steps, the field data could be processed. All the data processing was done using the original field database without conversion. During the data processing the secondary attributes were added to the database, but the database retained its original format which can easily be used for the next cycle of a repeat inventory. Such an approach significantly increases overall productivity.

A comprehensive set of data processing procedures, i.e. calculation of secondary attributes and statistical data processing, is incorporated in the Field-Map Inventory Analyst software.

Field-Map Inventory Analyst facilitates the step-by-step calculation of secondary attributes to perform all tasks shown in Figure 5. The statistical data processing tasks are formulated and easily implemented (Figure 6). The results of statistical data processing, in the form of standardised tables and charts, are produced automatically and can be used for NFI reporting (Figure 7).

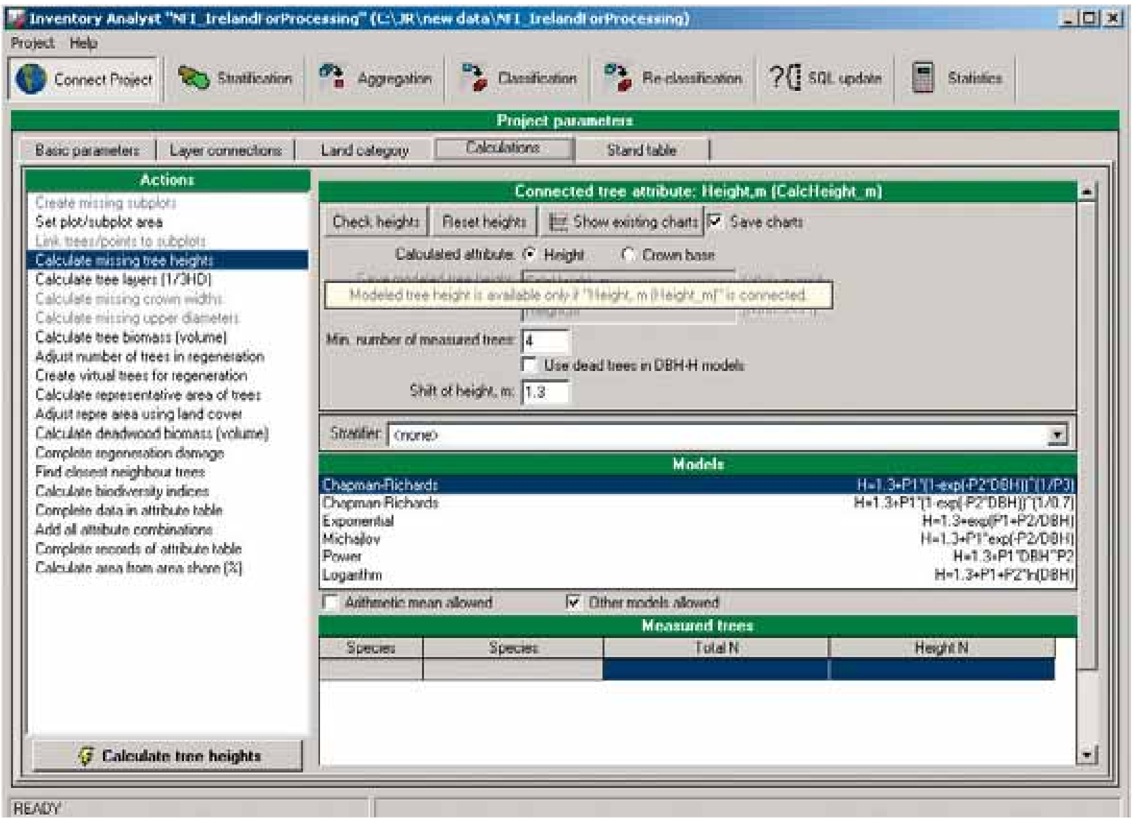


Figure 5. Field-Map Inventory Analyst.

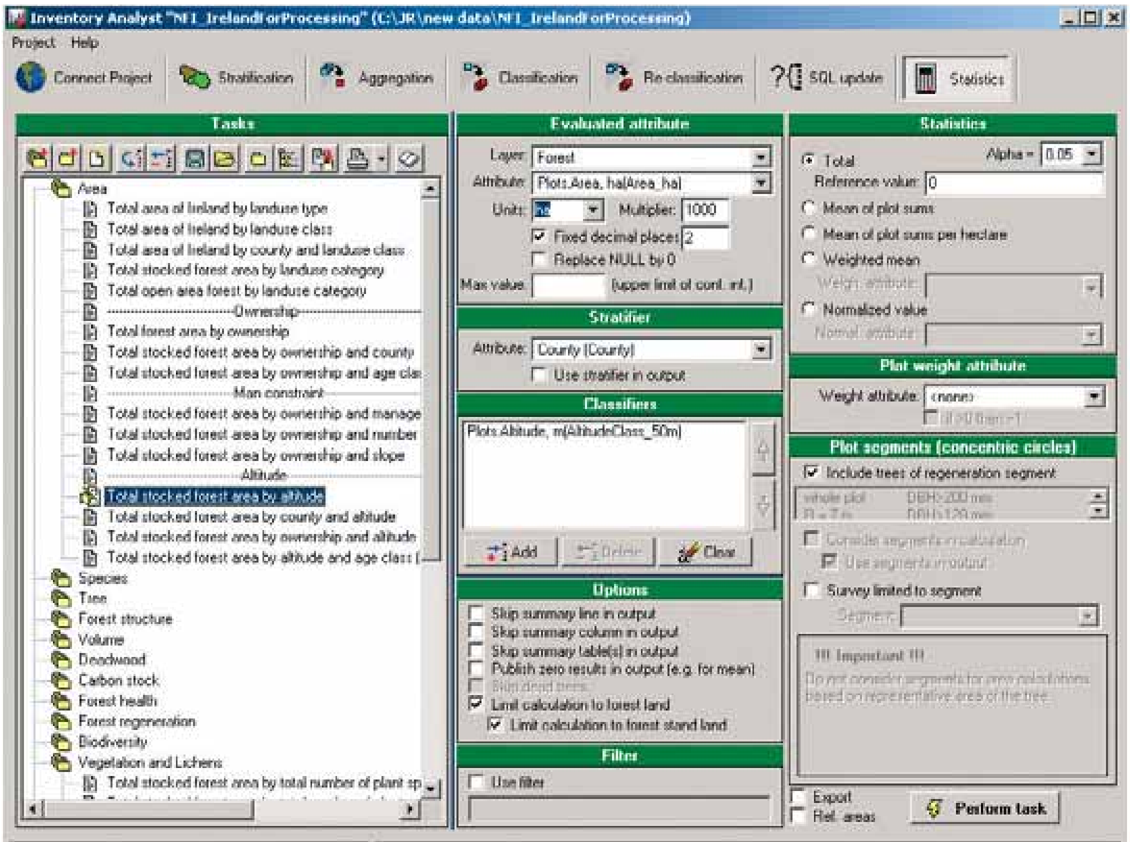
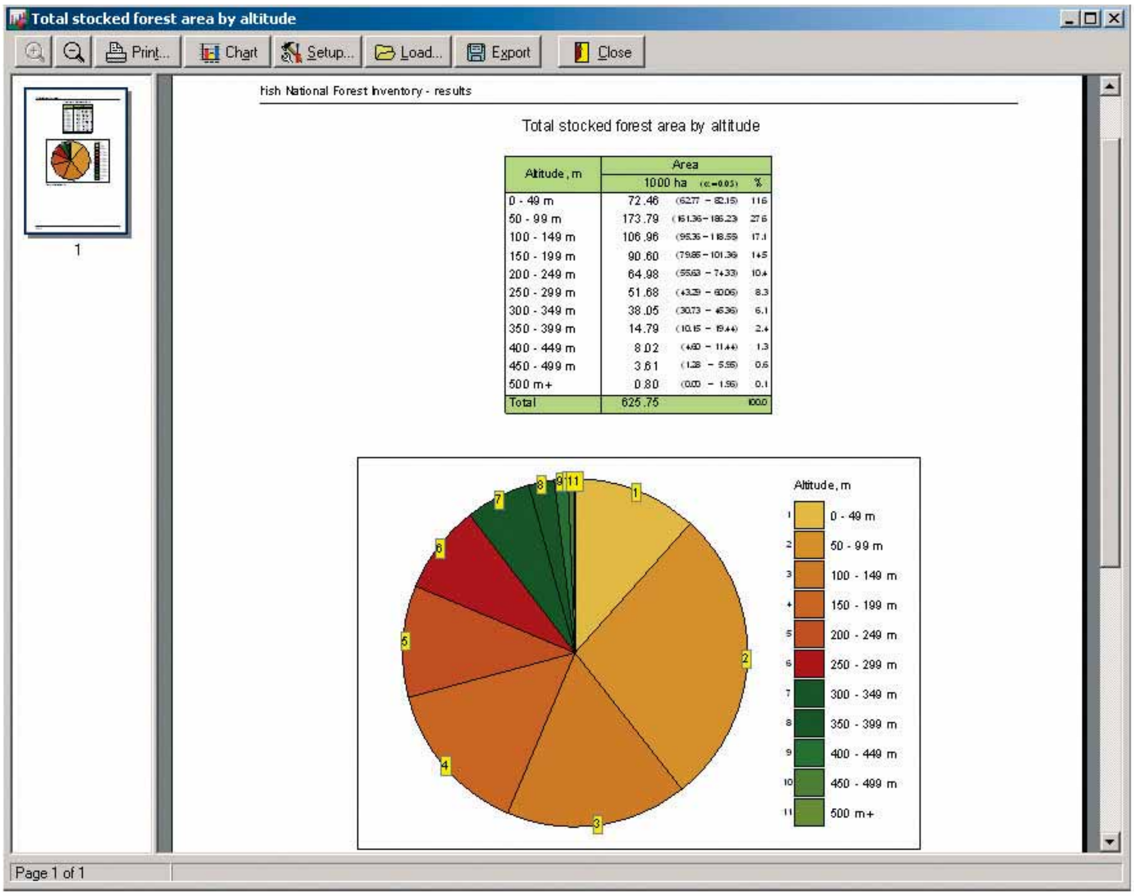


Figure 6. Field-Map Inventory Analyst – main screen of statistical data processing.



Altitude, m	Area 1000 ha	(α=0.05)	%
0 - 49 m	72.46	(62.77 – 82.15)	11.6
50 - 99 m	173.79	(161.36 – 186.23)	27.6
100 - 149 m	106.96	(95.36 – 118.55)	17.1
150 - 199 m	90.60	(79.85 – 101.36)	14.5
200 - 249 m	64.98	(55.63 – 74.33)	10.4
250 - 299 m	51.68	(43.29 – 60.06)	8.3
300 - 349 m	38.05	(30.73 – 45.36)	6.1
350 - 399 m	14.79	(10.15 – 19.44)	2.4
400 - 449 m	8.02	(4.60 – 11.44)	1.3
450 - 499 m	3.61	(1.28 – 5.95)	0.6
500 m+	0.80	(0.00 – 1.56)	0.1
Total	625.75		100.0

Figure 7. Field-Map Inventory Analyst – formatted output for NFI reporting.

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Ireland's National Forest Ireland – Results

John Redmond, Gerhardt Gallagher, Martin Černý and Radek Russ

1. Introduction

The information gathered in the NFI encompasses the traditional parameters such as area and species composition of the national forest estate as well as the growing stock (m^3) and forest management background. Also, for the first time in Ireland, information with regard to biodiversity, health and vitality, carbon content and soil type, is available for the entire forest estate. Features such as minor tree species and natural regeneration features are also included.

The picture that emerges is of an estate which has reached 10% of total land area, comprising spruce as the most predominant species but with a wide variety of other forest types and broadly distinguishable in three main forest categories defined by ownership. Wicklow is the county with the highest percentage of forest; Cork has the largest area. Growing stock is 70 million m^3, mostly comprising spruce and pine species. There is a significant quantity of variable quality growing stock in older broadleaves but, as native or semi natural woodland, it is likely much of this would not be available. The estate is primarily managed forest established on cultivated soil but interventions such as thinning and pruning are not as widely carried out as might have been anticipated. The estate is subject to a wide range of management constraints, most of them environmental.

There appears to be a sustainable level of biodiversity within Irish forests with many non-tree plant species frequent or abundant. Lichens while there in small amounts are widely present. There are also significant levels of open area and natural regeneration, the latter particularly evident in the non-grant aided private forest. Overall the estate appears healthy with levels of damage low. While peat has been a soil type associated with Irish forests in the past the inventory data indicates that this is now reducing as afforestation focuses on wet mineral soils. Although forests are generally relatively low lying, there appears to be a trend towards a movement away from higher elevations.

1.1 Presentation of Results

This paper outlines the primary results from the NFI. A comprehensive results document will be published in November 2007, containing ca. 150 statistical outputs, which describe the national forest estate. Forest attributes (e.g. ownership) are used to describe evaluated variables (e.g. area, volume) through the calculation of statistics (e.g. totals or means).

The analysis software (Field Map Inventory Analyst) produces standardised tables and charts for reporting purposes (Figure 1). The tables detail the calculated statistics with associated confidence intervals (a=0.05). Sub-totals are provided where classification or stratification is used. The percent composition of each category in the classifier is also given. Interpretation of the results is aided by the use of charts illustrating the evaluated variables, classified or stratified by forest attributes.

Associated with all forms of sampling, there is a sampling error. The confidence interval presented gives the estimated range of values which is likely to include the unknown population parameter with an associated probability.

Classes — Calculated statistics (total) — Confidence interval — Percentage

Species group	County / Growing stock: Kerry 1000 m³	Kerry (α = 0.05)	Kerry %	Wicklow 1000 m³	Wicklow (α = 0.05)	Wicklow %	Total 1000 m³	Total (α = 0.05)	Total %
Sitka spruce	3,019.2	(2,211.7 – 3,826.6)	57.7	2,517.1	(1,494.8 – 3,539.4)	60.3	5,536.3	(4,267.2 – 6,805.3)	58.9
Norway spruce	–	– –	–	246.5	(0.0 – 717.2)	5.9	246.5	(0.0 – 717.2)	2.6
Scots pine	120.0	(0.0 – 1,155.9)	2.3	59.9	(17.1 – 102.7)	1.4	179.9	(0.0 – 1,223.5)	1.9
other pine spp.	941.9	(0.0 – 2,002.4)	18.0	40.1	(0.0 – 88.5)	1.0	982.1	(0.0 – 2,042.6)	10.4
Douglas fir	–	– –	–	345.2	(125.9 – 564.5)	8.3	345.2	(125.9 – 564.5)	3.7
larch spp.	2.9	– –	0.06	135.0	(0.0 – 897.2)	3.2	137.9	(0.0 – 900.1)	1.5
other conifers	150.8	(0.0 – 1,208.5)	2.9	177.1	(0.0 – 1,160.4)	4.2	328.0	(0.0 – 1,772.1)	3.5
sessile and pedunculate oak	272.3	(106.6 – 438.0)	5.2	275.6	(47.6 – 503.7)	6.6	548.0	(283.8 – 812.2)	5.8
beech	36.3	(0.0 – 111.2)	0.7	150.9	(0.0 – 379.1)	3.6	187.3	(0.0 – 426.1)	2.0
ash	32.4	(9.1 – 55.7)	0.6	25.1	(0.0 – 80.2)	0.6	57.5	(27.0 – 88.0)	0.6
sycamore	–	– –	–	76.2	(0.0 – 340.5)	1.8	76.2	(0.0 – 340.5)	0.8
birch spp.	250.2	(79.1 – 421.2)	4.8	54.0	(0.0 – 160.7)	1.3	304.1	(103.1 – 505.2)	3.2
alder spp.	95.5	(48.4 – 142.7)	1.8	26.6	– –	0.6	122.2	(75.1 – 169.3)	1.3
other long living broadleaves	201.5	(77.5 – 325.5)	3.9	31.2	(0.0 – 104.2)	0.7	232.7	(106.3 – 359.1)	2.5
other short living broadleaves	102.7	(26.6 – 178.7)	2.0	19.5	(0.0 – 53.0)	0.5	122.2	(46.2 – 198.1)	1.3
Total	5,225.8	(3,836.5 – 6,615.1)	100.0	4,180.1	(3,030.6 – 5,329.6)	100.0	9,405.9	(7,624.5 – 11,187.3)	100.0

Sub-totals — Total

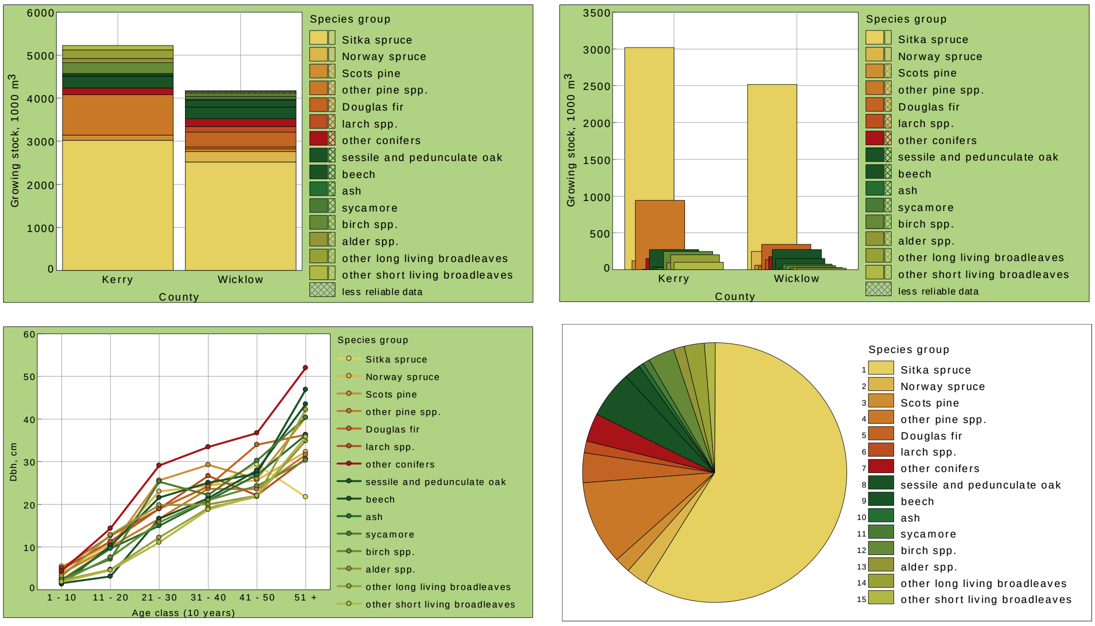

Figure 1. Example of standardised outputs.

The analysis of eight important forest variables are included in this paper. These are commonly classified by ownership and stratified by counties in some cases. The evaluated variables are:

1. Area
2. Species
3. Forest structure
4. Growing stock
5. Deadwood
6. Health and vitality
7. Soil
8. Vegetation and lichens

2 Area

In this section, the total land area of Ireland is classified by land-use type. The forest area is also classified by land-use category, ownership and age-class.

2.1 Total Area of Ireland by Land-Use Type

The assessment of area for the purposes of the NFI was based on an air photo interpretation exercise with subsequent field verification.

The total land area of the country is classified into 26 different land use types (Table 1). From a forest viewpoint, there are four categories of direct interest. First, the area of **Forest land** is estimated to be 697,730 hectares, which includes open areas that are integral to the forest such as forest roads, ridelines and setbacks.

The assessment of **Other woodland** includes land with tree cover that did not meet the criteria set down in the forest land definition and accounted for 49,270 ha (0.7%) (Table 1).
Also of significance is that 4% of the total land area was classified as **hedgerow** (Table 1). This would include all hedegrows with woody plant species present, such as tree or shrub species.

Bareland within the forest comprises 38,050 ha (Table 1). This category describes large areas of bareland that are managed by forest owners and have remained unplanted owing to legal, landscape or productivity issues.

Deforestation describes the conversion of forest to another landuse, implying the long-term or permanent loss of forest cover. The basis of the assessment was that an area of forest was present on the air photos but was absent on field inspection. The area of deforestation was estimated to be 6,010 ha, over the period 1998 to 2006 (Table 1).

Table 1. Total area of Ireland by land-use type.

Land-use type	Area		
	1000 ha	($\alpha = 0.05$)	%
Forest	697.73	(666.65 – 728.81)	10.0
Hedgerow	272.36	(252.30 – 292.43)	3.9
Other Woodland	49.27	(40.59 – 57.94)	0.7
Bareland within Forest Ownership Boundary	38.05	(30.42 – 45.68)	0.5
Deforestation	6.01	(2.97 – 9.05)	0.09
Individual Tree	5.61	(2.67 – 8.54)	0.08
Scrub	88.12	(76.55 – 99.69)	1.3
Grassland	3,757.02	(3,705.37 – 3,808.66)	53.9
Cropland	379.31	(355.81 – 402.80)	5.4
Bog and Heath	890.79	(856.21 – 925.37)	12.8
Cutover Peat (Domestic)	96.53	(84.43 – 108.63)	1.4
Cutover Peat (Industrial)	68.89	(58.65 – 79.14)	1.0
Bare Rock	75.70	(64.97 – 86.43)	1.1
Bare Soil	17.22	(12.08 – 22.36)	0.2
Stone Wall	2.80	(0.73 – 4.88)	0.04
Quarry	7.61	(4.19 – 11.03)	0.1
Road - Paved	84.91	(73.55 – 96.27)	1.2
Built Land (Rural)	111.75	(98.74 – 124.76)	1.6
Built Land (Urban)	63.28	(53.46 – 73.11)	0.9
Green Space (Rural)	57.28	(47.93 – 66.63)	0.8
Green Space (Urban)	23.63	(17.61 – 29.65)	0.3
Track - Unpaved Access Route	17.62	(12.42 – 22.82)	0.3
Other	1.60	(0.03 – 3.17)	0.02
Water Body	140.19	(125.65 – 154.73)	2.0
Coastal Complex	20.43	(14.83 – 26.03)	0.3
Sea	2.40	(0.48 – 4.33)	0.03
Total	6,976.11		100.0

2.2 Total Forest Area by Land-Use Category.

The forest area is divided into two land-use categories on the basis of field classification; Forest and Forest Open Area. Forest Open Area is an integral component of the forest estate, including features such ridelines and setbacks from watercourses. Ten percent of the total forest area is composed of Forest Open Area, with the remaining 90% being classed as stocked forest land[1] (Table 2).

Table 2. Total forest area by land-use category.

Land-use category	Area		
	1000 ha	(α = 0.05)	%
forest	625.75	(596.25 – 655.24)	89.7
forest open area	72.10	(61.62 – 82.57)	10.3
Total	697.84	(666.89 – 728.79)	100.0

2.3 Total Forest Area by Ownership

In terms of forest ownership, the NFI results are classified into three distinctive ownership classes:

1. **Public**: all state owned forests, including those owned by Coillte, National Parks and Wildlife, Bord na Mona and the Office of Public Works.
2. **Private (grant aided)**: private afforested land which was either in receipt of a grant and/or premium since 1980.
3. **Private (other)**: private plantations or naturally regenerated forests.

The public forest estate accounts for 57% of the total forest area (Table 3), the majority of which is owned by Coillte Teoranta (The Irish Forestry Board). Forest land in the private (grant aided) estate and private (other) estate comprises 30% and 13% of the total forest area respectively.

Table 3. Total forest area by ownership.

Ownership	Area		
	1000 ha	(α = 0.05)	%
public	397.46	(381.49 – 413.44)	57.0
private (grant aided)	212.20	(197.39 – 227.01)	30.4
private (other)	88.18	(77.45 – 98.91)	12.6
Total	697.84		100.0

2.4 Total Stocked Forest Area by Ownership and Age Class

The development of the forest estate's age structure can be traced to afforestation programmes which became substantial in the 1950s and peaked during the mid-1990s. The most significant aspect is that more than 60% of the forest area is less than 20 years old (Table 4 and Figure 2). The potential timber supply from these areas is significant, but as nearly half of the area is in private (grant aided) ownership, there are logistical issues that need solutions in order to realise this potential. The temporarily unstocked category represents those areas which have been felled and not yet restocked (Table 4 and Figure 2).

[1] Stocked forest land is the total Forest area, excluding Forest Open Area.

Table 4. Total stocked forest area by ownership and age class.

Age class (10 years)	Ownership / Area					
	public			private (grant aided)		
	1000 ha	(α = 0.05)	%	1000 ha	(α = 0.05)	%
temporarily unstocked	10.02	(6.12 – 13.92)	2.8	0.81	(0.00 – 1.92)	0.4
1 - 10	94.38	(84.00 – 104.75)	26.3	104.80	(93.61 – 115.99)	56.0
11 - 20	91.59	(81.22 – 101.96)	25.5	74.51	(64.67 – 84.35)	39.9
21 - 30	66.13	(57.12 – 75.15)	18.4	4.43	(2.03 – 6.82)	2.4
31 - 40	58.38	(49.70 – 67.06)	16.2	0.75	(0.00 – 1.59)	0.4
41 - 50	26.21	(20.37 – 32.06)	7.3	0.06	(0.00 – 0.15)	0.03
51 +	12.70	(9.00 – 16.39)	3.5	1.62	(0.43 – 2.81)	0.9
Total	359.41	(344.28 – 374.54)	100.0	186.99	(173.02 – 200.95)	100.0
Age class (10 years)	**Ownership / Area**					
	private (other)			Total		
	1000 ha	(α = 0.05)	%	1000 ha	(α = 0.05)	%
temporarily unstocked	0.40	(0.00 – 1.20)	0.5	11.22	(7.09 – 15.35)	1.8
1 - 10	11.23	(8.17 – 14.29)	14.2	210.41	(196.75 – 224.06)	33.7
11 - 20	16.20	(12.22 – 20.17)	20.3	182.30	(169.14 – 195.45)	29.1
21 - 30	16.02	(11.97 – 20.06)	20.2	86.58	(76.71 – 96.45)	13.8
31 - 40	12.15	(8.53 – 15.77)	15.3	71.29	(62.03 – 80.54)	11.4
41 - 50	7.44	(4.81 – 10.07)	9.4	33.72	(27.40 – 40.04)	5.4
51 +	15.92	(11.90 – 19.95)	20.1	30.24	(24.81 – 35.66)	4.8
Total	79.35	(69.10 – 89.60)	100.0	625.75		100.0

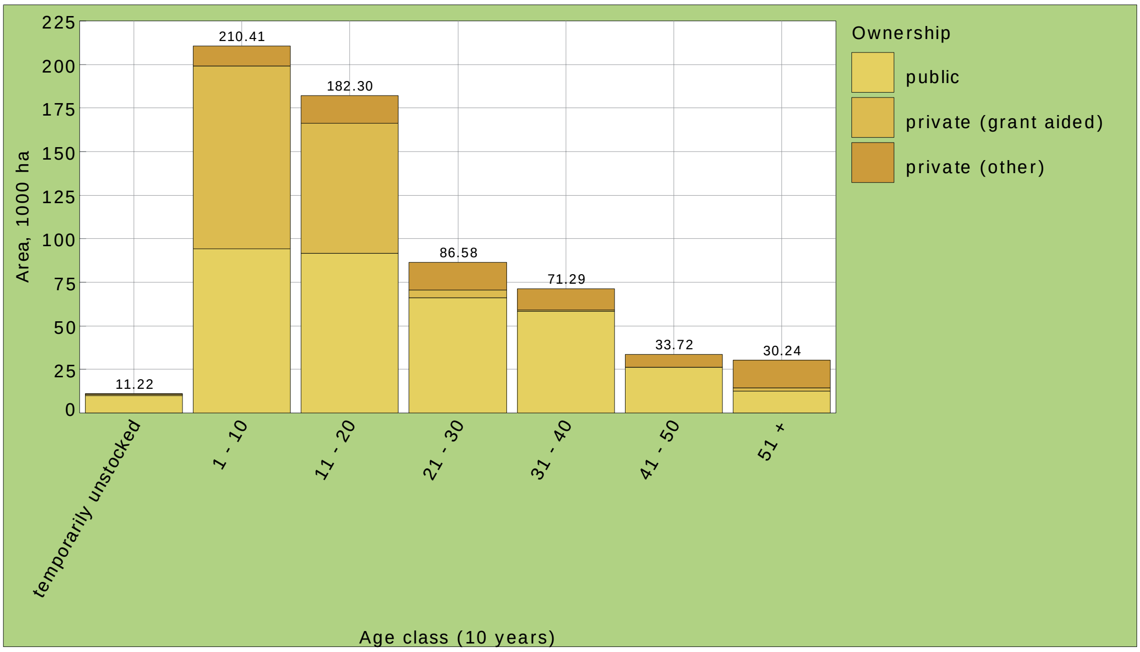

Figure 2. Total stocked forest area by ownership and age class.

3. Species

In this section the species composition is calculated using the representative area of individual tree species. The total area of the plot is proportionately allocated to all trees measured on the plot depending on the tree's size, i.e. dbh and height.

Assessment of species composition using representative area allows minor species within a stand to be represented nationally. Conventional stand level inventory usually discounts minor species occurring within the stand. For example, a hedgerow within a plantation or native species occurring naturally along a riparian zone may not be included in a stand level inventory.

3.1 Broad Species Groups

Nearly one quarter (24%) of the total forest area has broadleaf tree cover (Table 5 and Figure 3). Coniferous cover dominates, comprising 74% of the total forest area. As the proportion of each plot represented by broadleaf species is used in this calculation, each species type includes trees from both pure and mixed stands.

Table 5. Total stocked forest area by species type (conifer/broadleaf).

Species (conifer/broadleaf)	Ownership / Area					
	public			private (grant aided)		
	1000 ha	(α=0.05)	%	1000 ha	(α=0.05)	%
conifer	290.02	(275.66 – 304.38)	80.7	157.71	(144.72 – 170.69)	84.4
broadleaf	59.37	(51.87 – 66.87)	16.5	28.47	(22.68 – 34.26)	15.2
temporarily unstocked	10.02	(6.12 – 13.92)	2.8	0.81	(0.00 – 1.92)	0.4
Total	359.41	(344.28 – 374.54)	100.0	186.99	(173.02 – 200.95)	100.0
Species (conifer/broadleaf)	Ownership / Area					
	private (other)			Total		
	1000 ha	(α=0.05)	%	1000 ha	(α=0.05)	%
conifer	14.85	(10.60 – 19.10)	18.7	462.58	(450.57 – 474.59)	73.9
broadleaf	64.10	(54.93 – 73.27)	80.8	151.95	(140.34 – 163.55)	24.3
temporarily unstocked	0.40	(0.00 – 1.20)	0.5	11.22	(7.09 – 15.35)	1.8
Total	79.35	(69.10 – 89.60)	100.0	625.75		100.0

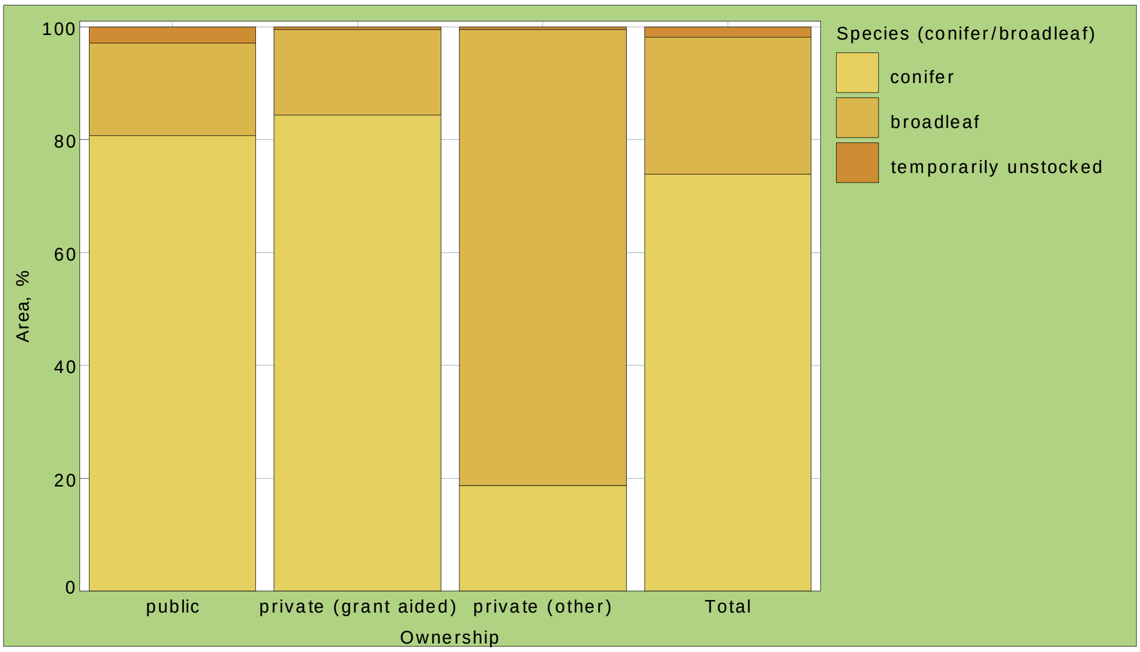

Figure 3. Total stocked forest area by species type (conifer/broadleaf).

3.2 Total Stocked Forest Area by Species Group

As certain tree species within the Irish forest estate represent small minorities, the NFI will have encountered few samples. The limited number of samples of these species lead to less reliable estimates for evaluated variables. To address this, certain species were grouped on the basis of similarities in growth form. The most common species in Ireland's forest estate is Sitka spruce, occupying 53% of the stocked forest land (Table 6 and Figure 4). 'Other pine spp.' species are the next most common, representing 10% of the forest area. 'Other short living broadleaves' also make-up a significant component (8%) of the national estate, which includes species such as willow and hazel.

Table 6. Total stocked forest area by species group.

Species group	Area		
	1000 ha	(α = 0.05)	%
Sitka spruce	327.83	(314.45 – 341.21)	52.5
Norway spruce	25.96	(20.72 – 31.20)	4.1
Scots pine	7.34	(4.76 – 9.92)	1.2
other pine spp.	63.61	(55.79 – 71.42)	10.2
Douglas fir	10.20	(6.84 – 13.56)	1.6
larch spp.	22.96	(18.17 – 27.74)	3.7
other conifers	4.68	(2.60 – 6.77)	0.7
sessile and pedunculate oak	14.63	(11.11 – 18.15)	2.3
beech	8.71	(6.11 – 11.32)	1.4
ash	19.16	(15.07 – 23.26)	3.1
sycamore	8.06	(5.24 – 10.87)	1.3
birch spp.	29.70	(24.86 – 34.53)	4.7
alder spp.	11.50	(8.16 – 14.83)	1.8
other long living broadleaves	9.55	(7.07 – 12.02)	1.5
other short living broadleaves	50.64	(44.30 – 56.98)	8.1
temporarily unstocked	11.22	(7.09 – 15.35)	1.8
Total	625.75		100.0

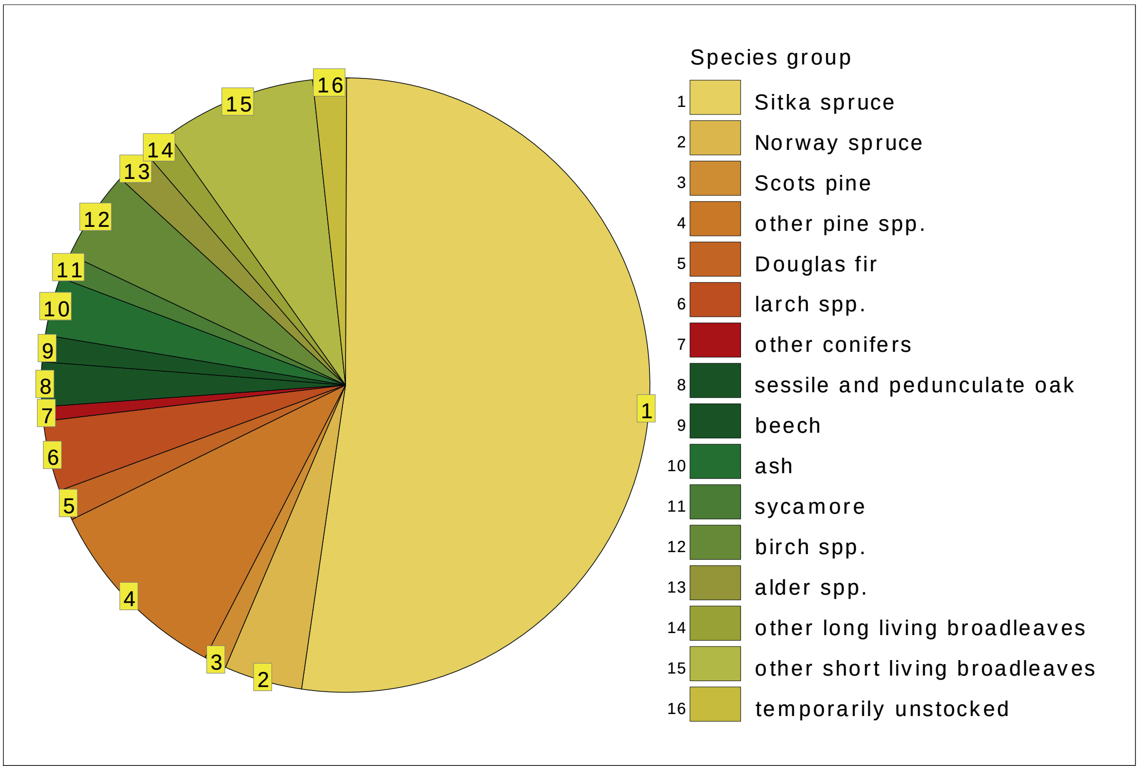

Figure 4. Total stocked forest area by species group.

3.3 Total Stocked Forest Area by Number of Tree Species

Forty-five percent of the forest estate consists of single species forest stands, while 28% of the forest estate contain two tree species (Table 7 and Figure 5). Three or more species occur in 27% of the forest estate. From a tree species diversity viewpoint, it is important to note that 5% of the forest estate contains five, six or more tree species growing together.

Table 7. Total stocked forest area by number of tree species.

Number of tree species	Area		
	1000 ha	(α = 0.05)	%
one	280.79	(265.45 – 296.12)	44.9
two	177.10	(163.19 – 191.01)	28.3
three	84.15	(73.57 – 94.73)	13.4
four	42.45	(34.65 – 50.25)	6.8
five	15.60	(10.76 – 20.44)	2.5
six	9.64	(5.80 – 13.47)	1.5
more than six	4.81	(2.10 – 7.53)	0.8
temporarily unstocked	11.22	(7.09 – 15.35)	1.8
Total	625.75		100.0

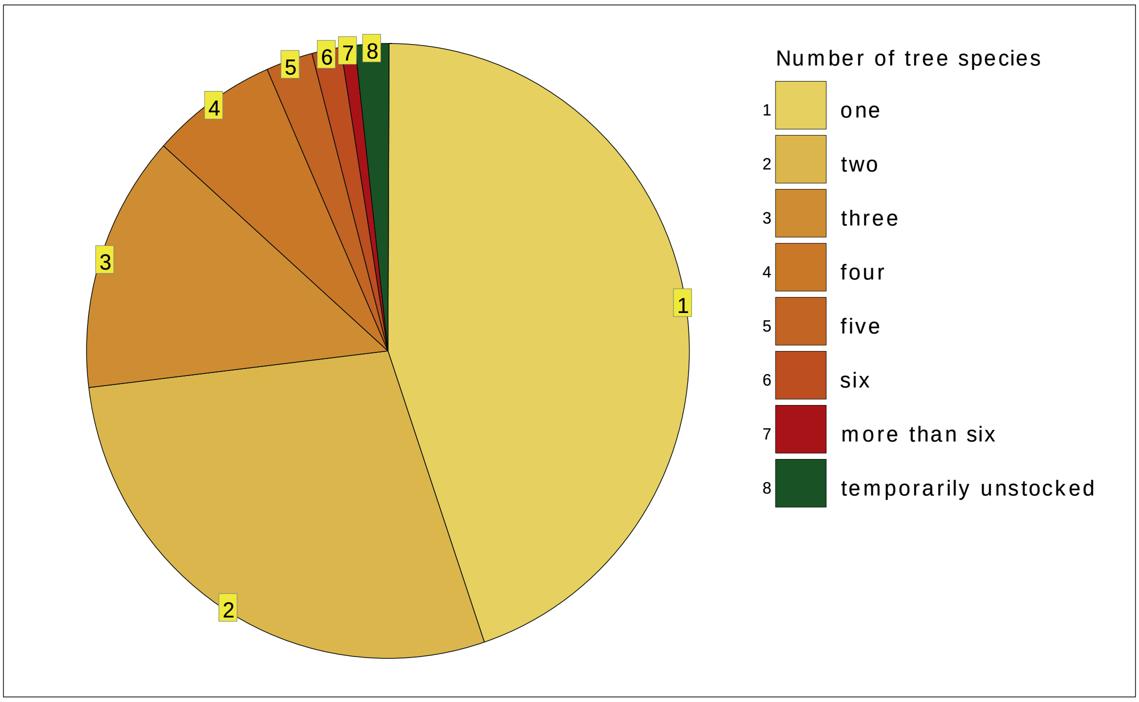

Figure 5. Total stocked forest area by number of tree species.

4. Forest Structure

Forest structure broadly categorises the forest estate using attributes such as growth stage.

4.1 Total Stocked Forest Area by Rotation Type

Rotation type describes the land type on which the storey[2] has been established and how the storey was established (i.e. artificially or naturally). Afforestation accounted for 65% of the total forest area and reforestation for 20% (Table 8). The semi-natural[3] category accounted for 13% of the total stocked forest area.

Table 8. Total stocked forest area by rotation type.

Rotation type	Area		
	1000 ha	($\alpha = 0.05$)	%
afforestation	406.72	(392.49 – 420.95)	65.0
reforestation	126.06	(114.18 – 137.94)	20.1
semi-natural	81.75	(71.69 – 91.81)	13.1
temporarily unstocked	11.22	(7.09 – 15.35)	1.8
Total	625.75		100.0

4.2 Total Stocked Forest Area by Growth Stage

Growth stage describes the development of a storey on the basis of canopy closure and dbh. The proportion of the total stocked forest area distributed among the growth stages is highest in the earlier development stages (Table 9), where it peaks at the small pole stage (17%). The high forest growth stage represents 13% of the total stocked forest area. As illustrated in Figure 6, the distribution of area among the first seven growth stages is reasonably uniform, which is an important factor in the development of a sustainable timber supply.

Table 9. Total stocked forest area by growth stage.

Growth stage	Area		
	1000 ha	($\alpha = 0.05$)	%
post establishment	96.92	(85.90 – 107.93)	15.5
pre thicket	80.53	(70.56 – 90.49)	12.9
thicket	90.75	(80.17 – 101.32)	14.5
small pole	108.54	(97.09 – 119.99)	17.3
pole-stage	68.04	(58.79 – 77.29)	10.9
incoming high forest	61.38	(52.45 – 70.31)	9.8
high forest	83.39	(73.37 – 93.42)	13.3
overmature	12.14	(8.35 – 15.93)	1.9
uneven-aged	12.84	(8.47 – 17.21)	2.1
temporarily unstocked	11.22	(7.09 – 15.35)	1.8
Total	625.75		100.0

[2] A storey describes the differentiation of the trees into distinct layers. As a plot may cross stand boundaries there may be more than one storey present on the plot, which could be at two different thinning stages.

[3] Semi-natural forest land is defined as forest land where greater than 80% of the trees regenerated naturally. This forest land includes native and non-native tree species usually not managed in accordance with a formal or an informal plan. It generally indicates natural succession type forests.

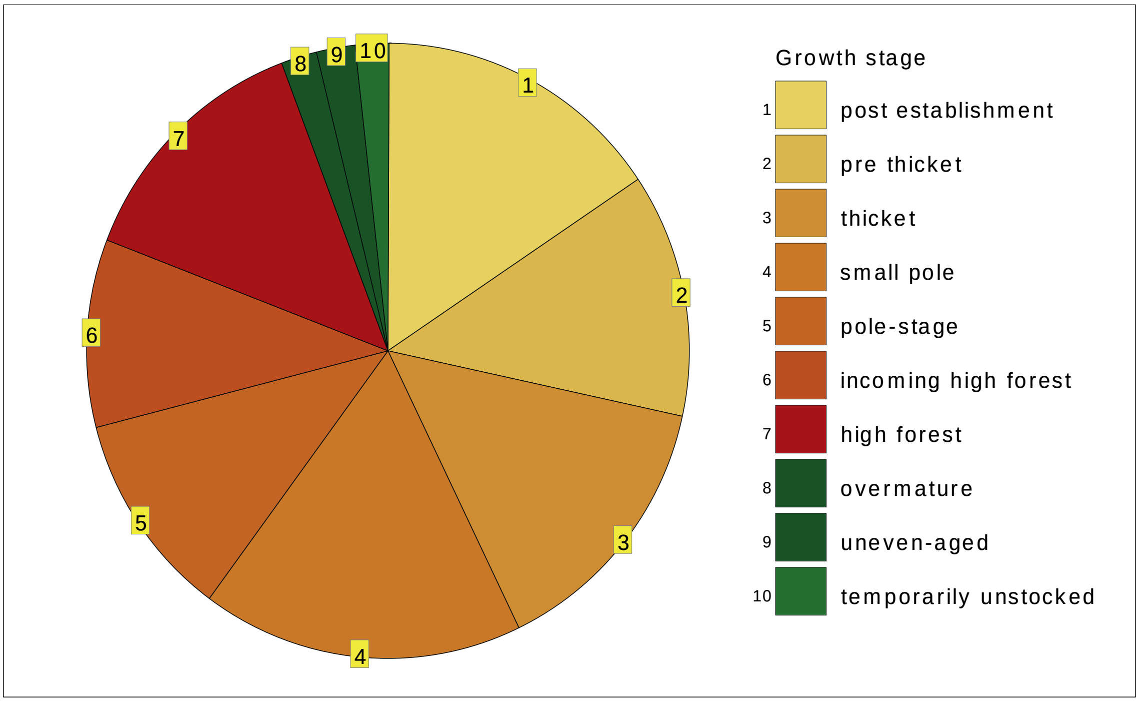

Figure 6. Total stocked forest area by growth stage.

4.3 Thinning Status

In response to discussions concerning thinning status at the NFI conference in Portlaoise on July 11th 2007, an assessment of thinning status using threshold basal area has been used to outline the level of thinning present in the national forest estate.

The classification of thin status was based firstly on whether the forest was thinned, i.e. some of the trees were cut or harvested to provide growing space for the remaining trees. Where no thinning had taken place, an ocular assessment of the growth stage of the forest storey determined the thin status. As this assessment was based on a subjective ocular assessment by field-team members, and taking on board comments expressed at the conference, the classification procedure was amended to remove the subjectivity involved in the field assessment.

The amendments undertaken were based on assessing individual plots that had been classified as 'No thinning'. If a 'No thinning' designation was given, it meant that the trees belonged to a storey that was at a development stage where thinning was possible, but had not been carried out. If the storey was at a development stage where thinning was not possible, it was classified as 'Juvenile forest'. The revised thin status assessment is outlined in section 4.3.1.

The results are presented in two sections; section (4.3.2) assesses the total stocked forest estate classified by thin status, and section (4.3.3) assesses the total stocked forest estate excluding 'Juvenile forest'. The objective is to estimate the total stocked forest area that is at a development stage where thinning can occur.

4.3.1 Revised thin status assessment

The revised assessment of whether the storey was at a development stage where thinning was possible was made on the basis of species, height, basal area and stocking. For a given species and height a threshold basal area can be calculated, which indicates the basal area at which the stand becomes fit for thinning (Coillte, 1998). An example of the process is outlined below:

- **Species**: Sitka spruce
- **Height**: 10 m
- **Stocking**: 2400 stems/ha
- **Basal area (as per plot)**: 35 m^2/ha.
- **Thin threshold basal area**: 33 m^2/ha.

As the threshold basal area is lower than the plot basal area per hectare, this plot is classified as 'No thinning', as no thinnings have taken place and it is at a development stage where thinning could occur.

It is also important to note that while an area may be at a development stage for a thinning to be undertaken, this may be impractical from an accessibility or financial viewpoint. Stability or incipient windblow concerns are also significant factors influencing the level of 'No thinning'. Some of these 'No thinning' areas may be scheduled for thinning subsequent to the NFI assessment but were not thinned on the date of survey. Such changes will be captured in future NFIs.

4.3.2 Total stocked forest estate by thin status

The combination of 'No thinning' and 'Juvenile forest' represents the total area of the forest estate which has not been thinned. This accounts for 86% of the total forest estate (Table 10 and Figure 7). As more than 60% of the total stocked forest estate is less than 20 years old, this high figure is not surprising.

Thinning operations have been carried out on 12% of the total stocked forest estate, with subsequent thinning accounting for nearly 6% of the forest estate (Table 10). As the majority of the private (grant aided) estate is less than 20 years old, 'Juvenile forest' is the dominant category accounting for 87% of the total.

Table 10. Total stocked forest estate classified by thin status and ownership.

Thin status	Ownership / Area					
	public			private (grant aided)		
	1000 ha	($\alpha=0.05$)	%	1000 ha	($\alpha=0.05$)	%
no thinning	111.38	(99.73 – 123.02)	31.0	21.38	(15.89 – 26.86)	11.4
juvenile forest	181.51	(167.75 – 195.26)	50.5	161.59	(148.29 – 174.88)	86.5
respacing	–	– –	–	–	– –	–
first thinning	19.53	(14.21 – 24.85)	5.4	3.19	(0.98 – 5.39)	1.7
2nd thinning	10.47	(6.61 – 14.33)	2.9	–	– –	–
subsequent thinning	26.51	(20.58 – 32.43)	7.4	0.03	(0.00 – 0.08)	0.02
temporarily unstocked	10.02	(6.12 – 13.92)	2.8	0.81	(0.00 – 1.92)	0.4
Total	359.41	(344.28 – 374.54)	100.0	186.99	(173.02 – 200.95)	100.0

Thin status	Ownership / Area					
	private (other)			Total		
	1000 ha	($\alpha=0.05$)	%	1000 ha	($\alpha=0.05$)	%
no thinning	34.18	(27.37 – 40.99)	43.0	166.93	(153.53 – 180.34)	26.7
juvenile forest	30.55	(24.23 – 36.87)	38.5	373.65	(358.86 – 388.43)	59.7
respacing	0.01	(0.00 – 0.02)	0.01	0.01	(0.00 – 0.02)	0.001
first thinning	2.75	(0.76 – 4.74)	3.5	25.47	(19.43 – 31.51)	4.1
2nd thinning	1.42	(0.02 – 2.83)	1.8	11.90	(7.80 – 15.99)	1.9
subsequent thinning	10.04	(6.40 – 13.68)	12.7	36.57	(29.77 – 43.37)	5.8
temporarily unstocked	0.40	(0.00 – 1.20)	0.5	11.22	(7.09 – 15.35)	1.8
Total	79.35	(69.10 – 89.60)	100.0	625.75		100.0

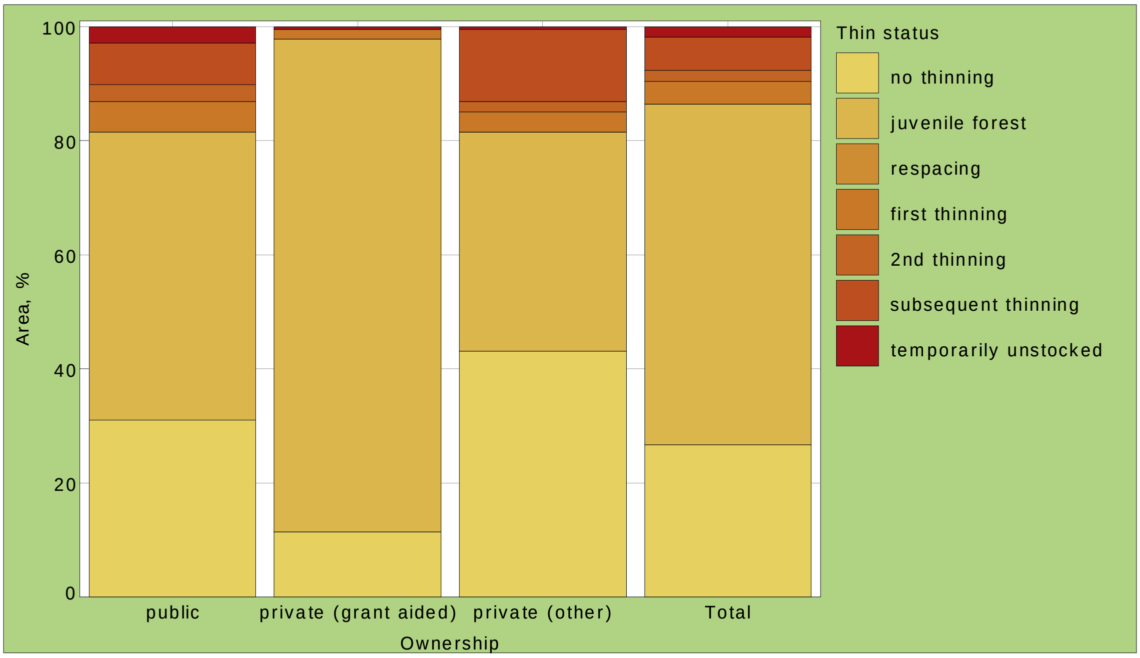

Figure 7. Total stocked forest estate classified by thin status and ownership.

4.3.3 Total stocked forest estate by thin status (excluding juvenile forest)

In this sub-section, the 'Juvenile forest' has been removed from the analysis, thereby concentrating on the portion of the estate that is at a development stage where a thinning could have taken place, but has not for some unknown reasons.

In total, 240,880 ha were at a development stage where thinning could have taken place. More than 69% of this area has not been thinned (Table 11 and Figure 8). The remainder of the area is at various stages of thinning, with subsequent thinning accounting for 15% of the area.

The total stocked forest estate classified by thin status and ownership (excluding 'Juvenile forest' and 'Temporarily unstocked') is presented in Table 11 and Figure 8. In total, there are 24,590 ha of the Private (grant aided) estate at a development stage where a thinning could have occurred. However, 87% of this area has not been thinned. Two-thirds (66.4% or 111,308 ha) of the public estate at a development stage where a thinning could have taken place, has not been thinned. The analysis does not include reasons as to why thinnings did or did not take place.

Table 11. Total stocked forest estate classified by thin status and ownership, excluding juvenile forest.

Thin status	Ownership / Area					
	public			private (grant aided)		
	1000 ha	($\alpha = 0.05$)	%	1000 ha	($\alpha = 0.05$)	%
no thinning	111.38	(99.73 – 123.02)	66.4	21.38	(15.89 – 26.86)	86.9
respacing	–	– –	–	–	– –	–
first thinning	19.53	(14.21 – 24.85)	11.6	3.19	(0.98 – 5.39)	13.0
2nd thinning	10.47	(6.61 – 14.33)	6.2	–	– –	–
subsequent thinning	26.51	(20.58 – 32.43)	15.8	0.03	(0.00 – 0.08)	0.1
Total	167.88	(154.34 – 181.43)	100.0	24.59	(18.71 – 30.48)	100.0

Thin status	Ownership / Area					
	private (other)			Total		
	1000 ha	(α=0.05)	%	1000 ha	(α=0.05)	%
no thinning	34.18	(27.37 – 40.99)	70.7	166.93	(153.53 – 180.34)	69.3
respacing	0.01	(0.00 – 0.02)	0.02	0.01	(0.00 – 0.02)	0.003
first thinning	2.75	(0.76 – 4.74)	5.7	25.47	(19.43 – 31.51)	10.6
2nd thinning	1.42	(0.02 – 2.83)	2.9	11.90	(7.80 – 15.99)	4.9
subsequent thinning	10.04	(6.40 – 13.68)	20.7	36.57	(29.77 – 43.37)	15.2
Total	48.40	(40.40 – 56.41)	100.0	240.88	(226.20 – 255.57)	100.0

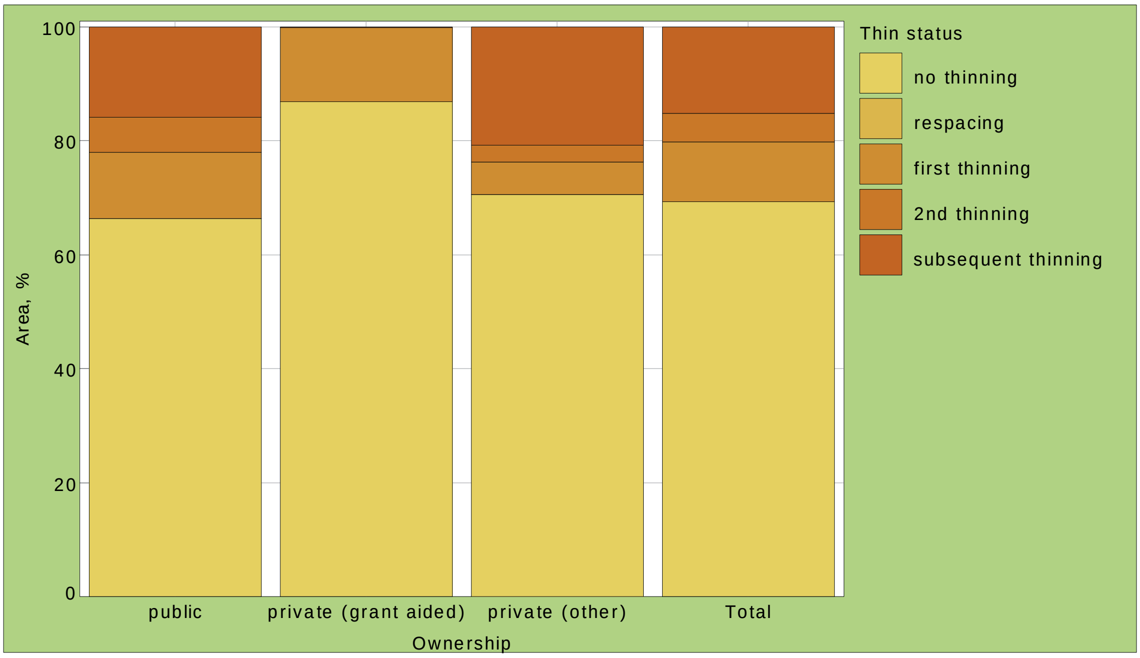

Figure 8. Total stocked forest estate classified by thin status and ownership, excluding juvenile forest.

5. Growing Stock

This section contains a description of the volume or growing stock (m^3) of the national forest estate and how it is related to attributes, such as species and ownership. Biomass estimates for carbon storage are included in the NFI Results publication.

5.1 Total Growing Stock by Species Group and Ownership

The Forestry Commission (FC) single tree volume equations (Matthews and Mackie, 2006) were used to estimate standing volume for each tree on the plot with a minimum dbh of 7 cm. The stem volume is measured, overbark, from ground to 7 cm top diameter for coniferous trees. For broadleaf species, the stem volume is measured from ground to timber height. Timber height concerns merchantable material only, and is the distance from the base to the highest point on the main stem where the diameter is not less than 7 cm overbark (Matthews and Mackie, 2006). The total growing stock of the national forest estate was estimated to be 70.1 million m^3, the majority (74%) of which is located in the public forest estate (Table 12 and Figure 9). Sitka spruce accounts for 61% of the total growing stock, while 'other pine spp' account for 11%. The private (other) estate accounts for 15% of the total growing stock, the majority of which belongs to broadleaf tree species.

Table 12. Total growing stock by species group and ownership.

Species group	Ownership / Growing stock: public 1000 m³	(α=0.05)	%	private (grant aided) 1000 m³	(α=0.05)	%
Sitka spruce	35,604.0	(32,855.2 – 38,352.8)	68.9	5,405.7	(4,804.1 – 6,007.2)	71.2
Norway spruce	1,712.2	(1,278.2 – 2,146.3)	3.3	363.9	(290.9 – 436.8)	4.8
Scots pine	501.5	(266.4 – 736.7)	1.0	45.8	– –	0.6
other pine spp.	6,544.2	(5,760.9 – 7,327.5)	12.7	469.1	(101.7 – 836.6)	6.2
Douglas fir	1,474.2	(1,163.2 – 1,785.1)	2.9	39.8	– –	0.5
larch spp.	894.8	(239.8 – 1,549.9)	1.7	384.3	(156.7 – 611.9)	5.1
other conifers	1,060.1	(0.0 – 2,393.1)	2.1	116.2	– –	1.5
sessile and pedunculate oak	716.9	(415.9 – 1,017.9)	1.4	145.3	(0.0 – 365.4)	1.9
beech	904.7	(604.3 – 1,205.1)	1.8	–	– –	–
ash	459.0	(282.4 – 635.5)	0.9	135.2	(59.4 – 211.0)	1.8
sycamore	181.2	(69.6 – 292.8)	0.4	44.6	(38.8 – 50.3)	0.6
birch spp.	602.9	(461.2 – 744.6)	1.2	140.6	(0.0 – 547.7)	1.9
alder spp.	311.3	(134.1 – 488.5)	0.6	109.9	(0.0 – 333.5)	1.4
other long living broadleaves	161.6	(98.6 – 224.6)	0.3	100.7	(0.0 – 320.0)	1.3
other short living broadleaves	417.3	(284.0 – 550.7)	0.8	87.3	(0.0 – 213.2)	1.2
Total	51,546.1	(48,399.4 – 54,692.7)	100.0	7,588.1	(6,767.1 – 8,409.1)	100.0

Species group	Ownership / Growing stock: private (other) 1000 m³	(α=0.05)	%	Total 1000 m³	(α=0.05)	%
Sitka spruce	1,503.0	(697.9 – 2,308.0)	13.7	42,512.6	(39,562.8 – 45,462.5)	60.6
Norway spruce	694.1	(0.0 – 2,580.2)	6.3	2,770.2	(2,179.5 – 3,361.0)	4.0
Scots pine	369.0	(246.1 – 491.9)	3.4	916.3	(591.2 – 1,241.4)	1.3
other pine spp.	690.5	– –	6.3	7,703.9	(6,449.7 – 8,958.1)	11.0
Douglas fir	410.2	(177.9 – 642.5)	3.7	1,924.2	(1,566.1 – 2,282.3)	2.7
larch spp.	308.9	(0.0 – 1,076.1)	2.8	1,588.0	(877.8 – 2,298.2)	2.3
other conifers	473.1	(0.0 – 3,284.9)	4.3	1,649.4	(203.5 – 3,095.3)	2.4
sessile and pedunculate oak	1,522.8	(1,085.8 – 1,959.8)	14.0	2,385.0	(1,779.8 – 2,990.2)	3.4
beech	825.8	(260.4 – 1,391.2)	7.5	1,730.5	(1,183.3 – 2,277.8)	2.5
ash	908.1	(701.4 – 1,114.8)	8.3	1,502.3	(1,248.3 – 1,756.2)	2.1
sycamore	367.6	(72.3 – 662.9)	3.3	593.4	(185.4 – 1,001.3)	0.8
birch spp.	1,089.6	(591.3 – 1,587.9)	9.9	1,833.1	(1,563.3 – 2,102.8)	2.6
alder spp.	428.2	(347.9 – 508.5)	3.9	849.4	(664.5 – 1,034.3)	1.2
other long living broadleaves	516.0	(316.8 – 715.2)	4.7	778.3	(645.2 – 911.4)	1.1
other short living broadleaves	868.2	(599.4 – 1,136.9)	7.9	1,372.8	(1,147.2 – 1,598.5)	2.0
Total	10,975.2	(9,282.7 – 12,667.6)	100.0	70,109.4	(66,398.6 – 73,820.2)	100.0

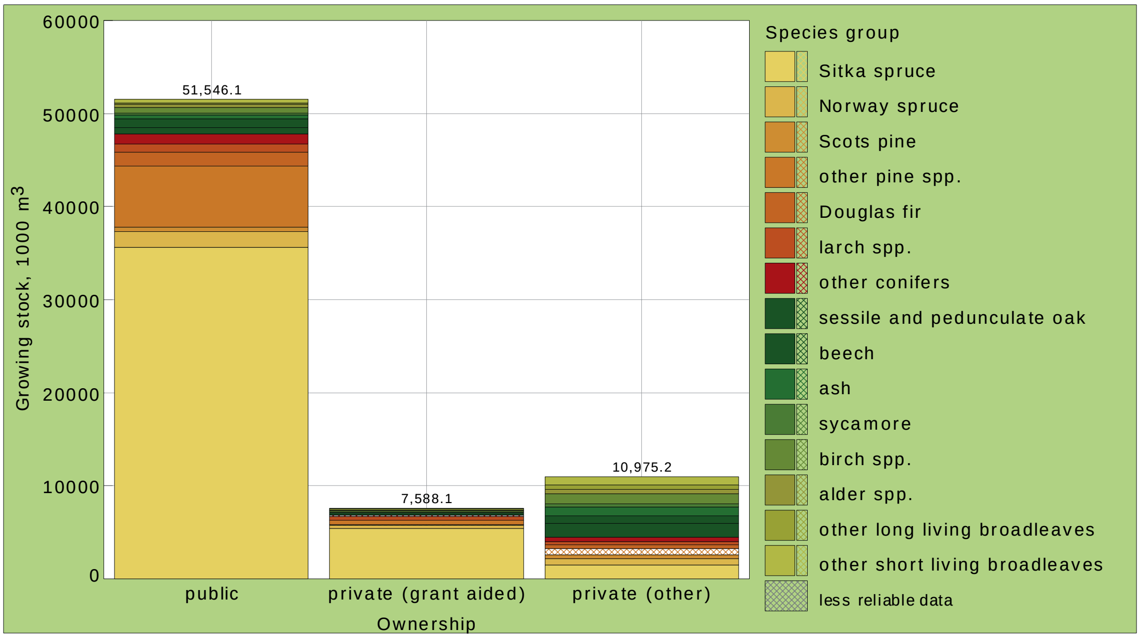

Figure 9. Total growing stock by species group and ownership.

5.2 Total Growing Stock by County and Ownership

The distribution of growing stock between the counties is a reflection of the total forest area and the age structure of the forests in each county. The distribution of species within each county will also influence the total growing stock. County Cork contains the highest percentage (13.5%) and county Louth the lowest percentage (0.5%) of the national growing stock (Table 13 and Figure 10). Counties Clare, Donegal, Kerry, Galway, Laois, Mayo, Tipperary and Wicklow combined have 50% of the national growing stock or between 5 and 8% each.

Table 13. Total growing stock by county and ownership

County	Ownership / Growing stock					
	public			private (grant aided)		
	1000 m^3	($\alpha = 0.05$)	%	1000 m^3	($\alpha = 0.05$)	%
Carlow	1,013.6	(296.2 – 1,731.0)	2.0	47.4	– –	0.6
Cavan	1,400.3	(825.0 – 1,975.7)	2.7	199.7	(0.0 – 628.0)	2.6
Clare	2,985.9	(2,247.3 – 3,724.4)	5.8	815.9	(530.2 – 1,101.6)	10.7
Cork	7,579.2	(6,368.1 – 8,790.3)	14.8	600.3	(352.7 – 847.9)	7.9
Donegal	4,125.0	(3,311.8 – 4,938.2)	8.0	170.3	(0.0 – 393.6)	2.2
Dublin	523.9	(0.0 – 1,093.1)	1.0	35.0	(0.0 – 182.3)	0.5
Galway	4,707.9	(3,847.0 – 5,568.7)	9.1	542.1	(367.3 – 717.0)	7.1
Kerry	3,503.7	(2,634.4 – 4,373.0)	6.8	647.1	(434.7 – 859.5)	8.5
Kildare	641.6	(361.3 – 921.8)	1.2	15.7	(0.0 – 77.6)	0.2
Kilkeny	1,353.6	(924.1 – 1,783.1)	2.6	257.2	(0.0 – 609.8)	3.4
Laois	3,264.3	(2,429.2 – 4,099.4)	6.3	209.3	(0.0 – 668.1)	2.8
Leitrim	1,656.2	(993.9 – 2,318.5)	3.2	460.1	(219.9 – 700.4)	6.1
Limerick	2,173.3	(1,382.1 – 2,964.5)	4.2	270.5	(114.7 – 426.2)	3.6
Longford	125.4	(0.0 – 286.9)	0.2	159.2	(13.2 – 305.3)	2.1
Louth	81.6	– –	0.2	–	– –	–
Mayo	2,947.3	(2,368.4 – 3,526.2)	5.7	361.9	(202.4 – 521.3)	4.8
Meath	654.1	(238.8 – 1,069.3)	1.3	85.0	(35.1 – 135.0)	1.1
Monaghan	510.8	(0.0 – 1,890.3)	1.0	76.0	– –	1.0
Offaly	962.7	(551.2 – 1,374.3)	1.9	357.9	(0.0 – 794.1)	4.7
Roscommon	1,323.8	(632.0 – 2,015.5)	2.6	673.6	(442.6 – 904.6)	8.9
Sligo	1,858.0	(1,128.2 – 2,587.8)	3.6	504.7	(307.6 – 701.7)	6.7
Tipperary	2,381.0	(1,826.2 – 2,935.8)	4.6	673.1	(191.4 – 1,154.7)	8.9
Waterford	1,482.4	(900.3 – 2,064.5)	2.9	61.9	(0.0 – 142.8)	0.8
Westmeath	686.0	(351.3 – 1,020.7)	1.3	95.2	(8.4 – 182.1)	1.3
Wexford	740.8	(404.5 – 1,077.2)	1.4	70.9	(0.0 – 156.2)	0.9
Wicklow	2,863.8	(1,830.1 – 3,897.5)	5.6	198.2	(123.6 – 272.7)	2.6
Total	51,546.1	(48,399.4 – 54,692.7)	100.0	7,588.1	(6,767.1 – 8,409.1)	100.0

County	Ownership / Growing stock					
	private (other)			Total		
	1000 m³	(α = 0.05)	%	1000 m³	(α = 0.05)	%
Carlow	200.4	(0.0 – 697.3)	1.8	1,261.4	(555.4 – 1,967.4)	1.8
Cavan	13.0	– –	0.1	1,613.0	(990.6 – 2,235.4)	2.3
Clare	647.0	(266.8 – 1,027.2)	5.9	4,448.8	(3,563.3 – 5,334.3)	6.3
Cork	1,382.7	(914.8 – 1,850.6)	12.6	9,562.2	(8,216.4 – 10,908.0)	13.5
Donegal	426.6	(205.7 – 647.4)	3.9	4,721.8	(3,867.1 – 5,576.6)	6.7
Dublin	154.7	(97.3 – 212.1)	1.4	713.5	(238.7 – 1,188.3)	1.0
Galway	315.8	(99.7 – 532.0)	2.9	5,565.8	(4,664.5 – 6,467.2)	7.9
Kerry	1,075.0	(0.0 – 2,302.3)	9.8	5,225.8	(3,836.5 – 6,615.1)	7.5
Kildare	289.5	(0.0 – 626.4)	2.6	946.8	(591.1 – 1,302.5)	1.4
Kilkeny	289.1	(0.0 – 580.7)	2.6	1,899.8	(1,375.2 – 2,424.4)	2.7
Laois	517.4	(0.0 – 1,077.2)	4.7	3,991.0	(3,062.4 – 4,919.6)	5.7
Leitrim	117.1	(47.4 – 186.8)	1.1	2,233.5	(1,515.1 – 2,951.9)	3.2
Limerick	63.9	– –	0.6	2,507.7	(1,699.6 – 3,315.8)	3.6
Longford	110.7	(0.0 – 344.6)	1.0	395.3	(193.3 – 597.2)	0.6
Louth	265.4	(0.0 – 1,915.7)	2.4	347.0	(0.0 – 932.8)	0.5
Mayo	472.6	(172.8 – 772.4)	4.3	3,781.8	(3,125.1 – 4,438.4)	5.4
Meath	500.3	(170.9 – 829.6)	4.6	1,239.4	(801.5 – 1,677.3)	1.8
Monaghan	242.3	(62.7 – 421.8)	2.2	829.0	(84.9 – 1,573.2)	1.2
Offaly	555.0	(188.8 – 921.1)	5.1	1,875.6	(1,329.3 – 2,422.0)	2.7
Roscommon	755.0	(104.6 – 1,405.4)	6.9	2,752.4	(1,830.8 – 3,674.1)	3.9
Sligo	220.8	(0.0 – 441.7)	2.0	2,583.4	(1,801.8 – 3,365.0)	3.7
Tipperary	495.9	(284.1 – 707.7)	4.5	3,550.0	(2,867.6 – 4,232.4)	5.1
Waterford	370.9	(189.2 – 552.6)	3.4	1,915.3	(1,321.1 – 2,509.5)	2.7
Westmeath	206.0	(0.0 – 619.7)	1.9	987.2	(562.9 – 1,411.6)	1.4
Wexford	170.1	(0.0 – 550.7)	1.5	981.8	(612.2 – 1,351.4)	1.4
Wicklow	1,118.1	(552.1 – 1,684.1)	10.2	4,180.1	(3,030.6 – 5,329.6)	6.0
Total	10,975.2	(9,282.7 – 12,667.6)	100.0	70,109.4	(66,398.6 – 73,820.2)	100.0

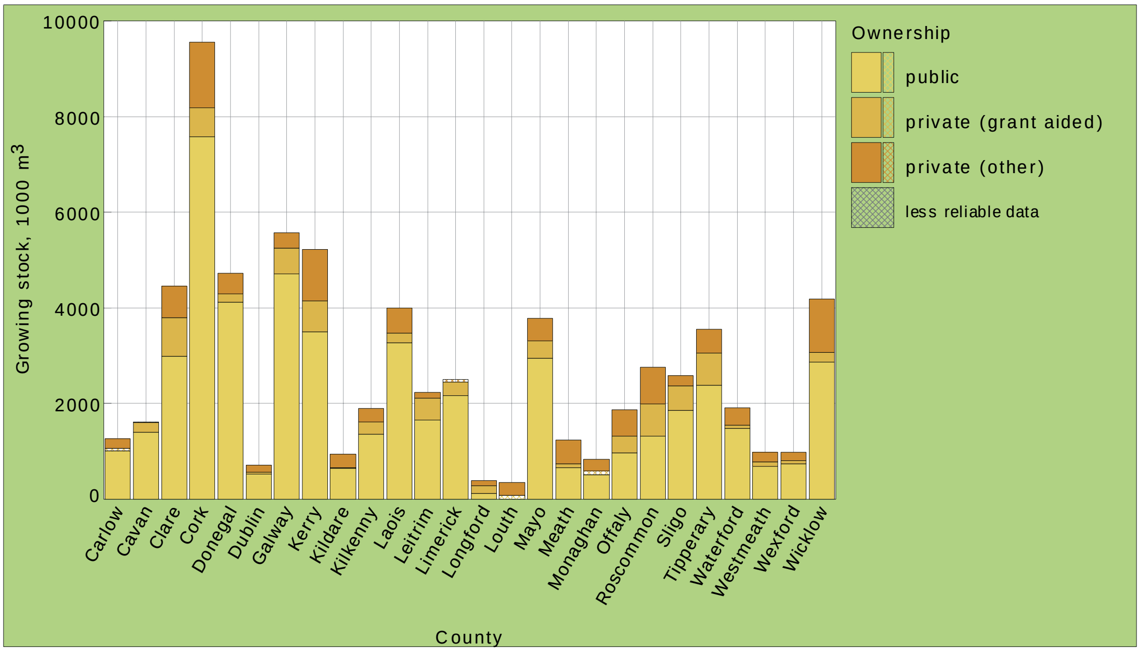

Figure 10. Total growing stock by county and ownership.

5.3 Mean Growing Stock Per Hectare by Ownership and Species Group

The mean growing stock per hectare for the national estate is 112 m^3/ha (Table 14 and Figure 11). Owing to the young age structure of the private (grant aided) forest estate, the growing stock per hectare is only 41 m^3/ha in this category.

Table 14. Mean growing stock per hectare by ownership and species group.

Species group	Ownership / Growing stock			
	public		private (grant aided)	
	m^3/ha	($\alpha = 0.05$)	m^3/ha	($\alpha = 0.05$)
Sitka spruce	176	(161 – 191)	48	(41 – 56)
Norway spruce	211	(179 – 244)	41	(30 – 53)
Scots pine	198	(163 – 234)	105	(81 – 129)
other pine spp.	125	(106 – 145)	37	(10 – 63)
Douglas fir	272	(207 – 337)	10	– –
larch spp.	117	(79 – 156)	26	(13 – 39)
other conifers	401	(377 – 425)	115	(0 – 689)
sessile and pedunculate oak	191	(173 – 209)	102	(0 – 259)
beech	170	(121 – 218)	–	– –
ash	123	(37 – 210)	27	(0 – 55)
sycamore	91	(0 – 298)	19	(14 – 24)
birch spp.	52	(35 – 69)	47	(28 – 66)
alder spp.	116	(93 – 139)	23	(17 – 29)
other long living broadleaves	37	(28 – 45)	89	(0 – 542)
other short living broadleaves	19	(13 – 25)	19	(8 – 30)
All	145	(134 – 156)	41	(34 – 47)

Species group	Ownership / Growing stock			
	private (other)		All	
	m^3/ha	($\alpha = 0.05$)	m^3/ha	($\alpha = 0.05$)
Sitka spruce	370	(324 – 416)	133	(123 – 144)
Norway spruce	275	(0 – 611)	104	(46 – 163)
Scots pine	423	(242 – 605)	202	(37 – 367)
other pine spp.	398	– –	120	(96 – 143)
Douglas fir	367	(90 – 645)	255	(191 – 319)
larch spp.	268	(231 – 306)	70	(49 – 91)
other conifers	260	(0 – 1,015)	361	(299 – 423)
sessile and pedunculate oak	267	(219 – 314)	190	(153 – 228)
beech	213	(184 – 241)	172	(149 – 196)
ash	142	(120 – 164)	83	(65 – 102)
sycamore	168	(135 – 201)	107	(85 – 128)
birch spp.	96	(81 – 111)	67	(57 – 76)
alder spp.	105	(75 – 134)	86	(71 – 101)
other long living broadleaves	75	(59 – 92)	71	(54 – 89)
other short living broadleaves	42	(33 – 52)	29	(24 – 34)
All	137	(113 – 162)	112	(104 – 120)

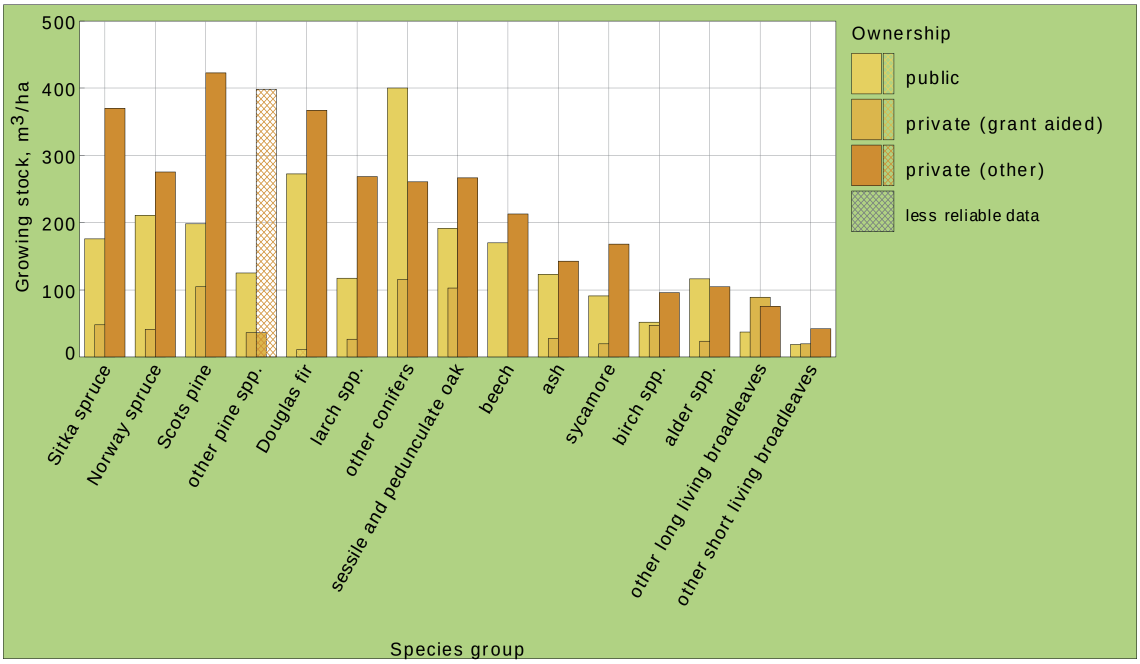

Figure 11. Mean growing stock per hectare by ownership and species group.

5.4 Total Growing Stock by Species Group and Assortment Category

Tree volume was categorised by top diameter on the basis of individual tree dbh (Matthews and Mackie, 2006). The percentage overbark volume to specified overbark top diameter (no minimum length) was calculated for three assortment categories.

- Pulp (7-13.9 cm top diameter)
- Pallet (14-19.9 cm top diameter)
- Sawlog (20 cm+ top diameter).

Overall the breakdown for pulp, pallet and sawlog is 29%, 28% and 43%, respectively (Table 15 and Figure 12). These estimates do not incorporate downgrade due to factors such as the stem straightness attribute.

Table 15. Total growing stock by species group and assortment category.

Assortment (TD OB)	Species group / Growing stock					
	Sitka spruce			Norway spruce		
	1000 m³	(α = 0.05)	%	1000 m³	(α = 0.05)	%
Pulp (7-13.9 cm)	12,962.3	(12,089.6 – 13,835.1)	30.5	755.2	(572.7 – 937.6)	27.3
Pallet (14-19.9 cm)	13,122.1	(12,010.7 – 14,233.5)	30.9	662.8	(474.4 – 851.2)	23.9
Sawlog (20+ cm)	16,428.2	(13,885.7 – 18,970.7)	38.6	1,352.3	(792.5 – 1,912.0)	48.8
Total	42,512.6	(38,744.8 – 46,280.4)	100.0	2,770.2	(1,985.3 – 3,555.2)	100.0
Assortment (TD OB)	Species group / Growing stock					
	Scots pine			other pine spp.		
	1000 m³	(α = 0.05)	%	1000 m³	(α = 0.05)	%
Pulp (7-13.9 cm)	96.2	(53.1 – 139.3)	10.5	2,572.7	(2,211.0 – 2,934.4)	33.4
Pallet (14-19.9 cm)	156.5	(95.6 – 217.3)	17.1	2,686.1	(2,269.9 – 3,102.3)	34.9
Sawlog (20+ cm)	663.7	(371.4 – 955.9)	72.4	2,445.0	(1,372.3 – 3,517.8)	31.7
Total	916.3	(570.5 – 1,262.1)	100.0	7,703.9	(6,284.0 – 9,123.7)	100.0

Assortment (TD OB)	Species group / Growing stock					
	Douglas fir			larch spp.		
	1000 m³	(α=0.05)	%	1000 m³	(α=0.05)	%
Pulp (7-13.9 cm)	497.1	(349.9 – 644.2)	25.8	488.6	(335.4 – 641.7)	30.8
Pallet (14-19.9 cm)	506.5	(325.6 – 687.5)	26.3	360.9	(220.6 – 501.3)	22.7
Sawlog (20+ cm)	920.6	(476.0 – 1,365.2)	47.9	738.5	(250.6 – 1,226.4)	46.5
Total	1,924.2	(1,274.6 – 2,573.7)	100.0	1,588.0	(968.2 – 2,207.8)	100.0

Assortment (TD OB)	Species group / Growing stock					
	other conifers			sessile and pedunculate oak		
	1000 m³	(α=0.05)	%	1000 m³	(α=0.05)	%
Pulp (7-13.9 cm)	185.7	(72.5 – 298.9)	11.3	148.1	(80.2 – 215.9)	6.2
Pallet (14-19.9 cm)	217.4	(90.6 – 344.3)	13.2	178.9	(131.6 – 226.3)	7.5
Sawlog (20+ cm)	1,246.2	(439.6 – 2,052.8)	75.5	2,058.0	(1,369.3 – 2,746.7)	86.3
Total	1,649.4	(719.8 – 2,579.0)	100.0	2,385.0	(1,653.5 – 3,116.5)	100.0

Assortment (TD OB)	Species group / Growing stock					
	beech			ash		
	1000 m³	(α=0.05)	%	1000 m³	(α=0.05)	%
Pulp (7-13.9 cm)	139.2	(99.2 – 179.2)	8.0	458.7	(345.5 – 571.9)	30.5
Pallet (14-19.9 cm)	220.2	(159.3 – 281.0)	12.7	389.4	(290.5 – 488.3)	25.9
Sawlog (20+ cm)	1,371.2	(823.9 – 1,918.5)	79.3	654.1	(444.9 – 863.3)	43.6
Total	1,730.5	(1,131.8 – 2,329.3)	100.0	1,502.3	(1,171.3 – 1,833.2)	100.0

Assortment (TD OB)	Species group / Growing stock					
	sycamore			birch spp.		
	1000 m³	(α=0.05)	%	1000 m³	(α=0.05)	%
Pulp (7-13.9 cm)	91.4	(35.1 – 147.7)	15.4	737.8	(589.4 – 886.1)	40.3
Pallet (14-19.9 cm)	61.7	(33.1 – 90.4)	10.4	487.9	(382.0 – 593.9)	26.6
Sawlog (20+ cm)	440.3	(203.4 – 677.1)	74.2	607.3	(409.6 – 805.1)	33.1
Total	593.4	(321.0 – 865.8)	100.0	1,833.1	(1,490.0 – 2,176.2)	100.0

Assortment (TD OB)	Species group / Growing stock					
	alder spp.			other long living broadleaves		
	1000 m³	(α=0.05)	%	1000 m³	(α=0.05)	%
Pulp (7-13.9 cm)	312.5	(199.0 – 426.1)	36.8	198.4	(139.0 – 257.8)	25.5
Pallet (14-19.9 cm)	277.3	(182.5 – 372.1)	32.6	137.0	(92.2 – 181.8)	17.6
Sawlog (20+ cm)	259.6	(132.7 – 386.4)	30.6	442.8	(187.7 – 698.0)	56.9
Total	849.4	(595.9 – 1,102.9)	100.0	778.3	(492.8 – 1,063.8)	100.0

Assortment (TD OB)	Species group / Growing stock					
	other short living broadleaves			Total		
	1000 m³	(α=0.05)	%	1000 m³	(α=0.05)	%
Pulp (7-13.9 cm)	739.9	(575.0 – 904.8)	53.9	20,383.7	(19,404.3 – 21,363.2)	29.1
Pallet (14-19.9 cm)	255.9	(197.8 – 314.0)	18.6	19,720.8	(18,513.2 – 20,928.3)	28.1
Sawlog (20+ cm)	377.0	(224.0 – 530.1)	27.5	30,004.9	(26,785.9 – 33,223.9)	42.8
Total	1,372.8	(1,108.6 – 1,637.1)	100.0	70,109.4	(65,682.1 – 74,536.7)	100.0

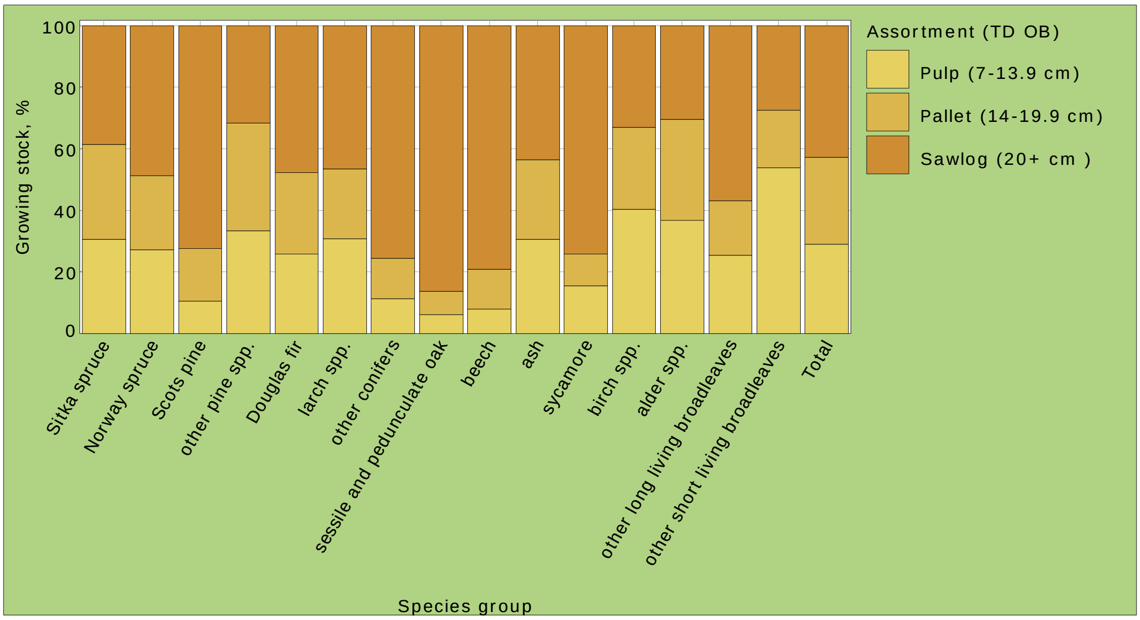

Figure 12. Total growing stock by species group and assortment category.

6. Deadwood

The NFI contained the first comprehensive assessment of deadwood in the Irish forest estate. Deadwood is defined as lying logs over 7 cm mid diameter and over 1 m in length, stumps over 20 cm top diameter and standing dead trees with a minimum dbh of 7 cm. The assessment of deadwood was broken down into three primary categories; lying, standing and stump deadwood.

6.1 Total Deadwood Volume Stock by Deadwood Type and Ownership

The volume of deadwood in the national forest estate is 5.7 million m^3, inclusive of stump, lying and standing deadwood (Table 16 and Figure 13). The public forest estate accounts for 85% of the total deadwood or 4.8 million m^3. This is to be expected as the public forest estate is intensively managed and has a wide distribution of age-classes compared to the private estate.

Nearly half (49%) of the total deadwood volume is in the form of logs lying on the forest floor in various stages of decay. Logs with a minimum mid diameter of 7 cm and a minimum length of 1 m are included in the estimate.

Standing deadwood accounts for 33% of the total deadwood, while stump deadwood accounts for 19%. As stumps under 20 cm top diameter are excluded this figure will be a conservative estimate of the true volume contained in stumps.

Table 16. Total deadwood volume stock by deadwood type and ownership.

Ownership	Deadwood type / Volume stock					
	lying			standing		
	1000 m^3	($\alpha=0.05$)	%	1000 m^3	($\alpha=0.05$)	%
public	2,315.9	(1,425.0 – 3,206.8)	84.4	1,507.9	(1,128.0 – 1,887.7)	81.2
private (grant aided)	53.2	(20.0 – 86.4)	1.9	26.9	(0.0 – 57.5)	1.4
private (other)	376.2	(199.1 – 553.3)	13.7	323.6	(188.7 – 458.6)	17.4
Total	2,745.3	(1,839.3 – 3,651.2)	100.0	1,858.4	(1,459.8 – 2,257.0)	100.0
Ownership	Deadwood type / Volume stock					
	stump			Total		
	1000 m^3	($\alpha=0.05$)	%	1000 m^3	($\alpha=0.05$)	%
public	964.7	(765.8 – 1,163.7)	91.5	4,788.5	(3,745.2 – 5,831.9)	84.7
private (grant aided)	5.8	(1.6 – 10.1)	0.6	85.9	(40.0 – 131.8)	1.5
private (other)	83.8	(49.0 – 118.5)	7.9	783.6	(520.6 – 1,046.5)	13.8
Total	1,054.3	(853.9 – 1,254.7)	100.0	5,658.0	(4,592.0 – 6,724.1)	100.0

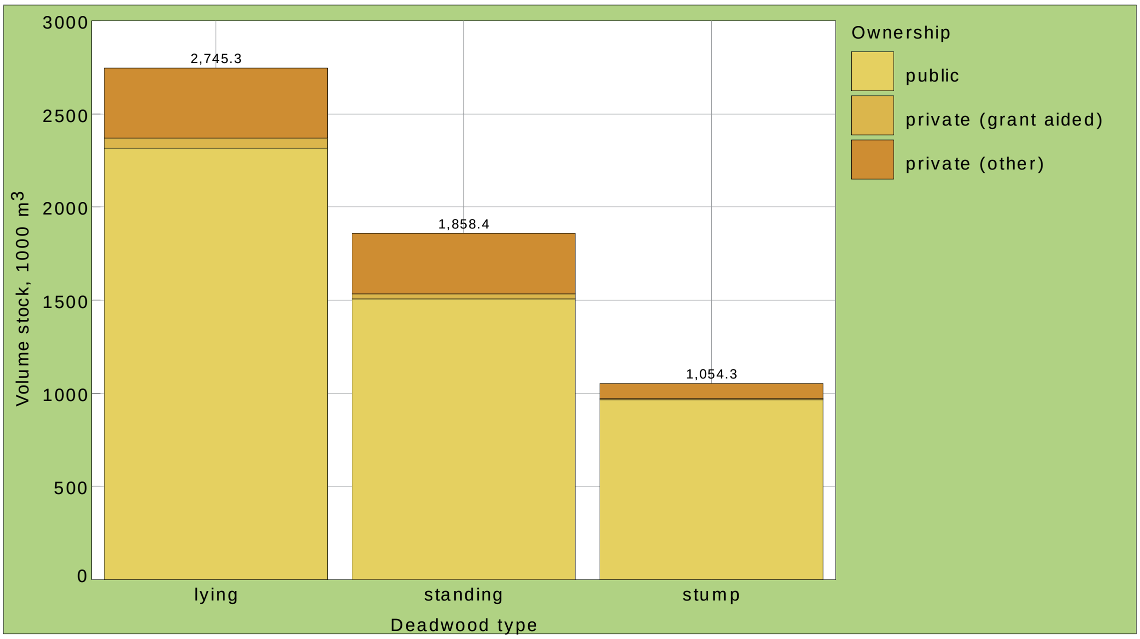

Figure 13. Total deadwood volume stock by deadwood type and ownership.

6.2 Mean Deadwood Volume Stock Per Hectare by Ownership

The mean deadwood volume stock per hectare for the entire national forest estate is 9 m^3/ha (Table 17). As the public estate is the most intensively managed and there is a wide distribution of age-classes, the average amount of deadwood is highest at 13.3 m^3/ha.

Table 17. Mean deadwood volume stock per hectare for the entire forest estate.

Ownership	Volume stock	
	m^3/ha	($\alpha = 0.05$)
public	13.3	(10.5 – 16.2)
private (grant aided)	0.5	(0.2 – 0.7)
private (other)	9.9	(6.6 – 13.2)
All	9.0	(7.3 – 10.7)

If the analysis includes only those sites where deadwood was present, the mean deadwood volume stock per hectare is estimated to be 20 m^3/ha (Table 18). The higher level of deadwood in the public estate is also expected due to the significant areas clearfelled each year.

Table 18. Mean deadwood volume stock per hectare for the portion of the forest estate where deadwood is present.

Ownership	Volume stock	
	m^3/ha	($\alpha = 0.05$)
public	21.5	(17.0 – 26.1)
private (grant aided)	7.7	(4.8 – 10.6)
private (other)	16.4	(11.0 – 21.8)
All	20.1	(16.4 – 23.8)

7. Health and Vitality

The forest health describes tree attributes relating to the health and vitality of the forest estate. Tree vitality, damage, defoliation and discolouration are all described.

7.1 Total Number of Trees by Defoliation Percentage

The level of defoliation was recorded for four species groups, on those trees that were at least 70 mm dbh. Nearly one third (30%) of the tree species assessed had no defoliation present (Table 19 and Figure 14). Defoliation of between 1 and 10% is present on 32% of the trees. A further 18% of the trees, had defoliation of between 11 and 20%. Norway spruce had the largest proportion of trees with no defoliation (48%) and 'Other pine spp.' the lowest (21%).

Table 19. Total number of trees by defoliation percentage (dbh above 7 cm) by species group.

Defoliation, %	Species group / Number of trees					
	Sitka spruce			Norway spruce		
	1000	(α=0.05)	%	1000	(α=0.05)	%
0 %	45,761	(39,132 – 52,391)	30.4	7,098	(4,269 – 9,928)	48.2
1 - 10 %	50,402	(43,524 – 57,281)	33.6	3,941	(2,318 – 5,564)	26.8
11 - 20 %	25,508	(21,201 – 29,816)	17.0	2,349	(1,159 – 3,539)	16.0
21 - 30 %	13,556	(10,650 – 16,462)	9.0	875	(0 – 1,798)	5.9
31 - 40 %	8,190	(6,047 – 10,333)	5.4	166	(0 – 454)	1.1
41 - 50 %	2,283	(1,333 – 3,233)	1.5	220	(0 – 512)	1.5
>50 %	4,651	(3,074 – 6,229)	3.1	68	(0 – 145)	0.5
Total	150,352	(138,282 – 162,422)	100.0	14,717	(10,507 – 18,927)	100.0

Defoliation, %	Species group / Number of trees					
	Scots pine			other pine spp.		
	1000	(α=0.05)	%	1000	(α=0.05)	%
0 %	864	(300 – 1,428)	43.9	6,544	(4,357 – 8,732)	21.0
1 - 10 %	409	(171 – 646)	20.8	8,079	(6,038 – 10,120)	26.0
11 - 20 %	448	(118 – 779)	22.8	7,681	(5,886 – 9,477)	24.7
21 - 30 %	116	(21 – 211)	5.9	4,693	(3,147 – 6,238)	15.1
31 - 40 %	56	(3 – 109)	2.9	1,744	(832 – 2,656)	5.6
41 - 50 %	40	(0 – 83)	2.0	1,091	(401 – 1,781)	3.5
>50 %	34	(0 – 88)	1.7	1,263	(445 – 2,080)	4.1
Total	1,967	(1,205 – 2,729)	100.0	31,095	(26,291 – 35,899)	100.0

Defoliation, %	Species group / Number of trees		
	Total		
	1000	(α=0.05)	%
0 %	60,268	(52,707 – 67,828)	30.4
1 - 10 %	62,831	(55,389 – 70,274)	31.8
11 - 20 %	35,987	(31,163 – 40,810)	18.2
21 - 30 %	19,239	(15,840 – 22,637)	9.7
31 - 40 %	10,156	(7,821 – 12,491)	5.1
41 - 50 %	3,634	(2,432 – 4,837)	1.8
>50 %	6,016	(4,249 – 7,783)	3.0
Total	198,131	(184,459 – 211,803)	100.0

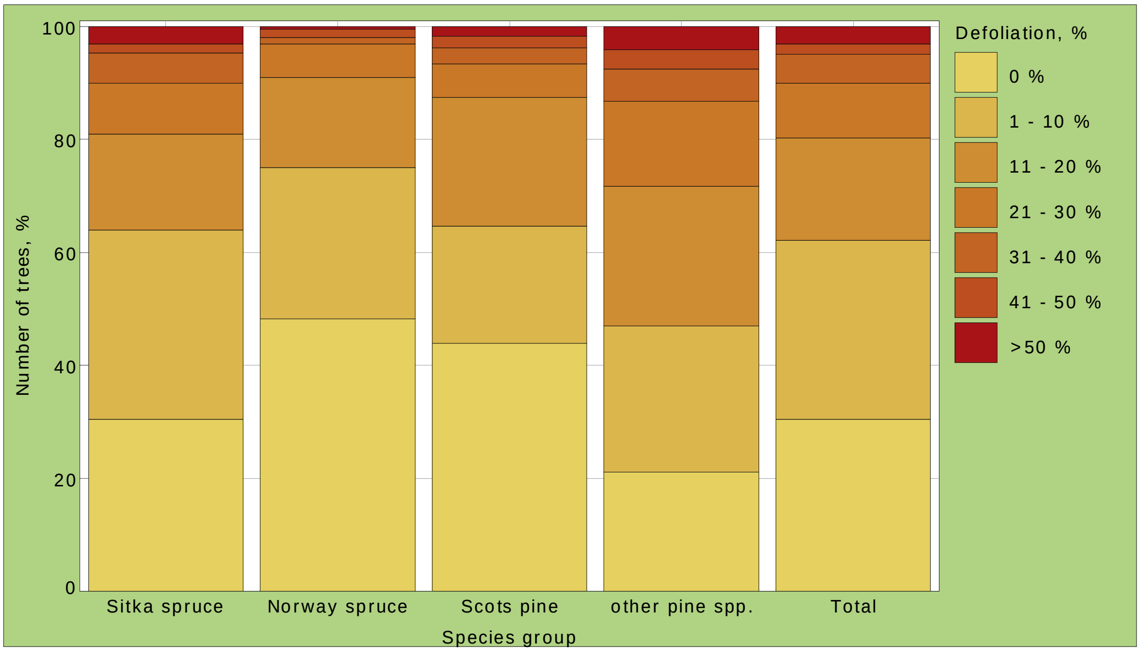

Figure 14. Total number of trees by defoliation percentage (dbh above 7 cm).

7.2 Total Number of Trees by Broadleaf Vitality

Broadleaf vitality was assessed on oak and beech tree species that were at least 70 mm dbh. It describes the capacity of the tree species to continue to grow in a healthy condition. In winter when foliage was absent from the tree, the degree of branching and condition of the bark were used as the basis of assessment.

In total 77% of the trees assessed were classified as undamaged and 17% as weakened (Table 20 and Figure 15). Sessile and pedunculate oak had the largest proportion of trees with no damage (83%) and beech the lowest (69%).

Table 20.Total number of trees by broadleaf vitality and species group (dbh above 7 cm).

Broadleaf vitality	Species group / Number of trees					
	sessile and pedunculate oak			beech		
	1000	(α=0.05)	%	1000	(α=0.05)	%
undamaged tree	3,514	(1,705 – 5,322)	82.7	1,849	(1,241 – 2,458)	68.6
weakened tree	409	(186 – 631)	9.6	734	(80 – 1,389)	27.2
moderately damaged tree	225	(104 – 346)	5.3	98	(16 – 180)	3.6
strongly damaged tree	100	(18 – 183)	2.4	16	(0 – 49)	0.6
Total	4,248	(2,410 – 6,085)	100.0	2,698	(1,792 – 3,604)	100.0

Broadleaf vitality	Species group / Number of trees		
	Total		
	1000	(α=0.05)	%
undamaged tree	5,363	(3,447 – 7,279)	77.1
weakened tree	1,143	(444 – 1,842)	16.5
moderately damaged tree	323	(160 – 486)	4.7
strongly damaged tree	116	(28 – 205)	1.7
Total	6,945	(4,893 – 8,998)	100.0

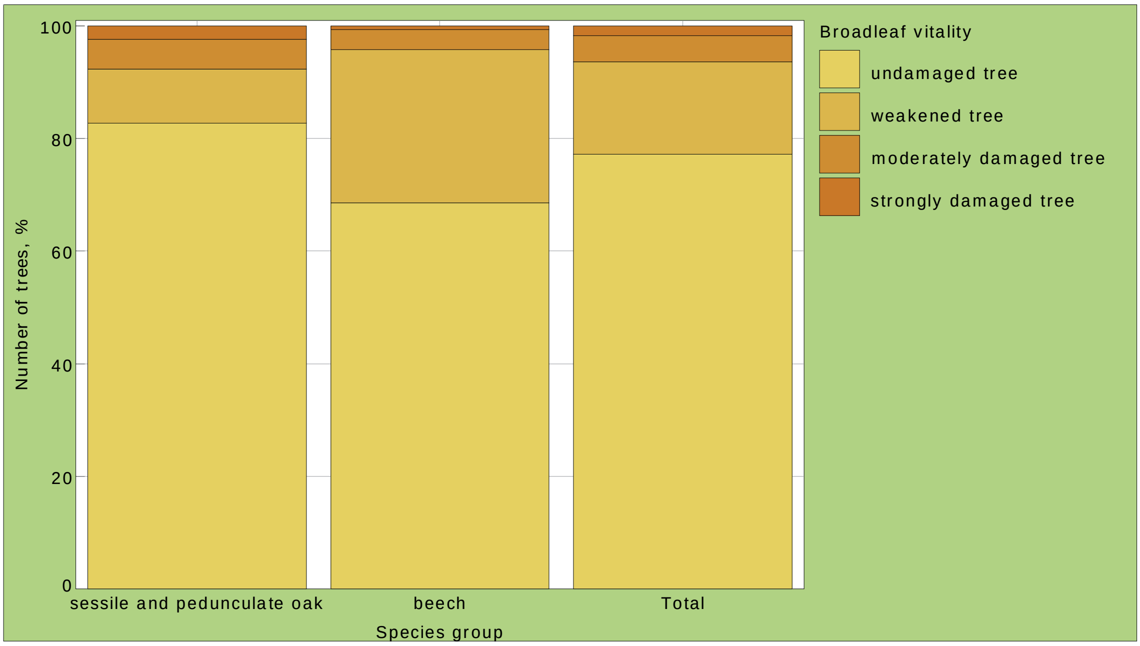

Figure 15. Total number of trees by broadleaf vitality and species group (dbh above 7 cm).

7.3 Total Number of Trees by Discolouration Intensity and Species Group

The level of discolouration in conifers was assessed on four species groups, by comparing the number of trees assessed in each discolouration category. Discolouration was only assessed on trees that were at least 70 mm dbh. Overall 90% of the trees assessed had no discolouration evident (Table 21 and Figure 16). Scots pine had the lowest level (1%) of any discolouration and other pine species the highest at 13%.

Table 21. Total number of trees by discolouration intensity and species group (DBH above 7 cm).

Discolouration, %	Species group / Number of trees					
	Sitka spruce			Norway spruce		
	1000	(α=0.05)	%	1000	(α=0.05)	%
0 %	136,258	(124,599 – 147,918)	90.7	13,557	(9,560 – 17,555)	92.2
1 - 10 %	5,326	(3,362 – 7,291)	3.5	305	(0 – 669)	2.1
11 - 20 %	4,228	(2,429 – 6,027)	2.8	324	(0 – 898)	2.2
21 - 30 %	2,260	(1,031 – 3,488)	1.5	42	(0 – 100)	0.3
31 - 40 %	1,482	(465 – 2,499)	1.0	195	(0 – 493)	1.3
41 - 50 %	772	(203 – 1,341)	0.5	8	(0 – 24)	0.05
>50 %	26	(0 – 78)	0.02	284	(0 – 856)	1.9
Total	150,352	(138,282 – 162,422)	100.0	14,717	(10,507 – 18,927)	100.0

Discolouration, %	Species group / Number of trees					
	Scots pine			other pine spp.		
	1000	(α=0.05)	%	1000	(α=0.05)	%
0 %	1,943	(1,182 – 2,705)	98.8	26,927	(22,452 – 31,403)	86.6
1 - 10 %	16	(0 – 39)	0.8	3,349	(2,110 – 4,587)	10.8
11 - 20 %	8	(0 – 24)	0.4	635	(270 – 1,000)	2.0
21 - 30 %	–	– –	–	158	(50 – 266)	0.5
31 - 40 %	–	– –	–	26	(0 – 78)	0.08
41 - 50 %	–	– –	–	–	– –	–
>50 %	–	– –	–	–	– –	–
Total	1,967	(1,205 – 2,729)	100.0	31,095	(26,291 – 35,899)	100.0

Discolouration, %	Species group / Number of trees		
	Total		
	1000	(α=0.05)	%
0 %	178,686	(165,552 – 191,820)	90.2
1 - 10 %	8,996	(6,651 – 11,341)	4.5
11 - 20 %	5,195	(3,238 – 7,153)	2.6
21 - 30 %	2,460	(1,226 – 3,695)	1.2
31 - 40 %	1,703	(645 – 2,762)	0.9
41 - 50 %	780	(210 – 1,349)	0.4
>50 %	310	(0 – 885)	0.2
Total	198,131	(184,459 – 211,803)	100.0

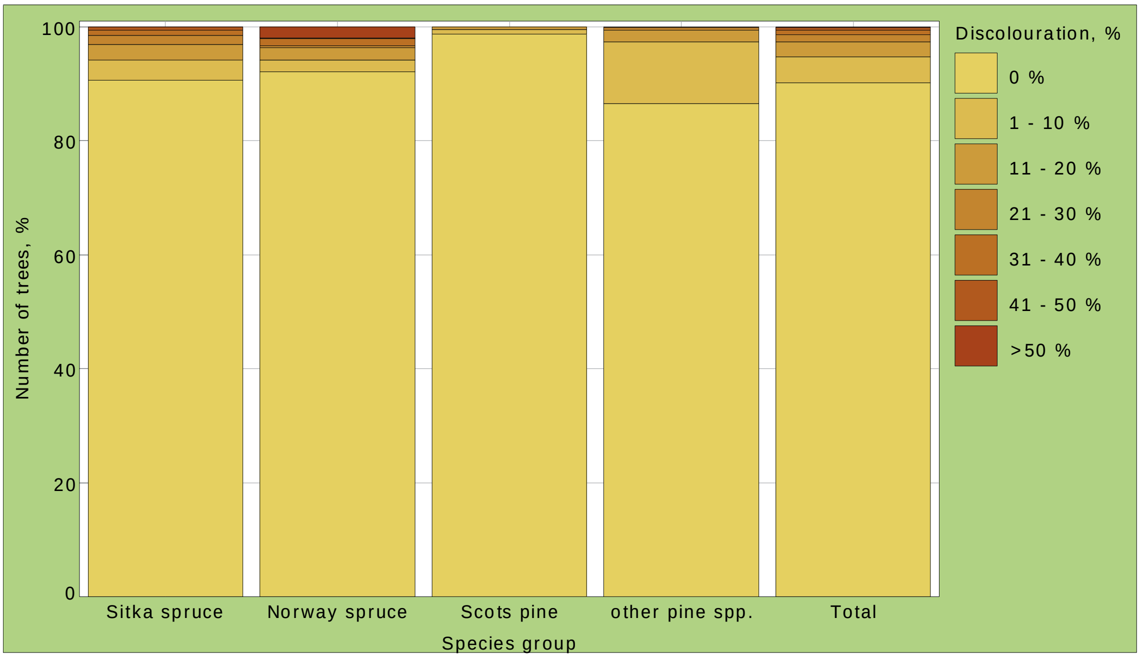

Figure 16. Total number of trees by discolouration intensity and species group (DBH above 7 cm).

8. Soil

This section describes one of the primary forest components, the soil. Soil properties significantly impact on forest management, in terms of tree growth, and environmental issues. The distribution of the forests over different soil groups has the potential to affect the sustainability of the forest estate, in both economic and environmental terms.

8.1 Total Stocked Forest Area by Soil Group and Ownership

Approximately 42% of the total stocked forest area is located on peats (Table 22 and Figure 17). Gleys (26%) and podzols (11%) are the other important soil groups in the forest estate. A higher proportion of the private (other) estate occurs on mineral soils. The private (grant aided) estate, in comparison to the public estate, has a higher percentage (34% compared to 24%) occurring on gleyed soils. A significant proportion (10%) of the public estate occurs on podzols.

Table 22. Total stocked forest area by soil group and ownership.

Soil group	Ownership / Area					
	public			private (grant aided)		
	1000 ha	(α = 0.05)	%	1000 ha	(α = 0.05)	%
basin peat	31.23	(24.82 – 37.65)	8.7	22.83	(17.21 – 28.45)	12.2
blanket peat	130.65	(118.82 – 142.48)	36.3	60.95	(52.19 – 69.71)	32.6
brown earth	19.23	(13.94 – 24.52)	5.4	13.21	(8.78 – 17.63)	7.1
brown podzolic	16.46	(11.56 – 21.36)	4.6	7.61	(4.22 – 10.99)	4.1
gley	85.70	(75.38 – 96.02)	23.8	63.59	(54.40 – 72.78)	33.9
grey brown podzolic	5.23	(2.42 – 8.04)	1.5	6.00	(3.00 – 9.01)	3.2
lithosol	8.80	(5.23 – 12.37)	2.4	2.00	(0.25 – 3.75)	1.1
podzol	53.28	(45.14 – 61.42)	14.8	8.40	(4.83 – 11.98)	4.5
regosol	1.20	(0.00 – 2.57)	0.3	–	– –	–
rendzina	2.00	(0.25 – 3.75)	0.6	–	– –	–
cutaway peat	5.22	(2.41 – 8.04)	1.5	2.00	(0.25 – 3.76)	1.1
sand	0.40	(0.00 – 1.19)	0.1	0.40	(0.00 – 1.20)	0.2
limestone pavement	–	– –	–	–	– –	–
Total	359.41	(344.28 – 374.54)	100.0	186.99	(173.02 – 200.95)	100.0

Soil group	Ownership / Area						
	private (other)			Total			
	1000 ha	(α = 0.05)	%	1000 ha	(α = 0.05)	%
basin peat	12.82	(8.58 – 17.05)	16.2	66.88	(58.38 – 75.37)	10.7
blanket peat	5.20	(2.40 – 7.99)	6.5	196.80	(184.25 – 209.35)	31.5
brown earth	20.03	(14.59 – 25.48)	25.1	52.47	(44.00 – 60.94)	8.4
brown podzolic	4.83	(2.12 – 7.53)	6.1	28.89	(22.51 – 35.28)	4.6
gley	14.01	(9.43 – 18.59)	17.7	163.30	(150.41 – 176.18)	26.1
grey brown podzolic	4.02	(1.59 – 6.44)	5.1	15.25	(10.60 – 19.90)	2.4
lithosol	3.59	(1.26 – 5.93)	4.5	14.39	(9.84 – 18.94)	2.3
podzol	4.83	(2.11 – 7.54)	6.1	66.51	(57.55 – 75.47)	10.6
regosol	2.82	(0.74 – 4.91)	3.6	4.03	(1.54 – 6.51)	0.6
rendzina	6.41	(3.32 – 9.49)	8.1	8.41	(4.89 – 11.92)	1.3
cutaway peat	–	– –	–	7.23	(3.93 – 10.53)	1.2
sand	0.40	(0.00 – 1.19)	0.5	1.19	(0.00 – 2.54)	0.2
limestone pavement	0.40	(0.00 – 1.20)	0.5	0.40	(0.00 – 1.20)	0.06
Total	79.35	(69.10 – 89.60)	100.0	625.75		100.0

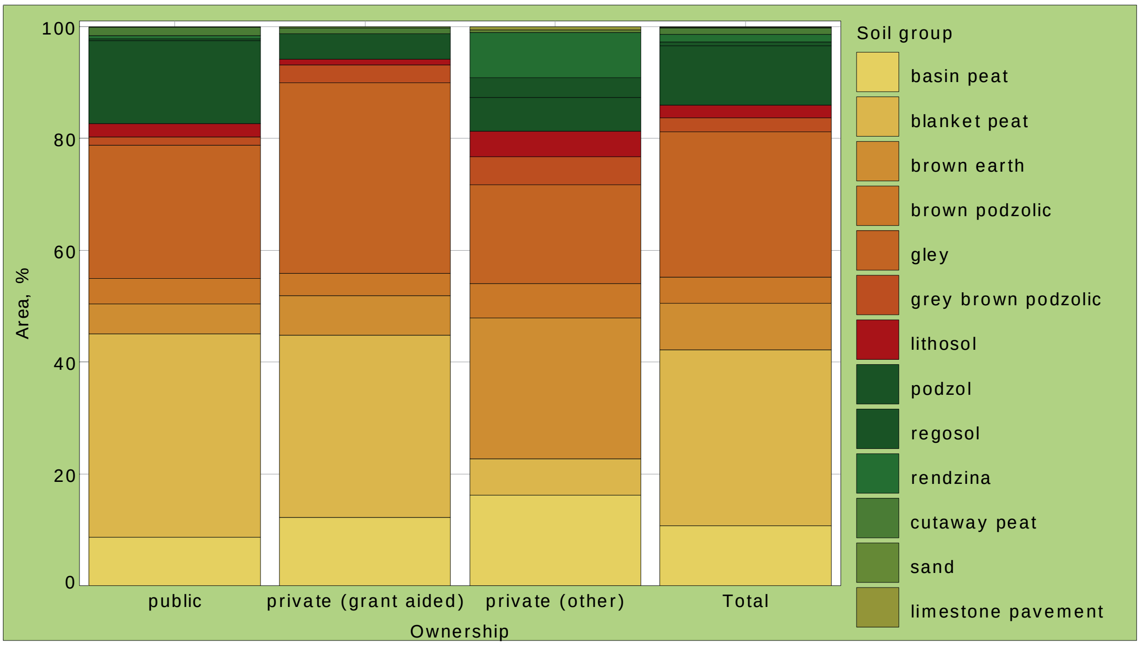

Figure 17. Total stocked forest area by soil group and ownership.

9. Vegetation and Lichens

The distribution of the number and coverage of ground vegetation in the national forest estate can vary greatly as it is influenced by a number of factors. The stage of development of a forest is one primary factor, as it impacts on a plants growing space by regulating light. Soil conditions can also impact on vegetation through factors such as fertility and moisture. In this section, the forest estate area in terms of plant number and coverage is described. The distribution of lichens in the national forest estate is also presented.

9.1 Total Forest Area by Total Number of Plant Species and Ownership

The total number of ground or shrub plant species is an important attribute as it can be used as a component in a biodiversity indicator. Just over three quarters (76%) of the forest estate is estimated to have 6 to 15 plant species present (Table 23 and Figure 18). The number of plant species present on a site is governed by the soil group and also the forest structure. Since the private (other) portion of the estate has a higher percentage of mineral soil groups and has a more diverse forest structure, greater numbers of plant species occur in these forest areas.

Table 23. Total forest area by total number of plant species and ownership.

Number of plant species	Ownership / Area					
	public			private (grant aided)		
	1000 ha	(α = 0.05)	%	1000 ha	(α = 0.05)	%
0	1.60	(0.03 – 3.17)	0.4	0.40	(0.00 – 1.19)	0.2
1 - 5	70.50	(60.62 – 80.39)	17.7	41.17	(33.50 – 48.84)	19.4
6 - 10	201.53	(186.86 – 216.20)	50.7	119.32	(107.12 – 131.52)	56.2
11 - 15	95.38	(84.20 – 106.56)	24.0	44.50	(36.55 – 52.45)	21.0
16 - 20	26.45	(20.22 – 32.68)	6.7	5.61	(2.68 – 8.54)	2.6
>20	2.00	(0.25 – 3.75)	0.5	1.20	(0.00 – 2.55)	0.6
Total	397.46	(381.49 – 413.44)	100.0	212.20	(197.39 – 227.01)	100.0

Number of plant species	Ownership / Area					
	private (other)			Total		
	1000 ha	(α = 0.05)	%	1000 ha	(α = 0.05)	%
0	–	– –	–	2.00	(0.25 – 3.76)	0.3
1 - 5	8.43	(4.91 – 11.95)	9.6	120.10	(107.86 – 132.35)	17.2
6 - 10	36.09	(28.87 – 43.31)	40.9	356.94	(340.62 – 373.26)	51.2
11 - 15	33.25	(26.29 – 40.21)	37.7	173.13	(159.07 – 187.19)	24.8
16 - 20	7.21	(3.89 – 10.52)	8.2	39.26	(31.75 – 46.78)	5.6
>20	3.21	(0.99 – 5.42)	3.6	6.41	(3.28 – 9.53)	0.9
Total	88.18	(77.45 – 98.91)	100.0	697.84		100.0

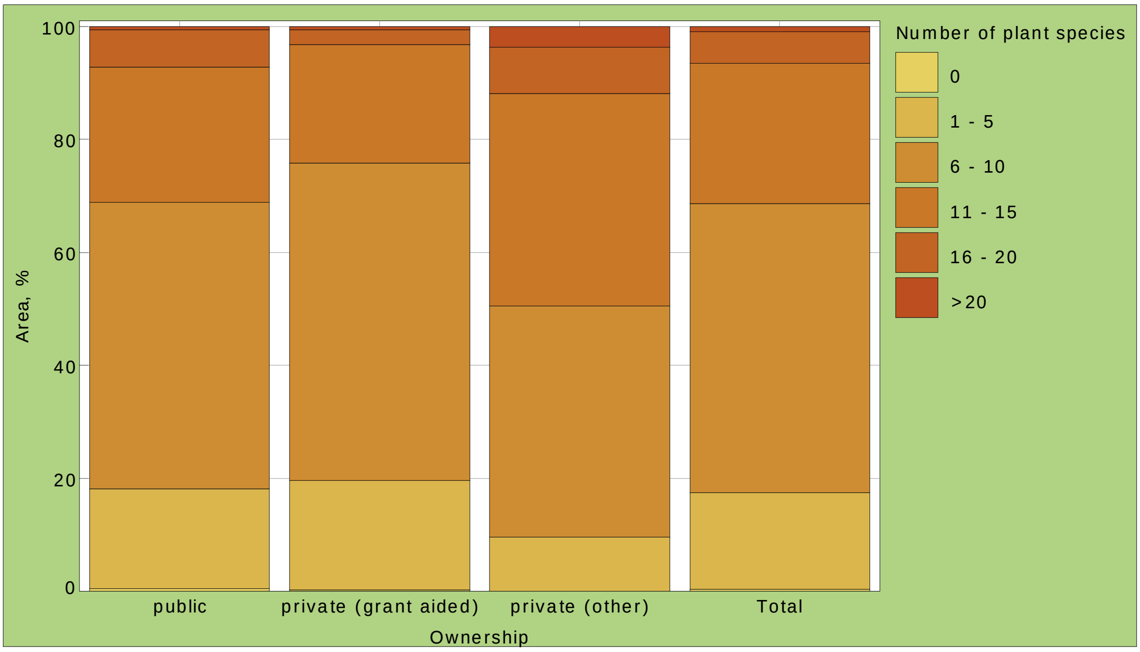

Figure 18. Total forest area by total number of plant species and ownership.

9.2 Total Forest Area by Vegetation Cover and Ownership

The percentage of the plot area with ground vegetation present forms the basis of this assessment. Two-thirds of the total forest area has an abundant vegetation cover (Table 24 and Figure 19). Approximately 6% of the total area has a vegetation cover of 6 to 25%. Vegetation cover within the 26% to 75% category occurred on 23% of the overall area. The percentage vegetation cover is highest in the private (grant aided) estate, as the young age structure of the forests will mean that the canopy closure has yet to occur.

Table 24. Total forest area by vegetation cover and ownership.

Vegetation cover	Ownership / Area					
	public			private (grant aided)		
	1000 ha	(α=0.05)	%	1000 ha	(α=0.05)	%
no presence	1.20	(0.00 – 2.56)	0.3	0.40	(0.00 – 1.19)	0.2
rare	2.01	(0.25 – 3.77)	0.5	1.60	(0.03 – 3.17)	0.8
sporadic (up to 1%)	3.20	(0.99 – 5.41)	0.8	2.00	(0.25 – 3.74)	0.9
infrequent (1-5%)	12.41	(8.09 – 16.74)	3.1	3.19	(0.98 – 5.39)	1.5
frequent (6-25%)	27.25	(20.89 – 33.60)	6.9	9.21	(5.47 – 12.95)	4.3
common (26-50%)	38.08	(30.64 – 45.52)	9.6	9.61	(5.79 – 13.43)	4.5
very common (51-75%)	65.64	(56.14 – 75.14)	16.5	22.41	(16.63 – 28.18)	10.6
abundant (75-100%)	247.67	(232.22 – 263.12)	62.3	163.79	(150.08 – 177.49)	77.2
Total	397.46	(381.49 – 413.44)	100.0	212.20	(197.39 – 227.01)	100.0
Vegetation cover	**Ownership / Area**					
	private (other)			Total		
	1000 ha	(α=0.05)	%	1000 ha	(α=0.05)	%
no presence	–	– –	–	1.60	(0.03 – 3.17)	0.2
rare	–	– –	–	3.61	(1.26 – 5.97)	0.5
sporadic (up to 1%)	0.80	(0.00 – 1.93)	0.9	6.00	(2.97 – 9.02)	0.9
infrequent (1-5%)	1.21	(0.00 – 2.57)	1.4	16.80	(11.79 – 21.82)	2.4
frequent (6-25%)	4.02	(1.54 – 6.50)	4.6	40.47	(32.82 – 48.13)	5.8
common (26-50%)	5.61	(2.68 – 8.53)	6.4	53.30	(44.59 – 62.01)	7.6
very common (51-75%)	14.41	(9.75 – 19.07)	16.3	102.46	(90.90 – 114.01)	14.7
abundant (75-100%)	62.14	(52.91 – 71.36)	70.4	473.60	(458.46 – 488.73)	67.9
Total	88.18	(77.45 – 98.91)	100.0	697.84		100.0

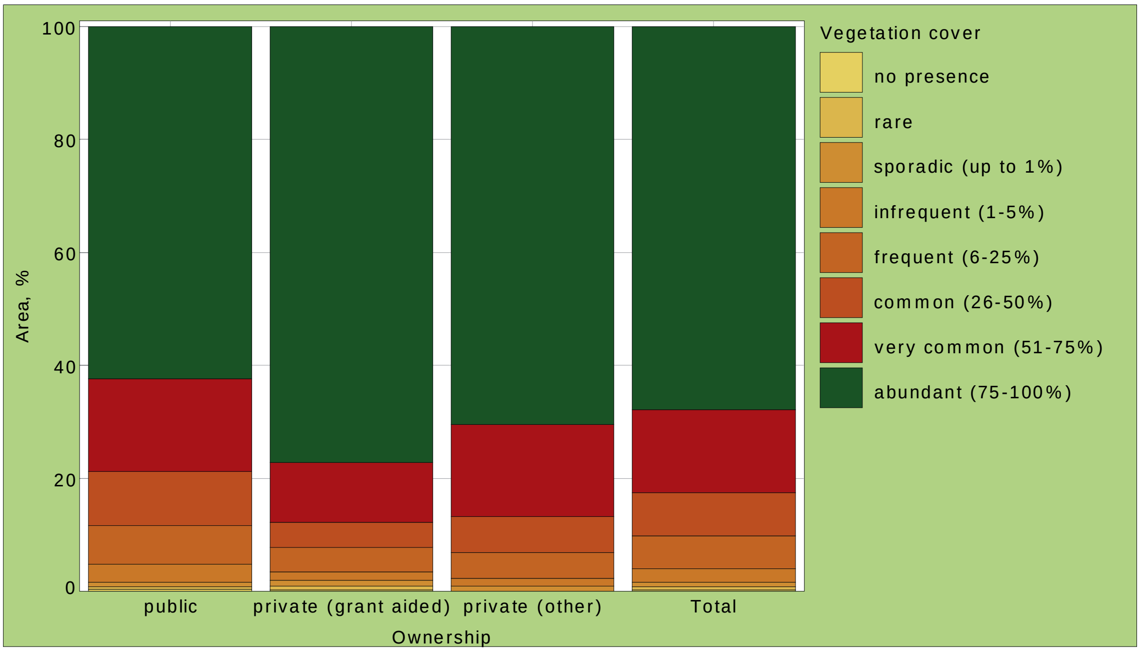

Figure 19. Total forest area by vegetation cover and ownership.

9.3 Total Stocked Forest Area by Tree Lichen Occurence and Ownership

The presence of lichens within the forest estate is another important environmental indicator of diversity. Over half (52%) of the forest estate had lichens occurring on trees (Table 25 and Figure 20). The presence of lichens in the private (other) estate is highest due to the diverse nature of forests in this category. The private (grant aided) estate has the lowest level (37%) of lichen occurrence, while the public estate had lichens present in over half (54%) of the estate. As the species distribution is similar in both estates, the difference is probably due to age structure, the private (grant aided) estate comprising relatively young first rotation forests.

Table 25. Total stocked forest area by tree lichen occurrence and ownership

Tree lichens	Ownership / Area					
	public			private (grant aided)		
	1000 ha	(α = 0.05)	%	1000 ha	(α = 0.05)	%
present	193.61	(179.74 – 207.48)	53.9	68.58	(59.04 – 78.12)	36.7
absent	165.80	(152.58 – 179.01)	46.1	118.40	(106.46 – 130.35)	63.3
Total	359.41	(344.28 – 374.54)	100.0	186.99	(173.02 – 200.95)	100.0

Tree lichens	Ownership / Area					
	private (other)			Total		
	1000 ha	(α = 0.05)	%	1000 ha	(α = 0.05)	%
present	62.92	(53.62 – 72.22)	79.3	325.11	(310.38 – 339.85)	52.0
absent	16.43	(11.50 – 21.37)	20.7	300.63	(285.90 – 315.37)	48.0
Total	79.35	(69.10 – 89.60)	100.0	625.75		100.0

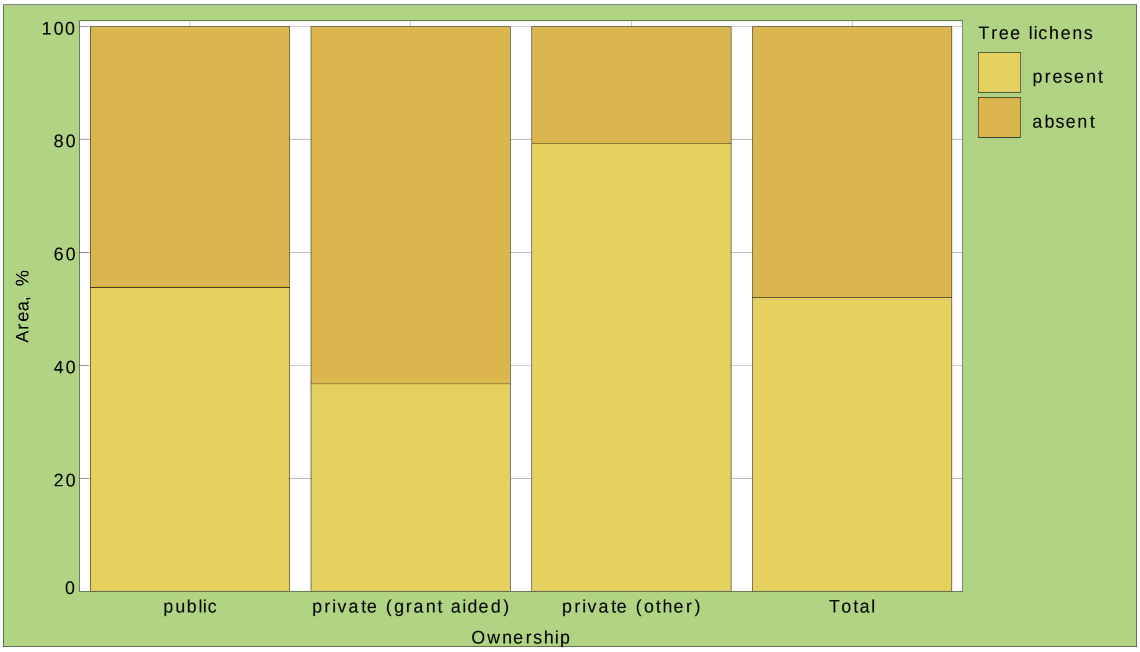

Figure 20. Total stocked forest area by tree lichen occurrence and ownership.

10. Summary

The main results from the NFI are outlined below:

- **Forest area**

  The NFI has confirmed that there is 10% forest cover in Ireland.

- **Age structure**

  Nearly two-thirds (63%) of the national forest estate consists of trees 20 yrs old or younger. The private (grant aided) estate makes up 46% of this area.

- **Species composition**

  Almost one-quarter (24%) of the entire forest estate consists of broadleaf tree species.

  Sitka spruce is the dominant species representing 53% of the national estate.

  Considerable areas of the forest estate (5%) contain five, six and more mixed tree species growing together.

- **Volume stock**

  The total growing stock by species group and assortment category stock present in the national forest estate is 70.1 million m^3.
  The mean growing stock per hectare is 112 m^3/ha.
  Nearly three quarters (74%) of the total growing stock is located in the public estate.

- **Thinning status**

  Overall, 69% (166,930 ha) of the national forest estate at a development stage where thinning could occur, has not been thinned for some reason(s). This has significant implications for timber supply.
  For example, 21,380 ha of the Private (grant aided) estate are at a development stage where thinning could occur but has not. If all of these areas had a first thinning, the potential yield could be approximately one million m^3 (45 m^3/ha). It is acknowledged that to thin all of these areas is unrealistic due to access and stability issues, but if even half of this area was thinned it would yield a significant volume.

- **Other**

  The volume of deadwood in the national forest estate is 5.7 million m^3, inclusive of lying, standing and stump deadwood.

  Approximately 42% of the total stocked forest area is located on peats. Gleys (26%) and podzols (11%) are the other important soil groups in the forest estate.

  Just over three quarters (76%) of the forest estate is estimated to have between 6 and 15 plant species present.

  Over half (52%) of the forest estate had lichens occurring on trees species

References

Coillte, 1998. Code of best practice for pre-sale measurement. Module 3 – Methodology for the assessment of Thinning Yield and the establishment of thinning control.

Matthews, R. and Mackie, E. 2006. *Forest Mensuration: a handbook for practitioners.* Forestry Commission, Edinburgh.

How Can We See The Carbon From The Trees?

Exploring the potential use of NFI data for the development of a state-of-the-art national forest carbon accounting system

Kevin Black and Gerhardt Gallagher

1. Summary

National reporting requirements to the United Nations Framework Convention on Climate Change on carbon (C) sequestration by Irish forests includes the estimation of changes in biomass, litter, dead wood and soil stocks, over time. National forest C inventory reporting procedures (CARBWARE) have, in the past, relied heavily on generalised stand-level yield models to simulate biomass C stock changes for different age classes and forest types. Therefore, these initial estimates were subject to a high degree of uncertainty due to incomplete inventory statistics on major forest C pools. The newly established National Forest Inventory (NFI) now provides the ideal opportunity to redevelop a state-of-the-art National reporting system, which is transparent, verifiable and compliant with International reporting guidelines. This paper describes the utilisation of NFI resources in the redevelopment of CARBWARE.

2. Introduction

Under the agreed terms of the Kyoto protocol, Ireland is committed to reduce green house gas (GHG) emissions by 13% above the 1990-base year level. Current estimates (1990-2004) suggest that GHG emission levels are 23% above the 1990 level (Mc Gettigan *et al*., 2006). Assuming a business as usual scenario, it is estimated that the contribution of National forests, under Article 3.3, may offset ca. 16% of the required GHG emissions for the first commitment period (2008 to 2012, Black and Farrell, 2006). However, the estimation of the extent to which forests sequester carbon in the mid to long-term is hindered by a high degree of uncertainty due to spatial heterogeneity and temporal variability. These estimates are continuously being refined and redeveloped as new research information and inventory data becomes available.

The COFORD-funded Irish carbon reporting system (CARBWARE), initially described by Gallagher *et al*. (2004) was implemented to meet reporting requirements to the United Nations Framework Convention on Climate Change (UNFCCC) on national forest sources and sinks. Whilst this model indicated the likely contribution of forests to the National C storage (sink) potential, the system relied on the use of generalised stand growth models to describe changes in forest carbon stocks because of the lack of NFI data. The availability of detailed NFI data now provides the opportunity to redevelop and improve estimates of national forest carbon stock changes. This is in line with the recommendations outlined in the International Panel on Climate Chance (IPCC) good practice guidance (GPG) for land-use, land-use change and forestry (LULUCF), which defines good reporting practice as "neither over- nor under-estimating so far as can be judged, and in which uncertainties are reduced as far as practicable".

3. National Reporting Obligations

In addition to reporting on C stock changes under Article 3.3 of the Kyoto protocol relating to afforestation, reforestation and deforestation activities since 1990, Ireland is also required to report C stock changes of the entire national forest estate to the EU and UNFCCC on an annual basis (Figure 1). The reporting obligations to the Kyoto protocol come into effect during the 1st commitment period (2008-2012). The IPCC-GPG recommends that national reporting systems should be transparent and verified by activity data, such as GIS and NFI information. All signatory countries are required to account for forest C stock changes in five different forest C pools:

- above-ground biomass;
- below-ground biomass;
- litter;
- dead wood;
- soil organic carbon.

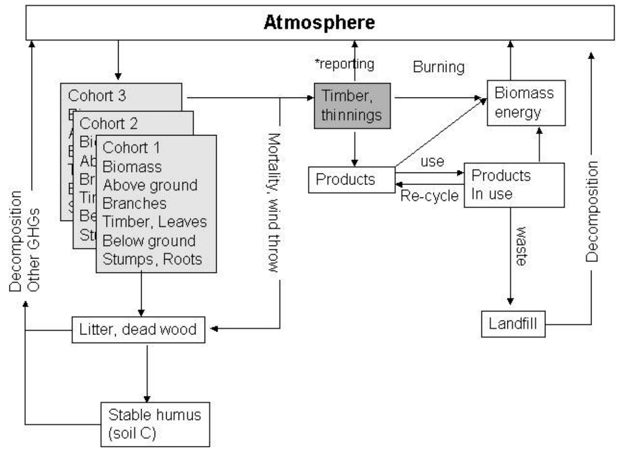

Figure 1. Flow diagram of proposed model including all components.
* For UNFCCC and Kyoto reporting, timber is assumed to be a source at harvest.

4. The Carbware System

CARBWARE will be redeveloped for use as a carbon accounting model that simulates the flow of carbon between forests, forest products and the atmosphere. It will also include emission factors (decomposition), not normally captured by conventional inventory procedures, such as those associated with thinning and cultivation (CLI-MIT programme). It will simulate these stocks and fluxes at the hectare scale, with time steps of one year. To scale up to a national level, NFI and IFORIS[1] data on planted areas, and species and soils substrata, will be used. Ideally, the most reliable method to estimate forest GHG gains and emissions is the use of NFI data, which is captured at regular time intervals. However, CARBWARE currently adopts a combined modelling and forest inventory data use approach due to the poor temporal resolution of NFI data (i.e. only one inventory to date).

5. Activity Data Sources

CARBWARE, the national C reporting model, uses multiple datasets for reporting purposes (Figure 2): FIPS, NFI, felling licence data, the soil association map[2], ecological site classification (Climate-Adapt) and other Forest Service databases, which will provide information on deforestation, wild fires, nitrogen fertilisation and thinnings.

Soil types, forest species and age-class spatial data set overlays will be used to create area based attribute tables. These will form the basis for measuring changes in afforested areas on different soils over time. Spatially explicit yield-class (productivity) attributes will be added to the age-species matrix using an ecological site classification system (Climate-Adapt under the COFORD funded CLI-MIT programme).

[1] IFORIS - Integrated Forestry Information System. Forest Service spatial database used for the processing of grants and premiums. The spatial distribution of forest parcels with associated attribute information such as species and age is used to update the Forest Inventory Planning System (FIPS) dataset.

[2] Soil and subsoil mapping project carried out by Teagasc and funded by the Forest Service and Environmental Protection Agency.

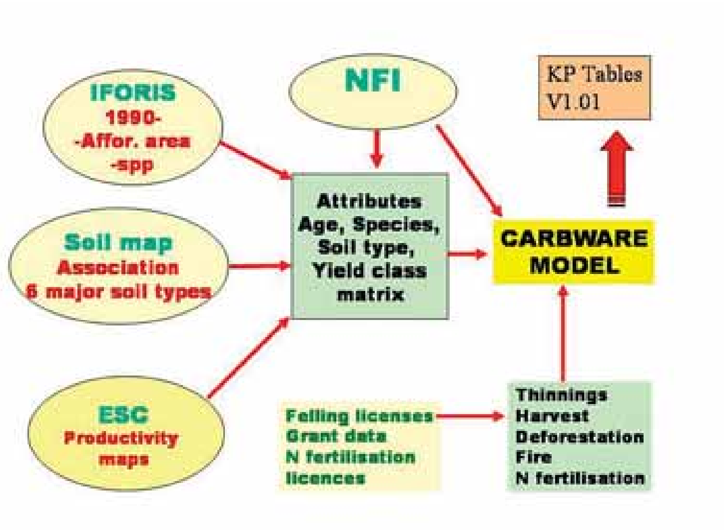

Figure 2. A schematic representation showing the flow of information from different GIS sources into the national C reporting model (CARBWARE).

NFI data will be used to define some of these spatial attributes and validate forest growth and C pool change models used for Kyoto reporting. Future repeat inventories and permanent plot data will provide the opportunity to directly estimate C stock changes over time for both Kyoto and UNFCCC reporting. However, CARBWARE models will still be used in the future to interpolate stock change estimates between inventory years.

5.1 Soils: The Unknown Carbon Store

Small changes in soil C stocks over the short to long term (5 to 50 years) are extremely difficult to measure because of the high background level of soil C. The current CARBWARE system assumes that soil C stocks are expected to decrease (C source) in peat soils following drainage and afforestation. This is due to the oxidation of previously non-decomposable organic matter following the creation of aerobic conditions. Alternatively, indirect modelling studies suggest that most wet mineral soils are a sink of C (take up C) because of the accumulation of organic matter in these soils (Black *et al.*, 2007; Black and Farrell, 2006). It has been recommended by some Kyoto sink reporting reviewers that soil stock changes should be measured directly. To this purpose, a paired-plot, soil sampling strategy will be adopted across a stratified NFI sub-sample (Figure 3).

An initial sub-sample of 150 plots will be reduced to 60 plots representing major soil types occurring on afforested land (Figure 3). The paired plot approach will compare a non-forest to a forest soil in the same location and on the same soil (Halliday *et al*. 2003). It is envisaged that these sites will be geo-referenced and re-sampled over the next 5 to 10 years for direct stock change estimates. This work is currently being conducted as part of the COFORD funded FOREST C and CARBiFOR II projects (CLI-MIT Programme).

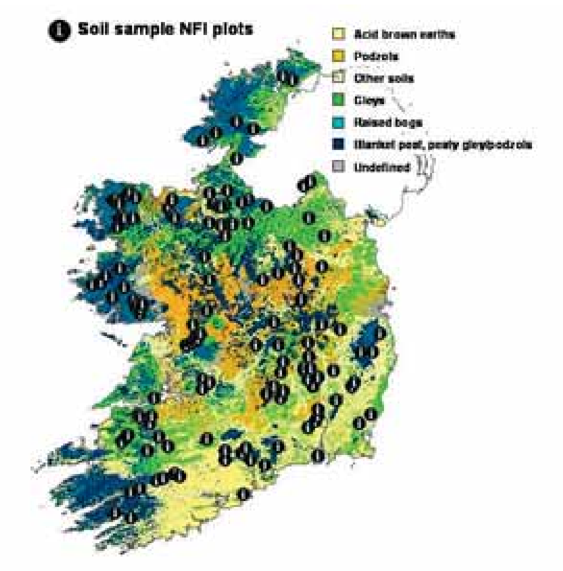

Figure 3. NFI sub-sample plots to be used for estimating major soil type C stock changes over time.

5.2 Biomass Growth and Related C Pool Models

Biomass models, form the basis for estimating above ground and below ground biomass. Similar models for Sitka spruce have been developed to estimate litter fall rates, and the decay of dead wood and litter on the forest floor (Black *et al*., 2004, 2007; Tobin *et al.*, 2006, 2007; Saiz *et al*., 2007). Functions for other species are currently being developed in the CARBiFOR II project.

These models can be applied to the current NFI data to estimate the national forest C stock. However, current CARBWARE estimates of **changes** in biomass, litter and dead wood over time are based on modified Forestry Commission stand-level models (Edwards and Christy, 1981) and research information from the previous COFORD funded project (CARBiFOR I, Figure 4). Sensitivity analyses of CARBWARE estimates suggest that the largest degree of uncertainty (ca. 30%) was associated with the estimation of the forest vegetation carbon sink. The uncertainty of the vegetation sink was affected most by forest management assumptions (i.e. forest stocking input data). This implies that stand management assumptions used in the model can significantly influence the uncertainty associated with the estimation of national forest sink capacity.

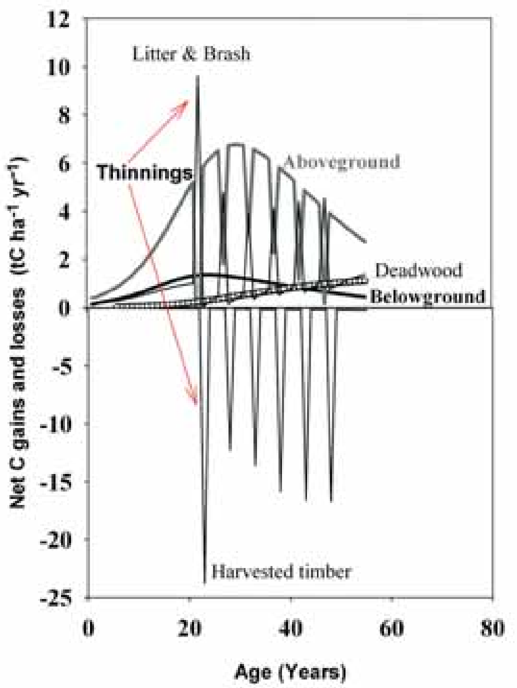

Figure 4. Outputs from the CARBWARE model showing net gains (positive) and losses (negative) of major C pools of a first rotation, yield class 22, Sitka spruce stand at 2.5 m spacing subjected to intermediate thinning.

Permanent plot data from Coillte, and NFI data in the future, will be used to provide the required variables (such as changes in tree dbh, height, crown characteristics, basal area and productivity indices) for parameterisation of single-tree growth models. The transition from stand-level-based growth models, which are only applicable to pure stands and a limited number of site indices and thinning regimes, to single-tree growth models, provides the advantage of accurately predicting growth where there are no predefined limits on species mixtures, silvicultural treatments and tree age/productivity. This is achieved by parameterising multiple variables relating to competition, mortality and site-specific factors. The ability to assess competition within a stand is linked to crown variables, which have been captured in the NFI and Coillte databases.

However, a major modelling constraint is that most permanent plot data (including NFI data) have many dbh measurements but only a limited number of height and live crown measurements. Common practice in this situation is that missing tree heights are derived from DBH using heuristic functions, which increases the level of uncertainty in the growth increment estimates. Another shortfall in the current NFI methodology is the limited number of height measurements in plots with small tress (dbh<7 cm). This results in a higher degree of uncertainty in C stock changes in young stands, which is particularly relevant to Article 3.3 activities, since related to afforested stands planted since 1990 (Black *et al.*, 2004).

6. Carbware Deliverables

- A GPG-LULUCF compatible, transparent and verifiable reporting system, which can be modified as new research information becomes available.
- Data interrogation activities can provide information arising from the NFI, relating to other forestry aspects such a biodiversity and timber forecasting.
- CARBWARE can be used for scenario analysis for government financing projections, policy issues relating to forestry management, end product and alternative wood utilisation (including biomass energy) and climate change.
- Single tree growth models, which can be used for timber and biomass forecasts in mixed and unconventionally managed stands.
- The expertise obtained through the development of the UNFCCC reporting aspect of CARBWARE will be extended to its application in a national accounting system (including all land-use emission activities) by the Environmental Protection Agency (EPA). This falls outside the scope of the programme but there are important implications with regards to review, traceability, transparency and credibility of the national reporting system as a whole.

7. Conclusions

Whilst it is envisaged that permanent plot data will be collected in repeat inventories in the future, it is not expected that this will occur within the reporting deadlines during the 1st commitment period. Despite this shortfall, the NFI will, however, provide an invaluable source of information for:

- Validation of single tree and stand biomass growth models.
- Estimation and validation of dead wood and litter C pool estimates.
- Validation of productivity and soil type maps.
- NFI plots will form the basis for the establishment of permanent soil C plots to assess soil C stock changes and parameterise soil C models (as part of the COFORD funded CLI-MIT programme).
- Define and validate forest area-species-age-soils type-productivity matrices used in CARBWARE.
- It is plausible that UNFCCC reporting will be based on repeat NFI data, which will be used to directly estimate C stock changes over time.

- It is also possible to develop single tree growth models in the future based on the repeat inventory of permanent plots.
- The use of the NFI as an information source for extending the range of prediction models and as an indicator of where additional sampling should be done.
- Statistical estimation and validation of thinning volumes and felling volumes removed over the period between subsequent NFI. This will validate other deforestation and felling data required for reporting.

The NFI is an excellent resource, particularly relevant for estimation forest C stock changes when repeat inventories are completed. However, the following considerations should be made to add value to the national forest carbon reporting system:

- A repeat inventory every five years to facilitate the direct estimation of stock changes.
- Inclusion of a forest biomass, litter and dead wood C estimation component in the NFI software (Field-Map™), similar to the timber volume estimation. However, the biomass functions should be user-definable and not embedded in the software. This requires national expertise and resources.
- The inclusion of heuristic models to define top height, basal area and stand productivity indices or yield classes. This is useful for forecasting and validation of GIS based productivity maps.
- The inclusion of the uncertainty associated with model errors when estimating carbon stocks in the NFI software.
- A larger height and crown sampling frequency of smaller trees to reduce C estimate and growth model uncertainty in younger stands.

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