The Second National Forest Inventory

Republic of Ireland

Field Procedures and Methodology

Department of
Agriculture,
Food and the Marine
An Roinn
Talmhaíochta,
Bia agus Mara

The Second National Forest Inventory – Republic of Ireland – Field Procedures and Methodology

Covering the National Forest Inventory, 2009 to 2012

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The Forest Service of the Department of Agriculture, Food and the Marine is Ireland's national forest authority. It is responsible for the regulation of 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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The Forest Service would like to express its appreciation to all those involved in the completion of the NFI. Sincere thanks are due to all landowners for facilitating access to their lands during the course of the NFI data collection.

Spatial Data

LIST OF ABBREVIATIONS

BA	Basal Area
BFC	British Forestry Commission
CI	Confidence Interval
cm	Centimetres
Dbh	Diameter at breast height
ECE	Economic Commission for Europe
FAO	Food and Agriculture Organisation of the United nations
FAWS	Forest Available for Wood Supply
FOA	Forest Open Area
FWPM	Fresh Water Pearl Mussel
GIS	Geographic Information System
GO	Generated Origin
GPS	Global Positioning System
ha	Hectares
IFER	Institute of Forest Ecosystem Research
LUT	Land Use Type
mm	Millimetres
NF	Non-Forest
NFI	National Forest Inventory
NHA	National Heritage Area
NO	New Origin
NPWS	National Parks and Wildlife Service
OLL	Other Long-Lived Species
OSi	Ordnance Survey of Ireland
OSL	Other Short-Lived species
RMSE	Root Mean Square Error
SAC	Special Area of Conservation
SFM	Sustainable Forest Management
SPA	Special Protection Area
Tm 1	First Team Member
Tm 2	Second team Member

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Chapter 1 INTRODUCTION

1.1 BACKGROUND

The national forest estate has increased from a modest 89,000 hectares (ha) or circa 1% of the national land area in 1928, to 731,650 ha or 10.5% of the national land area by the end of 2012. During the first 85 years of the 20th century, forestry in Ireland was almost exclusively the responsibility of the State, and by 1985 forest cover had increased to approximately 411,000 ha. The mid 1980s saw a significant increase in private forest development, with the introduction of EU-funded grant schemes aimed at encouraging private land owners, mainly farmers, to become involved in forestry. As a result, an additional 240,000ha have been afforested since this time, with over 80% being private planting. Today 53% of Irish forests are in public ownership while 47% are in private ownership.

Despite this increase in the amount of forest cover the State did not have a comprehensive inventory of the entire national forest estate until 2007. This previous lack of information on the composition of our forests, in relation to species, timber volumes, increment and biodiversity, had been an impediment to the sustainable management and utilisation of the national forest resource.

1.2 OBJECTIVES

The purpose of the NFI is to record and assess the current extent, state, composition of and change to Ireland's forest resource, both public and private, in a timely, accurate and reproducible manner to enable the sustainable development of our forest resource.

Between 2004 and 2006 the Forest Service carried out the first NFI of Ireland's forests, with results published in 2007. The 2006 NFI was the first purely statistical approach to forest inventory undertaken in Ireland to provide an assessment of growing stock in both the public and private national forest estates.

In order to assess changes in the state of Ireland's forests over time, Ireland's NFI was designed using permanent sample plots which facilitated a repeat measurement programme. This robust reporting strategy was adopted to provide credible information to address strategic objectives and reporting commitments (Figure 1). The fieldwork for the second cycle of the NFI began in 2009 and was completed in 2012

Figure 1. NFI international reporting obligations

1.3 INFORMATION NEEDS

Reliable, current and consistent information is required to inform domestic forest policy, to support forest research and fulfil national and international reporting commitments.

The undertaking of the NFI arose from a strategic action in the 1996 'Growing for the Future' (Anon. 1996) policy document for the development of the forest industry in Ireland. Data from the NFI is used to estimate carbon stocks through the calculation of forest biomass figures in Irish forests and greenhouse gas emissions associated with land-use change. The NFI was also initiated in response to demands for multi-resource information about Ireland's forests from international and national bodies such as the Food and Agricultural Organisation/Economic Commission for Europe (FAO/ECE).

1.4 NFI OVERVIEW

The NFI involved a detailed survey of permanent forest sample plots based on a randomised systematic grid sample design. A grid density of 2km x 2km provided sufficient forest plots 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 hectares (ha). Each circular NFI sample plot measures 25.24 metres (m) in diameter, comprising 500 m², and is permanent in nature to allow future re-sampling as required.

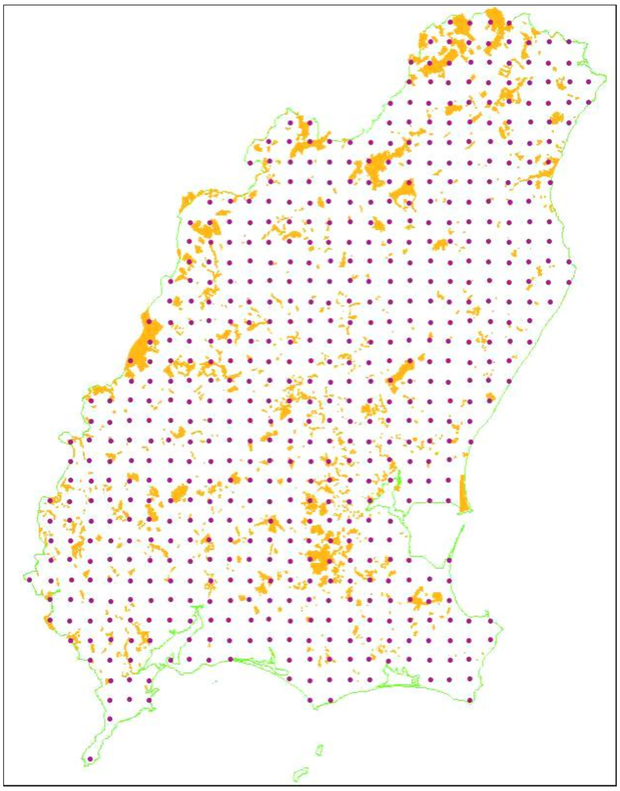


Figure 2. Primary sample grid for Co. Wexford. (© Ordnance Survey Ireland 2013)

Within each sample plot a variety of primary attributes were assessed, from the tree top to the soil underneath. For example, information was collected on: tree growth and development, the diversity of plant species and soil type.

The underlying technology used in the NFI, Field-Map consisted of an integrated system of hardware and software developed by the Institute of Forest Ecosystem Research Ltd (IFER). It allowed for the preparation of a NFI database, background maps, and plot generation. This in turn allowed for the creation of projects for field teams, which facilitated the field data collection process.

To carry out the data collection work, the Forest Service recruited professional foresters, with six foresters working in the field at any one time. In total, 1,742 forest plots were assessed throughout the country in the 2006 NFI. Due to the expansion of the forest estate, additional plots were assessed in the 2012 NFI; bringing the total number of NFI plots to 1,827. Training, field team support, validation and other quality control procedures were undertaken by two staff to ensure data quality and the smooth running of field operations.

Following the completion of field data collection work, primary data pre-processing and data analysis were completed. During data pre-processing the validity of the data was checked and data values were amended where necessary.

Secondary variables, such as volume increment, were also calculated. Data analysis involved the production of statistics which describe components of the national forest estate, e.g. volume of standing deadwood per hectare. Data analysis and results generation were undertaken by the Forest Service, in close collaboration with the IFER, and completed in 2013.

1.5 LAYOUT OF METHODOLOGY

The primary purpose of this methodology publication is to give the background to the NFI, outline the plot location and field data collection procedures and describe the data analysis techniques used. The range of attributes that were included in the inventory are described in detail, as well as data collection methodologies for these attributes. An appreciation of the contents of this manual will aid in the interpretation of the results and in understanding how the NFI differs from conventional, stand level inventories.

This publication is divided into four sections. Section A, chapters 2 to 7, describes the sample point selection and the fieldwork preparation processes. The navigation to and establishment of the plot centre is also explained in Section A. Field data attributes and collection techniques are detailed in Section B, chapters 8 to 15. In Section C, a summary of the field-work validation and data analysis procedures are presented in chapters 16 and 17.

1.6 OTHER NFI PUBLICATIONS

Two other NFI publications are available, namely:

- NFI Main Findings;
- NFI Results.

Both documents are available at: http://www.agriculture.gov.ie/nfi/.

SECTION A

SELECTION AND ESTABLISHMENT OF THE PLOT CENTRE

Chapter 2 SELECTION OF SAMPLE POINTS

A randomised systematic grid design was used to provide the required number of sample points necessary, to ensure the integrity and statistical accuracy of the results. A 2 km x 2 km grid was overlaid on the total land base of the Republic of Ireland, to create initial plot locations at the intersection of the grid lines. Each of these points was identified by six digit x and y Irish national grid co-ordinates.

Each plot centre was randomly located within a radius of 100 m from the grid intersection, by adding randomly generated numbers (-100 to +100) to each of the six digit x and y Irish national grid co-ordinates (Figure 3). This created 17,423 primary sample points. As the grid is permanent it allows for the periodic re-assessment of these primary sample points to monitor forest land-use change e.g. afforestation and deforestation.

Figure 3. Location of sample plots is randomised within 100m of 2km systematic grid.

2.1 DATA SOURCES

In this section the datasets used in the aerial photograph interpretation are outlined.

2.1.1 Primary dataset

The primary dataset used in the NFI was aerial photography obtained from Ordnance Survey Ireland (OSi). The most recent aerial photography is used to capture land use changes.

2.1.2 Secondary datasets

In order to capture forests that may not be apparent on the aerial photographs, e.g. recently planted forests, forest datasets were used to aid in the identification of Forest areas. These forest maps were laid over the sample points in 'wire-frame' format and used as an indicative guide as to where forests were located.

2.2 LAND-USE TYPES

Classification of land-use type (LUT) was carried out, using a GIS, by foresters who had considerable field experience in collecting NFI data, including the use of aerial photographs during navigation to the plot. The primary focus of the interpretation was to identify forest land. In tandem with this, other land-use types are identified for reporting purposes. This initial stage classified the 17,423 sample points derived from the 2 km x 2 km grid into Forest, Non-Forest or 'Check Plot' **land-use types** (Figure 4).

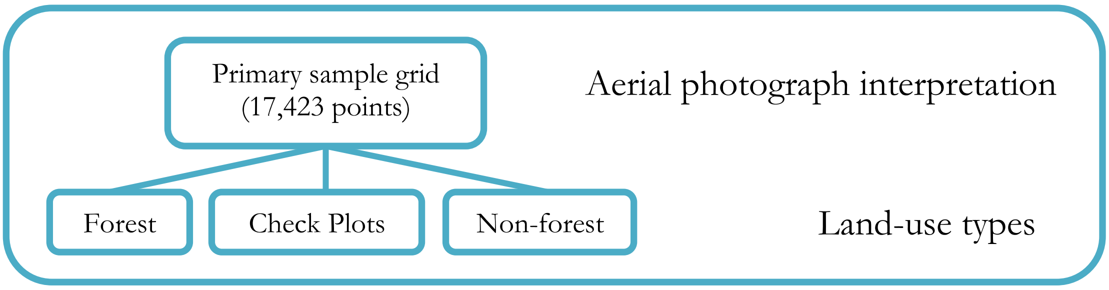


Figure 4. Overview of NFI land-use classification.

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 land-use type, 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. The LUT interpretation procedure is repeated during each NFI using the latest available aerial photographs to ensure that all primary sample points that could potentially have a 'Forest' LUT are assessed, as LUTs can change from one survey to the next.

2.2.3 Land-use types used in the NFI

The LUTs used in the aerial photograph interpretation exercise are shown in Table 1. Land-use types have been 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[1] guidelines and with the requirements of LULUCF[2], as specified under article 3.4 of the Kyoto protocol (IPCC 2001).

Table 1. Land-use types used in the NFI aerial photograph interpretation.

Land-use type	Land-use type
Forest	Green Space (Urban)
Bog and Heath	Green Space (Rural)
Built Land (Rural)	Hedgerow
Built Land (Urban)	Other Woodland
Sea and coastal complex	Quarry
Cropland	Road (Paved)
Cutaway Peat (Domestic)	Scrub
Cutaway Peat (Industrial)	Track (Unpaved)
Bare Rock	Water Body
Grassland	

1. **Forest**

   Land with a minimum area of 0.1 ha, 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

[1] Intergovernmental Panel on Climate Change

[2] Land use, land-use change and forestry

1. A tree is a woody perennial plant forming a single main stem or several stems, having a definite crown and capable of achieving a height of at least 5m. Woody shrubs such as Ulex spp. or Rhododendron are not defined as trees.
2. Forest areas include windbreaks, shelterbelts and corridors of trees with an area of more than 0.1 ha and a minimum width of 20 m.
3. Forest is 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 is determined by 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 out 1 m from the position of the pith-line[3] of the outermost trees. This is explained in more detail in Chapter 4
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.

2. Bog and Heath

Land dominated by bog and heath vegetation (*Calluna, Erica, Molinia, Eriophorum* spp.). These areas occur in upland and lowland areas throughout Ireland. This class occurs mostly on unenclosed land.

3. Built Land (Rural)

Land occupied by houses, farm buildings and other buildings in rural areas.

4. Built Land (Urban)

Land occupied by buildings, within towns and cities

5. Sea and Coastal Complex

Occurs in coastal areas and is usually a mixture of sea, sand, grass, shrub and rock.

6. Cropland

Land currently under agricultural crops or temporarily unplanted land, excluding grassland.

7. Cutaway Peat (Domestic)

Land where the original peat bog has been cutover for domestic peat use. These are generally small areas situated in the midlands and west of Ireland. They are characterised by the turf cutting ‘plot’ divisions of the bog.

8. Cutaway Peat (Industrial)

Land where the original peat bog has been cutover for industrial peat use. These are generally large areas situated in the midlands and west of Ireland. They are easily distinguished by the systematic harvesting bays.

9. Deforestation

The conversion of forest to another land-use, implying the longterm or permanent loss of forest cover.

10. Bare Rock

[3] Pith-line is a notional 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.

Exposed rock with little or no vegetation present. This can occur at low or high elevations and include scree slopes, mountain-tops, karst landscapes or rocky outcrops.

11. **Grassland**

Land predominantly under grass species, excluding bog and heath.

12. **Green Space (Rural)**

Green spaces located in rural areas such as parks, gardens and sports fields.

13. **Green Space (Urban)**

Green spaces located in urban areas such as parks, gardens and sports fields.

14. **Hedgerow**

Linear features (<20 m wide) that may or may not have tree and/or shrub species present.

15. **Other Woodland**

Groups of trees that do not meet the criteria specified in the forest definition. This category covers areas of trees less than 0.1 ha, or less than 20 m in width, and/or with a canopy cover of less than 20%.

16. **Quarry**

Man-made sand, gravel or stone quarries.

17. **Road (Paved)**

Any public or private paved road.

18. **Scrub**

Refers to vegetation types where the dominant woody elements are shrubs i.e. woody perennial plants, reaching a height of more than 0.5 m and less than 5 m in height at maturity and without a definite stem and crown.

19. **Track (Unpaved)**

Any unpaved public or private road.

20. **Water Body**

Any inland water including rivers, canals, reservoirs and lakes.

Chapter 3 PREPARATION FOR GROUND SURVEY

Plots classified as 'Forest' or 'Check' at aerial photography interpretation stage are referred to as the 'ground survey plots'. These ground survey plots become permanent sample plots if they were classed as 'Forest' or 'Forest Open Area' when visited in the field.

3.1 PREPARATION OF BACKGROUND MAPS AND INFORMATION

The preparation phase for the NFI field assessment included the collation of background information and the preparation of maps for each individual plot. This was compiled on a county by county basis to form a comprehensive project folder for each county. In order to aid efficient navigation to plot centres and efficient work planning, field teams used the following:

1. County map derived from OSi (1:250,000) data for each county outlining the general location of plots within a county
2. 1:50,000 OSi Discovery Series map to aid general plot location and work planning (Figure 5)
3. Colour aerial photographs at 1:15,000 scale also aids this process (Figure 6).
4. Digital maps, such as forest and stand boundaries and road infrastructure, are pre-loaded into the field-computer and this helps to complete the navigation to the plot centre (Figure 7).

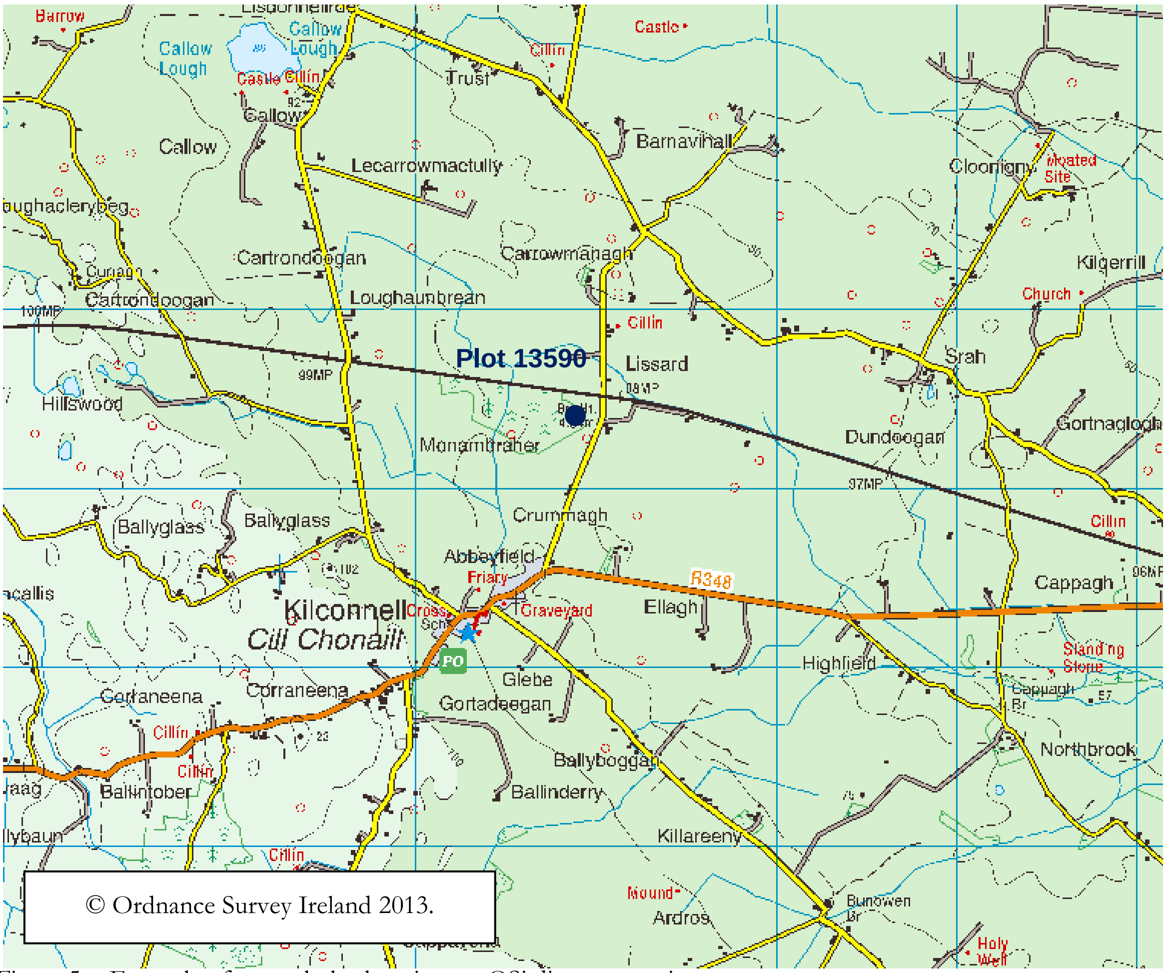


Figure 5. Example of general plot location on OSi discovery series map.

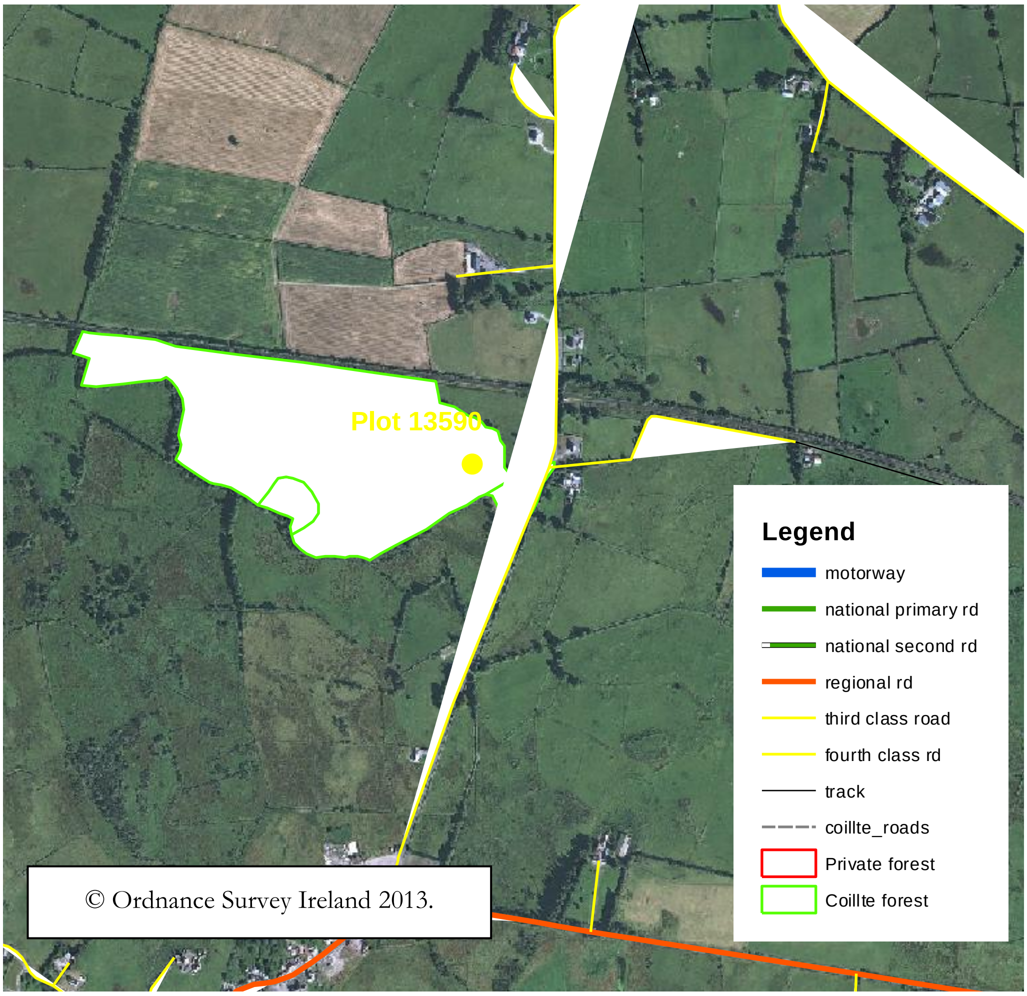


Figure 6. Example of plot location on aerial photograph.

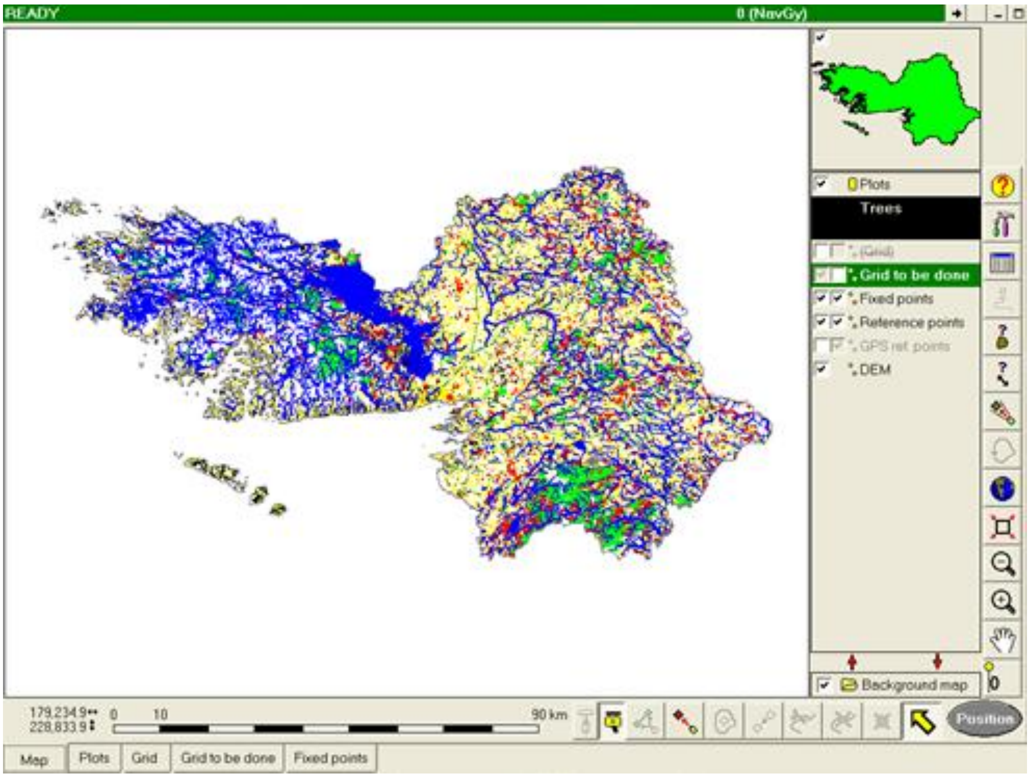


Figure 7. Example of digital map on the field computer at county level.

Chapter 4 ESTABLISHMENT OF THE PLOT CENTRE

Being able to precisely locate the plot centre is essential in the assignment of a definitive land-use class.

4.1 NAVIGATION TO GROUND SURVEY PLOTS

The exact location or centre of ground survey plots in the field is found by navigating to a six figure national grid co-ordinate using a combination of a GPS and compass/laser technology.

Field teams navigate as close as possible to the plot centre using a GPS and temporarily mark the position on the ground. Due to the variation in the individual GPS readings around the true position, navigation to the plot centre is completed with the compass/laser from the temporary marked point. 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. the angular offset of the magnetic north from true north) is calculated prior to navigation in the area where measurements will take place. This declination is incorporated into the electronic compass prior to locating the plot centre. An azimuth precision test is performed to ensure that no local magnetic field is affecting compass readings. Precision of plot centre location is between one and five metres, and is dependent on achieved precision of GPS position measurement and distance of navigation with the compass/laser.

The plot centre is marked with a pole and referred to as the Generated Origin (GO). 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[4] coordinate system to which all the measured entities (e.g. trees) are referenced. If the plot centre does not provide an ideal location for measurement, due to the obstruction of sight line(s), then an out-of-centre measurement procedure is used enabling measurement to take place from any point inside or outside of the plot, which has been referenced to the plot centre.

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

4.2 LAND-USE CATEGORIES

Once the plot centre has been located, that point on the ground is classified into one of three land-use categories: Forest, Forest Open Area, or Non-Forest (Figure 8). The total forest area includes both Forest and Forest Open Area.

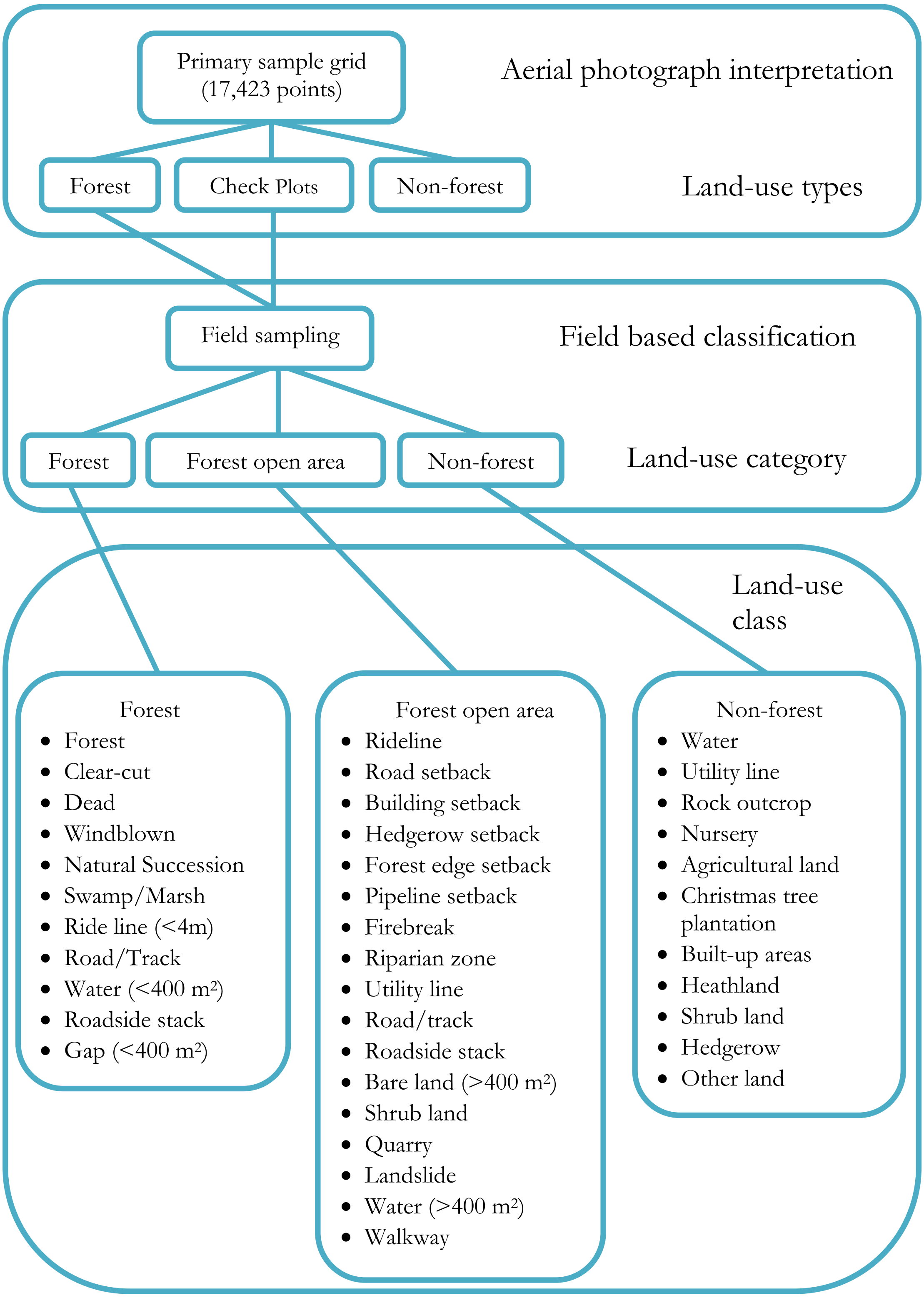


Figure 8. NFI land classification overview.

Chapter 5 FOREST BOUNDARY

A land-use category can be assigned where there is >90% of one land-use category occurring on the plot. Where two land-use categories occur in a plot, a plot shift is undertaken. However before this is initiated, the boundary between the land-use categories must be clearly identified.

5.1 FOREST BOUNDARY

Definition: 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.

Application: The forest area is determined by the forest boundary. Being clearly able to identify the boundary between the land-use categories is essential for the correct assignment of plot land-use category.

Measurement and Description:

Explanatory notes:

1. The presence of man-made boundaries which delineate parcels of land is a well defined feature on the Irish landscape, e.g. hedgerows or stonewalls. 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 a boundary feature, the edge of the Forest is determined by extending 1 m from the position of the pith-line of the outermost trees (Figure 9).
3. All areas where the boundary feature is ≥5 m and ≤20 m from the pith-line are classified as Forest Open Area.
4. All areas where the boundary feature is <5 m from the pith-line are classified as Forest.
5. Outlier trees ≥20 m from the nearest tree in the main body of trees will not be included in the forest (Figure 10). Usually occurs in natural succession land.

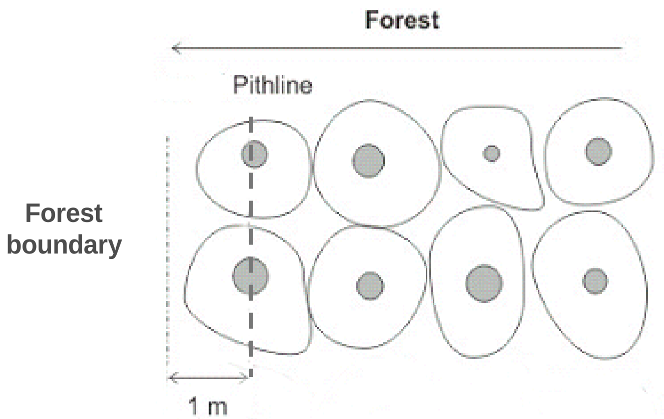


Figure 9. Establishing the Forest boundary where there is no boundary feature.

It is important to restate that Forest is 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 aerial photograph interpretation. However a feature on the ground (such as a fence) may dictate a change to another predominant land-use. An example of this is shown in Figure 11. In the photograph, the canopy cover of the trees was continuous. However, the timber fence delineated the forest boundary, thereby excluding the trees in grassland as they belong to the non-forest land-use category.

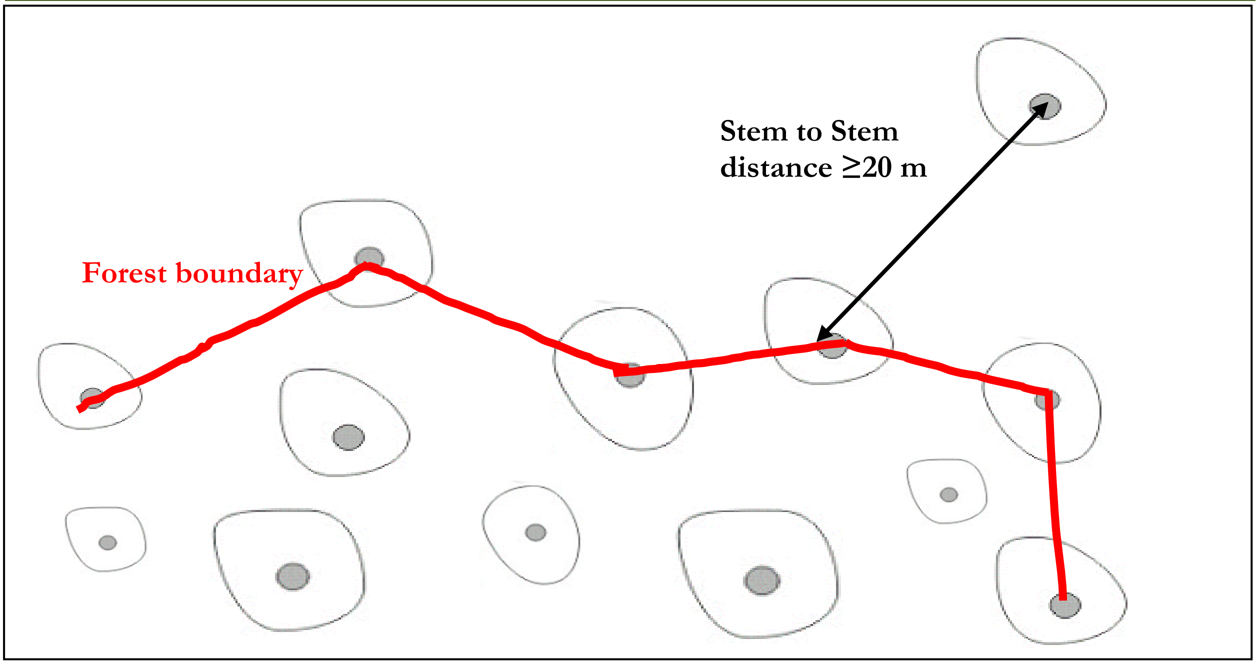


Figure 10. Identifying outlier trees.

Figure 11. Forest boundary, survey pole marks the plot centre in grassland.

5.2 Identifying the Forest and Forest Open Area boundary

In this subsection six examples describing the identification of the Forest and Forest Open Area boundary are presented.

Example 1

In this example the man-made boundary (hedgerow) is a more permanent feature than the fence line (Figure 12). The set-back from the pith-line to the hedgerow is wider than 5 m and narrower than 20 m, thereby conforming to the Forest Open Area classification. If the set-back was wider than 20 m it would be classified as Non-Forest.

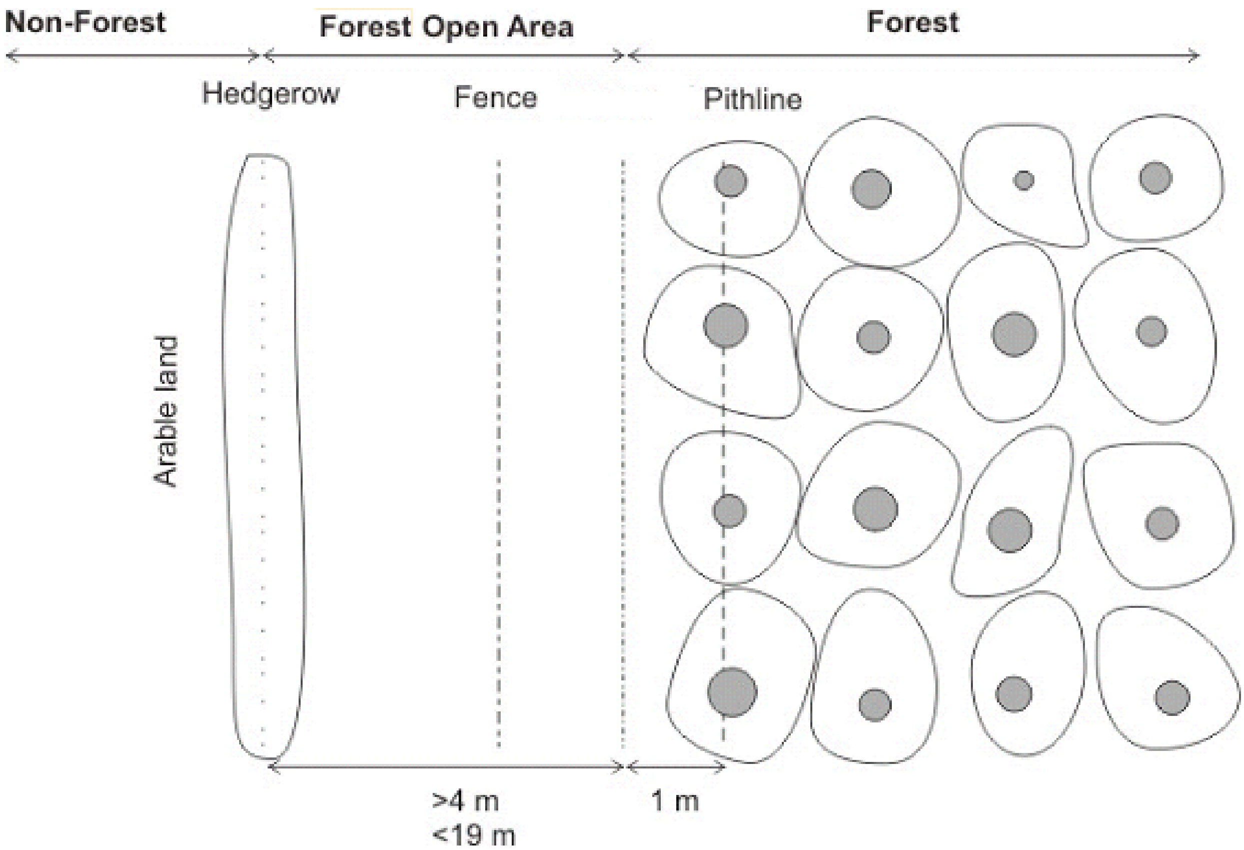


Figure 12. Identifying the forest boundary, example 1.

Example 2

A farmer decides to plant a wet area in a field, a fence is erected to stock proof the plantation (Figure 13). There is no definitive boundary such as a hedgerow or stonewall. The fence-line is then the boundary between Forest and Non-Forest. As in the previous example, the distance between the pith-line and fence would need to be ≥5 m and ≤20m in order to constitute Forest Open Area.

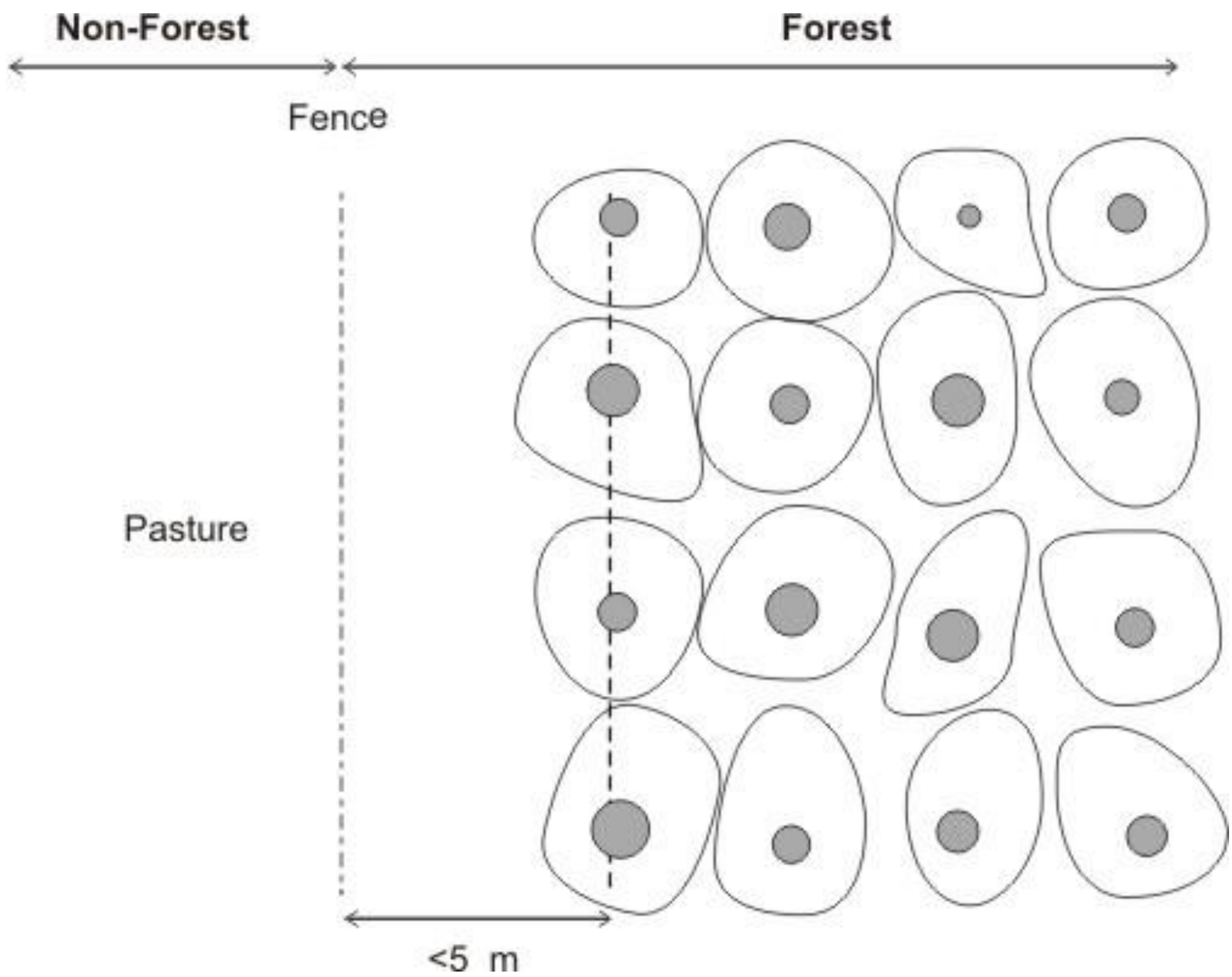


Figure 13. Identifying the forest boundary, example 2.

Example 3

In the absence of a definitive feature (such as a stone wall, hedgerow or fence) the outer row of trees should be used to determine the boundary. This boundary occurs 1 m from the pith-line (Figure 14). Where there is a firebreak present, it will be classified as Forest Open Area. This could occur on an unenclosed heathland site. If the firebreak was wider than 19 m it would be classified as Non-Forest.

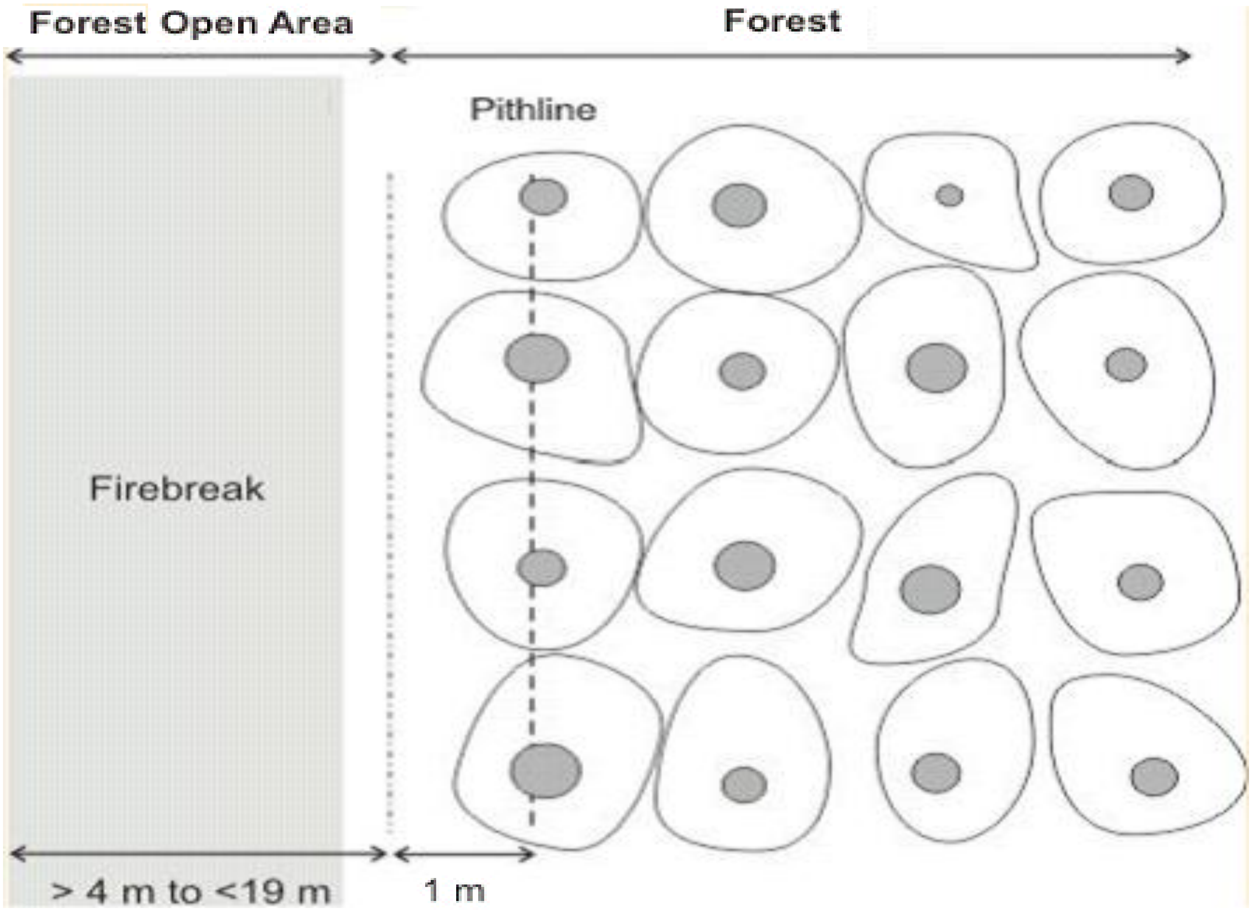


Figure 14. Identifying the forest boundary, example 3.

Example 4

The road in this example (Figure 15) may be classified as Non-Forest as it is a paved public road. In the case of a bog road/mountain track/right of way, the NFI field team will have to decide whether or not the road is integral to forest management, and classify accordingly. The fence is not the forest boundary, as the road is a more permanent feature. If it was a forest road integral to forest management, it would be classified as Forest Open Area, where the road was at least 6 m wide from pith-line to pith-line.

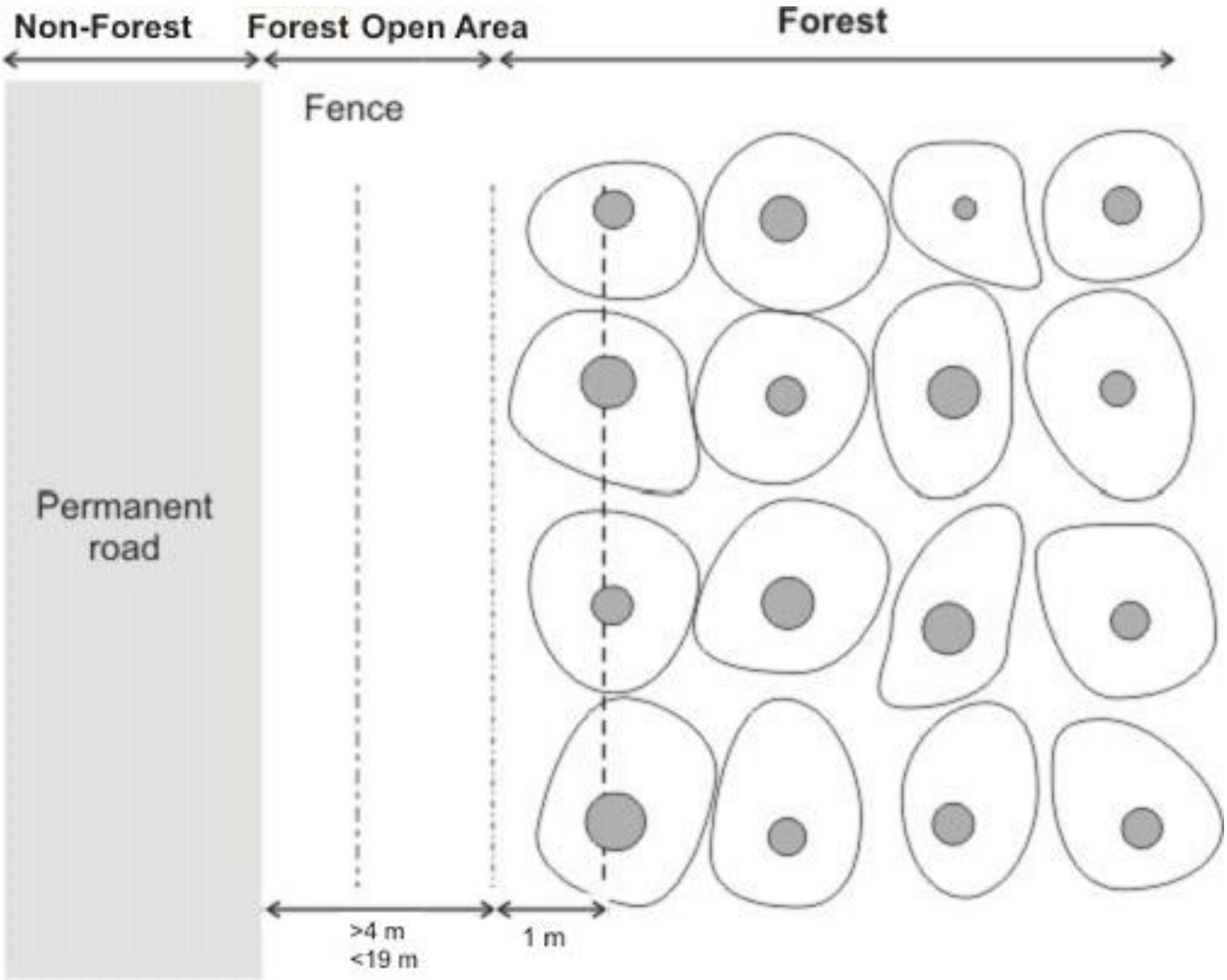


Figure 15. Identifying the forest boundary, example 4.

In figure 16 below the original field boundary has been eroded by agricultural activities. The strip of land that was once between the stone wall (dashed yellow line) and fence line has changed from Forest to Non-Forest.

Figure 16. Identifying the forest boundary, example 5.

In figure 17 below, the plot centre landed between two fence lines, which lie to the right of an open drain (dashed yellow line). In this case the open drain is considered the dividing line between the forest land on the right and the non-forest land on the left as it is the most permanent feature. This plot was classified as Forest Open Area as there was a set-back from the forest edge >5 m.

Figure 17. Identifying the forest boundary, example 6.

Chapter 6 PLOT SHIFT

6.1 PLOT SHIFT

If two land-use categories occur in the plot, i.e. the plot centre lands in Forest but a portion of the plot is assigned to Forest Open Area or to Non-Forest, a plot shift should be considered. Plot shifting is where the original plot centre (generated origin (GO)) is moved to a new location (new origin (NO)), to ensure that >90% of the plot area is assigned to one land-use category. The flowchart detailed in Figure 18 aids in the decision making process.

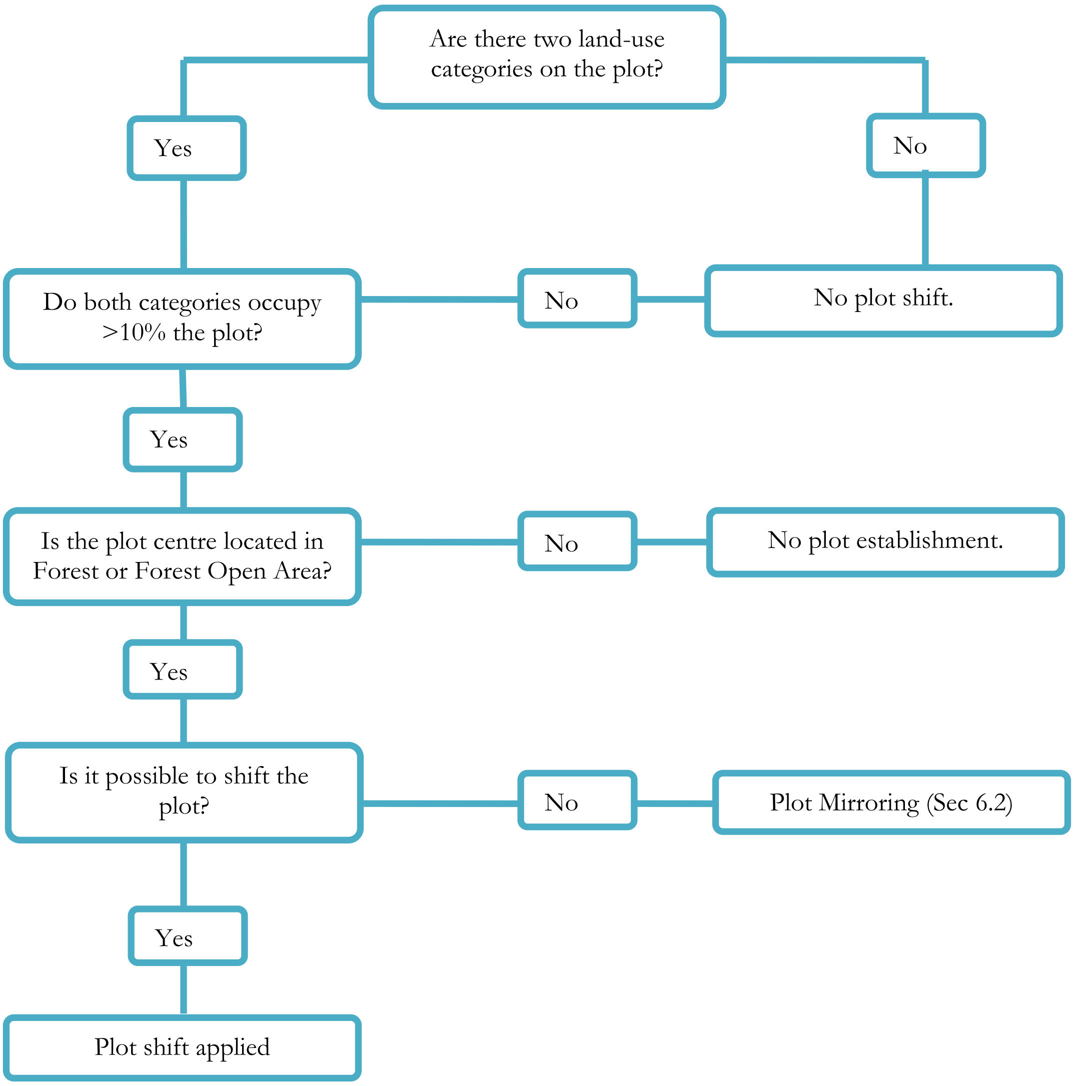


Figure 18. Plot shift decision diagram.

6.1.1 New plot establishment

Where plot shifting is necessary, the new plot centre is moved by the length of the plot radius (12.62 m) from the original position perpendicular to the boundary between the two land-use classes. The positions of the generated and new origin are recorded, which may be checked later during validation. For examples see Figure 19.

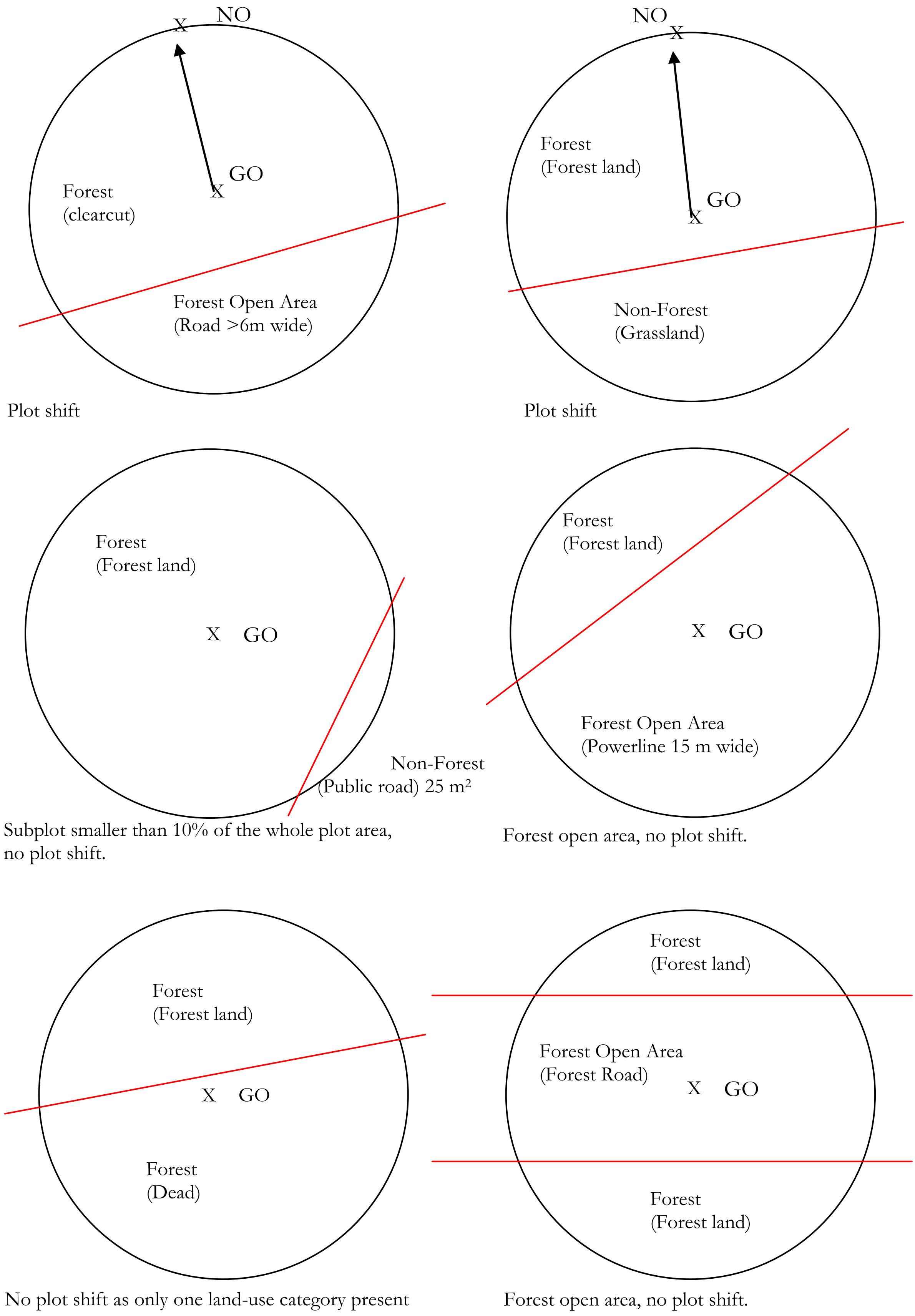


Figure 19. Plot shift examples. GO=generated origin NO=new origin

6.1.2 More than one plot shift

In certain circumstances it is not possible to attain >90% of the plot area assigned to one of the land-use classes in one plot shift. In this situation a plot needs to be shifted more than once, but cannot be shifted across a different land-use class. As in the previous section, the new plot centre is moved 12.62 m from the original position perpendicular to the boundary between the two land-use classes.

In Figure 20 the first move is perpendicular to the public road. Moving the plot centre across the forest road is not permitted. As there is still >10% Forest Open Area occurring within the plot after the first move, the plot is shifted for a second time perpendicular to the Forest boundary. If the original plot centre had landed on the road, no shift would have been required.

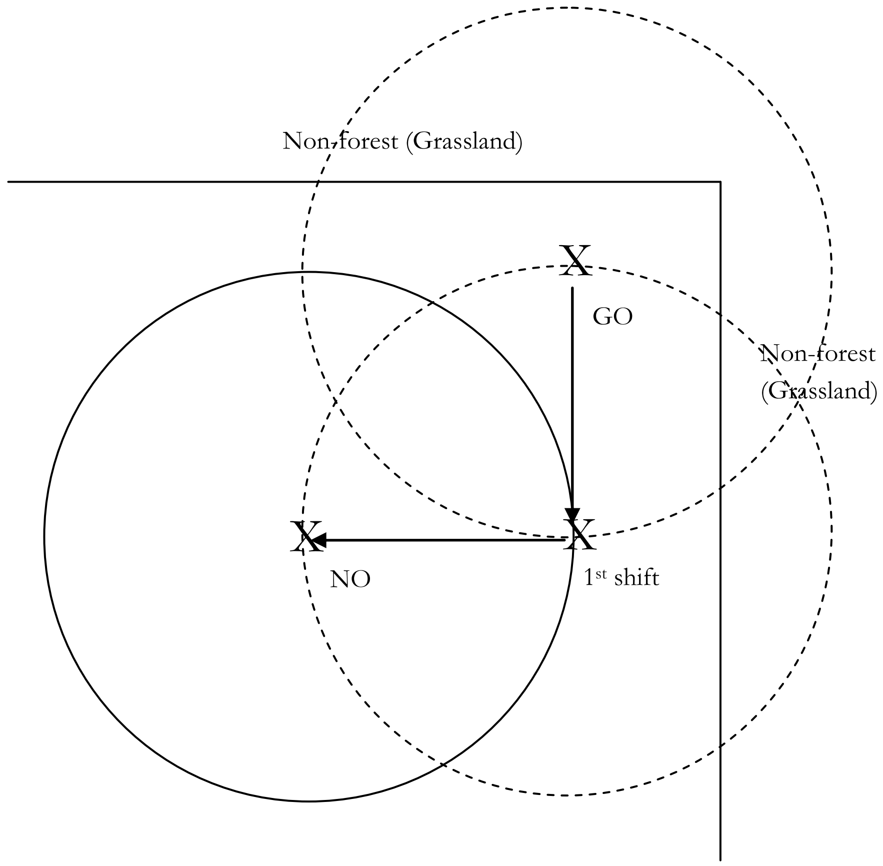


Figure 20. More than one plot shift.

6.1.3 Land-use change on established plots and plot shifting

Where a forest plot has been established in a previous NFI cycle there is a possibility that a change of land-use category may occur, which requires a plot shift. For example, if a forest plot is intersected by a new forest road, this may result in the forest plot now containing >10% forest open area. The flowchart detailed in Figure 21 describes how to handle this situation the field.

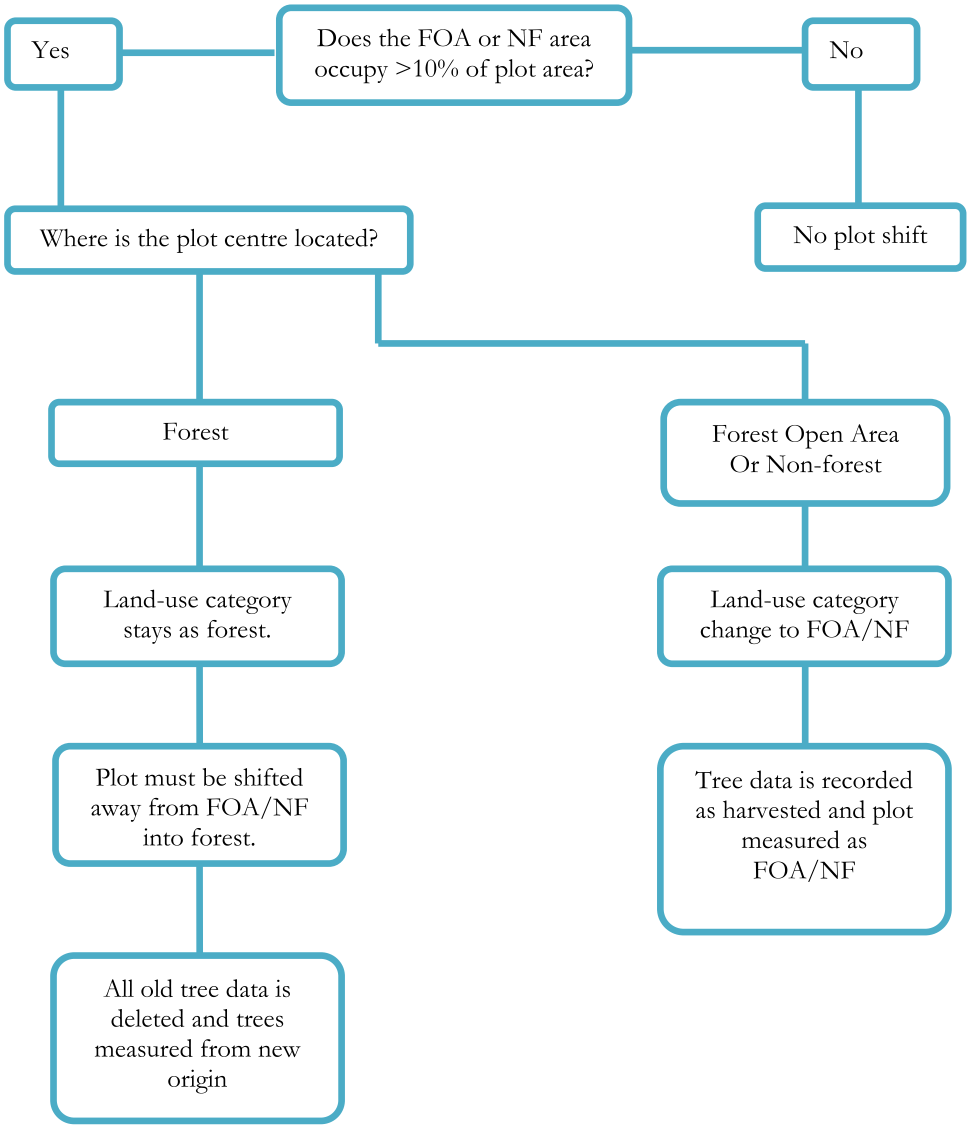


Figure 21. Land-use change on established plots.

6.2 PLOT MIRRORING

Plot mirroring only occurs in the Forest Open Area land-use category, where a plot lands on a linear feature such as a rideline or forest road. In plot mirroring, the data collection is confined to the land-use category where the plot centre is located. Other land-use categories occurring on the plot are excluded.

In the example in Figure 22 data is only recorded for attributes occurring on the rideline. Any attributes occurring on the hatched areas are excluded. Attributes are assessed on the basis that the whole plot occurs on the rideline. For the purpose of data collection, the attributes occurring on the rideline are mirrored onto the hatched area.

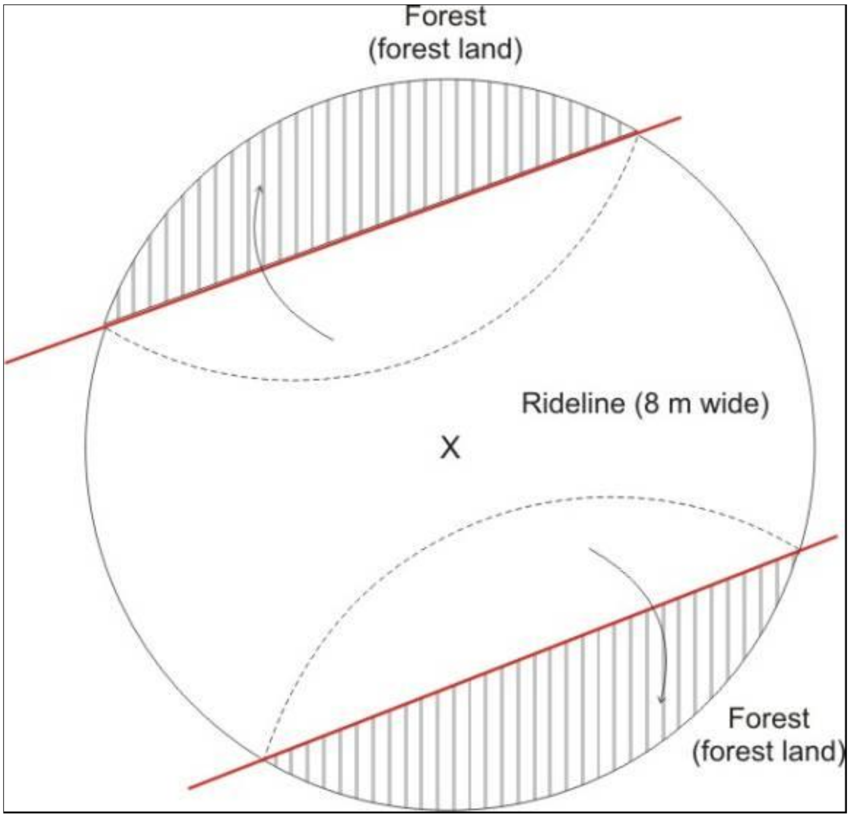


Figure 22. Plot mirroring.

Chapter 7 DATA COLLECTION OVERVIEW

7.1 HARDWARE AND SOFTWARE OVERVIEW

The NFI used computer-aided field data collection techniques. These techniques comprised field computers, specialised measurement equipment and system software. A full list of NFI equipment is included in Appendix 1, while the specifications of some hardware components are presented in Appendix 2.

The underlying technology used in the NFI is an integrated system of hardware and software developed by IFER[5]. The software, Field-Map™, is specialised inventory software that allows for the preparation of a NFI database, background maps and plot generation. This in turn provides for the creation of projects for field teams, which facilitates the field data collection process. Inventory data is uploaded to a central database via USB memory sticks.

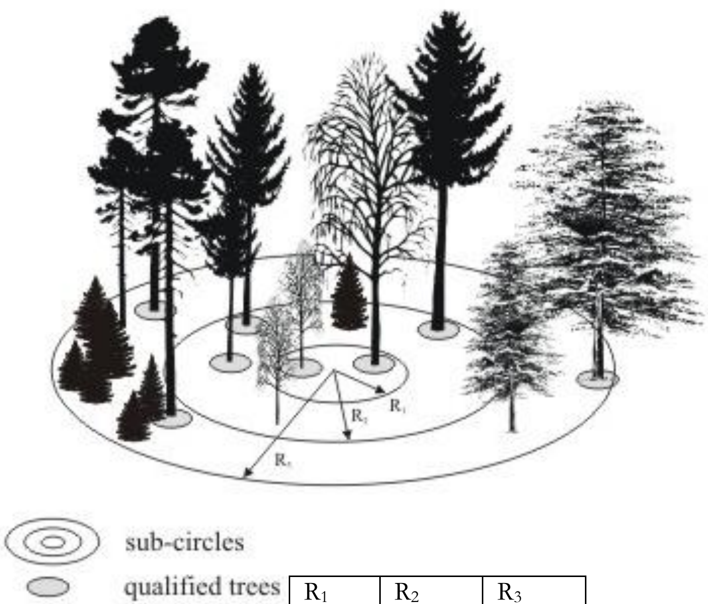
The NFI database is a full relational database containing 127 tables. The database also features a spatial map component, which is a layer containing the locations of field plots and ancillary background map data used for navigation to field plots. Selected layers (e.g. trees) have a spatial reference (i.e. position relative to the plot centre). Each of the data layers and attributes will be described in more detail in subsequent chapters.

7.2 PLOT DESIGN

In this section the individual ground survey plot design is described and some of the information collected on site is summarised.

The exact location of the centre of ground survey plots is identified in the field by navigating to a six digit Irish national grid co-ordinate using both GPS and electronic compass/laser technology. The area of the circular sample plot is 500 m^2 (i.e. 25.24 m in diameter). All stated dimensions relate to horizontal distances. Adjustments for slope are automatically made by the laser/range-finding equipment.

Plots are assessed using the concentric circle approach, comprised of three concentric circles each with a different radius. Inclusion of trees for mapping and assessment is dependent on three predefined Dbh thresholds, which are defined according to concentric circle. Trees of different dimensions are mapped and described on each particular plot (Figure 23). The decision about which trees qualify is based on their position, with respect to distance from the plot centre and their Dbh. Within the 12.62 m circle all trees with a Dbh greater than 200 mm are mapped and assessed. All trees greater than or equal to 120 mm Dbh and within the 7 m circle are mapped and assessed. Within the 3 m circle all trees with a Dbh of 70 mm and greater are mapped and assessed. Within the 3m circle, all small trees with a Dbh of less than 70 mm and height >20 cm are assessed, but not mapped.



	R_1	R_2	R_3
Sub-circle radius (m)	3.00	7.00	12.62
Sub-circle area (m^2)	28.3	153.9	500.0
Threshold Dbh (mm)	70	120	200

Figure 23. Concentric plot design.

[5] Institute of Forest Ecosystem Research, www.ifer.cz

7.3 Overview of attributes included

Ireland's NFI assesses the current state and development of the forest estate in relation to standing trees, forest structure, forest regeneration, deadwood and other site characteristics.

Tree positions are mapped using a combination of electronic compass and laser. The Dbh of each tree is recorded, along with other descriptive parameters such as species, age, social status, timber quality, branchiness and damage. A sub-sample of seven trees per species, the 'height trees', were selected for height measurement, based on the distribution of Dbh of the measured trees (Figure 24). An upper stem and base diameter were also measured for a maximum of five trees (Dbh ≥ 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 trees' regardless of Dbh, horizontal crown projection is measured. Vitality is assessed for all 'height trees' of *spruce, pine, oak* and *beech* species which are dominant or co-dominant (crown is in the upper level).

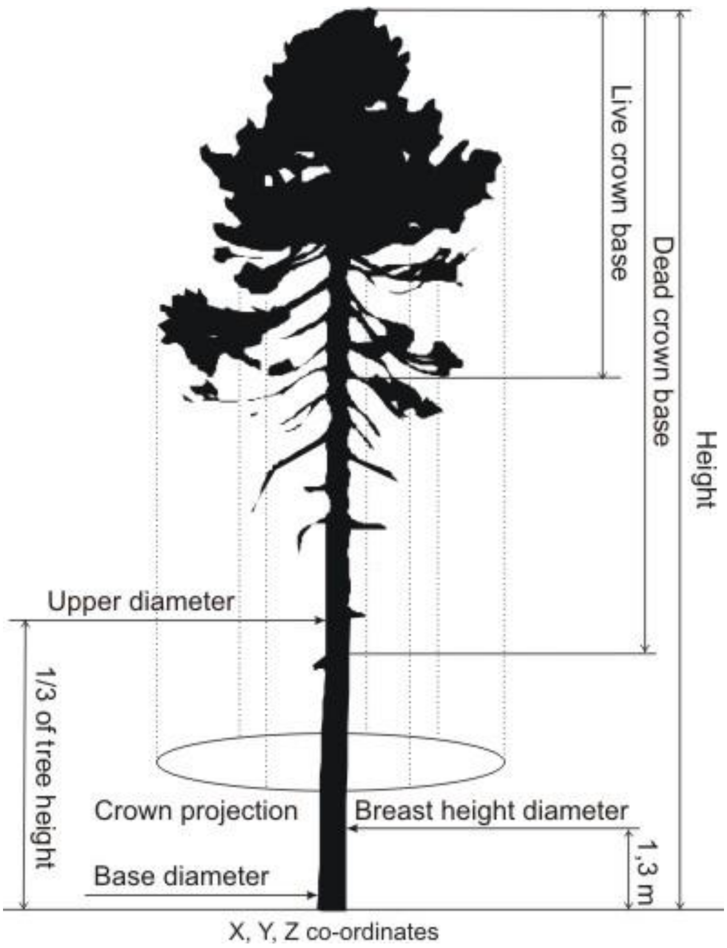


Figure 24. Visual representation of tree data collected.

A description of the forest stand in the 12.62 m plot is 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, by species, with a minimum height of 20 cm and within the 7 m plot is recorded as the stocking level.

Site characteristics with reference to the entire plot are described in detail, such as soil type and terrain. Ground vegetation over the whole plot is identified and quantified as a percentage cover on the plot. The dimensions and quantities of deadwood are also assessed; this includes stumps, lying and standing deadwood. A summary of the main NFI attributes collected is presented in Table 2.

Table 2. Main NFI attributes.

Plot	**Deadwood**
Plot id	Branch cover
Plot area	Stump presence
Land-use category	Stump diameter, height and decay status
Forest structure	Dead logs presence
Stand layer type, canopy closure and composition	Dead logs distribution
Social status	Dead log mid-diameter, length and decay status
Fork	**Site**
Dead tree	Altitude
Forest diversity	Relief form
Species composition	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	Principal soil
Dead crown base	Peat texture
Stem quality (straightness, branchiness)	Soil texture
Damage	Drainage
Negative factor limiting regeneration	Moisture
Type, intensity and age of regeneration tree damage	Soil depth
Tree mechanical damage type, intensity and age	Peat depth
Peeling intensity and age	Litter description
Stem rot	**Regeneration**
Tree break	Presence
Tree root damage type, intensity and age	Origin
Other tree damage type	Protection
Defoliation	Regeneration distribution
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 naturalness
Moss cover	Cultivation type
Fern cover	Growth stage
Brush cover	Thin status
Shrub cover	Rotation type
	Stocking

7.4 PLOT WORKFLOW OVERVIEW

The next section describes an overview of the field data collection procedures workflow, following on from the establishment of the plot centre. Each plot varies and not all attributes are applicable to all plots. The first team member (Tm 1) inputs the data into the computer and operates the laser and compass whilst the second team member (Tm 2) is primarily involved with the measurement of tree attributes. Generally team roles alternate with each subsequent plot assessed. A minimum of two plots would be assessed in any one day.

7.4.1 Stage 1: Plot, site and forest descriptions.

If required Tm 2 will begin cleaning the plot, by removing some side branches or brush as is necessary to allow movement and good site lines throughout the plot. A soil pit is dug by Tm 2 to ascertain soil type, structure and drainage. The litter and humus layers are usually described at this stage along with the terrain classification. A pole is placed at the plot centre to act as a visual reference for the team members and the direction of magnetic north is found by Tm 1. This will act as the starting point from which the trees likely to be mapped are numbered, carried out by Tm 2 sweeping around the plot from magnetic north in a clockwise direction pinning laminated numbers to each tree which qualifies for measurement under the concentric circle plot design (Figure 25). The distance from plot centre is checked using a loggers tape. Tree Dbh is checked using a Dbh tape

Figure 25. Tree numbering on the plot.

When Tm 2 cleans the plot and numbers the trees, Tm 1 will fill out all the visually assessable site attributes such as County, LUT and surface topography. The basic Forest attributes such as owner, planting year, tree distribution and thin status etc. are also entered. As Tm 1 and 2 complete their respective roles they will be moving about over the entire plot and will be constantly communicating on every aspect of the plot descriptions including the vegetation cover on site, identifying each individual plant and its frequency within the 12.62 m circle, and the presence of deadwood.

Note: At this stage all attributes do not have to be complete or immediately measured, the data collection software allows attributes to be measured or changed at any stage, for example any additional plants found can be added at any time.

7.4.2 Stage 2: Mapping trees.

The equipment is set up to begin mapping the qualifying trees by calibrating the compass and connecting it and the laser to the computer. Tm 1 will generally position him/herself at the plot centre although any position may be used as long as it is referenced to the plot centre. Tm 2 will carry a Dbh tape and reference pole to each numbered tree, working sequentially, positioning the pole in front of each tree whilst Tm 1 records its distance and azimuth from the centre using the laser and compass, thus mapping each tree.

Tm 2 measures the Dbh and describes the attributes of each tree as it is mapped. Where mapped trees are present from a previous NFI their position is checked and their attribute data updated. Unless these trees were mapped incorrectly during the previous NFI their current position will correspond to the trees previously mapped location. If any trees were harvested their previous position is verified by locating the stump and their attributes are updated to 'Harvested tree'. Dead standing trees that meet the criteria regarding Dbh and radii are mapped and assessed as are live fallen trees e.g. windblown trees. Lying dead trees are assessed as deadwood but not mapped.

As the team progresses around the plot both team members check whether any un-numbered trees (i.e trees within the plot but thought to be outside the Dbh or radii thresholds) should be mapped. When the last numbered tree is mapped and assessed a re-check is carried out by verifying that all previously mapped trees, if present, are accounted for and that all newly qualifying trees are mapped and described. Any trees found not to be mapped but meeting Dbh threshold criteria are immediately numbered and mapped. Borderline trees i.e. trees on the Dbh and/or the radii threshold are checked independently by both team members to determine if they should be mapped or not. The distance as measured by the loggers tape is used as the definitive measurement for distance in this instance.

7.4.3 Stage 3: Further attributes collected on selected trees

Seven height trees are selected from across the Dbh range and which are distributed regularly throughout the plot. These trees will also have their crown projections measured and a selection of these trees will also be further assessed for upperstem diameter and vitality.

Heights, living/dead crown height and crown projections are measured for each tree by Tm 1 taking a suitable position where the tree top can be seen. In dense canopy Tm 2 assists by shaking the tree. Upper stem diameter measurements are also recorded for trees ≥20 cm Dbh. Tree vitality is then described for each of the Height trees

7.4.4 Stage 4: Finishing the plot

The Dbh and height of small trees present in the 3 m circle are recorded. Any dead wood is described as stumps, logs or branches by sweeping around the plot in a similar fashion used to map the trees with Tm 2 measuring and Tm 1 inputting the data. Tm 2 will assess stocking at this time using the loggers tape in the 7 m circle and begin collecting and packing any equipment used during the measurement of the plot. When the plot is complete Tm1 begins the checks of the data to ensure there are no blank or erroneous values. Tm 2 will then repeat the checks. Once all checks are complete and both team members are satisfied that all required data are collected and verified the numbers on the trees are collected. This is the last task to be done on each plot as it allows the easy identification of trees that present with any blank or erroneous values e.g. a missing Dbh or decreasing height. The incorrect or missing attribute value can then be easily re-measured if necessary before leaving the plot.

SECTION B

FIELD DATA COLLECTION

Chapter 8 PLOT

This chapter details the type of information that is recorded to describe the environment in which the plot occurs.

8.1 ACCESSIBILITY

Definition: All plots are recorded as being either accessible or inaccessible.

Application: Inaccessible plots are excluded from the data analysis.

Measurement and Description: If it was physically impossible to walk to the plot, due to difficult terrain such as marshy ground, the plot was classified as inaccessible.

Attribute **Accessibility**

1. **Accessible**: It was possible to reach the plot centre.
2. **Inaccessible**: It was not possible to reach the plot centre.

8.2 LAND USE CATEGORY

Definition: Broad classification of land-use type on the plot.

Application: Identification of forest land.

Measurement and Description: Broadly describes accessible plots in the field.

Attribute **Land-use category**

1. **Forest**: Land with a minimum area of 0.1 ha, a minimum width of 20 m, trees present 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*.
2. **Forest Open Area**: Forest Open Area is a non-stocked area (>400 m^2 and <2 ha) enclosed within the forest boundary.
3. **Non-Forest**: Areas that do not conform to the Forest or Forest Open Area definitions.

8.3 LAND-USE CLASS

Definition: Sub-classification of land-use category.

Application: Descriptive classification of land-use.

Measurement and Description: Forest, Forest Open Area and Non-Forest are sub-classified.

Attribute **Land-use class**

Forest

1. **Forest**: This is an area that complies with the forest definition and does not meet any of the other sub-category definitions listed below.
2. **Clear-cut**: The trees in this area have recently been felled with no-evidence of replanting, though the potential to replant exists. As there is generally a requirement by law to replant these areas, they are temporarily unstocked.
3. **Dead**: This is an area that contains dead trees; this may be due to biotic (animal) or abiotic (climatic, nutritional) factors. At least 80% of the trees have to be dead at the time of assessment.
4. **Windblown**: This is an area where the trees have been windblown. At least 80% of the trees have to be windblown at the time of assessment.
5. **Natural Succession**: This is an area where the trees have colonised previously non-forest land. These lands must conform to the forest definition.

6. **Swamp/Marsh**: These areas can have a high water table all year round (e.g. edge of lake) or can be seasonally flooded. They must conform to the forest definition.
7. **Rideline**: This is an unplanted area within the forest boundary that is >3 m and <6 m wide, from pith-line to pith-line.
8. **Road**: This is a forest road within the forest boundary that is >3 m and <6 m wide, from pith-line to pith-line.
9. **Water**: A water body that is located within the forest boundary and that is <400 m^2 in area. This sub-category also includes streams that are <3 m wide, from pith-line to pith-line.
10. **Roadside stack**: This area is <400 m^2 and is used for the purpose of stacking timber. It must either have timber present or evidence of previous timber stacking.
11. **Gap with shrubs (<400 m^2)**: A gap in the canopy that is <400 m^2 and contains shrub species.
12. **Gap without shrubs (<400 m^2)**: A gap in the canopy that is <400 m^2 and does not contain shrub species. The gap can be due to a number of biotic or abiotic factors or to the area having been left unplanted.

Forest Open Area

1. **Rideline**: An unplanted strip used to sub-divide large forest areas and facilitate access for forest management. It must be >6 m wide from pith-line to pith-line.
2. **Road setback**: **An area** that is >5 m and <20 m wide from pith-line to road edge.
3. **Building setback**: An area that is >5 m and <20 m wide from pith-line to boundary feature.
4. **Hedgerow setback**: An area that is >5 m and <20 m wide from pith-line to hedgerow.
5. **Forest edge setback**: An area that is >5 m and <20 m wide from pith-line to boundary feature.
6. **Pipeline setback**: **An area** that is >5 m and <40 m wide from pith-line to pith-line or boundary feature.
7. **Firebreak**: An unplanted area for the purpose of forest protection, that is >5 m and <20 m wide from the pith-line to the boundary.
8. **Riparian zone**: An area left unplanted due to the presence of a water body, that is >6 m and < 40 m wide from pith-line to pith-line when situated within the forest. At the forest edge, it should be >5 m and <20 m wide from pith-line to the centre of the stream.
9. **Utility line**: This is an area that occurs under a utility line. The unplanted area beneath the power line must be <40 m from pith-line to pith-line when situated within the forest stand. When situated at the forest edge, the unplanted area should be <20 m. If there is another predominant land-use (e.g. agricultural or Christmas trees) occurring in the exclusion area then the area becomes Non-Forest regardless of width.
10. **Road**: This is an unpaved forest road within the forest boundary that is >6 m wide from pith-line to pith-line.
11. **Roadside stack**: These areas must be >400 m^2 and used for the purpose of stacking timber. They must either have timber present or evidence of previous timber stacking present.
12. **Bare land (>400 m^2)**: These are gaps in the canopy that are >400 m^2 and less than 2 ha in size. The gaps can be due to a number of biotic or abiotic factors or to the area having been left unplanted. No other land use-type should predominate on the site.
13. **Shrub land**: This is an area within the forest boundary that has shrub species present on >80% of the plot.
14. **Stone, sand and/or gravel quarry**: This is a quarry, used for forest roading which conforms to the Forest Open Area definition.
15. **Landslide**: The movement of soil, peat or rock down slope that has a minimum width of 20 m.
16. **Water**: Water body that is <1000m^2 in size or consisting of a stream/river >3 m and <6 m wide from pith-line to pith-line.
17. **Walkway**: This is an unpaved forest track used for the purposes of recreation within the forest boundary that is >6 m wide from pith-line to pith-line.

Non-Forest

1. **Water**: Water body that is >0.1 ha in size or consisting of a stream/river >6 m wide from pith-line to pith-line.
2. **Utility line**: This is an area that occurs under a utility line. The unplanted area must be wider than 40 m from pith-line to pith-line, when situated within a forest. When situated at a forest edge, the setback distance must be greater than 20 m.
3. **Rock outcrop**: An area of outcropping rock that is situated outside the forest boundary, including scree and limestone pavement.

4. **Nursery**: An area used for the production of tree seedlings.
5. **Agricultural land**: An area used for the purpose of agriculture.
6. **Christmas tree plantation**: An area used for the production of Christmas trees.
7. **Built-up areas**: An area >400 m^2 that has buildings present.
8. **Heathland**: An area of bog and heath that is located outside the forest boundary.
9. **Shrub land**: This is an area outside the forest boundary where shrub species are the dominating vegetation.
10. **Hedgerows**: A row of woody plants used to demarcate spaces and property boundaries. The hedgerow may contain a mixture of trees and shrubs.
11. **Other land**: An area that is not readily conforming to any of the Non-Forest sub-categories defined in this section.

8.4 MAGNETIC DECLINATION

Definition: Magnetic declination is the angular offset of magnetic north from true north.

Application: As the magnetic fields around the earth are continually changing, so too will the magnetic declination. As the positions of trees on the plot are recorded using an electronic compass it is important to be able to relocate these trees for validation or future measurements. When a sample plot is revisited in the future, the magnetic declination will have changed but when the azimuth is readjusted for the new declination the trees can be relocated.

Measurement and Description: The magnetic declination is calculated from current position which is stated as degrees of latitude and longitude and altitude from sea level in meters. This information is obtained from the GPS.

Attribute **Magnetic Declination**

1. The magnetic declination is recorded in degrees.

8.5 COUNTY

Definition: A sub-national geographic division.

Application: Facilitates regionalisation of results.

Measurement and Description: One of the 26 counties is selected.

8.6 PHYSIOGRAPHIC DIVISIONS

Definition: Physiographic divisions are significant divisions for soil formation in Ireland.

Application: The classes give an indication of the type of landscape in the area where the plot is located. Assessment is based on the plot altitude, soil group and appearance of the landscape.

Measurement and Description: Five major physiographic divisions are used in this classification (Gardiner and Radford 1980).

Attribute **Physiographic Division**

1. **Mountain and hill**: Mountain and hill soils occurring at elevations of 365-500 m, with steep slopes common. These soils are mainly peaty podzols, peaty gleys, blanket peat and lithosols. Outcropping rock is common. The majority of these areas occur on the higher mountain slopes.
2. **Hill**: Hill soils are predominantly acidic and occur between 150-365 m. The largest of these areas is the old red sandstone uplands of Munster. The principal soils in these areas are brown podzolics but other soils included in this division are rendzinas and outcropping rock of the Burren area.
3. **Rolling lowland**: Rolling lowland soils occur at elevations below 150 m. Acid brown earths and brown podzolics make up the majority of the soils. Extensive areas of gleyed soils are also included, such as those formed on the Castlecomer plateau.
4. **Drumlins**: Drumlins consist of a thick cover of boulder clay deposited in the form of small hills. As these hills were formed beneath moving ice, the ridges tend to be parallel to the direction of ice flow. Drumlins occur

mainly in the north-west, west and some midland areas, and the landscape is characterised by the 'eggs in the basket' similarity. Gley soils dominate in these areas.

5. **Flat to undulating lowland**: Flat to undulating lowland generally occur at elevations below 100 m. Brown earths and grey brown podzolic soils dominate this area. It stretches from the Golden Vale across the central plain to the east coast, as well as occupying large areas of east Galway and Roscommon.

8.7 Relief form

Definition: Classification of different elevations of the earth's surface (Anon. 1998b).

Application: The classes give an indication of the position of the plot in the landscape (Figure 26).

Measurement and Description: The relief form is categorised into seven classes (Anon. 1998b). Assessment is based on the area in the vicinity of the plot.

Attribute **Relief Form**

1. **Crest**: The generally convex uppermost portion of a hill, usually convex in all directions with no distinct aspect.
2. **Upper slope**: The upper portion of the slope immediately below the crest of the hill; it has a specific aspect.
3. **Middle slope**: Area between the upper and lower slope; the surface profile is generally neither distinctly concave nor convex and will have a straight surface profile with a specific aspect.
4. **Lower slope**: The area toward the base of a slope; generally has a concave surface profile with a specific aspect.
5. **Toe slope**: The area demarcated from the lower slope by a decrease in slope gradient.
6. **Depression**: Any area concave in all directions; it may be at the base of a slope or in a generally level area.
7. **Level**: Any flat area (i.e. slope <5^{o}) where the surface profile is generally horizontal and straight with no significant aspect.

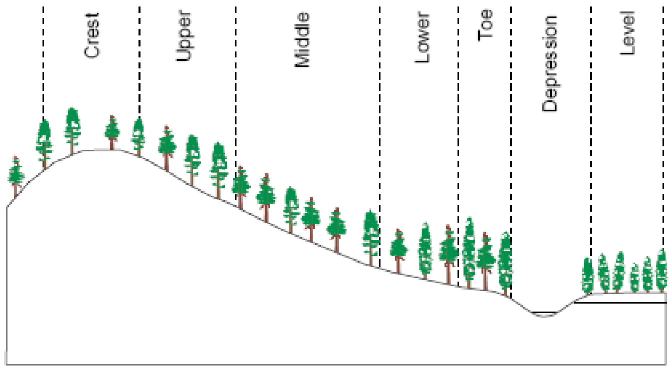


Figure 26. Relief form (Anon. 1998b).

8.8 Surface topography

Definition: The general land surface shape in which the plot occurs.

Application: The classes give an indication of the topography of the area where the plot is located.

Measurement and Description: The surface topography is categorised into three classes (Anon. 1998b). Assessment is based on the area in the vicinity of the plot.

Attribute **Surface Topography**

1. **Concave**: Surface profile is mainly 'hollow' in one or several directions.
2. **Convex**: Surface profile is mainly 'rounded' like the exterior of a sphere.
3. **Straight**: Surface profile is linear, either flat or sloping in one direction.

8.9 Altitude

Definition: Altitude is the height of the plot above sea level.

Application: Altitude is an important factor in tree growth, with productivity generally reduced at higher elevations. Exposure and more impoverished soil types are the main limiting factors at higher elevations.

Measurement and Description: The altitude (m) of the plot centre is determined using GPS.

8.10 Aspect

Definition: Aspect describes the orientation of the slope.

Application: Aspect indicates how exposed the plot is to factors such as wind, e.g. a site with a SW aspect will be exposed to the prevailing winds.

Measurement and Description: It is measured using the clinometer functionality on the laser rangefinder and categorised by the cardinal points of a compass.

Attribute **Aspect**

1. Flat: (slope of $<5^o$).
2. North.
3. Northeast.
4. East.
5. Southeast.
6. South.
7. Southwest.
8. West.
9. Northwest

8.11 Slope

Definition: The measurement of the steepness of terrain, the ratio of vertical rise to horizontal distance expressed in degrees.

Application: From a forest management viewpoint, the slope will indicate the traversability of the site where the plot is located.

Measurement and Description: The slope of the plot is measured in degrees using the clinometer across the extent of the plot, i.e. from plot edge to plot edge.

8.12 Anthropogenic Factors

Definition: These are human induced factors that may have changed the original nature of the plot area.

Application: This classification is important, as these factors may constrain forest management.

Measurement and Description: Assessment is based on the presence of an anthropogenic factor within the 12.62 m plot.

Attribute **Anthropogenic Factors**

1. **None**: There are no human induced factors influencing forest management on the site.
2. **Archaeological features**: A site or monument that is part of our national heritage.
3. **Recreation**: The plot is located within a site where recreation is a primary function.
4. **Mine areas and quarry**: Site is being actively mined or quarried.
5. **Mine dump and spoils**: Residue from mining operations are present on the site.
6. **Landfill**: The disposal of refuse is taking place on the site.
7. **Other**: Other human induced factors influencing forest management on the site.

8.13 Trees

Definition: Identifies those plots with trees ≥ 7cm Dbh.

Application: Used to identify those plots with trees ≥7cm Dbh.

Measurement and Description: Assessed visually by looking at the size of trees, i.e. Dbh and checking with a Dbh tape.

Attribute **Trees**

1. **Trees present**: Trees ≥7 cm present on the 12.62 m plot.
2. **Small trees present**: Trees <7 cm present on the 12.62 m plot.
3. **No trees present**: No trees are present on the 12.62 m plot.
4. **All trees harvested**: Trees were present previously, now all trees have been removed.

8.14 Small Trees

Definition: Identifies those plots with trees <70 mm Dbh, within the 3 m plot.

Application: Used to identify those plots with trees ≤70 mm Dbh.

Measurement and Description: Dbh and height of trees on the 3m plot is assessed.

Attribute **Small trees**

1. **Small trees present**: Trees <70 mm present on the 3 m plot.
2. **No small trees present**: No trees <70 mm are present on the 3 m plot.

8.15 Deadwood

Definition: Deadwood present on the plot.

Application: Used to identify those plots with deadwood present.

Measurement and Description: Assessed visually by looking on the 12.62 m plot for dead branches, stumps and/or logs.

Attribute **Deadwood**

1. **Stumps or logs present**: Stumps present that have a top diameter ≥ 10 cm. Logs present that have a mid-diameter ≥ 7 cm and are ≥ 1 m in length.
2. **No wooden debris present**: There are no branches, stumps or deadlogs present on the plot.

8.16 Photograph

Definition: An image recorded by a digital camera.

Application: Plot photographs provide a desk check facility for ambiguous or difficult plots requiring verification. They also provide pictorial evidence in making land-use allocation decisions.

Measurement and Description: After plot cleaning to provide a clearer view of the plot, four photographs are taken from the centre of the plot, with the first photograph facing north and then in the three other cardinal directions, east, south and west.

8.17 Move plot

Definition: Specifies whether the generated plot origin was moved in the field due to the presence of another land-use category on the plot.

Application: Useful for the field team to know if the plot was moved in the previous NFI prior to navigation.

Measurement and Description: If the plot centre was moved, Yes is selected otherwise No is entered.

8.18 Name/address/telephone

Definition: Land owner name, address and other contact details.

Application: Used by field team and project manager to contact land owner.

Measurement and Description: Text entered by field team.

8.19 Road access

Definition: Describes how accessible by road the plot is.

Application: Used by field team and project manager to assess difficulty of access to the plot.

Measurement and Description: Whether or not the plot is within or further than 100 m from the nearest road.

Chapter 9 INVENTORY CYCLE

This chapter details the information relating to the inventory cycle.

9.1 INVENTORY CYCLE

Definition: Inventory cycle at which the plot was first established.

Application: Identify plots belonging to a particular inventory cycle.

Measurement and Description: Inventory cycle is identified by date of plot assessment.

Attribute **Inventory cycle**

1. **1st cycle**: Plot established between 2004 and 2006.
2. **2nd cycle**: Plot established between 2009 and 2012.

9.2 PLOT STATUS

Definition: Details the status of the plot at each cycle.

Application: Allows the status of the plot to be tracked between inventory cycles.

Measurement and Description: Data is entered after the plot centre is established.

Attribute **Plot status**

1. **Centre located**: Plot centre from previous cycle is located.
2. **Centre located, Forest to FOA**: Plot centre from previous cycle is located, but land use type has changed from Forest to Forest Open Area, e.g. a forest road is constructed.
3. **Centre located, FOA to Forest**: Plot centre from previous cycle is located, but land use type has changed from Forest Open Area to Forest, e.g. a rideline is replanted following clearfelling.
4. **New plot**: A new plot centre is established, due to afforestation or natural-succession. This forest was not present during the 1st cycle.
5. **New plot, forest missed 1st NFI**: A new plot centre is established, due to afforestation or natural-succession. However, this forest was present during the 1st cycle, but excluded in error at that time.
6. **GO moved in forest, due to new OA**: Plot centre from previous cycle is relocated, due to presence of another land use category, e.g. GO moved away from new forest road.
7. **GO move error 1st NFI, return to GO**: Plot centre was moved in the 1st cycle in error. Plot is relocated to GO, in 2nd cycle.
8. **GO should have moved 1st NFI, move GO**: Plot centre was established at GO in 1st cycle, but should have been moved at that time due to the presence of another land use type. GO was moved in 2nd cycle.
9. **FOA 1st NFI, should have been Forest**: Plot was classified as FOA in 1st cycle in error. Should have been forest in both cycles.
10. **Forest 1st NFI, should have been FOA**: Plot was classified as Forest in 1st cycle in error. Should have been FOA in both cycles.
11. **Forest 1st NFI, should have been NF**: Plot was classified as Forest in 1st cycle in error. Should have been Non-Forest in both cycles.
12. **Deforestation**: There has been a change of land use category on the plot from Forest (1st cycle) to Non-Forest (2nd cycle).
13. **Inaccessible**: Forest plot was visited in the 1st cycle, but field data collection was not undertaken in the 2nd cycle due to restrictions on access.

9.3 Date

Definition: Date of plot assessment.

Application: Identify date of plot assessment.

Measurement and Description: Date is entered for each cycle.

9.4 Team member

Definition: Persons responsible for field data collection.

Application: Used by project manager for selection of validation plots and for data correction.

Measurement and Description: Team member 1 is the person entering the data and team member 2 is the other field team member.

9.5 Note

Definition: Note relating to some aspect of the plot, which is not covered by the existing variables.

Application: Used by field team and project manager to provide extra information about the plot.

Measurement and Description: Text entered by field team.

Chapter 10 FOREST

This chapter outlines the data collected with descriptive attributes describing the forest on the plot, similar to the information which is collected in stand level inventories.

10.1 PLANTING YEAR

Definition: Details the year when the main crop was established.

Application: The planting year is used to assess the age diversity of the national forest estate.

Measurement and Description: The assessment of planting year is based on the dominant layer in the plot. Planting year information is provided for the Coillte and private grant-aided forest areas.

Attribute **Planting year**

1. **Planting year**: Numerical value.

10.2 OWNERSHIP

Definition: Specifies land ownership.

Application: Forest ownership type is important as it has the potential to impact on timber supply.

Measurement and Description: Forest Service and external datasets are used to specify ownership type. Assessment is based on the location of the plot centre.

Attribute **Ownership**

1. **Coillte**: Forest land owned by Coillte.
2. **Private (grant aided)**: Private afforested land which was or is in receipt of grant and/or premium over the period 1980 to present.
3. **Private (non grant aided)**: Private forest land which was not established with grant aid since 1980. This category includes estate planting and natural succession land.
4. **National Parks and Wildlife Service (NPWS)**: Forest land owned by the NPWS.
5. **Farm partnership**: Grant aided forest that is privately owned, but is being managed by Coillte.
6. **Other**: Not belonging to any of the above, e.g. Bord na Móna, Electricity Supply Board, Department of Defence or any local authority.

10.3 EUROPEAN FOREST TYPE (EFT)

Definition: Broad forest type classification system based on species composition.

Application: Broad classification of forets types, used mainly to refine subsequent attributes.

Measurement and Description: The assessment of EFT is based on the dominant canopy cover on the 12.62 m plot.

Attribute **European forest type**

1. **Conifer**: More than 80% of coniferous tree species.
2. **Broadleaf**: More than 80% of broadleaf tree species.
3. **Mixed**: A forest composed of broadleaved and conifer species, the minor category making up at least 20% of the canopy.
4. **Temporarily unstocked**: Forest temporarily unstocked due to factors such as fire or following harvest, but are expected to be replanted.
5. **Forest open area**: Forest Open Area is a non-stocked area enclosed within the forest boundary.

10.4 Forest type

Definition: A standardised system of nomenclature adopted to classify forests based on the composition of tree canopy cover.

Application: Classification of the forest area into broad forest types provides a useful means of assessing and interpreting the NFI results.

Measurement and Description: The categories were based on those used in the 'Inventory of Private Woodlands – 1973' (Purcell 1973). Classification is based on the percentage canopy cover on the plot. The assessment of forest type takes place over the 12.62 m plot, but where there are two distinct forest types occurring on the plot, classification is based on the forest type where the plot centre is located.

Attribute **Forest Type**

1. **Conifer high forest**: A forest composed of more than 80% (by canopy cover) coniferous trees (CHF).
2. **Broadleaf high forest**: A forest composed of more than 80% (by canopy cover) broadleaved trees (BHF).
3. **Mixed high forest**: A forest composed of broadleaved and conifer species, the minor category making up at least 20% of the canopy (MHF).
4. **Felled-unplanted**: A forest where more than 80% of the canopy has been felled and which has not been replanted.
5. **Felled-replanted**: A forest where more than 80% of the canopy has been felled and which has been replanted within the last two years.
6. **Blown-unplanted**: A forest where more than 80% of the canopy has been blown and which has not been replanted.
7. **Blown-replanted**: A forest where more than 80% of the canopy was blown and which has been replanted.
8. **Burned-unplanted**: A forest where more than 80% of the canopy has been burned and it has not been replanted.
9. **Burned-replanted**: A forest where more than 80% of the canopy has been burned and which has been replanted. Evidence of burnt trees/tall stumps must be present on site.
10. **Undeveloped**: An undeveloped conifer forest is where at least 81% of the planted trees are unlikely to ever produce a pulpwood or high forest stand.
11. **Scrub**: Broadleaf forest, usually semi-natural broadleaf forest, which is unlikely ever to become a high forest. Depending on management, scrub species may include *Quercus, Salix, Corylus* and *Ilex*.

10.5 Forest subtype

Definition: Describes if one or more species occur.

Application: Indicates the level of species diversity.

Measurement and Description: The assessment of forest subtype is based on the 12.62 m plot. The classification of forest subtype is based on canopy cover (Table 3).

Table 3. Examples of forest type and associated subtype.

Forest type	Forest subtype	Example species	Mix Ratio
CHF	Pure	Sitka spruce	None
CHF	Mixed	Sitka spruce: Hybrid larch	80:20
BHF	Pure	Oak	None
BHF	Mixed	Oak: Beech	80:20
MHF	Mixed	Oak: Scots pine	50:50

Attribute **Forest Subtype**

1. **Pure**: The dominant species occupies more than 80% of the canopy.
2. **Mixed**: A forest is rated as 'mixed' when the dominant species has between 20-80% of the canopy.

10.6 MIXTURE TYPE

Definition: Mixture type describes the species distribution of trees. If there is more than one species present, the plant distribution may follow a predefined structure e.g. planting in groups.

Application: The planting of trees in groups is a common feature in plantations recently established in Ireland (Figure 27).

Measurement and Description: Assessment is carried out on the 12.62 m plot.

Attribute **Mixture type**

1. **Uniform**: The structure is uniform throughout the plot where one tree species is present.
2. **Individually mixed**: There is more than one species present, with the species mixture occurring in a random manner.
3. **Group mixed**: The structure is based on groups of trees of each species. Line mixtures are included in this category.

Figure 27. Individually mixed forest on left and a group mixed forest on right.

10.7 TREE DISTRIBUTION

Definition: The distribution of trees in terms of spatial arrangement.

Application: The spatial arrangement is of interest due to site access and management considerations during operations such as thinning (Figure 28).

Measurement and Description: Assessment is carried out on the 12.62 m plot.

Figure 28. Regular tree distribution.

Attribute **Tree distribution**

1. **Regular**: The trees are distributed uniformly, e.g. 2 m x 2 m square spacing.
2. **Group**: The trees are distributed in groups.
3. **Random**: The trees are distributed randomly with no particular pattern.

10.8 EVEN/UNEVEN AGED

Definition: Uniformity of tree age within the plot.

Application: The even/uneven aged classification is used to assess the diversity of tree age within the national estate, which is used as an indicator for biodiversity.

Measurement and Description: The assessment of even/uneven aged is based on the assessment of tree canopy in the 12.62 m plot.

Attribute **Even/uneven Aged**

1. **Even aged**: A forest, in which there is no or a relatively small age difference between trees in the canopy. Greater than 80% of the canopy is made up of trees that have an age difference of 4 years or less.
2. **Uneven aged**: Between 20-80% of the canopy is made up of trees that have an age difference of 5 years or more.

10.9 ESTABLISHMENT TYPE

Definition: Establishment type describes the land type on which the forest has been established and how the storey was established (i.e. artificially or naturally).

Application: Establishment type is used to identify new, artificially established plantations. This is required for the purpose of carbon stock reporting under the Kyoto agreement.

Measurement and Description: The assessment of establishment type takes place on the 12.62 m plot.

Attribute **Establishment Type**

1. **Afforestation**: The man-made establishment of new forests on treeless lands which did not carry forest in contemporary history. Implies a transformation from Non-Forest to Forest.
2. **Reforestation**: The man-made establishment of trees on lands that have been cleared of forest within the relatively recent past. Generally identified by the presence of stumps and deadwood on the site.
3. **Semi-natural**: Forests established by natural regeneration, i.e. greater than 80% of the tree species regenerated naturally. Native and non-native tree species are included. This forest land may not be managed in accordance with a formal or an informal plan applied regularly over a sufficiently long period (5 years or more). It generally indicates natural succession type forests.

10.10 DEVELOPMENT STAGE

Definition: Development stage of the forest.

Application: This is used to assess the development stage of the forest estate.

Measurement and Description: The growth stage of a forest is primarily determined by canopy in early uears followed by thinning suitability and potential end products in later years. The assessment of growth stage takes place on the 12.62 m plot.

Attribute **Growth Stage**

1. **Post establishment**: A recently established forest that is not at free growing stage.
2. **Pre-thicket**: The forest is established, but the green branches are not yet touching.
3. **Thicket**: Forest where the canopy has closed but the lower branches are mainly green.
4. **Small pole**: Forest where the canopy has fully closed and the lower branches are dead.
5. **Pole**: A forest at a stage where it could be thinned or in the early stages of thinning.
6. **High forest**: A forest that has a high proportion of sawlog approaching or at normal rotation length.
7. **Overmature**: Forest retained beyond normal rotation length, resulting in the presence of large trees.
8. **Multistoried**: Forest with trees present at various stages of development, i.e. height.

10.11 THIN STATUS

Definition: Previous history and frequency of harvesting operations.

Application: Thin status indicates the intensity of forest management by assessing the number of intermediate fellings.

Measurement and Description: The classification of thin status is based 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 the basal area /ha of the stand is calculated to determine if the forest is ready to be thinned (see Appendix 6).

Where a thinning had occurred, the stocking level and the decomposition of stumps was used as an indicative guide to the number of thinnings. The assessment of thin status takes place for each storey on the 12.62 m plot.

Attribute **Thin Status**

1. **Juvenile forest**: This is a forest that has not reached the development stage for first thinning.
2. **Respacing/pre-commercial thinning**: The spacing of the forest has been altered prior to the first thin stage. Mainly associated with naturally regenerated stands.
3. **First thinning**: The forest has received a first thinning, generally identified by the presence of extraction racks, and stumps arising from selective thinning may be present. All stumps have the same state of decomposition.
4. **Second thinning**: The forest has received a second thinning, generally identified by the presence of extraction racks and stumps arising from selective thinning. The stumps are grouped into two different stages of decomposition.
5. **Subsequent thinning**: Any thinning post second thinning. Generally the forest is well opened up and the decomposition of the stumps is grouped into a number of different stages.
6. **No thinning**: No thinning has taken place in the forest, but the forest is at a development stage where thinning could have taken place. These areas remain unthinned due to numerous reasons such as; high windthrow risk, economic considerations or thinning may be imminent. See Appendix 6 for further details on the classification of no thinning.

10.12 NATIVENESS

Definition: Species that have arrived and inhabited an area naturally, without deliberate assistance by man. For trees in Ireland usually taken to mean those present after post-glacial recolonisation and before historic times.

Application: From an ecological perspective, the quantification of the forest estate in terms of its nativeness is of interest.

Measurement and Description: A number of different native woodland types are found across Ireland, each influenced by soil type, climate and other physical factors. Native tree species for the purpose of the NFI are listed in Table 4. The species list is primarily based on the list of species eligible for inclusion in Ireland's Native Woodland Scheme (Anon. 1998c).

The assessment of nativeness is based on the species canopy cover in the 12.62 m plot. The number of tree species was used as a guide in canopy cover estimation.

Attribute **Nativeness**

1. **Native**: More than 80% of the canopy is comprised of native species.
2. **Mixed**: Between 20-80% of the canopy is comprised of native species.
3. **Non-native**: More than 80% of the canopy is comprised of exotic species.

Table 4. Native tree species for the National Forest Inventory.

Common Name	Botanical Name
Alder	*Alnus glutinosa*
Silver birch	*Betula pendula*
Downy birch	*Betula pubescens*
Ash	*Fraxinus excelsiorr*
Elm	*Ulmus glabra*
Sessile Oak	*Quercus petrea*
Pedunculate Oak	*Quercus robur*
Strawberry tree	*Arbutus unedo*
Scots pine	*Pinus sylvestris*
Hazel	*Corylus avellana*
Crab apple	*Malus sylvestris*
Aspen	*Populus tremula*
Wild cherry	*Prunus avium*
Eared willow	*Salix aurita*
Goat willow	*Salix caprea*
Rusty willow	*Salix cinerea ssp. Oleifolia*
Rowan	*Sorbus aucuparia*
Yew	*Taxus baccata*
Whitebeam	*Sorbus aria*

10.13 Height growth status

Definition: Indicates level of height growth on the plot..

Application: This is used to assess the health and vitality of the forest estate.

Measurement and Description: Forest nutrient status is an ocular assessment of the current condition of the forest crop. Discolouration and needle size is used to evaluate the nutritional status of the tree. Naturally dead or dying needles/leaves are not considered. The assessment of nutrient status takes place on the 12.62 m plot.

Attribute **Height growth status**

1. **Growing satisfactorily**: Trees are growing normally
2. **Leader growth decreasing**: The leader growth increment is decreasing, when it should be increasing.
3. **Trees stagnating**: Trees have very little height growth. In conifer trees, needles are short and trees are in check. Foliage maybe discoloured, yellow/brown in appearance.

10.14 Pruning or shaping

Definition: Indicates if the forest has been shaped or pruned.

Application: This is used to assess timber quality in the forest estate.

Measurement and Description: Pruning is the manual removal of branches from the stem of a tree. Shaping is the removal of competing tree leaders and side branches in order to improve the quality of broadleaf tree form. The assessment takes place on the 12.62 m plot.

Attribute **Pruning or Shaping**

1. **Pruning**: Trees have been pruned.
2. **Shaping**: Trees have been shaped.
3. **No pruning or shaping**: No trees have been pruned or shaped.
4. **Pruning and shaping**: Trees have been both pruned and shaped.

10.15 MANAGEMENT CONSTRAINTS

Definition: Factors influencing forest management in the plot.

Application: Constraints that potentially have a bearing on forest management operations and timber supply.

Measurement and Description: Assessment is based on presence or absence of a management constraint within the 12.62 m plot. More than one management constraint may be entered for each plot.

Attribute **Management Constraint**

1. **No constraints**: There are no factors influencing forest management to the extent that normal forest management practices will be affected.
2. **Boulders present**: The presence of large boulders in the plot will impact on forest management, particularly in relation to harvesting access.
3. **Utility line present**: Forest management in the plot will be influenced by the presence of an overhead utility line.
4. **Amenity/recreation**: The plot is located in an area where recreation is a primary management constraint.
5. **Landscape sensitivity**: The plot is located in an area of high landscape value. Any forest operations undertaken in these areas will need to take cognisance of this fact.
6. **Designated areas of special protection**: The plot is located in an area which is protected by Irish and/or EU law, as the area is of scientific or public interest. Forest management in these areas will be influenced by the type of designation. Consultation with relevant bodies and modified forest operations are carried out on these sites. Designations include: Special Protection Area (SPA), National Heritage Area (NHA), Special Area of Conservation (SAC), Nature Reserves, National Park, Archaeological sites, Acid Sensitive and Fisheries Sensitive areas.
7. **Limestone pavement**: Forest plots located on limestone pavement, karst features, e.g. the Burren in Co. Clare.
8. **Other**: A management constraint not mentioned in the above list.

10.16 NEGATIVE FACTORS

Definition: Negative factors impacting on the survival, growth and development of the trees.

Application: This is used to identify factors impacting on the growth and development of the trees.

Measurement and Description: Assessment is carried out on the 12.62 m plot. More than one negative factor may be entered for each plot.

Attribute **Negative Factor**

1. **No negative factor**: Forest has no dominant negative factor.
2. **Light deficiency**: Due to the presence of an overstorey, the forest is not growing optimally.
3. **Vegetation competition**: Vegetation competing with the growing trees reducing tree survival potential.
4. **Grazing/browsing**: Damage by animals feeding on the shoots and foliage of the tree.
5. **Current erosion**: Erosion is affecting tree growth, such as stream erosion following heavy rainfall.
6. **Exposure**: Extremes of weather conditions, such as drought or high winds, do not provide ideal conditions for tree growth.
7. **Swamped soil**: Saturated soil/peat providing inadequate growing conditions.
8. **Frost**: Frost may damage the photosynthetic tissue of a tree's growing parts, thereby reducing tree growth and impacting on tree form.
9. **Herbicides**: Inaccurate application of herbicides may have an adverse effect on tree growth and health.
10. **Nutrition deficiency**: Elements required for healthy tree growth are absent, which can be manifested by chlorotic foliage and a poor growth rate.

11. **Insects**: Damage by insects, which reduce a tree's vitality. Examples include: defoliation by aphids or pine shoot moth.
12. **Squirrel**: Damage to trees caused by squirrel, characterised by peeling and tree top break.
13. **Phytophora ramorum**: A fungal disease affecting some tree species, including; Beech, Japanese larch and Noble fir.
14. **Other factors**: Negative factor other than those described above.

10.17 AVAILABILITY FOR WOOD SUPPLY

Definition: Describes the likely availability of the forest area in terms of supply of wood.

Application: Constraints that potentially have a bearing on management operations and timber supply.

Measurement and Description: Assessment is based on presence of constraint within the 12.62 m plot. The classification was carried out during data processing using data already collected in the field

Attribute **Availability for wood supply**

1. **Available**: Forest where any legal, economic, or specific environmental restrictions do not have a significant impact on the supply of wood. Includes: Areas where, although there are no such restrictions, harvesting is not taking place, for example areas included in long-term utilization plans or intentions.
2. **Unlikely**: Forest where physical productivity or wood quality is too low or harvesting and transport costs are too high to warrant wood harvesting, apart from occasional cuttings for autoconsumption. Areas include:
   - Forest Type is scrub;
   - Height growth status is stagnating;
   - Severe water logging;
   - Excessive slope (>30^{o}).
3. **Not available**: Forest with legal restrictions or restrictions resulting from other political decisions, which totally exclude or severely limit wood supply, *inter alia* for reasons of environmental or biological diversity conservation, e.g. protection forest and other protected areas, such as those of special environmental, scientific, historical, cultural or spiritual interest. Areas classified as National Parks and Nature Reserves are included in this class.

Chapter 11 STAND LAYERS

Each storey in the plot is classified and described in relation to: storey type, species composition, age, age range, age determination, canopy cover and stocking.

11.1 STOREY TYPE

Definition: Classification of forest describing differentiation of the trees into distinct storeys.

Application: Storey type describes the vertical structure or diversity of the forest canopy.

Measurement and Description: A storey must make up at least 10% of the canopy and be not more than two-thirds of the height of the main storey before it is recorded as a separate storey. The assessment of storey type takes place on the 12.62 m plot.

Attribute **Storey Type**

1. **Main storey**: The main storey is comprised of trees, which are all largely even-aged and these trees present a regular appearance with one canopy layer.
2. **Secondary storey**: The secondary storey is comprised of trees, which are largely even-aged and these trees present a regular appearance of one canopy layer beneath the main storey.
3. **Reserved storey**: The reserved storey is the main storey in the forest for the purposes of providing amenity and shelter for game and forest management, and for natural regeneration. The numbers of trees are low and the canopy cover may not be uniform.
4. **Multi-storied**: The forest is irregular with no uniform differentiation in vertical structure due to its regeneration from multiple disturbances, such as thinning, windblow or fire. The trees may be irregular in height, age and/or species composition.

11.2 CANOPY COVER

Definition: The percentage of the plot area occupied by tree species in each storey.

Application: Canopy cover will indicate the amount of gaps present in the forest canopy.

Measurement and Description: The canopy cover of each storey is recorded in 5% intervals. In stands with a young storey, the potential canopy cover attainable by the storey should be assessed. In mixtures, stocking is an indicator of canopy cover, but the structure of the mixture will ultimately be the defining factor. For example, a row mixture of oak and Scots pine may have a stocking comprised of 75% oak and 25% Scots pine. However as the mixture is a row mixture the potential canopy cover on the plot will 50% oak and 50% Scots pine (Figure 29). The assessment of canopy cover takes place for each storey on the 12.62 m plot.

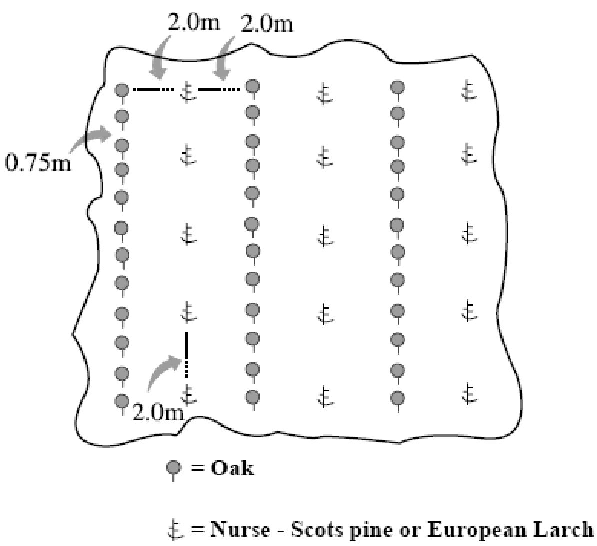


Figure 29. Canopy cover in a mixture (Anon. 2003).

11.3 Tree species

Definition: Name of the tree species.

Application: One of the primary attributes used for the classification of NFI results.

Measurement and Description: All planted tree species on the 12.62 m plot are recorded. The species of naturally regenerated trees that are greater than 20 cm in height are also recorded. A full list of tree species used in the NFI is given in Appendix 5.

11.4 Stocking

Definition: The number of trees per unit area for each species in a storey.

Application: This will indicate the density of trees, which is an important attribute in assessing the productive potential of the forest estate.

Measurement and Description: For each storey, all planted trees within the 7 m plot and all natural regenerated trees ≥ 20 cm in height within the 7 m plot are counted. All dead trees are excluded.

11.5 Age and age range

Definition: Age is defined as the total number of years the tree has been present in the forest. Age range identifies the youngest and oldest trees by species in each storey.

Application: Tree storey age is used to indicate the age structure, whilst age range indicates the age diversity.

Measurement and Description: The minimum, maximum and average age of the trees, by species, is given for each storey. Age range tends to increase with the level of natural regeneration in a storey.

11.5.1 Age determination

Definition: Age determination describes the source used to quantify the age of the trees in each storey.

Application: Tree age determination indicates the level of confidence given for the attributes 'age' and 'age range'. Known planting years give the most accurate indication, whilst estimations using the forester's silvicultural knowledge and experience give a best estimate of age and age range.

Measurement and Description: In a plantation forest, the date of planting is considered year 0 even though the tree may be 3 years old from seed. In coppiced stands the tree age is defined as the age of the stem above the root stock in years (not the age of the rootstock or the total age from seed). The assessment of tree age takes place on the 12.62 m plot. The means by which the age was determined is also recorded.

Attribute **Age Determination**

1. **Forest database**: Age is available from forest records.
2. **Increment core**: An increment core is taken from a tree outside the plot. A tree of similar dimension to those within the plot is sampled.
3. **Stump**: The rings are counted on one of the freshly cut stumps within the plot.
4. **Whorl counting**: Whorl counting is used to estimate age, primarily in young stands.
5. **Estimation**: The age is estimated based on silvicultural knowledge.

Chapter 12 TREES

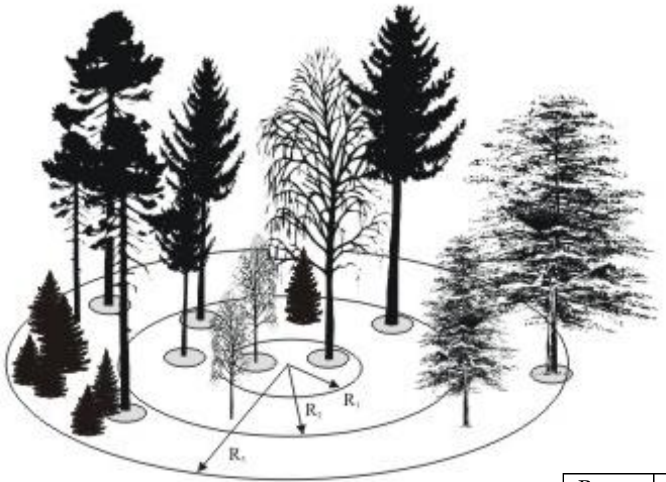
This chapter details the information that is collected on the individually mapped trees within the plot.

12.1 MAPPED TREES

Definition: Individual trees are those which satisfy the threshold diameter limits for the concentric plot design.

Application: The description of individual trees depict the national forest estate in terms of tree related attributes, such as Dbh and height.

Measurement and Description: Whether trees that are mapped depends on their reaching certain threshold diameters at breast height (Figure 30). All attributes defined in this chapter are for those trees that are mapped.



sub-circles

qualified trees

	R_1	R_2	R_3
Sub-circle radius (m)	3.00	7.00	12.62
Sub-circle area (m^2)	28.3	153.9	500.0
Threshold Dbh (mm)	70	120	200

Figure 30. Concentric plot design.

12.2 TREE TYPE

Definition: Tree type describes the current status of the tree on the plot.

Application: Identification of trees that will be processed differently during data analysis.

Measurement and Description: Assessment is based on the presence of trees on the plot and comparison with the trees measured in a previous assessment.

Attribute **Tree Type**

1. **New plot tree**: Tree measured for the first time, i.e. trees in a newly established plot or move plot.
2. **No change**: Trees that were measured in previous inventory cycle and are still standing. Dead standing trees are included.
3. **Harvested tree**: Tree present in previous cycle but harvested since. The number of growing seasons prior to the assessment date when the tree was harvested has to be estimated.
4. **Ingrowth**: Tree was not measured in previous assessment as Dbh was below threshold. Tree Dbh is now large enough for tree to be included.
5. **Living to standing dead**: Tree was living and is now dead standing. Tree is mapped. The number of growing seasons prior to the assessment date when the tree died is estimated.

6. **Standing dead to lying dead**: Tree was dead standing and has now fallen to the ground. Tree is not remapped. The number of growing seasons from the previous NFI to when the tree fell onto the ground is estimated.
7. **Living to lying dead**: Tree was living and is now a deadlog. Tree is not remapped. The number of growing seasons prior to the assessment date when the tree fell onto the ground is estimated.
8. **Omitted by mistake**: Tree was above the Dbh threshold in the previous assessment but was omitted by mistake. The tree is now included. The decision between ingrowth and omitted tree is based on knowledge of feasible Dbh increment in between both inventory cycles for that particular tree species in the plot specific growing conditions. This can be estimated from the measured increment of similar sized trees within the plot.
9. **Measured by mistake**: Tree was included in the previous assessment by mistake e.g. a tree on the plot boundary. This tree is not remeasured.

12.3 HARVEST TYPE

Definition: Describes the felling type by which the tree was removed.

Application: By describing felling type the volume felled by harvest type can be calculated. As an NFI plot may include more than one management regime, it is necessary to record harvest type at tree level.

Measurement and Description: Where a tree that was present in the previous cycle is harvested, the harvest type is recorded.

Attribute **Harvest Type**

1. **Respacing/pre-commercial thinning**: The spacing of the forest has been altered prior to the first thin stage. Mainly associated with naturally regenerated stands.
2. **First thinning**: The forest has received a first thinning, generally identified by the presence of extraction racks and stumps arising from selective thinning may be present. All stumps have the same state of decomposition.
3. **Second thinning**: The forest has received a second thinning, generally identified by the presence of extraction racks and stumps arising from selective thinning. The stumps are normally grouped into two different stages of decomposition.
4. **Subsequent thinning**: Any thinning post second thinning. Generally the forest is well opened up and the decomposition of the stumps is grouped into a number of different stages.
5. **Clearfell**: A continuous block of trees that have been felled.

12.4 GROWTH PERIOD ADJUSTMENT

Definition: Specifies the number of growing seasons from when the tree died and the assessment date.

Application: This is only described for the following tree types: 'harvested tree', 'living to standing dead' and 'living to lying dead'. The information facilitates the precise estimation of annual increment.

Measurement and Description: For harvested trees the length of time is estimated from stump decomposition. For living to standing/lying dead trees the trees are still present on the plot allowing their Dbh to be measured. By comparing this to the Dbh measured at the previous cycle and the increment of the other live trees on the plot, an estimation can be made as to the number of years elapsed from death to the present date.

Attribute **Growth period adjustment**

1. **Number of years**: Numerical value.

12.5 SPECIES

Definition: Tree species is identified.

Application: One of the most defining aspects of any national forest estate is the species composition. It is important for timber production, carbon sequestration and biodiversity.

Measurement and Description: The species of each tree is recorded using a species list which is presented in Appendix 5.

12.6 TREE STATUS

Definition: Tree status indicates whether a tree is dead or alive.

Application: The segregation of standing trees into living and dead trees is used for growing stock and biomass calculation. It is also used in the quantification of the standing deadwood.

Measurement and Description: Classification is based on whether or not the tree is photosynthetically active or has a living cambium. The decay status is used to indicate how long the tree has been dead.

Attribute **Tree Status**

1. **Living tree**: Tree that is photosynthetically active or has a living cambium.
2. **Recently dead tree**: Tree that has died in the current or previous growing season.
3. **Dead tree from the past**: The tree has been dead for more than 2 years.

12.7 AGE

Definition: The number of growing seasons since initial planting or natural regeneration.

Application: The structure of the forest estate in terms of age distribution will indicate the sustainable economic, social and environmental future demands that the forest estate can meet.

Measurement and Description: The age of each tree is recorded using the same methodology as outlined in section 11.5.

12.8 DIAMETER AT BREAST HEIGHT

Definition: The diameter at breast height (Dbh) of a tree is the stem diameter at 1.3 m from ground level.

Application: Tree Dbh is one of the most important attributes in forest management. From a timber production viewpoint, the Dbh is used in the quantification of growing stock (i.e. timber volume of living trees). The Dbh distribution is also an important biodiversity indicator.

Measurement and Description: Trees are girthed using a diameter tape and the diameter is recorded to the nearest mm. The Dbh measurement convention detailed below and Figure 31 was adapted from the Forest Mensuration: a handbook for practitioners[6] (Matthews and Mackie 2006):

1. The Dbh of a tree is measured at 1.3 m from ground level. In order to retain consistency a pole of 1.3 m in length was used to identify the exact height of diameter measurement.
2. The diameter tape must be taut and at right-angles to the stem.
3. The measurement convention outlined in the following subsections are adhered to when measuring Dbh (Figure 31):
   a) On sloping ground, measure the diameter at 1.3 m from ground level on the upper side of the tree.
   b) On uneven or ploughed ground, measure the diameter at 1.3 m from the ground level at the base of the tree.

[6] © Crown copyright material is reproduced with the permission of the Controller of HMSO and Queen's printer for Scotland.

c) Where a swelling occurs at 1.3 m above ground level, measure the diameter above and below the swelling at an equal distance from the 1.3 m point. In the case where a mean of two diameters cannot be taken, e.g. stem break, measure the diameter below the swelling at the point where it is smallest.

d) & e) On leaning trees, measure the diameter at 1.3 m from ground level on the underside of the tree, at right angles to the axis of the stem.

f) On coppiced trees, measure the diameter at 1.3 m from ground level and not stool level.

g) On trees that fork below 1.3 m, treat each stem as a separate tree and measure the diameter of each stem.

h) On trees that fork at 1.3 m, treat as one tree and measure the diameter below the fork at the point where it is smallest.

i) On trees where the forks have fused up to and above 1.3 m, measure the diameter below 1.3 m where it is smallest.

12.9 DBH HEIGHT

Definition: The height at which Dbh is measured.

Measurement and Description: This is usually recorded at 1.3 m. In some circumstances, as detailed in Figure 30, it is permissible to record the diameter at another height, provided that the height at which the diameter was measured is recorded.

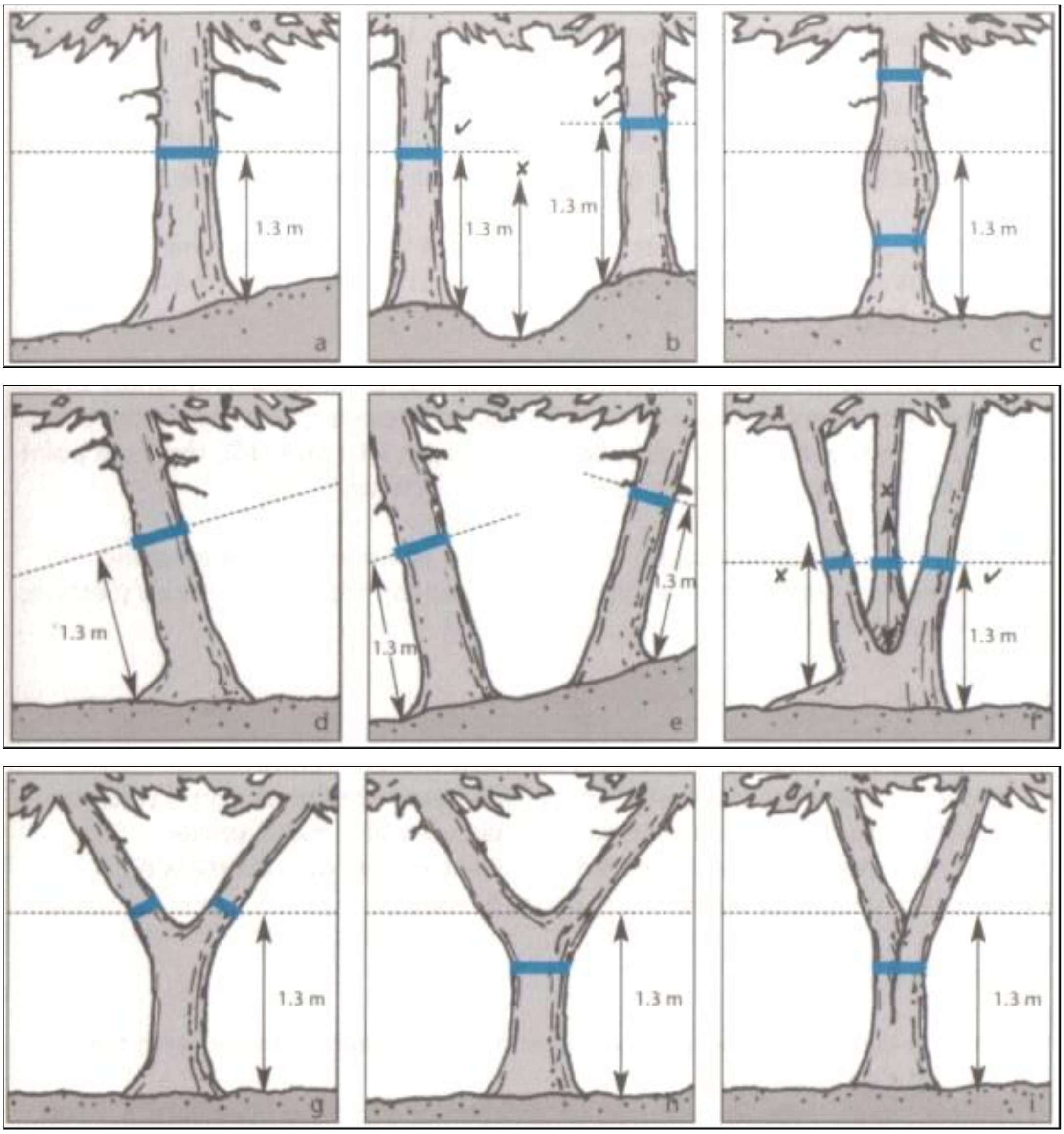


Figure 31. Dbh measurement convention.

12.10 TREE HEIGHT

Definition: The height of a tree is the vertical distance between the base of the tree and its tip (Figure 32).

Application: Tree height is an important variable in forest management, as it allows the quantification of tree growth and volume. The range of tree heights across the plot will indicate the diversity in the canopy structure.

Measurement and Description: Height is measured to the nearest cm using a laser rangefinder equipped with clinometer.

The selection of trees for which to obtain height measurements is based on on the assessment of the Dbh range for each tree species on the plot. If possible, seven uniform Dbh classes per species are created from which height sample trees are selected, one for each class (Figure 33). Trees with crown/leader damage or fork are excluded from the selection process.

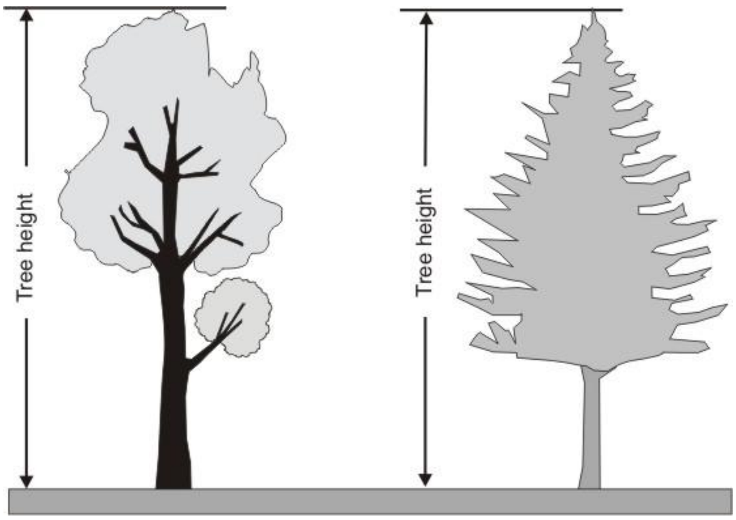


Figure 32. Tree height.

In pure stands, a maximum of seven height measurements are taken from across the Dbh distribution and, as far as possible, evenly distributed throughout the plot. In mixed stands, a maximum of seven height measurements are taken for each species occurring on the plot. If there are less than seven trees for any particular species, then all of the trees are sampled for height.

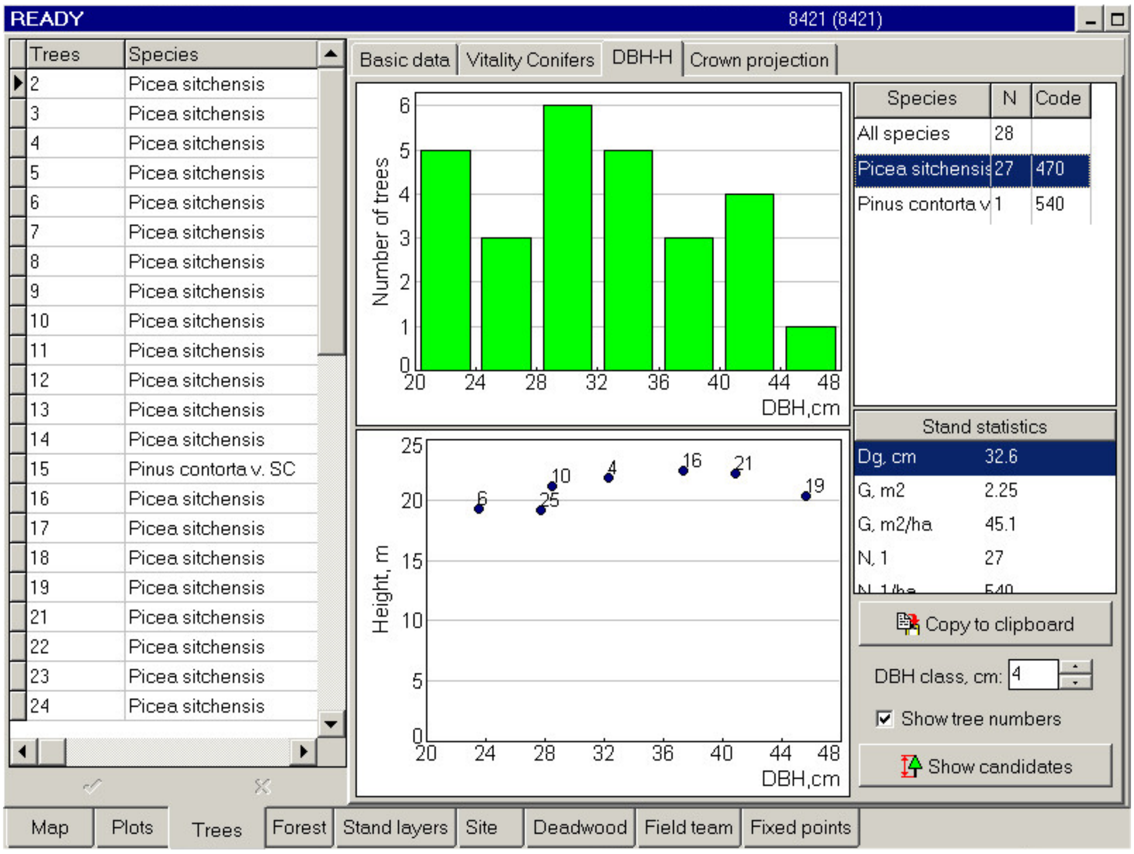


Figure 33. Field-Map™ representation of Dbh classes and sample height trees.

In order to obtain a precise height measurement, only straight single stemed trees should be chosen as candidates and the following conventions should be observed:

1. Measurement taken at a distance of 1.5 times the height of the tree.
2. On leaning trees, height measurement may be prone to error (Figure 34) and should only be measured if there are no other suitable candidates. Measurement takes place perpendicular to the direction of lean or as demonstrated in Figure 35. Trees with excessive lean are unsuitable for height measurement.
3. Height measurement on broadleaf trees should be to the true total height. (Figure 36). The edge of side branches should not be used as the point of sight.
4. On sloping ground, measurements should be taken across the slope. If this is not possible, measurements can take place from a position uphill of the tree.

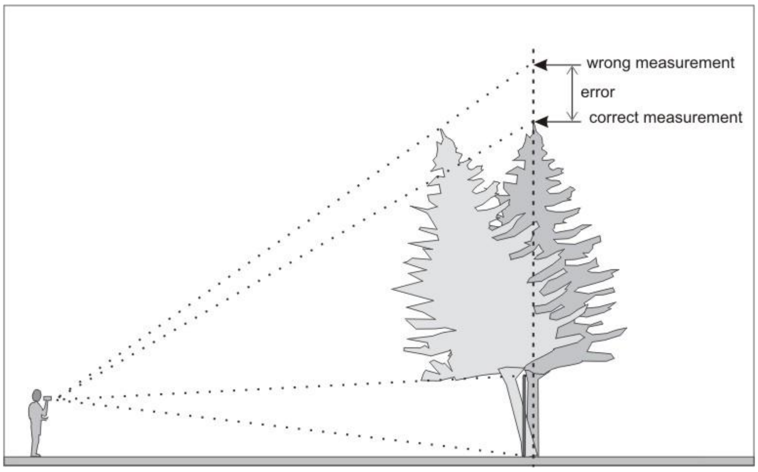


Figure 34. Height measurement error on leaning trees.

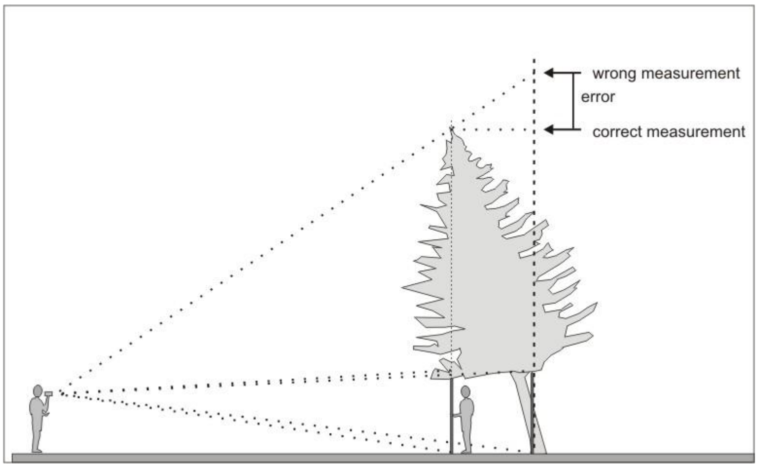


Figure 35. Height measurement on slanted trees.

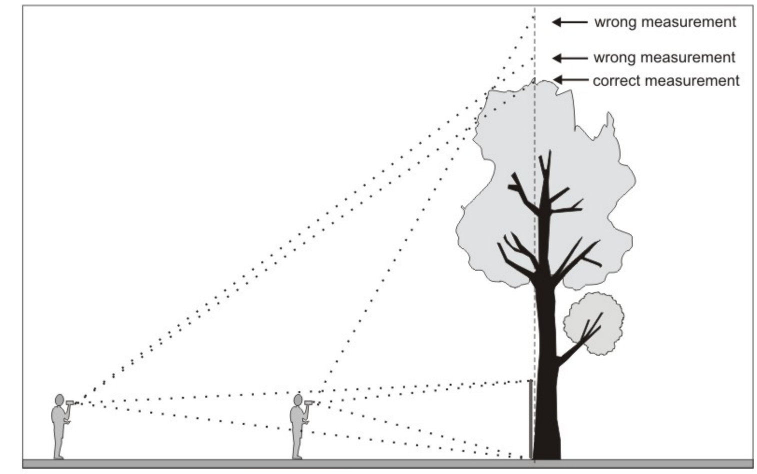


Figure 36. Height measurement on trees.

12.11 *Crown measurement*

This section details the crown attributes recorded for each tree: position of the living and dead crown base and crown projection.

12.11.1 Position of living and dead crown base

Definition: The vertical distance between the ground level and the base of the living and dead crown.

Application: The size of a tree crown is strongly correlated with tree growth. The crown displays the leaves/needles to allow the capture of radiant energy for photosynthesis. Thus, measurements of the tree crown are made to assist in the quantification and understanding of tree growth. These measurements also facilitate the assessment of crown biomass.

Measurement and Description: The living crown base is the lowest whorl of live branches. Epicormic shoots are not considered in regard to the live crown base. Determination of the live crown base on broadleaf trees is detailed in Figure 37. The height of the living crown base on each height sample tree is recorded to the nearest cm. The dead crown base is the lowest whorl of dead branches.

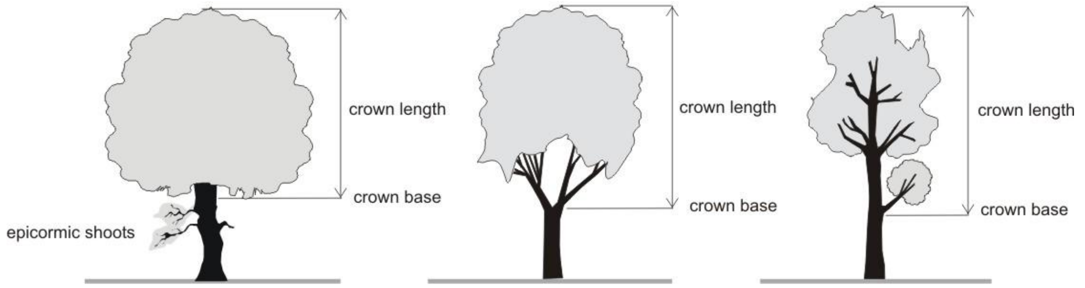


Figure 37. Crown base measurement on broadleaf trees.

12.11.2 Crown projection

Definition: Crown projection is the projection of the crown onto a horizontal plane.

Application: In the previous section, the measurement of the position of the live and dead crown base was outlined, while in this section the measurement of the distribution of the crown around the stem of the tree is specified. These three measurements allow the biomass of the crown to be estimated.

Measurement and Description: The projection of the crown (m^2) onto a horizontal plane is measured for each height sample tree. It is determined by indicating on the ground exactly where the edge of the crown is directly over-head. A minimum of four positions are mapped to gain an accurate representation of the crown projection (Figure 38). The position of the points are recorded on the local Cartesian coordinate system.

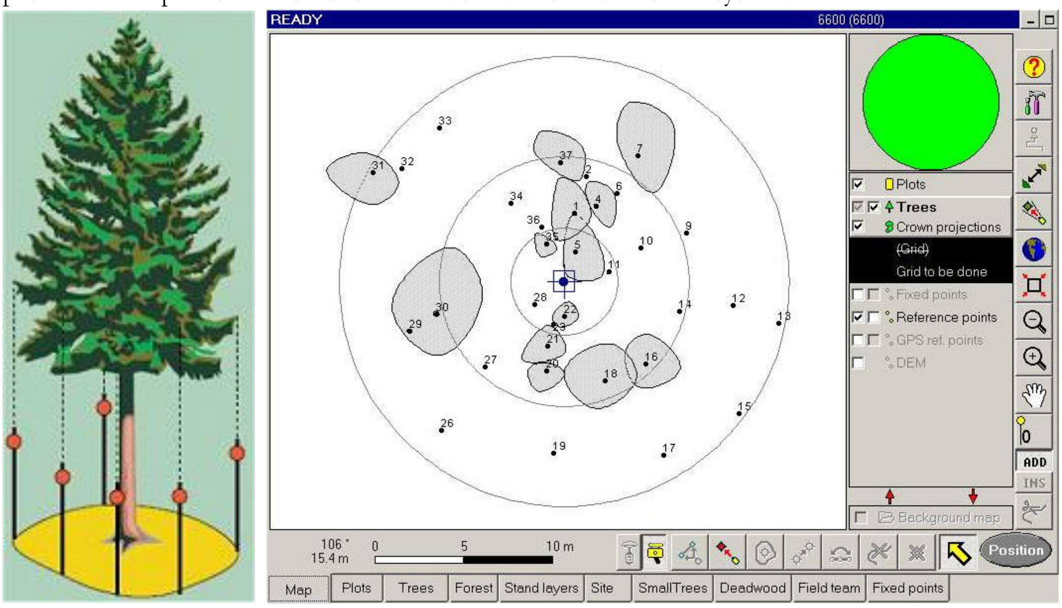


Figure 38. Representation of crown projections taken on a plot.

12.12 OTHER STEM DIAMETER MEASUREMENTS

This section describes the upper stem and base diameter attributes.

12.12.1 Upper stem diameter

Definition: The diameter of a tree stem, recorded at a height equal to 1/3 of the tree height.

Application: Obtaining an upper diameter measurement facilitates a more precise estimation of volume, as it provides additional information on the shape of the stem.

Measurement and Description: Trees included are randomly selected from height sample trees that have a Dbh ≥ 200 mm. In pure stands a maximum of five upper stem diameters are measured. In mixed stands, a maximum of five measurements are taken for the primary species, with a maximum of three measurements taken for each subsequent species present. Broken or bent trees are excluded from selection. Also excluded are heavily branched trees, due to poor stem visibility. An upper stem diameter is recorded (mm) at a height equal to 1/3 of the total tree height. This is determined using an electronic range finder and remote diameter scope (Figure 39).

If there is some obstruction on the stem (e.g. whorl of branches) at the measuring height that does not allow the measurement, then the measurement may be taken directly above or below the obstruction.

Attribute **Upper Stem Diameter**

1. **Diameter**: The diameter in mm is recorded.
2. **Height**: The height (cm), at which the upper stem diameter is measured, is recorded.

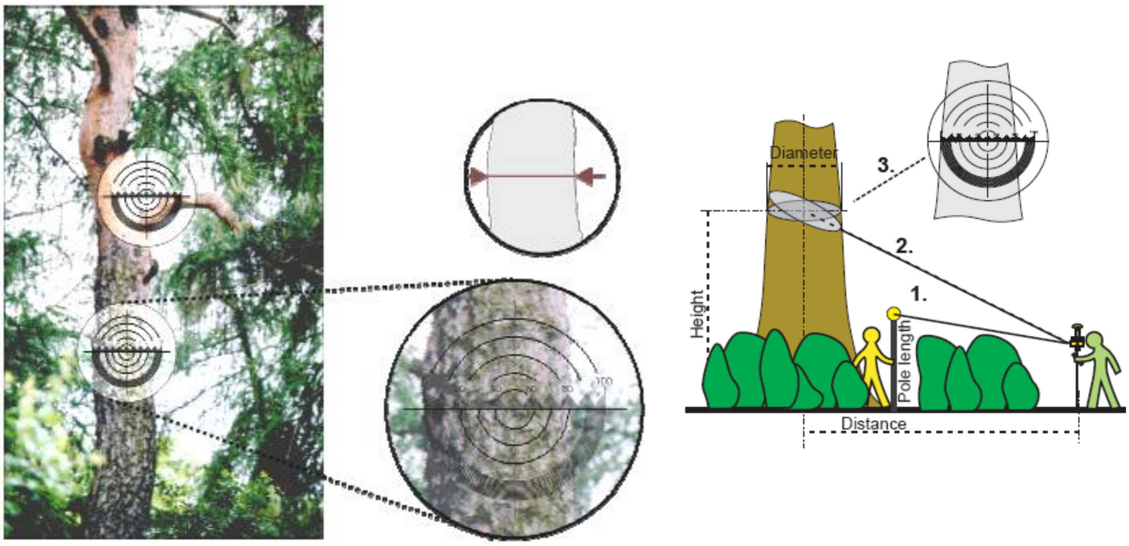


Figure 39. Diameter measurement at one third of the tree height.

12.12.2 Base diameter

Definition: Base diameter is the diameter of the stem measured at a height above ground level equal to one third of the diameter at ground level.

Application: The combination of the base and upper stem diameter measurement facilitates a more precise estimate of volume, as it provides additional information on the shape of the stem.

Measurement and Description: The base diameter is measured on each tree which has been sampled for upper stem diameter. The height above ground level at which diameter is measured is equal to one third of the base diameter at ground level (Figure 40). For example if the diameter at ground level is 66 cm then the base diameter is measured at a height of 22 cm from ground level. Base diameter is measured using a diameter tape and is recorded in mm.

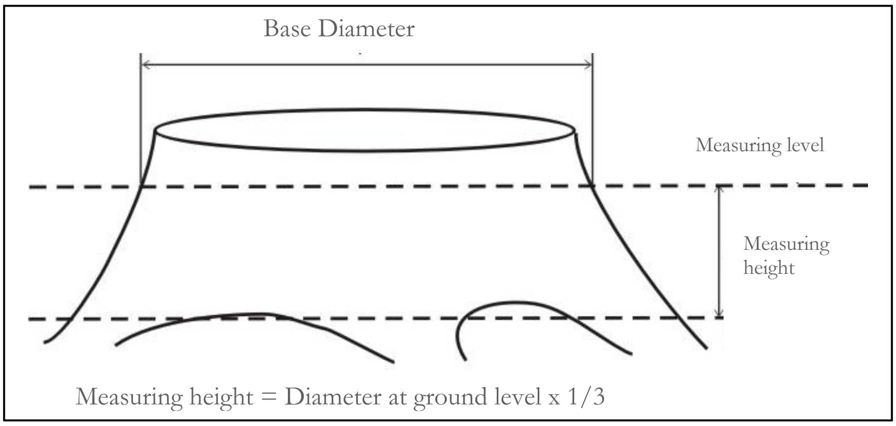


Figure 40. Base diameter.

12.13 TREE LAYER DESCRIPTIONS

Tree layer description attributes define the vertical position of a tree's crown and also describe competition between tree crowns. Tree layer and social status (IUFRO) describe the vertical position, while social status (Kraft) describes the vertical position and crown competition. Crown competition is also described by the attribute crown shape.

12.13.1 Tree layer

Definition: The distinctive layer in which a tree's crown occurs.

Application: Tree layer describes the position of the vertical crown structure into distinctive layers.
Measurement and Description: A tree layer may arise from a natural (e.g. fire) or man-made (e.g. clearfell) disturbance where trees develop as a uniform cohort.

Attribute **Tree layer**

1. **Main layer**: The tree occurs in the main layer.
2. **Secondary layer**: The tree occurs in the secondary layer, beneath the main layer.
3. **Reserved layer**: The tree occurs above the main layer in a reserved tree layer and is retained for the purpose of amenity, forest management, game management or natural regeneration.

12.13.2 Social status (IUFRO)

Definition: Social status (IUFRO) describes the vertical differentiation of the trees within the plot relative to the highest stand layer.

Application: This indicates the level of competition within the stand, thereby indicating the stage of tree development (Leibundgut 1958).

Measurement and Description: The position of the tree in relation to the crown position of the highest trees is specified (Figure 41).

Attribute **Social Status (IUFRO)**

1. **Upper**: The height of the tree is at least two-thirds the height of the highest trees.
2. **Middle**: The height of the tree is at least one-third the height of the highest trees.
3. **Bottom**: The height of the tree is lower than one third of the highest trees.

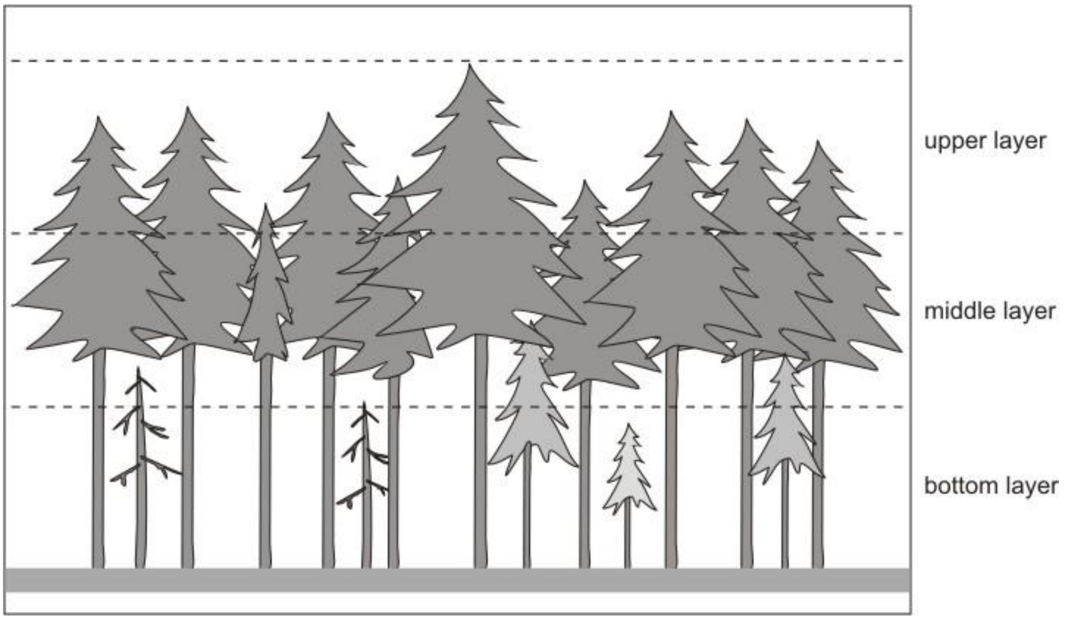


Figure 41. Social status (IUFRO).

12.13.3 Social status (Kraft)

Definition: Social status (Kraft) describes the relative position of the trees in terms of their vertical distribution and their inter-relationships.

Application: This indicates the level of competition encountered by the trees, thereby indicating the stage of tree development (Kraft 1884).

Measurement and Description: Within each stand, trees can be differentiated into crown classes as competition for light, nutrients and moisture sets in (Figure 42). As the weaker trees are crowded out by their more vigorous associates, their crowns become increasingly misshapen and restricted in size. Unless freed by random events or deliberate thinnings, such trees gradually become suppressed and die. This differentiation is described by assigning a social status to individual trees (Smith, *et al.* 1997). The social status of each mapped tree is recorded.

Attribute **Social Status (Kraft)**

1. **Dominant**: Trees with crowns extending above the general level of the crown cover and receiving full light from above and partly from the sides; larger than the average trees in the stand and with well-developed crowns.
2. **Main co-dominant**: Trees with crowns present in the general level of the crown cover and receiving full light from above and partly from the sides; larger than the average trees in the stand and with crowns well developed but possibly somewhat crowded on the sides.
3. **Co-dominant**: Trees with crowns forming the general level of the crown cover and receiving full light from above but comparatively little from the sides; usually with medium-sized crowns more or less crowded on the sides.
4. **Sub-dominant**: Trees shorter than those in the proceeding classes but with crowns extending into the canopy formed by co-dominant and main co-dominant trees; receiving little direct light from above but none from the sides; usually with small crowns considerably crowded on the sides.
5. **Suppressed**: Trees with crowns entirely below the general level of the crown cover, receiving no direct light either from above or from the sides.
6. **Other**: Trees that cannot be accurately described by the above categories e.g. windblow trees.

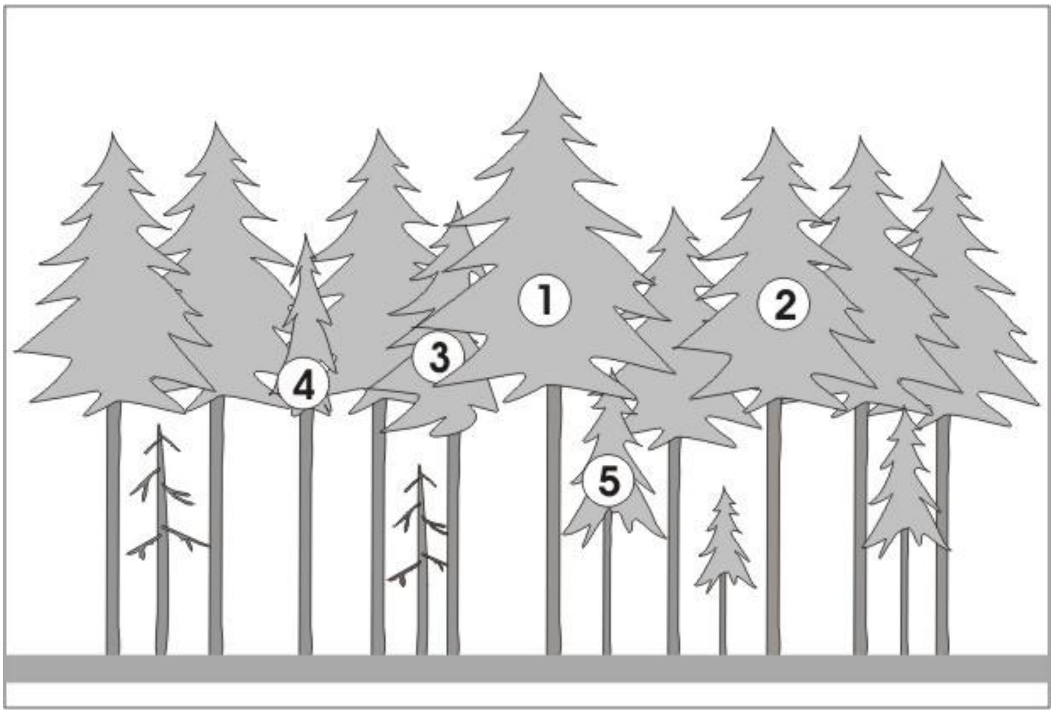


Figure 42. Social status (Kraft).

12.13.4 Crown shape

Definition: The distribution of the crown around the axis of the stem.

Application: This indicates the level of competition within the stand, thereby indicating the stage of stand development.

Measurement and Description: The internal competition between neighbouring trees affects the shape of the crown, potentially resulting in an irregular crown which could be offset to one or more sides. In a symmetrical crown, the branches and foliage are distributed evenly around the stem. Assessment is based on quantifying the distribution of the crown around the axis of the main stem. Apportioning the area surrounding the stem into four parts aids in the classification process (Figure 43).

Attribute **Crown Shape**

1. **Regular**: The distribution of the crown around the axis of the main stem is symmetrical.
2. **Slightly one-sided**: The distribution of the crown around the axis of the main stem is slightly one-sided.
3. **Strongly one-sided**: The distribution of the crown around the axis of the main stem is strongly one-sided.

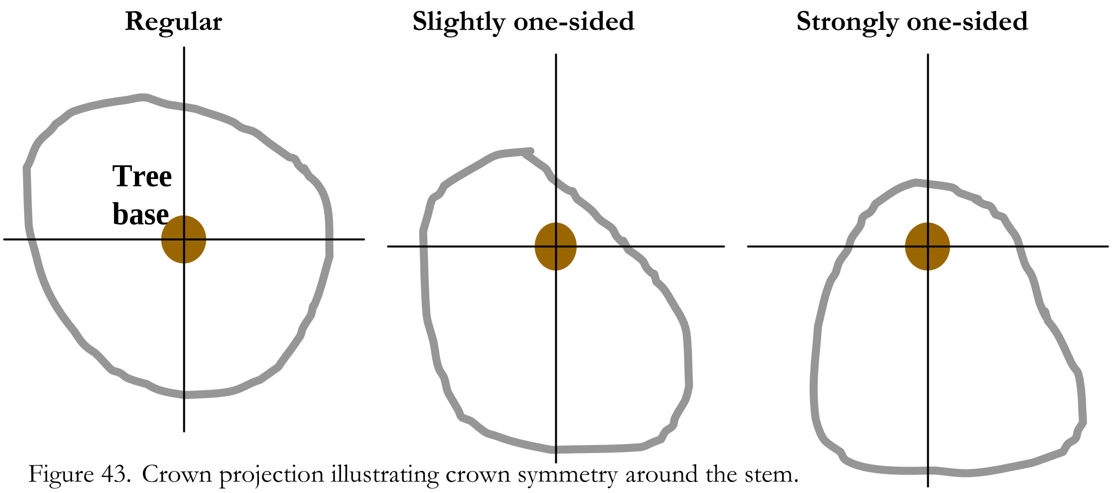


Figure 43. Crown projection illustrating crown symmetry around the stem.

12.14 BRANCHING

In this section, two attributes related to tree branching; branchiness and pruning, are described.

12.14.1 Branchiness

Definition: Describes the relative size and number of branches present on a tree.

Application: The size and number of branches impact on timber quality. This classification describes the level of branching on the individual trees.

Measurement and Description: Branchiness is defined in relation to the position, number and size of living and dead branches and is assessed along the first 6 m of the stem. Pruned trees are not assessed for branchiness. Classification of branchiness is based on three factors:

- **Branch frequency**: Branch frequency relates to the quantity of branches along the stem.
- **Branch diameter in relation to stem diameter**: The branch diameter at the point of branch entry is assessed relative to the stem diameter.
- **Species**: The classification should be species specific, as what may be considered medium branching in one species may be considered light branching in another, e.g. medium branching in *Picea sitchensis* will more than likely be considered light branching in *Pinus contorta*.

Attribute **Branchiness**

1. **Light**: Small diameter branches or medium sized branches which occur infrequently. This may occur on trees that are growing at high densities or in stands where an understorey is present.
2. **Medium**: Branches are present in a quantity and size that is deemed not to be either light or heavy.
3. **Heavy**: Large diameter branches which occur frequently. Common where a tree has had an unrestricted growing space e.g. an edge tree.

12.14.2 Pruning

Definition: Pruning is the manual removal of branches from the stem of a tree.

Application: Branches do not necessarily fall off when they cease to function. Some may fall off and act as access routes for infection by rotting fungi. The presence of a dead knot is more serious than a live knot, as the wood elements laid down around dead branch wood have no connection with the dead material (Smith *et al.* 1997). Dead knots are a serious defect in sawn timber as they are liable to fall out when dried. Manual pruning removes branches from the lower, more valuable portion of the stem.

Measurement and Description: The presence or absence of pruning is classified for each tree.

Attribute **Pruning**

1. **Low pruned (≤ 3 m)**: Branches manually removed up to a height of 3 m.
2. **High pruned (≥ 3 m)**: Branches manually removed up to a height greater than 3 m.
3. **No pruning**: No pruning has been carried out.
4. **Undeterminable**: Difficult to determine if pruning has been carried out.
5. **Brashed**: Tree has been brashed to provide access. Normally occurs on one side of the trees in straight lines through the forest.

12.15 STEM FORM

The stem form is described in terms of: tree fork, stem straightness and shaping.

12.15.1 Tree fork

Definition: Division of the main stem into two or more stems.

Application: The presence or absence of a fork starting below 5 m from ground level is noted, as this will impact on the merchantable assortment volumes recovered after harvesting.

Measurement and Description: Trees classified as being forked must have at least two main stems occurring below 5 m, where the diameter of one stem is at least half the diameter of the other (Figure 44). If more than one fork is present, the lowest occurring fork is noted.

Attribute **Stem Fork**

1. **No fork**: No fork present on the tree below 5 m.
2. **Fork below 1.3 m**: Forking present on the tree below 1.3 m.
3. **Fork 1.3-3 m**: Fork present between 1.3 m and 3 m.
4. **Fork 3-5 m**: Fork present between 3 m and 5 m.

Figure 44. Forked tree.

12.15.2 Stem straightness

Definition: Describes the straightness of the first 6 m of a tree's stem in terms of straight log lengths.

Application: The assessment of stem straightness is carried out to provide an indication of potential end products, which could be produced from the stem. For example, a large diameter log, if straight, has multiple end uses, but if crooked the end uses are limited.

Measurement and Description: A prototype method of assessing stem quality in standing Sitka spruce trees was developed in the early 1990s and is described by Methley (1998). Stem straightness was identified as the most important single factor affecting log quality in Sitka spruce. An assessment method based on a visual estimate of straight log lengths in the first 6 m of the stem was devised. The assessment of straightness is categorised into one of seven categories for all tree species. These categories are illustrated in Figure 45, which is an adaptation of a figure presented in MacDonald *et al.* (2001).

Attribute **Stem Straightness**

1. **Greater than or equal to 5 m**: A log with a minimum length of 5 m.
2. **One 4-5 m log**: A log with a minimum length of 4 m and maximum length of 5 m.
3. **One 3 m and one 2 m log**: One log 3 m in length and one log 2 m in length.
4. **One 2-3 m log**: A log with a minimum length of 2 m and maximum length of 3 m.
5. **Two 2 m logs**: Two logs with a minimum length of 2 m.
6. **One 2 m log**: A log with a minimum length of 2 m.
7. **No straight logs**: There are no straight logs present.

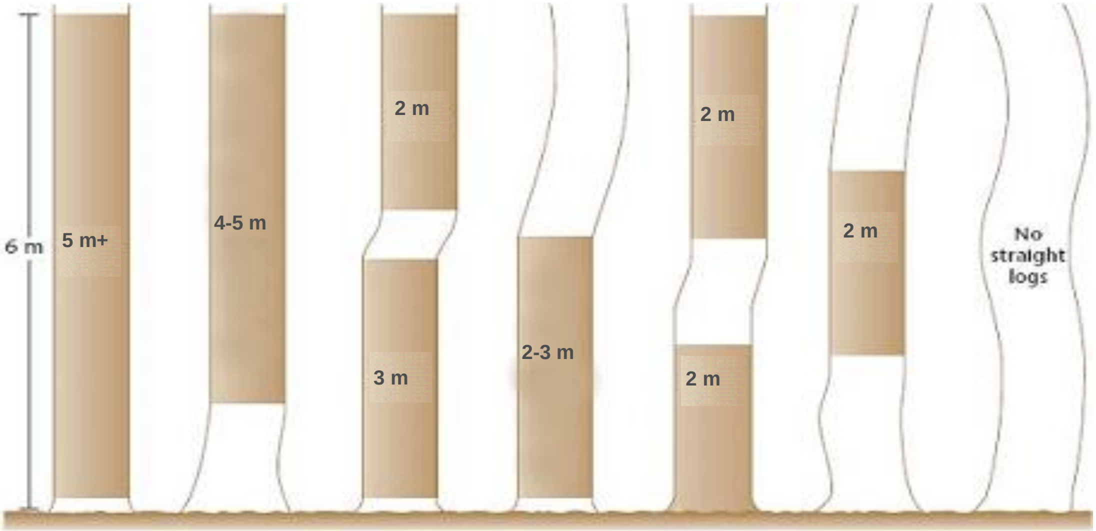


Figure 45. Assessment of stem straightness.

12.15.3 Shaping

Definition: Shaping is the removal of competing tree leaders and side branches in order to improve the stem quality of a broadleaf tree

Application: The classification will identify broadleaf tree species which are intensively managed for timber production.

Measurement and Description: The occurrence of shaping, where visible, is recorded.

12.16 Stem rot

Definition: Stem rot is the discoloration, softening and often disintegration of plant tissue as a result of fungal or bacterial infection.

Application: The presence or absence of rot will impact on the health and vitality of a forest. This can impact on harvesting returns and also indicate the level of biodiversity. Some indicators of rot are shown in figure 46.

Measurement and Description: The occurrence and type of stem rot is recorded.

Attribute **Stem Rot**

1. **No rot**: The tree shows no sign of rot.
2. **Inner rot**: An inner section of the tree has suffered rot, which may be identified by butt-swelling and resin exudation.
3. **Stem surface rot**: Rot is present at the stem surface.
4. **Stem cavity**: The rot has created a stem cavity.

Figure 46. Signs of tree rot: stem cavity, bracket fungus and mushrooms.

12.17 STEM AND PEELING DAMAGE

Definition: Damage to stems caused by biotic (e.g. deer), abiotic (e.g. wind) or by mechanical factors (e.g. harvesting or extraction machines) (Figures 47 and 48).

Application: Provides information on the health and vitality of the forest estate. There are also economic consequences due to the potential end product downgrade.

Measurement and Description: Abrasion of the bark resulting in a loss of bark/vascular cambium/wood from the stem surface. In the case of more than one instance of damage, it is the cumulative effect that is assessed. The degree and age of damage present on the stem is recorded.

Attribute **Stem Damage**

1. **No damage**: Damage is not present.
2. **Damage up to 1/8 of circumference**: Up to 1/8 of the stem circumference has been damaged.
3. **Damage to more than 1/8 of circumference**: More than 1/8 of the stem circumference of the tree has been damaged.

Attribute **Age of damage**

1. **New damage**: Damage took place within the current or the last growing season and is still relatively fresh.
2. **Old damage**: The damage took place 2 or more growing seasons ago.
3. **Repeated damage**: There is a mixture of old and new damage.

Figure 47. Stem damage.

Figure 48. Peeling damage.

12.18 ROOT DAMAGE

Definition: Damage to a tree's roots can be caused by biotic (e.g. deer), abiotic (e.g. wind) or by mechanical (e.g. harvesting or extraction machines) factors.

Application: These injuries may cause instability, can act as a route for infectious diseases and can cause a reduction in timber quality (Figure 49).

Measurement and Description: Root damage is assessed where visible on all individual trees.

Attribute **Root damage**

1. **No root damage**: Visible root damage is not present.
2. **Roots damaged**: Root damage present.

Figure 49. Root damage as a result of harvesting operations.

12.19 Tree vitality

Tree vitality is described using the following five attributes: vitality, growth tendency, defoliation, discolouration and broadleaf vitality.

12.19.1 Vitality

Definition: Tree vitality describes the capacity of a tree to survive and grow.

Application: The assessment of tree vitality is an important indicator of forest health.

Measurement and Description: Vitality is assessed for all individual trees.

Attribute **Vitality**

1. **Very Biotic**: Vigorous growth with little or no defoliation.
2. **Normal**: Regular tree with no serious defoliation or damage present.
3. **Weak**: Poorly performing tree. Serious defoliation damage to the crown.

12.19.2 Growth tendency

Definition: Growth tendency describes the annual height increment in the 2 years preceding the date of assessment.

Application: This is used to describe the rate of height growth in the forest estate.

Measurement and Description: Growth tendency is assessed for all trees.

Attribute **Growth Tendency**

1. **Increasing**: Annual height increment is increasing.
2. **Constant**: No differentiation in annual height growth for the two preceding years.
3. **Decreasing**: Annual height increment is decreasing or there is no height increment.

12.19.3 Tree defoliation

Definition: Tree defoliation is the abnormal loss of tree foliage.

Application: This is an important indicator of forest health and vitality.

Measurement and Description: Defoliation may occur as a result of environmental or man-made causes, such as, an early frost, nutrient deficiency, insects or diseases (Figure 50).

Defoliation is assessed on the spruce and pine trees for which height measurements were recorded. Defoliation is expressed as a percentage of full foliation. Defoliation is assessed twice, first for the whole tree and then for the upper one third of the tree. The assessed tree is compared to how a healthy tree would appear in the same growing conditions.

Figure 50. Defoliation on Sitka spruce.

12.19.4 Tree discolouration

Definition: Deviation from the usual colour of the living foliage for that species; dead or dying needles/leaves are excluded.

Application: Discolouration of a tree's foliage signifies that the tree is under stress, which could be due to factors such as nutrient deficiency or water-logging (Figure 51). This is an important indicator of the health and vitality of the forest estate.

Measurement and Description: Assessment is only made on spruce and pine trees that have been sampled for height. The colour change, trend and intensity are recorded.

Figure 51. Discolouration in Sitka spruce.

Attribute **Discolouration Type**

1. **Yellowing**: The foliage has a yellow appearance.
2. **Browning**: The foliage has a brown appearance.

Attribute **Discolouration Trend**

1. **From old to young**: The intensity of discolouration is more extreme in the older foliage, with a more limited occurrence in the newer foliage.
2. **From young to old**: The intensity of discolouration is more extreme in the young foliage, with a more limited occurrence in the older foliage.
3. **Evenly young and old**: Foliage age has no impact on the discolouration trend.

Attribute **Discoloration Intensity**

Describes the depth of discolouration in percentage, with 1 indicating a healthy needle and 100 severe discolouration indicating an unhealthy foliage.

12.19.5 Broadleaf vitality

Definition: Broadleaf vitality describes the capacity of a broadleaf tree to continue to grow in a healthy condition.

Application: This in an important indicator of vitality in the broadleaf forest estate.

Measurement and Description: Assessment is made on oak and beech trees that have been sampled for height.

Attribute **Broadleaf Vitality**

1. **Undamaged**: Tree growth is healthy
2. **Weakened**: Tree growth is slightly affected due to minor stress, such as minimal stem damage.
3. **Moderately damaged**: Tree growth is moderately affected due to considerable stress, such as prolonged periods of drought or defoliation caused by insect infestation.
4. **Strongly damaged**: Tree is under severe stress, significantly affecting tree growth/survival. High levels of defoliation and/or dieback. Serious crown damage may also be present.

12.20 OTHER DAMAGE

Definition: This includes any other factors which cause damage to trees.

Application: Damage which impacts on tree growth and which has not been defined in other sections in this chapter.

Measurement and Description: If there is damage to individual trees present in the plot, determine the primary cause and classify accordingly.

Attribute **Other Damage**

1. Insect
2. Fungus
3. Deer
4. Squirrel
5. Vole
6. Other animal damage
7. Poor drainage
8. Exposure
9. Elevation
10. Storm, windbreak
11. Crown competition
12. Fire
13. Frost
14. Drought
15. Salt
16. Air pollution
17. Herbicide
18. Poor nutrition
19. pH extreme
20. Unsuitable site
21. Other damage

12.21 TREE BREAK

Definition: Tree break details the presence or absence of defects along the bole or in the crown of the tree.

Application: These injuries may cause a reduction in the quality and quantity of timber recovered at harvest.

Measurement and Description: Wind is the primary cause of tree break damage. All categories of damage affect the quality, quantity and future value of timber. See Figure 52 for examples of the categories.

Attribute **Tree Break**

1. **No break**: There are no signs of the breakage or damage listed below.
2. **Tree top break**: Less than two year's leader growth has been broken.
3. **Crown break**: The crown of the tree is broken, more severe than tree top break, but still occurring in the live crown.
4. **Stem break**: The stem below the live crown is broken. Note that the remaining stem must be greater than 1.3 m in height to be a tree, otherwise it is a stump.
5. **Bent, curved or slanted tree**: The tree is bent or slanted, e.g. basal sweep or partially windblown tree. The tree is not lying on the ground.
6. **Substitute tree top**: The tree top was damaged and replaced with a new leader, resulting in a kink in the stem otherwise described as a 'bayonet' feature.

7. **Lying living tree**: This is where the tree is lying on the ground and is still living, i.e. windblown tree. Trees that are obviously supported by another tree are also included in this category.
8. **Replicated tree top**: The presence of a fork on the main stem occurring more than 5 m above ground level.

Figure 52. Tree break categories.

Chapter 13 SMALL TREES

Trees classified as small trees, include all planted trees less than 7 cm Dbh, and naturally regenerated trees greater than 20 cm in height and less than 7 cm Dbh.

13.1 PRESENCE OF AN OVERSTOREY

Definition: An overstorey is a storey of trees that occurs above a regenerating secondary storey of small trees.

Application: Identifies the portion of the forest estate regenerating beneath an overstorey (Figure 53).

Measurement and Description: Assessment is carried out on the 12.62 m plot.

Attribute **Presence of an Overstorey**

1. **Absent**: There is no overstorey present, i.e. afforestation, or reforestation after a clearfell.
2. **Present**: There is an over storey present, i.e. trees from a previous rotation were retained. An example of this is the continuous cover, shelterwood system.

Figure 53. Regeneration below forest stand and free area occurrence of regeneration.

13.2 ORIGIN OF REGENERATION

Definition: Indicates whether the tree was artificially introduced or else regenerated naturally.

Application: This is used in the assessment of natural regeneration in the forest estate.

Measurement and Description: Assessment is carried out on the 7 m plot.

Attribute **Origin of Regeneration**

1. **Planting >80%**: The majority of small tree canopy, i.e. ≥80%, is the result of planting.
2. **Planting 50-80%**: The majority of small tree canopy, i.e. 50-80%, is a result of planting.
3. **Natural >80%**: The majority of small tree canopy, i.e. ≥80%, is the result of natural regeneration.
4. **Natural 50-80%**: The majority of tree canopy, i.e. 50-80%, is a result of natural regeneration.

13.3 Silvicultural treatment

Definition: Describes the operations that have taken place during the stand establishment stage.

Application: This is used to assess the intensity of management that the young trees are receiving.

Measurement and Description: Assessment is carried out on the 12.62 m plot.

Attribute **Silvicultural Treatment**

1. **No management**: No silvicultural interventions has occured, which is common with naturally regenerated small trees.
2. **Site preparation**: Site preparation has been provided, e.g. mounding.
3. **Respacing**: Release cutting or opening up of the forest stand has taken place.
4. **Fencing**: The area has been fenced to exclude livestock, deer, rabbit or hare.
5. **Extraction of logging residues**: Harvest residues have been removed.
6. **Leaving residues**: Residues resulting from harvesting operations are left on site, e.g. windrowing.

13.4 Small tree attributes

This section details the small tree measurements recorded and the small tree damage.

13.4.1 Small tree measurements

Definition: Attributes measured on individual small trees: age, height, Dbh and origin.

Application: Individual small tree measurements are used to assess the current growth and productive potential of young forest stands. All small trees occurring within the 3 m plot are assessed.

Measurement and Description: The age, height and Dbh (if tree is above 1.3 m in height) of each small tree is recorded. The origin of small trees, i.e. planted or naturally regenerated, is also recorded. The same age, Dbh and height measurement conventions used in the previous chapter are used for the small tree measurements.

13.4.2 Small tree damage

Definition: Biotic or abiotic damage present on individual trees.

Application: This is used to identify the most common types of damage present on small trees.

Measurement and Description: A description of the damage is made for all small trees that had measurements recorded.

Attribute **Small Tree Damage**

1. **No damage**: Damage is not present on the tree.
2. **Terminal damage**: Terminal shoot damage exists on the tree, such as dieback, forking, or grazing.
3. **Fraying**: Fraying by deer, leading to stem and shoot damage.
4. **Peeling up to 1/8 of the circumference**: Peeling of the stem by animals where less than 1/8 of the bark of the circumference has been removed.
5. **Peeling more than 1/8 of the circumference**: Peeling of the stem by animals where more than 1/8 of the bark of the circumference has been removed.

Chapter 14 DEADWOOD

Definition: Solid or rotting logs, stumps, and branches.

Application: All living organisms have finite life spans after which they become part of the decaying portion of the ecosystem. Soft-bodied organisms and small plant structures generally decay rapidly and provide a quick turnover of nutrients, an addition to the forest floor, and/or food for forest wildlife. Large woody material contains very significant stores of carbon and energy and is the foundation of an important forest food web. This large material usually decays more slowly and therefore provides a more steady input of energy and longer-lasting structures (Stevens 1997). Deadwood also provides habitat for plants, animals and insects and a source of nutrients for soil development.

Measurement and Description: Deadwood is assessed on the whole plot (i.e. 12.62 m) and categorised into three components: branch, log and stump. Standing dead trees are assessed as individual trees.

14.1 BRANCH

Definition: Non-living branch residue on the forest floor.

Application: Calculation of biomass in harvesting residue.

Measurement and description: Branches must be less than 7 cm in diameter at the largest end. Branch cover is assessed on the whole plot. Where the branch residue is present in piles (e.g. windrows), then the total coverage is estimated based on the amount of wood in the piles.

Attribute **Branch Coverage**

1. **No presence**: No branch or harvesting residue present on the plot.
2. **Rare (0-0.2%)**: Total coverage of branch or harvesting residue present on the plot is less than 0.2% of the plot area.
3. **Sporadic (0.2 to 1%)**: Total coverage of branch or harvesting residue present on the plot is between 0.2 and 1% of the plot area.
4. **Infrequent (1-5%)**: Total coverage of branch or harvesting residue present on the plot is between 1 and 5% of the plot area.
5. **Frequent (6-25%)**: Total coverage of branch or harvesting residue present on the plot is between 6 and 25% of the plot area.
6. **Common (26-50%)**: Total coverage of branch or harvesting residue present on the plot is between 26 and 50% of the plot area.
7. **Very common (51-75%)**: Total coverage of branch or harvesting residue present on the plot is between 51 and 75% of the plot area.
8. **Abundant (76-100%)**: Total coverage of branch or harvesting residue present on the plot is between 76 and 100% of the plot area.

14.2 DEAD LOG

Definition: Lying dead logs or its parts.

Application: Calculation of biomass in lying dead logs.

Measurement and Description: Logs present with a minimum mid diameter of 7 cm and a minimum length of 1 m. Only the portion of the log occurring within the plot is included. Assessment of the log length stops at 7 cm top diameter (Figure 54). The mid diameter and length of the log is recorded in cm.

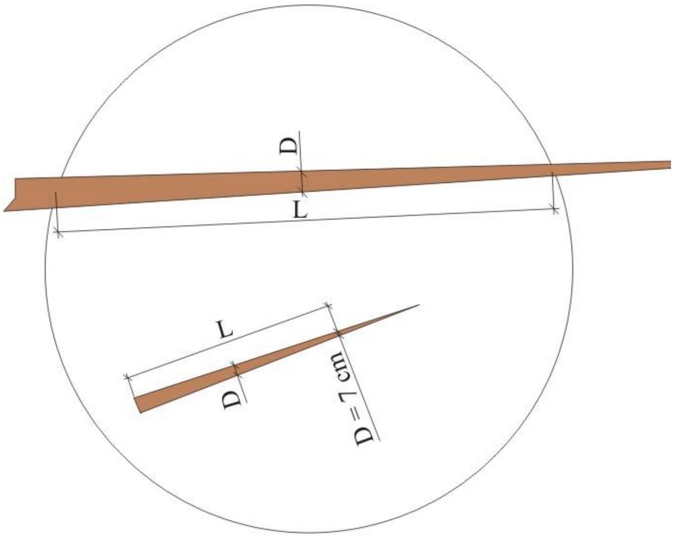


Figure 54. Dead log measurement.

Where a dead standing tree is assessed, it is handled in the same way as living trees for volume calculation, during data processing. Total height is modelled based on Dbh and the whole tree volume calculated. In the example presented in Figure 55, a portion of the dead stem has fallen to the forest floor. As this portion of the tree volume is included in the standing tree volume, it should not be included as lying deadwood.

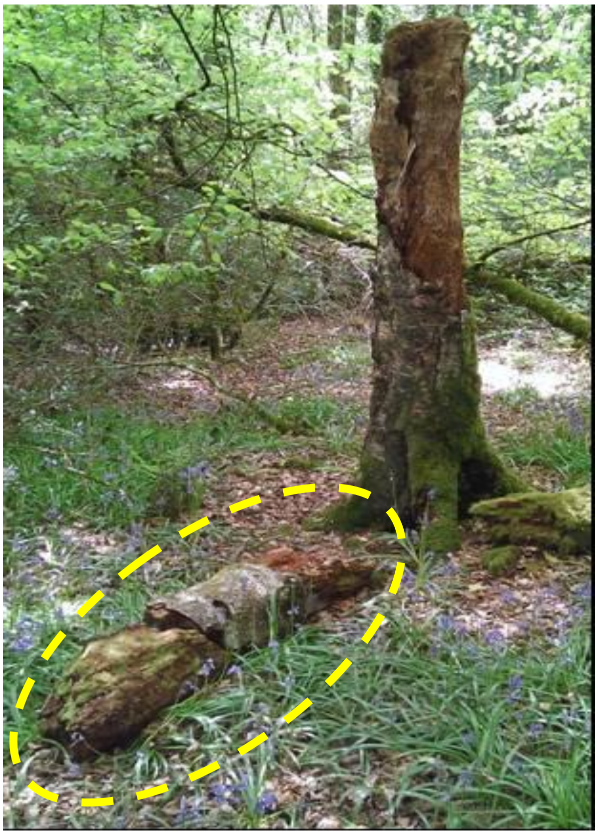


Figure 55. Standing dead tree.

14.2.1 Dead log category

Definition: Categorisation of dead logs based on a threshold diameter and length.

Application: This attribute is used to describe the size of dead logs present.

Measurement and Description: The assessment of dead logs is on the 12.62 m plot. Recently cut logs are excluded, as these will likely be removed from the forest. Where the logs have not been collected and are showing signs of decomposition, they are included as dead logs.

Attribute **Dead Log Category**

1. **No dead logs**: There are no dead logs present.
2. **Only dead logs under threshold diameter**: Logs are present, but they have a mid-diameter of less than 7 cm and/or they are less than 1 m in length.
3. **Dead logs present**: Logs are present with a minimum mid diameter of 7 cm and a minimum length of 1 m.

14.2.2 Dead log distribution

Definition: The spatial distribution of dead logs on the plot.

Application: The distribution of dead logs impacts on the decomposition of the deadwood and also on its habitat value (Figure 56).

Measurement and Description: The assessment of dead log distribution is on the 12.62 m plot.

Attribute **Dead log distribution**

1. **Deadwood distributed randomly**: Random distribution of dead logs within the plot.
2. **Deadwood islands**: The dead logs are located in isolated piles.
3. **Windrows**: Deadwood is located in linear piles.

Figure 56. Dead logs randomly distributed and dead logs in windrows.

14.3 Stump

Definition: The base of a tree remaining in the ground after most of the stem has been harvested.

Application: Calculation of volume and biomass in stump deadwood (Figure 57).

Measurement and Description: Stumps occurring on the 12.62 m plot are included in the assessment. A stump must have a minimum top diameter of 10 cm and height of less than 130 cm. A stump with a height of greater than 130 cm is considered a standing dead tree. The stump top diameter and height is recorded in cm.

Figure 57. Stump deadwood.

14.3.1 Stump category

Definition: Categorisation of stumps based on a threshold top diameter.

Application: This attribute is used to describe the size of stumps present on the site.

Measurement and description: Assessment is based on the 12.62 m plot.

Attribute **Stump Category**

1. **No stumps present**: There are no stumps present on the plot.
2. **Stumps under threshold diameter**: Stumps are present, but they have a top diameter of less than 20 cm.
3. **Stumps present**: Stumps are present with a minimum top diameter of 20 cm.

14.4 Decay status

Definition: Decay status describes the level of decomposition of the deadwood.

Application: Assessing the decay status of logs and stumps allows for the quantification of carbon lost from the decaying wood. The status of the decaying wood will also influence the type of organism that can utilise the wood, thus affecting the biological diversity.

Description and Measurement: The decay status of all stumps and dead logs recorded on the 12.62 m plot is assessed.

Attribute **Decay Status**

1. **Solid wood**: Wood is intact, no signs of decomposition.
2. **Rotten sapwood, solid heartwood**: Outer part of wood is rotten, inner core is solid.
3. **Rotten heartwood, solid sapwood**: Outer part of wood is solid, inner core is rotten.
4. **Rotten wood**: Timber is rotten throughout, but maintains its original shape.

14.5 Decay status (COST[7])

Definition: Decay status describes the level of decomposition of the deadwood.

Application: Assessing the decay status of logs and stumps allows for the quantification of carbon lost from the decaying wood. The status of the decaying wood will also influence the type of organism that can utilise the wood, thus affecting the biological diversity. Recommended for use across Europe.

Description and Measurement: The decay status of all stumps and dead logs recorded on the 12.62 m plot is assessed.

Attribute **Decay Status**

1. **Fresh piece of wood**: Wood is intact, no signs of decomposition.
2. **Bark intact**: Bark intact, wood solid.
3. **Bark all or partly missing, wood solid**: Bark has all or partly rotten away, wood solid.
4. **Bark absent, wood soft**: Bark missing, wood soft.

14.6 Deadwood type

Definition: Deadwood type describes whether the deadwood is conifer or broadleaf

Application: Assessing the deadwood type will provide information on the rate of decomposition. The deadwood type will also influence the type of organism that can utilise the wood, thus affecting the biological diversity.

Description and Measurement: The deadwood type of all stumps and dead logs recorded on the 12.62 m plot is assessed.

Attribute **Deadwood Type**

1. **Conifer**: Conifer tree species.
2. **Broadleaf**: Broadleaf tree species.

[7] Definition was based on harmonisation of variables during COST E43 process.

Chapter 15 SITE

This chapter details the type of information that is recorded to describe the non-tree elements in which the plot occurs. Descriptive attributes relating to soils are also detailed in this chapter. The litter and humus layers are described first, followed by sections detailing the composition of the soil type, parent material and soil structure. Cultivation and terrain classification are covered in the final sections.

15.1 VEGETATION COVER

Definition: The structure, cover and species composition of plants within the plot.

Application: Quantifying the percentage vegetation cover on the plot allows for the assessment of plant diversity. Tree species are excluded in the vegetation cover assessment. All plant species present, including grass, herb, moss, fern, shrub and brush cover, are recorded.

Forest managers have used plant diversity for considerable time to indicate site/ground conditions, in particular nutrient availability (Anderson 1950). The assessment of plant diversity is an important indicator which can be used in the monitoring of Sustainable Forest Management. The structure/range of the vegetation present will also be indicative of the insect diversity.

Measurement and Description: The total vegetation cover and vegetation type on the entire plot is quantified into percentage classes, based on an adjusted Braun-Blanquet scale (Braun-Blanquet 1983). This scale is also used to classify individual plant species, which are named. Appendices 3 and 4 detail the list of plant and shrub species recorded.

Attribute **Vegetation Type**

1. Grass
2. Herb
3. Moss
4. Fern
5. Brush (*Rubus* and *Ulex* spp.)
6. Shrub

Attribute **Vegetation Cover**

1. **No presence**: No vegetation cover on the plot.
2. **Rare (0-0.2%)**: Total vegetation cover on the plot is less than 0.2% of the plot area.
3. **Sporadic (0.2 to 1%)**: Total vegetation cover on the plot is between 0.2 and 1% of the plot area.
4. **Infrequent (1-5%)**: Total vegetation cover on the plot is between 1 and 5% of the plot area.
5. **Frequent (6-25%)**: Total vegetation cover on the plot is between 6 and 25% of the plot area.
6. **Common (26-50%)**: Total vegetation cover on the plot is between 26 and 50% of the plot area.
7. **Very common (51-75%)**: Total vegetation cover on the plot is between 51 and 75% of the plot area.
8. **Abundant (76-100%)**: Total vegetation cover on the plot is between 76 and 100% of the plot area.

15.2 TREE LICHENS

Definition: A lichen is an organism consisting of an outer fungal body enclosing photosynthetic algae.

Application: Lichens are unique, as they consist of two totally unrelated life forms, an alga and a fungus, living together in a complex but balanced state of mutual interdependence. The presence or absence of different lichen types can indicate changing patterns in air quality.

Measurement and Description: For the purpose of the NFI, lichens have been classified into three growth forms (Broad 1989) (Figure 58). The type of trees on which the lichens occur and lichen coverage on the plot is recorded.

Attribute **Lichen Type**

1. **Crustose**: Encrusting forms that spread over and into the surface substrate on which they grow.
2. **Folicose**: Leafy forms that spread horizontally over the substrate. Attached by root-like threads called rhizinae.
3. **Fruticose**: Shrubby or beard-like forms that may be erect or pendulous.

Figure 58. Examples of crustose (left), folicose (middle) and fruiticose (right) lichens.

Attribute **Tree Type**

1. **Conifers**: Lichens present on coniferous tree species.
2. **Broadleaf with smooth bark**: Lichens present on broadleaf tree species with smooth bark.
3. **Broadleaf with rough bark**: Lichens present on broadleaf tree species with rough bark.

Attribute **Coverage**

- **Rare (0.1-5%)**: Lichens are present on trees occupying between 0.1 and 5% of the plot area.
- **Sporadic (6-25%)**: Lichens are present on trees occupying between 6 and 25% of the plot area.
- **Frequent (51-75%)**: Lichens are present on trees occupying between 51 and 75% of the plot area.
- **Abundant (76-100%)**: Lichens are present on trees occupying between 76 and 100% of the plot area.

15.3 Litter and humus

The litter layer and humus are described in this section.

15.3.1 Litter layer

Definition: The non-living, slightly decomposed organic material on the surface of the forest floor is defined as the litter layer.

Application: Even in an undecomposed state, litter is an important component of the forest. The partially decayed stem wood, branches and leaves are able to store water, prevent water loss from evaporation and reduce erosion.

Measurement and Description: The presence of a litter layer in the plot is assessed when the soil pit is dug, which takes place within the 12.62 m plot. The composition of the litter layer is categorised, with the depth (mm) of each component recorded. Recently afforested lands, particularly those previously improved for agriculture, may have a grass/herb derived litter layer.

Attribute **Litter Type**

1. Grass
2. Leaves
3. Needles
4. Moss

15.3.2 Humus

Definition: Organic layers at the soil surface, where leaf litter and other organic matter are decomposing and being incorporated into the upper mineral soil.

Application: Humus consists of undecayed to mostly decayed organic matter, usually leaves/needles, which are broken down into soil by decomposers (microorganisms, insects, earthworms) and exposure to light, wind, rain, etc. Humus contains many nutrients that are recycled in the soil when it is broken down.

Measurement and Description: The humus form and thickness of the humus sub-layers are described, including the agents of decomposition (Horgan *et al.* 2003).

Attribute **Humus Type**

1. **No humus**: There is no humus present. The litter layer may not have formed yet or could have been removed due to surface runoff or flooding.
2. **Mor humus**: This is raw humus, composed of unincorporated organic material, usually distinct from the mineral soil. It comprises the current litter layer overlying a matted layer of partly decomposed material.
3. **Moder humus**: This is the intermediate between mor and mull. The current litter layer overlies partly decomposed material, which is not matted as in mor.
4. **Mull humus**: This is the humus-rich layer of forested soils consisting of mixed organic and mineral matter. The humus is being incorporated into the soil, i.e. there is no clear differentiation between the soil and humus layer.

15.4 Soil Description

This section describes the soil condition, soil group and principal soil type.

15.4.1 Soil Condition

Definition: Broad classification into peat and mineral soil.

Application: Soil condition allows for the broad classification of soil based on the peat and mineral soil depth. The classification is used to distinguish mineral soils and peats.

Measurement and Description: Soil condition is assessed when the soil pit is dug. Peat and soil depth are measured to the nearest cm.

Attribute **Soil Group**

1. **No peat:** Mineral soil with no peat present.
2. **Less than 30 cm of peat:** Mineral soil overlain with less than 30 cm of peat.
3. **More than 30 cm of peat:** More than 30 cm of peat present.
4. **Mineral soil less 20 cm:** Mineral soil less than 20 cm in depth.

15.4.2 Soil group

Definition: A standardised system of nomenclature used to classify soils into groups.

Application: Soil group has a bearing on several parts of the ecosystem. The type of soil can affect the growth of trees and other vegetation by influencing moisture and nutrient availability. These same characteristics also affect other parts of the ecosystem, such as water quality.

Measurement and Description: The soil group classification used in the NFI is a modification of the ten great soil groups (Gardiner and Radford 1980) to include sand, making 11 great soil groups.

Attribute **Soil Group**

1. Brown earth
2. Grey brown podzolic
3. Brown podzolic
4. Podzol
5. Gley
6. Rendzina
7. Basin peat
8. Blanket peat
9. Regosol
10. Sand
11. Lithosol

Each soil group is briefly described in the following section. The photographs labelled **©Teagasc 2007** were reproduced with the permission of Teagasc from a presentation to the Forest Service (Radford 2004). Photographs labelled **©Coford 2007** were reproduced with the permission of COFORD from *A Guide to Forest Tree Species Selection and Silviculture in Ireland* (Horgan *et al.* 2003).

Brown earth

Relatively mature, well-drained mineral soils, derived from parent materials of acidic or basic status (Figures 59-61). These soils possess a rather uniform profile with little differentiation in horizons and no removal and deposition of materials such as iron oxides, humus or clay, although constituents such as calcium and magnesium may be leached to some extent.

Figure 59. Brown earth.

Figure 60. Acid brown earth.

Figure 61. High base brown earth.

Grey brown podzolic

These well-drained mineral soils are similar to the brown earths, except that clay has been translocated from the surface to a sub-surface layer (B horizon) (Figures 62). They are usually formed from glacial drift of predominantly limestone composition and have a medium to high base saturation status.

Figure 62. Grey brown podzolic.

Brown podzolic

Well-drained, acid mineral soils, derived mainly from acidic parent materials such as shale, granite or sandstone (Figure 63). Located on hills and rolling lowland. They are formed under the influence of the podzolisation process, subject to some leaching. Due to the presence of iron oxides the B horizon has a reddish-brown colour. This group occupies approximately 12% of the land area of the country.

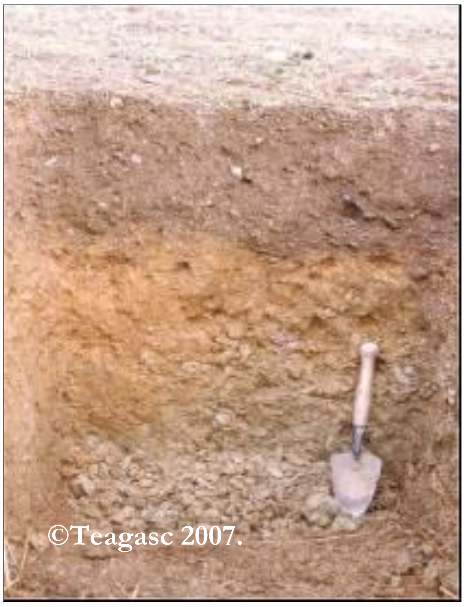


Figure 63. Brown podzolic.

Podzol

These soils are subject to intense leaching of minerals, particularly iron and aluminium, and are formed from acidic parent materials (Figures 64 and 65). They have a distinct sequence of horizons, with a subsurface layer of removal, the A2 horizon and subsurface layer of accumulation, B horizon. Due to severe leaching of iron and cementation, some podzols may develop a thin impervious 'iron pan' in the B horizon. They may have a peaty surface layer of less than 30 cm drained or 45 cm undrained and are located on mountain and hill land, where the high rainfall is a major factor in their development. They occupy approximately 8% of the land of the country.

Figure 64. Podzol.

Figure 65. Peaty podzol.

Gley

This group contains soils in which the effects of drainage impedance dominate (Figure 66). They develop under conditions of permanent or intermittent waterlogging. The mineral horizons of Gleys are grey or blue-grey in colour, with distinct rusty mottling frequently evident. Rooting depth is usually limited, aeration is poor and rate of organic matter decomposition is slow. The impeded condition may be due to a high water level, seepage or springs, or it may be due to the impervious nature of the parent material.

Figure 66. Gley.

Rendzina

These are well-drained, shallow mineral soils (Figure 67). They are very dark with a high lime content. Derived from limestone bedrock, or limestone sands and gravels such as eskers, they are less than 50 cm in depth.

Figure 67. Rendzina.

Peats

For an area to be classified as a peat soil, the peat depth has to be greater than 30 cm on drained and 45 cm on undrained land. Peats are divided into two groups:

- **Basin peat**

Basin peat consists of fen peat and raised bog. Fen peat originally formed under the influence of base rich ground water in shallow lakebeds and depressions in the landscape. It is usually alkaline in its lower layers but as it develops, the upper layers become more acidic and the vegetation changes from one dominated by *Phragmites* and *Carex* species to one of *Sphagnum* and *Calluna* species, resulting in raised bog.

- **Blanket peat**

Blanket peat occurs in wet, cold and acid conditions in elevated areas and at lower elevations along the western seaboard. Blanket peat usually extends over the entire landscape, covering the hills and valleys. Its vegetation is usually dominated by acid-loving plants, such as *Sphagnum, Calluna, Tricophorum, Eriophorum* and *Molinia* species. When it occurs at elevations greater than 150 m it is described as 'high level'; below this, it is described as 'low level' blanket peat.

Regosol

This group consists of mineral soils, which are immature and show little distinct horizon development (Figure 68). They occur in low-lying flat areas along river courses, lake-beds or at mouths of river estuaries. The texture varies from sands to clays, drainage ranges from excessive to poor. May be acid or alkaline depending on the source of the deposits.

Figure 68. Regosol.

Lithosol

Very shallow and stony mineral soils, usually overlying solid or shattered bedrock (Figure 69). Located mainly at higher elevations where they are associated with podzols. These soils are frequently characterised by outcropping rock and may occur on steep slopes.

Figure 69. Lithosol.

Sand

Soils occurring in this group are found in coastal regions and are characterised by the high percentage (>90%) of sand content (Figure 70). These soils have very little horizon differentiation. Due to the absence of clay and silt particles, these soils have poor nutrient and moisture retention capacity.

Figure 70. Sand.

Limestone pavement

A natural occurrence of exposed limestone typified by flat and incised surface. This land-form is found in the Burren area in the midwest of Ireland.

While this land-form has no soil or peat present it is included as a soil group due to the presence of forests in this area.

Figure 71. Limestone pavement.

15.4.3 Principal soil

Definition: Principal soil categorises the soil groups into more descriptive classes e.g. gleys are further categorised into gleys and peaty gleys.

Application: In order to further describe soil fertility/management.

Measurement and Description: Principal soil is assessed when the soil pit is dug. In the attribute list below 'flushed' describes peat with a sufficient nutrient content that permits the growth of more demanding species, such as *Mollina*. 'Unflushed' peat is characterised by the presence of *Calluna* species.

Attribute **Principal Soil**

- Basin peat (unmodified)
- Basin peat (industrial cutaway)
- Basin peat (domestic cutaway)
- Basin peat (cutaway and reclaimed)
- Fen peat (unmodified)
- Fen peat (man modified)
- Marl
- Interdrumlin peat
- Blanket peat - high level (flushed)
- Blanket peat - high level (unflushed)
- Blanket peat - high level (industrial cutaway)
- Blanket peat - high level (domestic cutaway)
- Blanket peat - high level (cutaway and reclaimed)
- Blanket peat - low level (unflushed)
- Blanket peat - low level (flushed)
- Blanket peat-low level (cutaway and reclaimed)
- Acid brown earth
- Alkaline brown earth
- Brown podzolic
- Gley
- Peaty gley
- Grey brown podzolic
- Lithosol
- Podzol
- Peaty podzol
- River alluvial
- Lake alluvial
- Esturine alluvial
- Coastal sand
- Rendzina
- Coastal sand

15.5 SOIL AND PEAT STRUCTURE

Peat and soil texture are described in this section, as well as the assessment of peat and soil depth. Soil moisture, drainage, cultivation and site roughness are also included.

15.5.1 Peat texture

Definition: Peat texture is a measure of the decomposition or humification of peat.

Application: Peat texture is used as a criterion in peat classification.

Measurement and Description: The classification scale is based on the 'von Post scale' (Von Post 1924), which uses values ranging from 1 to 10, where 1 is the least decomposed. This scale has been simplified and expanded as detailed below.

Attribute **Structure**

1. **Fibric**: Degree of decomposition is from 1 to 3, very light in colour, full of non-decomposed plant remains, primarily *Sphagnum* species. When squeezed the water is a light brown colour.
2. **Hemic**: Degree of decomposition is from 4 to 6 and it is dark brown in colour. Identification of plant residues is difficult.
3. **Sapric**: Degree of decomposition is from 7 to 10. It is black in colour, greasy in texture and identification of plant remains is very difficult.
4. **Peat with mineral materials**: This covers areas where reclamation has taken place or where most of the peat has been removed or incorporated into the mineral layer. The peat has been altered by the addition of mineral materials and fertilisers.

15.5.2 Soil texture

Definition: Soil texture refers to the relative proportions of the various size particles in the mineral fraction of the soil.

Application: The soil texture is a significant soil characteristic to assess, as it is an important indicator of plant growth. For example, sandy soils generally have low organic content and poor moisture retention ability.

Measurement and Description: Classes of texture are based on different proportions of sand, silt and clay (Figure 72). In the field, the percentages of sand, silt and clay particles in a soil are estimated by feel. The soil is rubbed between fingers and thumb and an estimate of the amount of sand, silt and clay present is made.

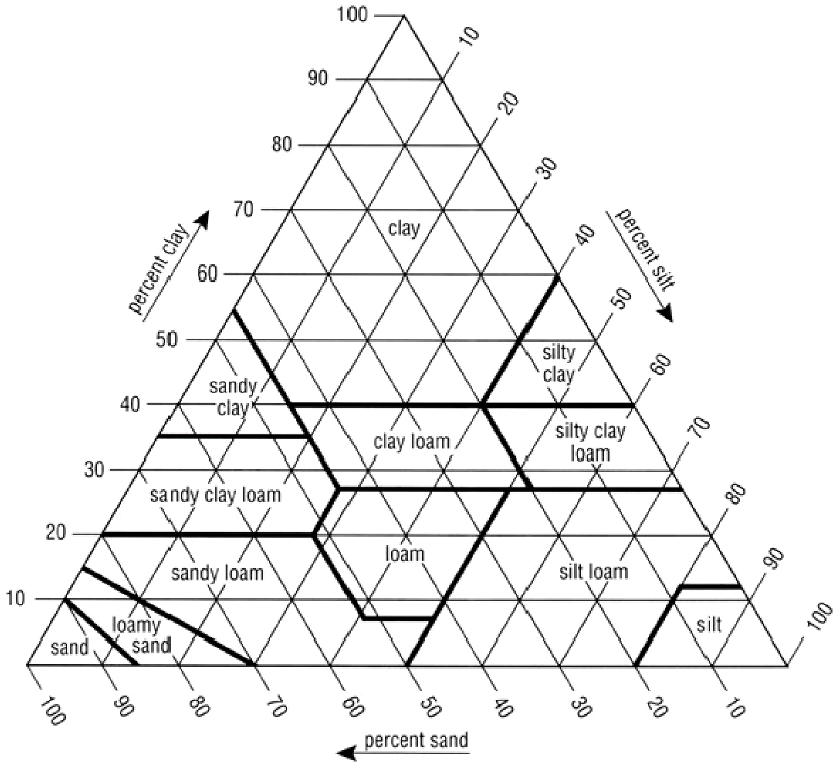


Figure 72. Percentages of clay, silt and sand in the basic textural classes (Anon. 1993).

Assessment of soil texture: Accurate measurements of soil texture requires laboratory analysis, but for practical purposes, texture can be assessed by hand, using the following method.

Take about a dessert spoonful of soil. If dry, wet up gradually, kneading thoroughly between finger and thumb until soil crumbs are broken down. Enough moisture is needed to hold the soil together and to show its maximum stickiness. Follow the paths in the diagram below (Figure 73) to get the texture class:

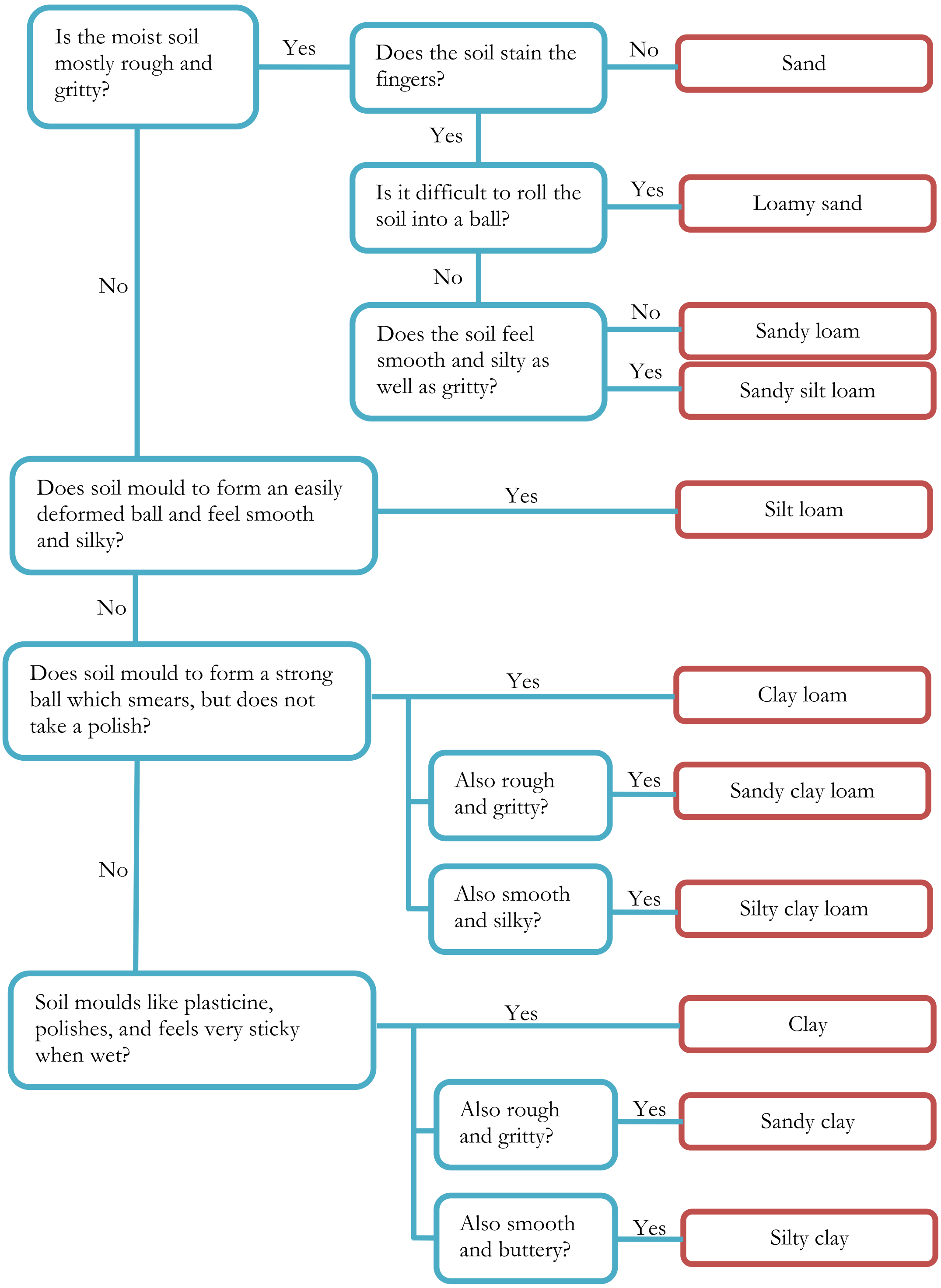


Figure 73. Assessment of soil texture (Anon. 2005).

15.5.3 Soil/peat depth

Definition: The depth of peat and soil.

Application: Soil and peat depth are important factors in tree growth. Forest management is also affected, in terms of access and stability.

Measurement and Description: The depth of mineral soil is measured in the soil pit. Peat depth may also be measured using a soil stick. Soil or peat depth (cm) is recorded to a maximum of 100 cm. In the case where both soil and peat are present (e.g. a peaty gley), the maximum combined recording depth is also 1 m.

15.5.4 Soil moisture

Definition: Moisture contained in the soil above the water table.

Application: Soil moisture describes the availability of moisture in forest soils, thereby affecting tree growth.

Measurement and Description: In the field, the soil moisture can be estimated by feel. The time of year and any extremes of weather conditions are taken into account.

Attribute **Soil Moisture**

1. **Dry**: The soil is dry with little or no moisture present, e.g. excessively drained coastal sand.
2. **Moist**: The soil is moist with some moisture present, e.g. Most mineral soils or drained peatland.
3. **Wet**: The soil is wet with a lot of moisture present, e.g. undrained peat soil.

15.5.5 Soil drainage

Definition: Soil drainage describes the capacity of the soil to drain water.

Application: This attribute can influence both silvicultural and harvesting practices.

Measurement and Description: Assessment is made on the 12.62 m plot. Soil structure, slope and topography are all taken into consideration.

Attribute **Soil Drainage**

1. **Excessive**: Soil has poor moisture retaining ability, e.g. coastal sand.
2. **Good**: Site is dry and the soil profile shows no sign of water impedance, e.g. brown podzolic with shale parent material.
3. **Moderate**: No significant sign of water impedance, e.g. podzol.
4. **Imperfect**: Drainage is restricted due to the soil texture or presence of an iron pan. When the soil pit has been dug, the hole may partially fill with water, e.g. surface water gley.
5. **Poor**: Soil has poor capacity to drain excess water. The soil pit will usually fill with water as it is being dug, e.g. ground water gley.
6. **Very poor**: Site is very wet, i.e. water present at the surface, e.g. blanket peat – low level.

15.6 Soil cultivation

Definition: Soil cultivation describes treatments applied to the soil in order to make the soil more suitable for the natural regeneration or establishment of planted trees.

Application: The future development of the stand can be significantly influenced by soil cultivation. For example, mounding will encourage the establishment of trees due to benefits such as the raised planting position, which is free from competing vegetation. The method of cultivation can impact on the future stand development and management.

Measurement and Description: Assessment of the cultivation type present is made on the 12.62 m plot.
Attribute **Cultivation**

1. **Mounding**: Drains are opened at regular intervals with the spoil from the drain being used to create raised planting mounds (Figure 74).
2. **Ripping**: A vertical steel plate, with horizontal tines attached, is pulled through the soil at a depth of 30-60 cm with the purpose of uplifting and shattering any impermeable layers and loosening the soil.
3. **Agricultural ploughing**: An agricultural plough turns over one to two sods into which the trees are planted. The site may also be completely ploughed.
4. **Pit/slit planting**. The trees are planted into a pit/slit opened with a spade. No mechanical site preparations are present.
5. **Single mould board ploughing (SMB)**: A plough with one large board is used to turn a sod leaving a deep drain beside the plough ribbon (Figure 75).
6. **Double mould board ploughing (DMD)**: A plough with two large boards facing in opposite directions is used to turn two sods, leaving a deep drain in between the two plough ribbons (Figure 76).
7. **Machine planted**: A cultivating machine attached to a tractor opens a planting channel using a short ripping arm. Trees are then inserted into the planting channel which is closed in using a set of wheels. Planting lines are very straight (Figure 77).
8. **No cultivation**: There was no soil cultivation, the trees regenerated naturally.

Figure 74. Mounding.

Figure 75. Single mould board ploughing (Hart 1991).

Figure 76. Double mould board ploughing (Hart 1991).

Figure 77. Soil cultivation: mechanical planting.

15.7 Terrain classification

This section describes attributes that are used to assess terrain.

15.7.1 Ground roughness

Definition: Site roughness is concerned with the presence of obstacles which may restrict movement across the land surface.

Application: The roughness of a site will dictate machine accessibility. This will be of importance in carrying out forest operations.

Measurement and Description: The classification is based on the size and frequency of obstacles. In many forests, plough furrows and drains are the main obstacles as are tree stumps after harvesting operations. Although ground roughness is assessed visually, sample plots can be used to establish standards. Assessment is made on the 12.62 m plot.

Attribute **Roughness:**

1. **Very even**: Low obstacles infrequent and taller obstacles isolated or absent e.g. ripping or machine planting.
2. **Slightly even**: Low obstacles moderately frequent and taller obstacles isolated e.g. shallow mounding or scrap mounding.
3. **Uneven**: Low obstacles frequent and taller obstacles infrequent e.g. deep mounding or ploughing.
4. **Rough**: Low obstacles frequent and taller obstacles moderately frequent e.g. rough ploughing or rock outcrops.
5. **Very rough**: Sites more severe than the rough classification e.g. a lot of boulders on the surface.

15.7.2 Ground conditions/capacity

Definition: Describes the bearing capacity of the soil.

Application: Ground conditions will dictate machine accessibility. This will be of importance in carrying out forest operations.

Measurement and Description: The ground condition classification used is adapted from a British technical note (Forestry Commission 1996). It is based on soil type and rainfall (Table 5). Rainfall can quickly alter ground conditions and will affect the ground condition class. This will vary from one time of the year to another and should be considered in long term classification.Assessment is made on the 12.62 m plot

Attribute **Ground conditions**

1. **Very good**: Freely drained gravels and sandy soils.
2. **Good**: Firm mineral soils.
3. **Average**: Soft mineral soils, including gleys.
4. **Poor**: Peaty gleys and podzols. Also wet gleyed soils.
5. **Very poor**: Soft, wet, deep peats.

Table 5. Ground condition class (Forestry Commission 1996).

Soil Class	**Description**	**Ground Condition Class**	
		Low Rainfall	**High Rainfall**
Sand/Gravel	Gravels and sandy soils, very freely drained.	Very good	
Firm Mineral Soils	Freely drained coarse-loamy and fine-loamy brown earths and podzols.	Good	
	Coarse-loamy gleys on indurated material.	Good	
	Loamy non-peaty ironpan intergrade soil (<5 cm peat).	Good	
Soft Mineral Soils	Imperfectly drained fine-loamy brown earths.	Average	Poor
	Gleys (no peat).	Average	Poor
Shallow and deep peats	Peaty iron pan soils (peat 5-45 cm.)	Average	Poor
	Peaty gleys and humic gleys (peat 5-45 cm)	Poor	Very poor
	Hill peat (relatively firm, not too wet, >45 cm)	Poor	Very poor
	Other deep peats (soft, wet, >45 cm)	Very poor	Very poor

SECTION C
VALIDATION
AND
DATA ANALYSIS

Chapter 16 VALIDATION OF FIELDWORK

16.1 BACKGROUND

The field data collection element of the second cycle National Forest Inventory (NFI) commenced in October 2009 and finished by December 2012. To ascertain the quality of field data collection, 94 plots or 5.6% of the 1,680 plots visited in the field, were completely re-measured in four separate validation stages between 2011 and 2012. These validation stages were carried out jointly between the Forest Service, Department of Agriculture, Food and the Marine and IFER – Monitoring and Mapping Solutions. In addition 32 plots were checked by the Forest Service between 2011 and 2012 as part of a quality assurance exercise. The objective of the validation exercise was to assess the data quality from field teams by directly comparing re-measured plots against field team's data and to use this information to guide best practice on data quality throughout the field data collection period.

16.2 FIELD DATA COLLECTION STAFF

The second cycle NFI field data collection was carried out by three different groups of people. The first set of operatives, were full time Forest Service staff members and initiated field data collection in autumn 2009. This team completed 350 plots or 20% of the total number of second cycle plots. Data processing was carried out on this 20% of plots, which proved useful in identifying methodological issues for all subsequent field data collection.

In June 2011, three internal staff were redeployed to assist with NFI field data collection, two of which worked on a part time basis and the other worked in a full time role.

A third group of operatives consisting of four people, who worked full time on field data collection, commenced work in October 2011. This third group was comprised of four temporary full-time staff recruited specifically for field duties. One person from University College Cork, working on an Environmental Protection Agency (EPA) funded research fellowship, also worked full-time on field data collection for one year.

It should be noted that in contrast to the first cycle NFI, staffing was more stable in the second cycle with no staff turnover. Nine staff completed the second cycle data collection, two of which were part time operatives; whereas a turnover of 12 staff completed the first cycle data collection. The lower staff numbers contributed to higher data quality, as staff had a greater opportunity to build up knowledge and expertise. Greater cost efficiencies were also achieved as less training was required.

16.3 VALIDATION METHODOLOGY

In order to achieve objective sampling of the validation plots random sampling was used. The selection criteria for sampling were based on the field team combination and the number of plots validated proportional to the total number completed by each team combination. The individual team makeup was subject to change over the course of the NFI and thus selection had to be from across the range of the individual members and the team combinations.

Validation was divided into four two week stages, starting in October 2011 the first stage covered 25 plots; the second started in March 2012 covered 20 plots; the third stage in July 2012 covered 25 plots and the fourth in November 2012 covered 24 plots. A total of 94 plots were jointly assessed (Figure 78).

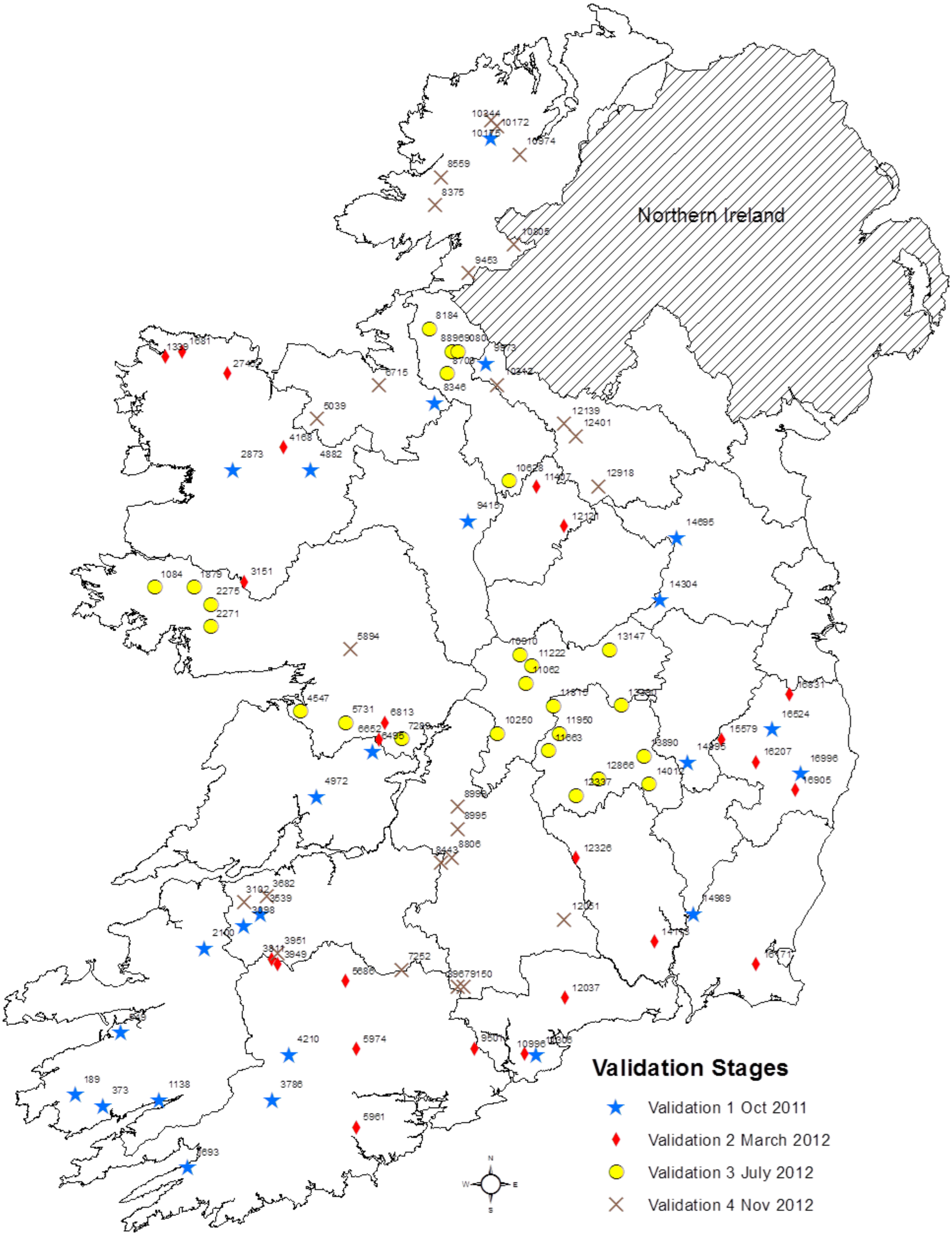


Figure 78. Location of validated plots.

16.4 Plot measurement

All validated plots were completely re-measured and described using the same technology and methodology as the NFI field teams. A direct on-site comparison of the field team data with the validation data was carried out. The individual trees were identified from the field team data and all attributes were compared using the Field-Map software. Important differences were discussed directly at the forest plot, and trees with large difference in Dbh and height were again re-measured to ensure the accuracy and consistency of validation measurements.

16.5 Ranking system

The quality of the original field team data was compared with the validation team data. Any mistakes found in the attributes of each plot, both quantitative and qualitative, were ranked by importance, categorized by error type and weighted by plot type to give an overall validation score for each plot.

16.5.1 Importance of mistake

The mistake importance was ranked as follows:

0 - No Mistake: No Mistake

1 - Very minor: A mistake that will have no effect on the results generated.

2 - Minor: A mistake that will have minimal effect on the results generated.

3 - Acceptable: A mistake that will have a small effect on results generated, usually a subjective measurement e.g. physiographic division.

4 - Unacceptable: A mistake that will have a large effect on results generated, usually an objective measurement e.g. incorrect Dbh, missing trees on plot.

5 - Major: A mistake that will detrimentally affect national results e.g. Forest or Non–Forest land-use classification.

16.5.2 Mistake categorisation

Each mistake was categorised into one of three areas namely:

- **Dendrometric and equipment measurement:** This includes the quality of all equipment-measured variables on the plot and is mainly concerned with tree measurement. Accuracy of plot centre navigation is included in this category.
- **Trees and forest layers description:** This covers the descriptive attributes associated with the trees on the plot e.g. species identification, stand layers, deadwood and small trees description.
- **Site description:** Describes all non-tree attributes e.g. soil, plants, etc.

16.5.3 Mistake weighting

Each mistake was weighted differently according to whether the plot was Forest (trees above threshold Dbh present), or Forest (only trees below threshold Dbh), Forest (no trees), and Forest Open Area.

In Forest plots with trees above threshold Dbh all dendrometric and equipment measurement mistakes were multiplied by 3 to give a higher weighting to these mistake types, trees and forest layers mistakes were multiplied by 2 and site description mistakes by 1 as illustrated in Table 6.

Table 6. Weighting of mistakes on Forest plots (trees present above threshold Dbh)

Dendrometric and equipment measurement	X 3
Trees and forest layers description	X 2
Site description	X 1

In Forest plots with trees under threshold Dbh only, or without trees, or Forest Open Area plots, dendrometric measurements are minimal as are the tree and forest layers descriptions. Thus the weighting on dendrometric errors is reduced to 1. The weighting is increased to 3 on site description mistakes, as these are the main variables to be described.,with the weighting of tree and forest layer descriptions maintained at 2, as shown in table 7.

Table 7. Weighting of mistakes **on** Forest plots (trees present under threshold Dbh), Forest (no trees present) and Forest Open Area plots.

Dendrometric and equipment measurement	X 1
Trees and forest layers description	X 2
Site description	X 3

16.5.4 Overall ranking

Overall ranking is a summation of the above mistake importance, categorisation and weighting and is divided into 3 levels as follows:

- **Good:** Score 0-9. These plots are acceptable and can readily be processed for results generation.
- **Acceptable:** 10-19. Plots at the lower end of this scale have small effect errors that can be processed. Plots at the higher end of this scale may have some larger errors. Some of these errors can be eliminated through a logical checking process- some cannot and need to be further evaluated.
- **Re-Measure:** 20-30. All plots in this category have unacceptable mistakes and should be completely re-measured.

16.6 SUMMARY RESULTS

Out of the 94 jointly assessed plots the number to be re-measured was 6(6.4%), the number categorized as "acceptable" was 23(24.4%) and those termed "Good" was 65(69%), the summary results are shown in table 8. These figures show a marked improvement in data quality over the first cycle.

Table 8. Summary of validation results

Rating	% Plots Validated					
	Stage 1	Stage 2	Stage 3	Stage 4	**Total 2nd cycle**	Total 1st cycle
Good	88	55	68	63	**69**	58
Acceptable	12	30	28	29	**25**	32
Remeasure		15	4	8	**6**	10
Total	100	100	100	100	**100**	100

Following the results of the second validation stage in March 2012 the Forest Service undertook a more targeted quality assessment of 32 plots between April and May 2012; based on specific team combinations. However, despite the excellent results of the validation exercise, a significant threat to data quality emerged in the field data collection process due to trees omitted by mistake. These plots were completely re-measured and assessed using the same methodology as the joint assessment plots. The results of this assessment were as follows: 12 (38%) were categorized as "Good", 11 (34%) of plots were "Acceptable" and the number to be re-measured was 9 (28%). This error type could have had a significant impact on NFI volume estimates. Substantial changes to the make-up of teams, the nature of operative roles and a program of re-measurement of an additional 28 plots were instigated shortly after, which corrected the situation. This experience clearly points to the requirement for full-time only operatives to be used in all further cycles of the NFI.

16.7 RE-MEASUREMENT PLOTS/ERRORS COMMENTARY

In total six re-measure plots, or a 6% overall failure rate, presented during the entire validation programme. Errors that led to this categorization included numerous incorrect Dbh measurements, trees omitted by mistake from mapping, incorrect height measurements, omitted upper diameters, entirely omitted deadwood and a systematic error in the recording of deadwood which had previously (1st NFI cycle) been recorded as mapped trees.

Trees omitted from mapping remained an issue throughout the data collection process, but much less so after the review following the second March 2012 validation and follow up independent check. However this is an area that requires constant vigilance due to its high potential impact on NFI results.

The data quality in this second cycle NFI is significantly improved when compared to the first cycle NFI with the percentage 'Good' validation plots increasing from 58% to 69% and re-measure plots decreasing from 10% to 6% over a greatly expanded number of validation plots. Improvement in the validation results can be attributed to:

1. Greater knowledge and experience from the first NFI of direct field data collection prior to training NFI field staff.
2. An expanded validation programme increasing from 50 plots in the first cycle to 94 in this second cycle. Field staff are aware that a comprehensive validation of their work is being carried out.
3. A clear, written field methodology available to all teams.
4. Well-resourced training materials and maps.
5. On site mentoring of field teams.
6. Data quality spot checks.
7. Good technical support availability to all field teams.
8. Good equipment backup and availability.

16.7.1 Field team update

Field teams were brought together for briefing sessions following each stage of the validation process. During these sessions, the field team members discussed the classification of attributes. This ensured consistency in the classification of NFI attributes across all field teams.

16.7.2 Project management data check

As field teams completed plots, copies of the data were sent to the project manager for backup. Before the data was appended to the national NFI database the plot data was thoroughly checked. Any mistakes or inconsistencies were checked with the field staff and the necessary corrections made. This worked very well as the field staff were able to remember plots due to the short passage of time.

16.8 Recommendations

It is a strong recommendation that, in order to be assured of data quality, all future cycles of the NFI should be carried out using full time staff only.

To ensure there are no issues in the early stages of data collection the following recommendations are made for future NFI:

- Field teams to be accompanied in the first two-weeks of field measurement by experienced person. Any uncertainty can be addressed immediately, followed by a complete check and feedback to the teams.
- Initiate validation closer to the initiation of field data collection to highlight early any necessary changes to improve data quality. This is particularly important for new operatives without prior field data collection experience.

However in conclusion it can be said that a significant improvement in data quality for the second cycle NFI has been achieved when compared with the first cycle. The results from the validation show that data quality is very good and forms a reliable basis for results generation.

Chapter 17 DATA ANALYSIS

Analysis of the NFI data is predominantly carried out by Forest Service and IFER. This chapter outlines the procedure used to model the main attributes (Dbh, height and volume). The production of statistics using Field-Map™ Inventory Analyst is also outlined. This information is taken from the Field-Map™ Inventory Analyst user guide (Cerny *et al.* 2005).

17.1 TREE HEIGHT

A sub-sample of trees (Dbh ≥7 cm) was measured for tree height during the field survey. A maximum of seven trees per species per plot were sampled for height. The sample trees were chosen regularly along the range of tree diameters within the plot. Based on this rule, 9,437 (i.e. 31.6%) of the 29,822 mapped trees have been measured for height. In the first NFI cycle, 7,559 (i.e. 33.6%) of the 22,477 mapped trees were measured for height. For the height model calculations, only live and undamaged trees were used.

17.1.1 Modelling tree height in the 2nd cycle

Based on the number sampled/measured trees, a plot Dbh-height model was calculated. Wherever the number of sampled trees for a species within a plot was sufficient, the local (i.e. plot) model was parameterised using linear or non-linear least squares. No attempt of parameterisation was done if the number of measured trees on a plot was less than four per species. If the parameterisation of the local model was unsuccessful due to an insufficient number of measured trees or their unfavourable distribution, then the global model (i.e. species for all plots) was used. The exponential model used to model the Dbh-height relationship was:

$$h = 1.3 + e^{P_1 + \frac{P_2}{dbh}}$$

For each tree species a global Dbh-height model was generated (Figure 79). If the number of height measured trees (≥4 per species) was sufficient on the plot then the local model was parameterised and used for the height calculation (Figure 80). If the local model could not be parameterised, then the global model for the respective species was used. However if at least one tree was measured then the global model was localised for that plot by adjusting one of the model parameters using the least squares method (Figure 81).

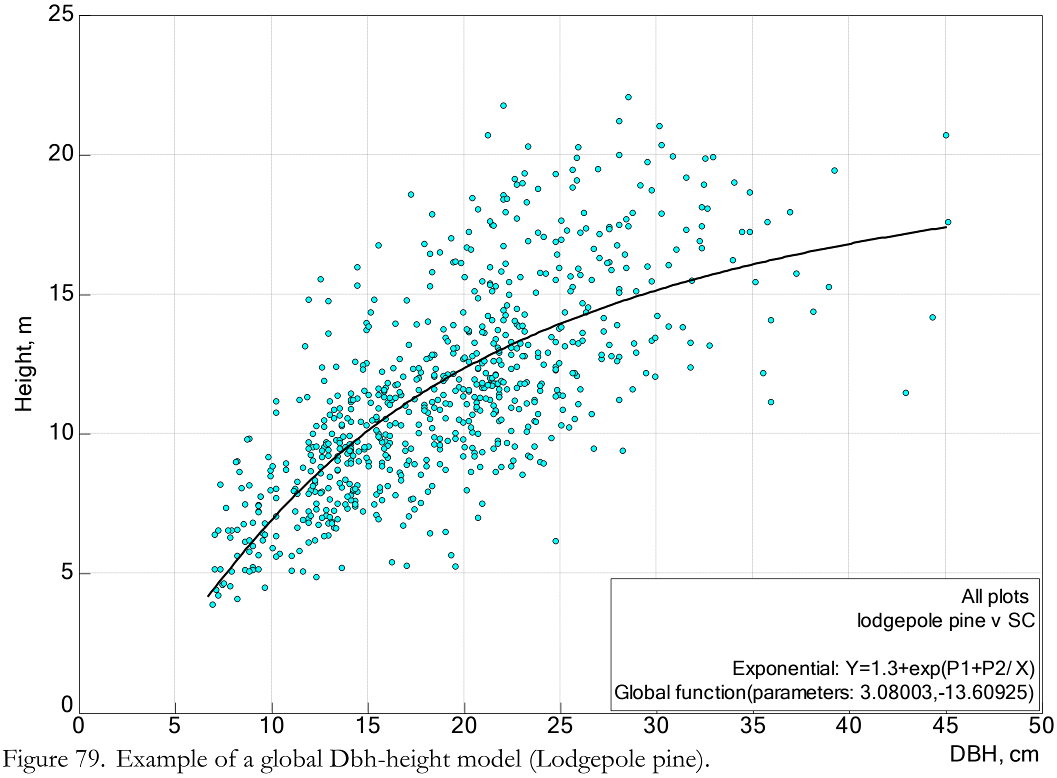


Figure 79. Example of a global Dbh-height model (Lodgepole pine).

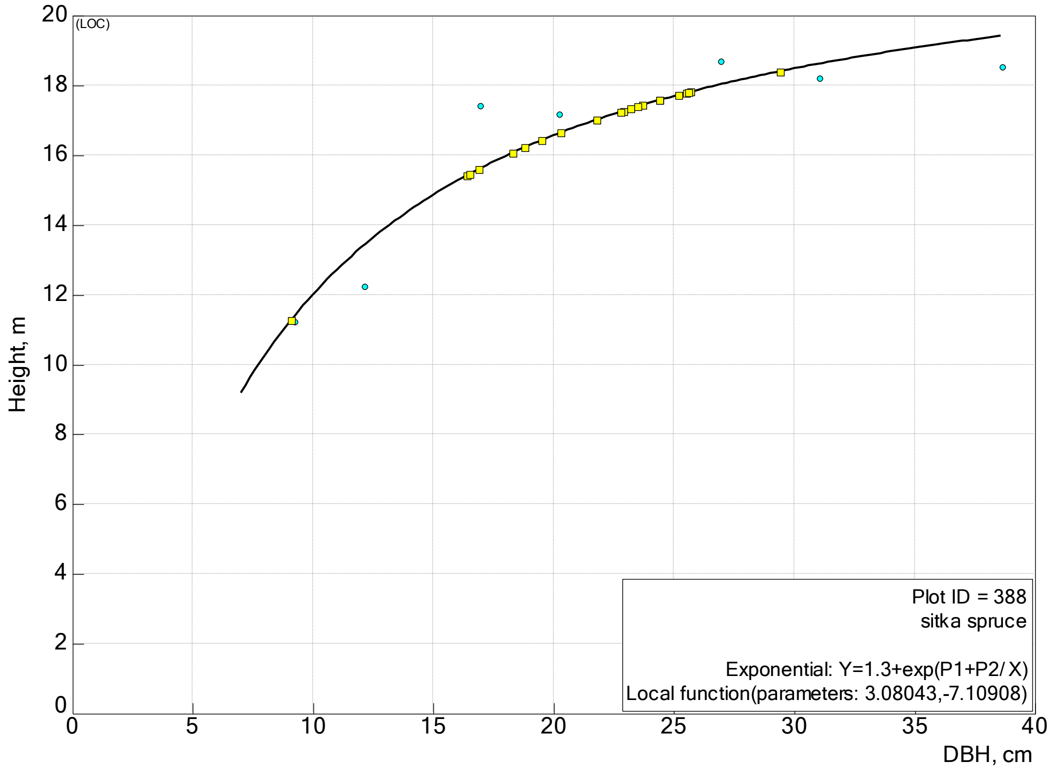


Figure 80. Example of species Dbh-height model for an individual plot.

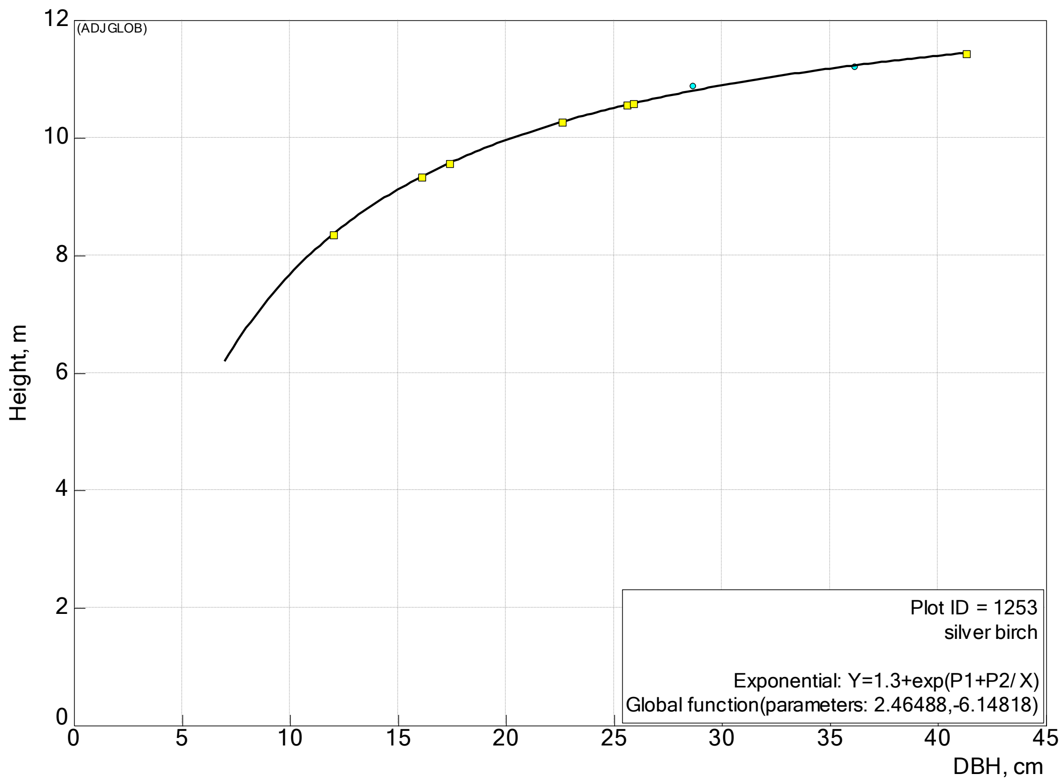


Figure 81. Global species Dbh-height model; adjusted using trees measured on the plot.

17.1.2 Modelling tree height on plots assessed for height in 1st cycle

Dbh – height models, created from the sample height trees on the plot, are used to estimate tree height for all trees on the plot. A plot level model is created where more than four trees are measured on the plot; otherwise the global species model is used.

If at least four of the same trees have been resampled for height in the second cycle and the heights have not decreased then the original model is adjusted for the height increase (Figure 82). The original model is not replaced as generating a new model could result in lower height increment for some trees. Where the first cycle height trees have been replaced with different height trees in the second cycle then a new model is generated for the second cycle trees.

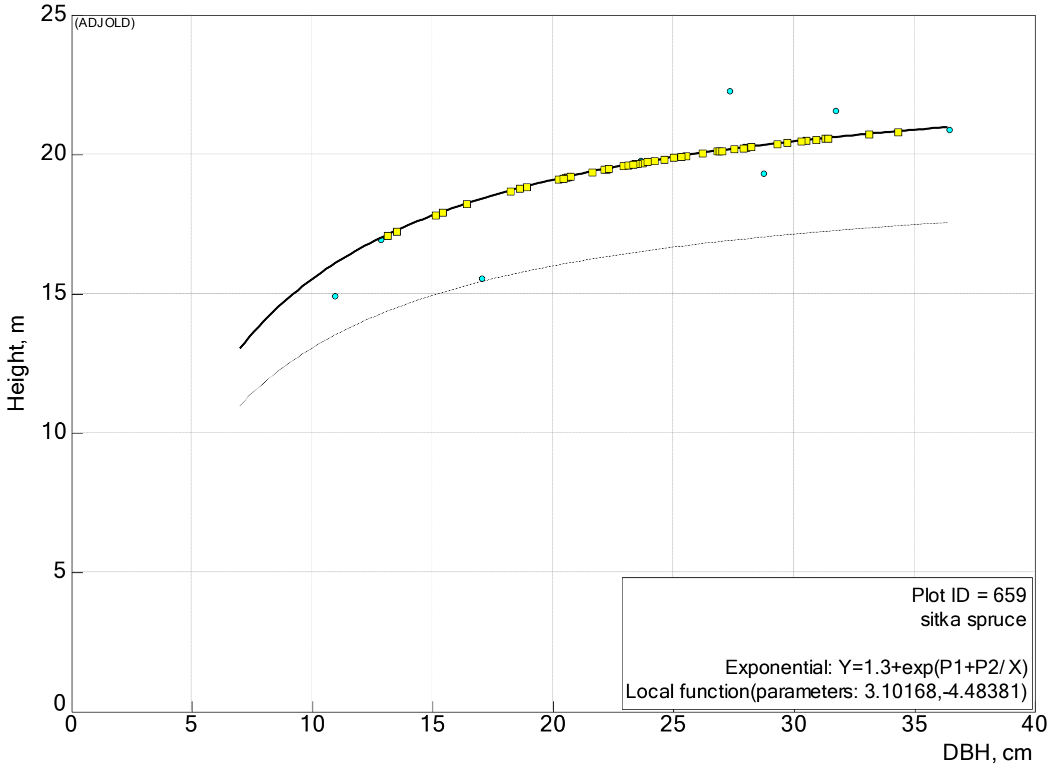


Figure 82. Plot Ht – Dbh model, continuous line is new model, dashed line old model.

17.1.3 Evaluation of Dbh-height modelling

The overall model fit is demonstrated using the chart of predicted versus observed heights (Figure 83). The standard deviation of 1.3 m and correlation coefficient 0.97 displays a good fit. An example of the global model for Lodgepole pine is presented in Figure 78. The global model has a characteristic curve, representing a mean height of Lodgepole pine for a given Dbh, across the entire population of the species..

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. The height increment is calculated as a difference of the consecutive modelled tree height values for every tree, as there is no guarantee that the particular tree will be again measured for height in the field. If a measured (1st cycle) and modelled value (2nd cycle) is used to generate a height increment value, the calculated height difference could combine growth and deviation from the model. This will not happen if modelled heights are used in both consecutive inventories.

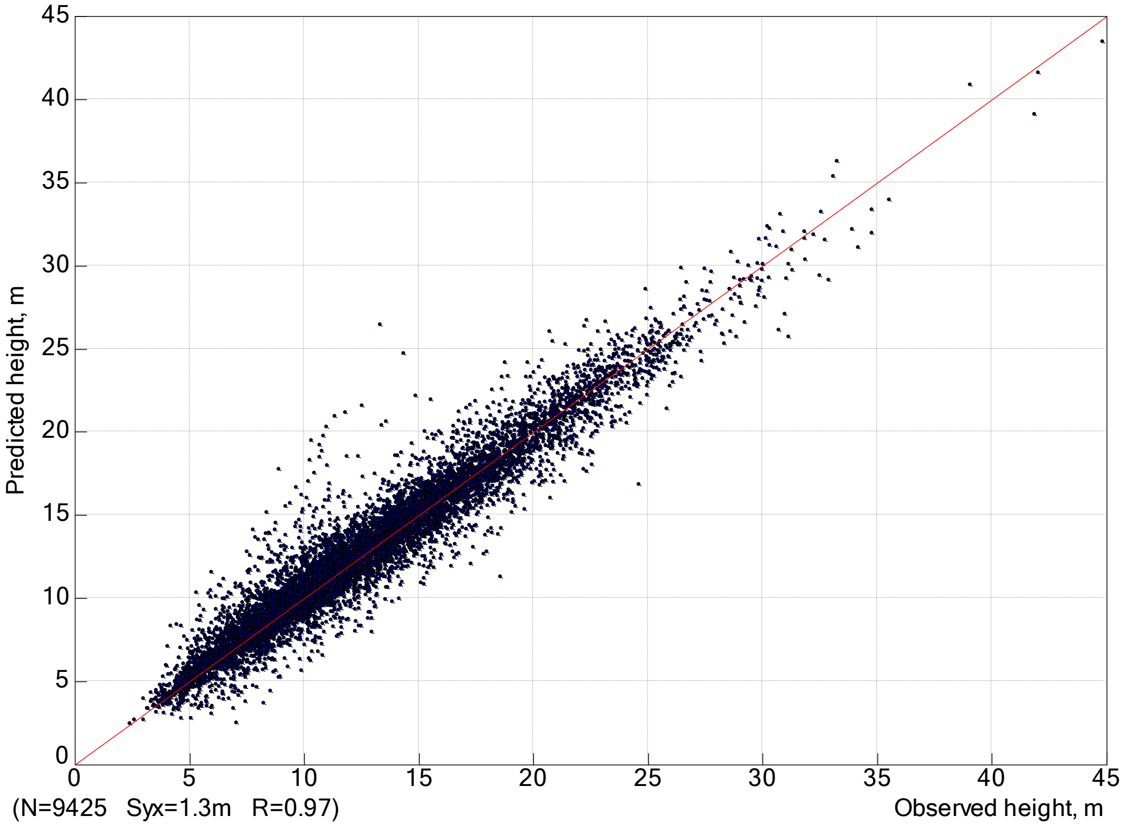


Figure 83. Predicted versus observed tree height.

17.2 MODELLING DBH INCREMENT

To calculate the Dbh increment of a particular tree it is necessary to have at least two Dbh measurements taken at different times. The difference between the two Dbh measurements is the Dbh increment.

As Ireland's NFI uses a concentric plot design to sample trees on the plot, trees are only eligible for inclusion for mapping and assessing when they satisfy the Dbh thresholds. However, when these plots are revisited during the second cycle, some or maybe all of the previously ineligible trees will have increased in Dbh and will be included for mapping and assessing, if they satisfy the Dbh thresholds. As these "ingrowth" trees were not measured in the first cycle it is not possible to calculate the increment between the two cycles directly, as the Dbh data is absent from the first cycle. The same problem occurs with harvested trees. Information is present for the first cycle, but no Dbh data is available at the time the tree was harvested.

K nearest neighbour (kNN) non-parametric modelling is used to estimate the missing Dbh values using software developed by IFER. In simplistic terms the model compares each tree which has no Dbh (e.g ingrowth, harvested trees) with all other trees that have a Dbh value, and uses predefined attribute information to find a tree that will be most similar in terms of the attribute data supplied.

17.2.1 Tree data

There are three categories of tree data present, namely:

1. First cycle Dbh unknown – e.g. ingrowth trees.
2. Second cycle Dbh unknown – e.g. harvested trees.
3. Dbh data is present for both cycles – Dbh increment can be calculated directly for these trees. Increment data from these trees form the basis of the kNN modelling process, and are the source of the Dbh data assigned to aforementioned categories i.e. calibration sample.

Each of the above categories are dealt with differently during the Dbh modelling process, a breakdown of the number and percentages of each tree type is shown in Table 9.

Table 9. Tree category and type assessed in the NFI.

Tree Category	Tree Type	Tree Number	% of Total
DBH Unknown 1st Cycle	Ingrowth	12,909	36%
	New plot tree	522	1%
	Omitted by mistake in 1st cycle	209	1%
DBH Unknown 2nd Cycle	Living to lying dead	284	1%
	Harvested tree	4,770	13%
	Standing dead to lying dead	78	0%
DBH known for both Cycles	No change	16,397	46%
	Living to standing dead	396	1%
Total		35,565	100%

17.2.2 Preparing tree data for the kNN process

A list of attributes that may be considered significant in terms of tree Dbh increment were defined and calculated (Table 10). For example Plot ID may be considered important as all trees present on the same plot will be growing under similar conditions.

Table 10. Attributes for used in kNN modelling.

Attribute list	Definition
IDPlots	Plot ID
Species	Tree species
SpecGroup	Trees are grouped into broad species categories
DBH	Tree Dbh
G	Tree basal area (BA)
H	Height (modelled)
Age	Tree age
RepreTreeN	Representative number of trees on the plot, individual tree expanded to whole plot due to concentric plot design
GMeanTree	Mean tree BA for plot
MeanDBHTree	Dbh of mean BA tree
SqrDBH	Dbh of mean BA (mBA) tree squared
PlotG	Sum of repre BA for all trees on plot, including small trees
PlotAge	Average age of mapped trees, weighed by basal area.
HDom	Average of tree heights on trees > mBA tree, excluding regeneration trees
RelDen	Plot representative tree number divided by plot mBA
DomSpec	Tree species with the greatest proportion of BA
PlotN	Number of all mapped trees on the plot.
ChPlotN	Change in tree number between NFI cycle
GLarge	Sum of BA for all the larger BA trees on the plot.
SocSt	Tree social status
RelDBH	Tree Dbh divided by Dbh of biggest tree on the plot
RelSize	Dbh divided by the mean DBH tree for the plot
TreeRank	The position of the tree on the plot sorted by increasing Dbh
Altitude	Plot altitude in metres

17.2.3 Selection process for Dbh modelling variables

From the attributes listed above, there are a large number of attributes and combinations of attributes which may be significant in terms of Dbh increment.

The kNN Dbh modelling is an iterative process, which aims to select the model with the lowest error. The process is run using core variables first. Other attributes are then added to reduce the modelling error. Only those variables that make a significant improvement are retained in the analysis. The model Root Mean Squared Error (RMSE) is used to evaluate each model. The RMSE quantifies how good the modelled variables are in comparison to the actual measured variables.

Stage 1 - Evaluate core variables for modelling

In stage 1 of the kNN modelling process, a series of models were formulated using five core variables to determine which combination of attributes is the most significant . The variables were IDPlots, Species, Dbh, Height and Age. The number of nearest neighbours selected by the model varied from 1 to 10. The model which performed best in the modelling process included all five parameters, and had a RMSE of 2.503 mm.

Stage 2 – Evaluate addition of other variables to the best stage 1 model

In stage 2 of the kNN modelling process, a series of models were formulated using the core five variables to which were added all other explanatory variables, one at a time. The number of nearest neighbours that were selected by the model varied from 1 to 10. The model which included Tree Rank with the core five parameters, performed best in the modelling process, having a RMSE of 2.422 mm.

Stage 3 - Evaluate the combination of the variables from the best stage 2 model

Those variables which performed well in stage 2, i.e. TreeRank and GMeanTree were retained for stage 3 of the kNN modelling process. A series of models were formulated using these variables. The number of nearest neighbours that were selected by the model ranged from 1 to 10. The model which excluded height, performed best in the modelling process, having a RMSE of 2.399 mm.

Stage 4 - Evaluate the parameter exponent weight

After determining which set of variables returned the lowest RMSE, there were 3 different parameter weight exponents for the *k*-nearest multivariate neighbours to be tested:

1. Equal weights (p=0), uses equal weights;
2. Inverse distance weighting (p=1), uses an inverse distance weighted average;
3. Square inverse distance weighting (p=2), uses an inverse squared distance weighted average.

The model evaluation was carried out again using the root mean squared error. It was found that using the inverse distance weighted average for the *k*-nearest multivariate neighbours resulted in the lowest RMSE.

Stage 5 - Evaluate the variable weights

The impact of weighting the input variables on the Dbh increment model was assessed next. Using the root mean squared error the optimum weight was ascertained (Table 11).

Table 11. Stage 5 variable weighting.

	IDPlots	Species	Dbh	Age	TreeRank	GMeanTree
Optimum weight	1	2	1	2	1	1

Stage 6 - Evaluate the number of nearest neighbours to use in final model

The final stage in the development of the Dbh increment model was to assess the optimal number of nearest neighbours for use in the model. Model evaluation was carried out again using the root mean squared error. The model which used 16 nearest neighbours performed best in the modelling process, having a RMSE of 2.34232 mm.

17.2.4 Evaluating the Dbh increment model

The RMSE of the final model was 2.3 mm. The poorest performing model had a RMSE of 3.6 mm. As Dbh increment was dependent on many factors, reduction in the RMSE proved difficult. To evaluate the overall precision of the estimation procedure, the model RMSE was divided by the average measured Dbh increment. The coefficient of determination (R^2) was 0.69. In Figures 84 and 85, graphical analysis shows where the model displayed bias in two areas for those trees that had:

1. A large measured Dbh increment, the model under estimated Dbh increment;
2. A small measured Dbh increment, the model over estimated Dbh increment.

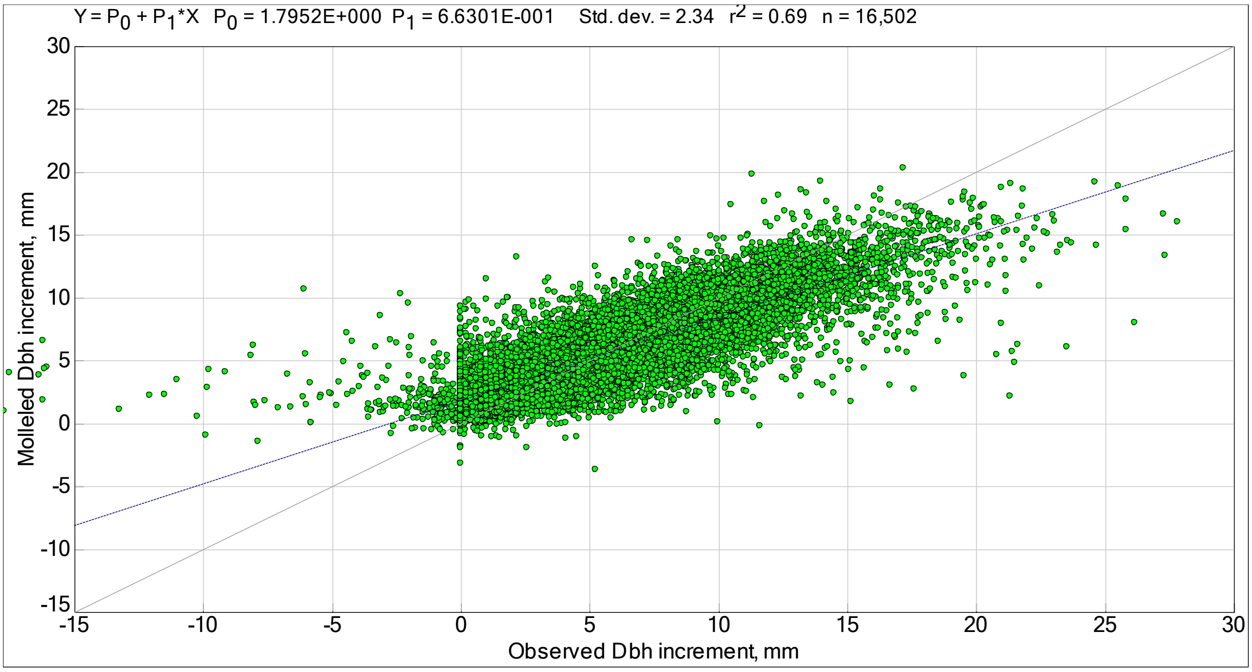


Figure 84. Comparison of modelled Dbh increment versus observed increment

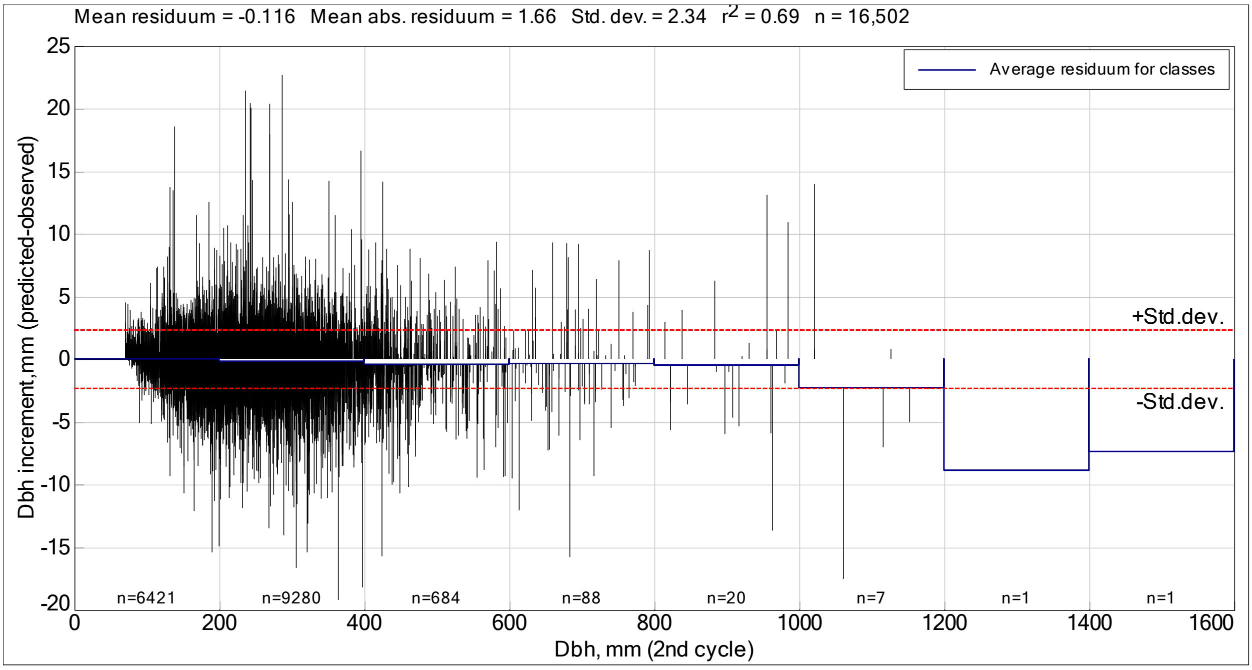


Figure 85. Assessment of residuals, modelled Dbh increment versus observed increment

17.3 VOLUME MODELS

This section details the estimation of standing volume for conifer and broadleaf species.

17.3.1 Conifer volume models

In the first NFI cycle, the British Forestry Commission (BFC) single tree volume equations (Matthews and Mackie 2006) were used to estimate the standing volume for each tree on the plot with a minimum Dbh of 7 cm. The stem volume was measured from the ground to 70 mm top diameter overbark.

Since the first cycle, conifer single tree stem profile models were generated using Irish data. Funded by the National Council for Forest Research and Development (COFORD), the TREEMODEL project[8] developed models for six conifer species; Sitka spruce, Lodgepole pine, Japanese larch, Douglas-fir, Norway spruce, and Scots pine. Tree data used to parameterise the model were obtained from the destructive sampling of trees in experimental plots in Ireland since 1971.

This new model uses the explanatory variables of Dbh and height to generate volume. The performance of the new conifer models is very good, with an R^2 of 0.99. Graphical analysis shows that the model produces unbiased results (Figures 86 and 87). The evaluation undertaken must be considered non-independent as the data used to evaluate the model is the same data that was used to generate the model.

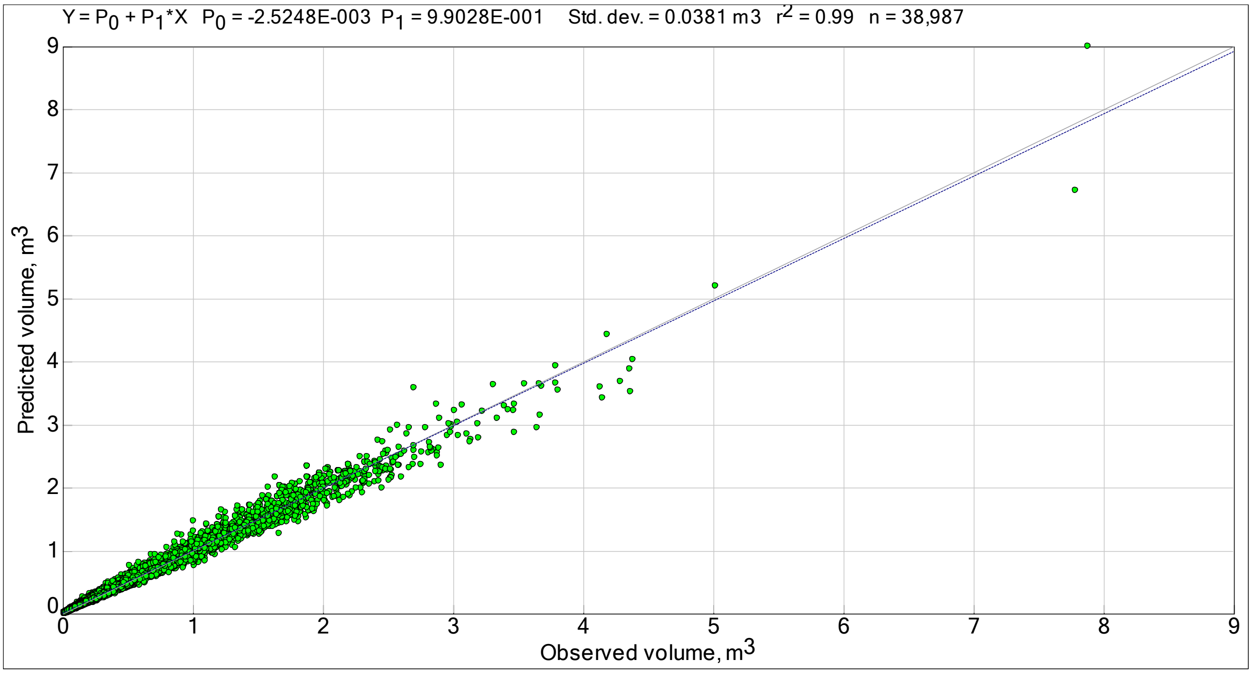


Figure 86. Comparison of modelled conifer volume versus conifer volume.

[8] http://www.coford.ie/researchprogramme/thematicareaestablishingandgrowingforests/forestplanningandmanagement/treemodel/

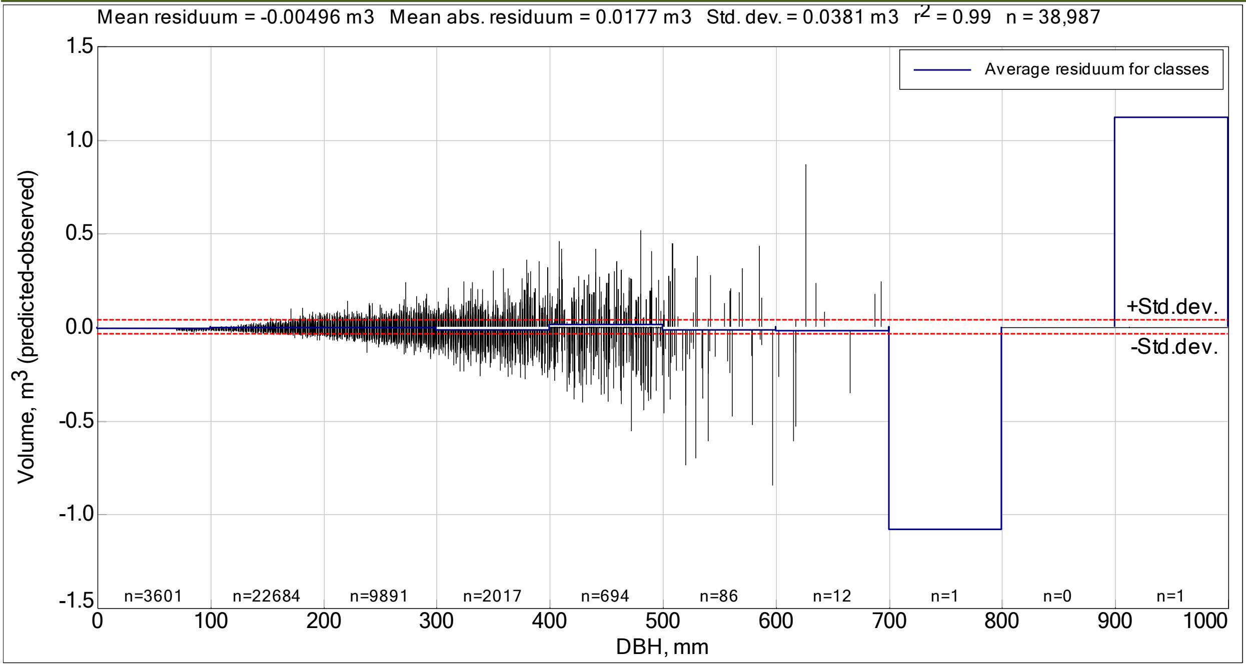


Figure 87. Assessment of residuals, modelled conifer volume versus observed volume

17.3.2 Broadleaf volume models

As with the conifer tree species, the British Forestry Commission single tree volume equations (Matthews and Mackie 2006) were used to estimate standing merchantable volume for each tree on the plot with a minimum Dbh of 7 cm in the first NFI cycle. The broadleaf stem volume was measured from the ground to timber height.

Following the completion of the second cycle field-work, single tree stem profile models have been developed for four broadleaf species. Stem profile data was collected non-destructively from broadleaf forests across Ireland by NFI field staff from January to May 2013 (Table 12).

Table 12. Trees sampled for broadleaf stem profile model.

COUNTY	Birch	Beech	Ash	Oak	Total
CARLOW	-	-	10	-	10
CAVAN	44	-	13	-	57
CLARE	40	14	85	13	152
CORK	22	44	61	31	158
DONEGAL	15	-	15	-	30
DUBLIN	-	64	3	1	68
GALWAY	16	27	73	81	197
KERRY	40	91	5	118	254
KILDARE	14	136	199	-	349
KILKENNY	1	7	70	79	157
LAOIS	-	101	14	22	137
LIMERICK	23	3	92	19	137
LONGFORD	38	-	-	19	57
MAYO	-	-	20	-	20
MEATH	-	45	67	2	114
OFFALY	15	1	33	37	86
ROSCOMMON	25	10	46	48	129
SLIGO	-	65	58	59	182
TIPPERARY	42	94	194	142	472
WATERFORD	35	169	68	113	385
WESTMEATH	51	1	64	-	116
WEXFORD	-	53	19	132	204
WICKLOW	252	63	13	398	726
Total	673	988	1,222	1,314	4,197

The model uses the explanatory variables of Dbh and height to generate volume. The performance of the broadleaf models was very good, with an R^2 of 0.97. Graphical analysis show that the model produced unbiased results in the main, but slightly underestimated the volume of large trees (Figures 88 and 89). Again, the evaluation undertaken must be considered non-independent as the data used to evaluate the model is the same data that was used to generate the model.

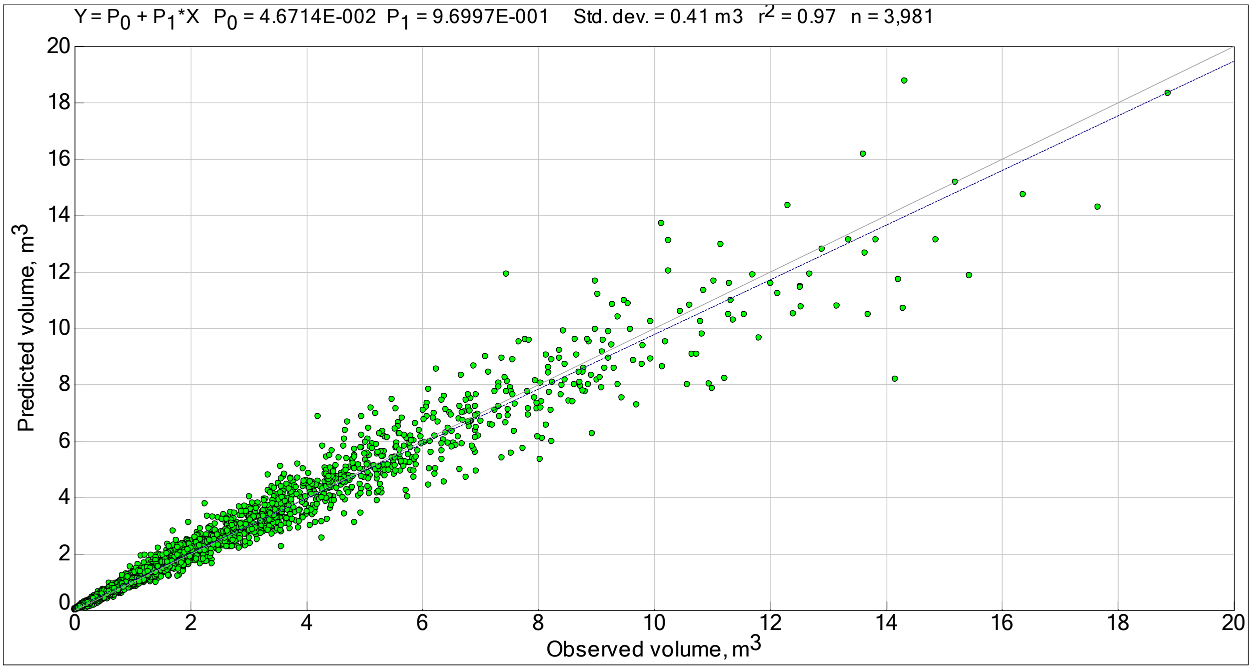


Figure 88. Comparison of predicted broadleaf volume versus observed volume.

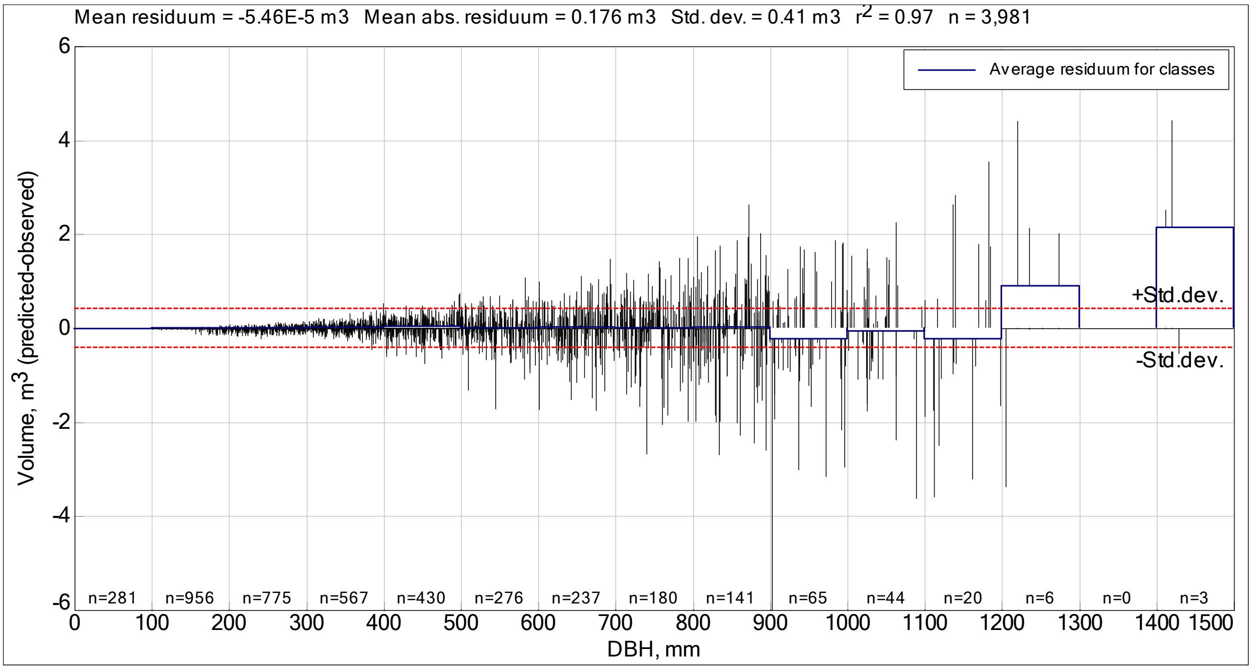


Figure 89. Assessment of residuals, modelled broadleaf volume versus observed volume

17.3.3 Volume model components

The stem profile volume models facilitate the production of volume equations to a specified top diameter or height. Stump height was set at 1% of the total tree height. Four different types of overbark tree volumes were produced in this second cycle namely:

1) Ground to 7 cm top diameter overbark;
2) Ground to tip overbark;
3) Stump to 7 cm top diameter overbark;
4) Stump to tip overbark.

17.4 ESTIMATING ANNUAL INCREMENT BETWEEN NFI CYCLES

An important feature of the NFI is the assessment of annual increment in the forest estate. To calculate increment two estimates are needed at different points in time. The difference between the two estimates is the total increment. The annual increment is generated by dividing the total increment by the time period in years.

In Ireland a trees growing season is generally from mid Spring to late Autumn. The growth rate varies over the growing season depending on the climatic conditions. Therefore to calculate annual increment, ideally, plots need to be assessed at the same time of the year when the time period between assessments is a whole growing season. Due to logistics of field data collection it is not possible to revisit a plot at exactly the same time of the year when first visited. Where a plot is not revisited at the same time, the increment period will be an integer. To calculate this increment period it is necessary to model tree growth over the growing season, this enables assessment of how much of the growing season has accrued at the point in time of plot visit..

17.4.1 Modelling cumulative tree increment

In the period 1961-1967, a study aimed at providing information on the dates of commencement, cessation, and seasonal pattern of basal area growth of Sitka spruce, Norway spruce, lodgepole pine and Scot's pine was undertaken by O'Muirgheasa (1970). On average growth commences on the 16th March and ceases on the 19th October. The percentage of average cumulative basal area growth over the calendar year for the four species is described in Figure 90.

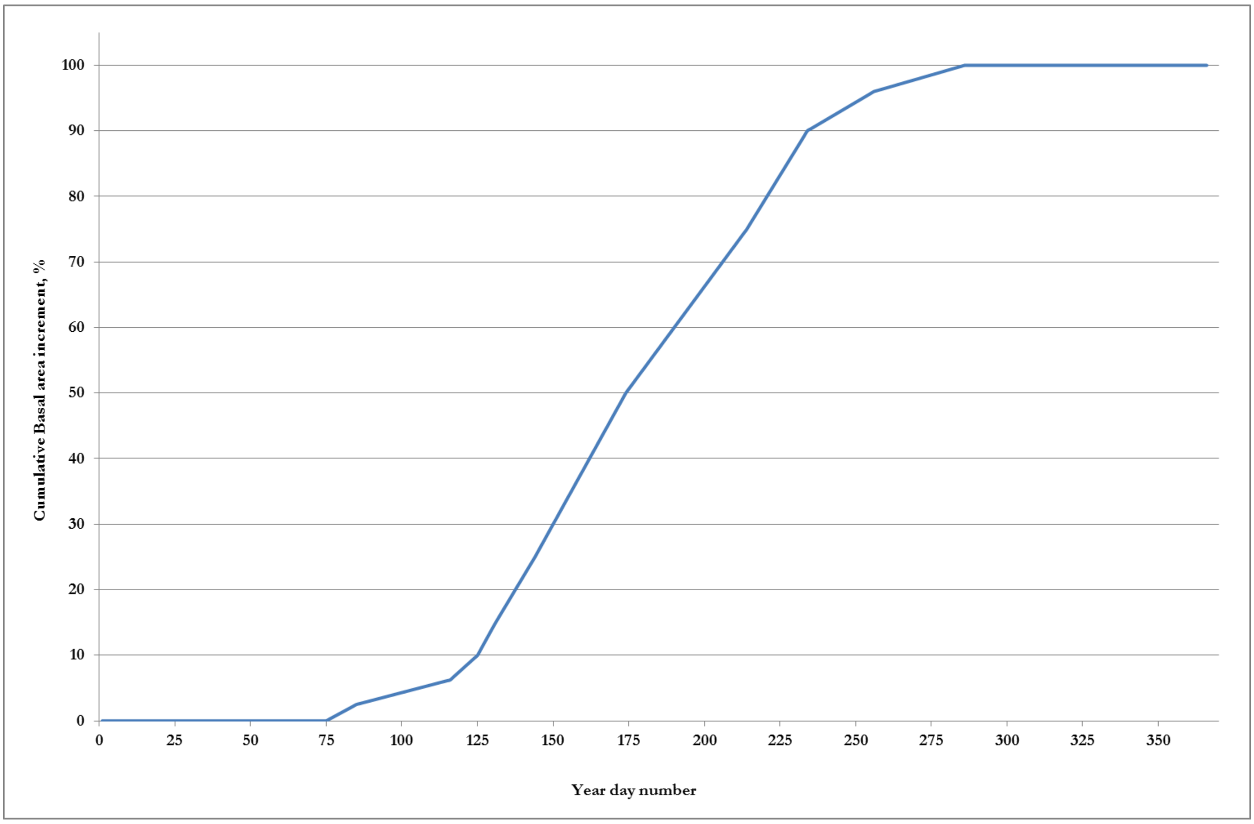


Figure 90. Cumulative basal area growth over the calendar year (O'Muirgheasa 1970).

17.4.2 Calculating increment period

Using the average daily increment data specified in Figure 90, the proportion of cumulative increment was assigned to each plot for both the 1st and 2nd cycle assessment dates. The cumulative increment for the 2nd cycle was then subtracted from the cumulative increment for the 1st cycle, to calculate the difference in increment between the sampling months. Finally, the monthly increment difference is subtracted from the sample year difference to calculate the increment period in years (Table 13).

Table 13. Calculating the increment period for individual NFI plots.

Plot ID	1st Cycle Date	2nd Cycle Date	1st Cycle Cumulative Growth	2nd Cycle Cumulative Growth	Sample Month Difference	Sample Year Difference	Increment Period Years
54	15-Aug-05	30-Jun-10	0.6968	0.4000	0.2968	5	4.7032
224	02-Aug-05	08-Jul-10	0.6129	0.4516	0.1613	5	4.8387
365	01-Feb-05	13-Apr-10	0.0000	0.0000	0.0000	5	5.0000
510	03-Jul-06	02-Jun-10	0.4194	0.2133	0.2060	4	3.7940
549	08-Jul-05	09-Jul-10	0.4516	0.4581	-0.0065	5	5.0065
624	10-Jul-06	02-Jun-10	0.4645	0.2133	0.2512	4	3.7488
669	21-Jul-05	09-Jul-10	0.5355	0.4581	0.0774	5	4.9226
803	11-Mar-05	05-Nov-09	0	1	-1	4	5

17.5 Forest area statistics - Plot area vs representative area

Forest area statistics for the purposes of NFI results were derived using two methods:

1. Plot Area

Variables collected at plot level (e.g. Ownership) represented the total plot area at a national level. The entire land base of Ireland is represented by 17,423 NFI plots with each one representing approximately 400 ha. For example, one plot classified as being privately owned will represent 400 ha of privately owned land nationally.

2. Representative Area

A representative area is calculated for each measured tree on the plot that is proportional to the tree size, i.e. the larger the tree, the greater the representative area. For each forest plot, where trees are present, the sum of individual tree representative areas will equal the total plot area of 500 m^2. Where the evaluated variable, forest area, is classified in terms of tree variables (e.g. species), the representative area is used to calculate forest area. For example, in order to estimate the total area of Norway spruce the portion of each plot represented by Norway spruce is aggregated to a national level.

17.6 Evaluated variables, classifiers, stratifiers

Various statistics are estimated for various evaluated variables; in most cases these statistics include area, volume and/or number of individuals. Statistics of evaluated variables are also calculated for different classes (such as tree species, ownership class etc.) and different strata (such as counties).

The following statistical variables can be estimated using Inventory Analyst. A review of the associated formulae is detailed in Table 14.

1. Population total (e.g. the total stand volume of a forested area);
2. Mean value (e.g. mean volume per hectare). Several variants of mean calculation can be applied.
   a) A simple **arithmetic mean** of plot totals.
   b) **Mean value per hectare** is calculated as a mean value of plot totals recalculated per hectare.
   c) A **weighted mean** can be calculated as a mean value of weighted means calculated for individual plots, for instance the weighted mean of the tree defoliation is calculated via weighing tree defoliation by the tree basal area.
   d) Another way is the so called **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 plot where the given variable is represented. An example of this would be normalised mean volume per hectare by species.
3. The confidence limit for $\alpha = 0.05$ for each statistical variable was estimated.

The following list of variables are presented in the following sections

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 is the area of inventory plot 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

Table 14. 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.*

17.7 STATISTICAL METHODS

The statistical methods used in the Inventory Analyst software represent standard methods used for simple and stratified sampling design (e.g. Thomson 1992).

17.7.1 Stratifying the population

A geographical region or population may be stratified into more homogenous areas (i.e. strata) such as habitat type, elevation, or soil type. Each stratum is treated as a separate sub-population, with the results from different strata combined using appropriate weights to obtain an overall estimate for the population. Even if a large geographic study area appears to be homogeneous, stratification into blocks (e.g. counties) can help to 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

$$\mu = \tau / N$$

Note: All the calculations 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 of the population mean (see 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 different stratification. Consequently, in order to avoid such a contradiction, only standard calculations supposing the normal distribution of variables were applied.

17.7.2 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 estimator $\hat{\tau}_h$ with respect to that design. Let $\text{var}(\hat{\tau}_h)$ denote the variance of $\hat{\tau}_h$, and suppose that one has an unbiased estimator $\widehat{\text{var}}(\hat{\tau}_h)$ of that variance.

Then an unbiased estimator of the overall population total τ 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:

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

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

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

If the stratum sample is selected by a simple random sampling procedure without replacements, then

$$\hat{\tau}_h = N_h \bar{y}_h$$

is an unbiased estimator of τ_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 τ is

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

having variance

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

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 $\hat{\tau}_{st}$ is

$$\hat{\operatorname{var}}(\hat{\tau}_{st}) = \sum_{h=1}^{L} N_h (N_h - n_h) \frac{s_h^2}{n_h} \qquad (1)$$

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*.

17.7.3 Estimating the population mean

Since $\mu = \tau / N$, 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

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

with unbiased estimator of variance

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

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

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

17.7.4 Confidence intervals

When all the stratum sample sizes are sufficiently large, an approximate 100(1-α)% 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 $\alpha/2$ 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

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

where

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

17.7.5 Considering variable weights

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

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

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

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 $w_i \cdot N/W$.

17.7.6 Using concentric circles at inventory plots

Data of trees of different dimensions (based on Dbh thresholds) were collected using concentric circles (see description of field data collection). Data collected using the concentric circle approach were processed as being collected from independent inventories within strata. Thus an unbiased estimator of the overall population total τ 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 summarised, assuming that the data from individual circles were uncorrelated:

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

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APPENDICES

APPENDIX 1 LIST OF NFI FIELD EQUIPMENT

Field Computer and Accessories

Hammerhead XRT™ 833 MHz field computer
Hammerhead XRT™ carry-case and pen
Hammerhead serial port replicator (Champs connector)
Hammerhead XRT™ battery x 6 (Rechargeable)
Hammerhead XRT™ mains 'ac adaptor' with power cable
Hammerhead XRT™ charger
Hammerhead XRT™ battery charger 'switching adapter' with power cable
Hammerhead XRT™ gold peak cigarette charger
Hammerhead XRT™ harness and docking plate
Usb flash drive x 2

Compass/laser and accessories

Mapstar™ Electronic compass
Impulse™ Laser
36" cable compass to computer
20" cable laser to compass
8 x AA batteries (re-chargeable)
Battery charger for AA batteries and power supply
Carbon monopod
1 x compass/laser cover bag

Reference pole and accessories

Telescopic main pole 4.57 m
Cover for telescopic main pole
2 x 1 m reference poles
2 x circular reflectors
1 x cylindrical reflectors
2 x large locking bolt for circular reflector
2 x small locking bolts for cylindrical reflectors

GPS and accessories

Trimble PRO XRT DGPS unit in hard case unit - 4 x GPS batteries and charger
Trimble PRO XRT backpack - 1 x Trimble PRO XRT carry case

Other items

- 2 x laminated sets of numbers
- 1 x backpack
- 1 x metal hard case
- 1 x Philips screwdriver
- 4 x socket extension lead
- 1 x spade
- 2 x tree loppers
- 2 x 'builders' 5 m tape
- 2 x 500 mm Dbh tape
- 1 x 800 mm Dbh tape
- 2 x silky hand saws
- 1 x slash hook
- 1 x 15 m loggers tape
- Centre poles
- Thumb-tacks (Plastic topped)
- Marking paint
- 2 x mobile phones (Vodafone and O_2)
- 1 x First-aid kit
- 1 x digital camera
- 1 x lump hammer

Reference Books

- Rushes, grasses and sedges (Fitter and Fitter 1984)
- Wild Flower ID (Rose 1981)
- Tree ID book (Johnson and Moore 2004)
- Fern ID (Merryweather and Hill 1992)
- General Soil map of Ireland, (Gardiner and Radford 1980).

APPENDIX 2 HARDWARE COMPONENTS

Field Computers

A hammerhead XRT™ (HHXRT) field computer was chosen as the computer for field data collection in the NFI (Figure 91). The HHXRT is a rugged pen-tablet field computer with similar capabilities to most office base PCs. It offered the suitable durability and performance necessary in harsh environmental conditions associated with the field phase of the NFI. Some technical specifications on the HHXRT are provided below:

- Pentium III 933 MHz processor with 256 MB RAM, 40 GB HDD and 8 MB ATI Rage Mobility graphics;
- Operating system is Microsoft Windows XP;
- 8.4" Daylight readable SVGA TFT with resistive touch screen;
- Ports are 1 x USB, 1 x RS232, 1 x docking, mic/spk, 2 x internal mini PCI slots, 2 x Type II/1 x Type III PCMCIA slots, Primary Li-ion battery (3 hrs operation)(external secondary option –additional 4 hrs);
- Dimensions are 250 x 190 x 35 mm; and
- Weight is 1.6 kg.

Figure 91. Hammerhead XRT™ field computer.

Global Positioning System (GPS)

The purpose of the GPS is to aid navigation to the plot centre. The Trimble Pro XR series of GPS units (Figure 92) use differential correction (DGPS) in order to achieve the accuracy needed in the NFI. This differential signal was provided from radio signals broadcast by the Commissioners for Irish Lights. As the DGPS signal is delivered in real time, the variation around the real position could be three metres.

Figure 92. A Trimble™ Pathfinder Pro XR Series GPS.

Laser Range Finder and Electronic Compass

The Impulse™ laser range finder, with built in inclinometer (Figure 93) and Mapstar™ electronic compass (Figure 94) are used for many purposes in the NFI. For example, to aid navigation to plot centres, to map tree positions, to measure tree height and crown projections, record the slope and aspect of plots.

Figure 93. Impulse™ laser range finder and remote diameter scope.

Figure 94. Mapstar™ electronic compass.

Remote Diameter Scope

A magnified remote diameter scope (Figure 93) is fitted to the laser rangefinder. This is used to obtain upper diameters of trees and to aid viewing objects. A graduated scale within the scope is used in the measurement of upper stem diameter (+/-10 mm).

Configuration of the Field Equipment

The laser rangefinder, remote diameter scope and electronic compass are arranged on a carbon monopod. GPS, Laser and compass are connected to the field computer via a serial port replication cable with two communication ports. The tablet PC is mounted in a harness, which is supported by shoulder straps, both hands are free for equipment control. The tablet PC remains visually clear at all times, during navigation to the plot and while plot measurement is undertaken (Figure 95).

Figure 95. Configuration of field equipment.

Reference Pole and Reflector

Two types of poles are used, namely a graduated telescopic main pole with built in plumb level and a graduated reference pole. The main pole is used for laser measurements while the reference pole is used for positioning on the plot.

Mobile Phone

The mobile phone is an integral component of field-work as it allowed communication links to be maintained to provide:

- Element of safety;
- Technical support;
- The relay of instructions and;
- Private owner contact.

APPENDIX 3 PLANT SPECIES

Aegopodium podagraria
Agrostis capillaris
Agrostis sppp.
Agrostis stolonifera
Achillea millefolium
Ajuga reptans
Alliaria petiolata
Allium ursinum
Anemone nemorosa
Anemone ranunculoides
Angelica sylvestris
Antennaria dioica
Anthriscus sylvestris
Anthoxanthum odoratum
Aquilegia vulgaris
Arctium minus
Arrhenatherum elatius
Arum maculatum
Aspplenium sppp.
Aspplenium ceterach
Aspplenium viride
Asppelium scolopendrium
Asppelium tricohomanes
Athyrium filix-femina
Atropa bella-donna
Betonica officinalis
Blechnum sppicant
Brachypodium pinnatum
Brachypodium sylvaticum
Bromus spp.
Buglossoides purpurocoerulea
Calamagrostis epigeios
Calamagrostis spp.
Calluna vulgaris
Caltha palustris
Calystegia sepium
Campanula spp.
Capsella bursa-pastoris
Cardamine spp.
Cardamine pratensis
Carex binervis
Carex pendula
Carex pilulifera
Carex spp.
Carex sylvatica
Cerastium fontanum
Ceterach officinarum
Chamerion angustifolium
Chelidonium majus
Chenopodium album
Chrysospplenium oppositifol
Circaea lutetiana
Cirsium arvense

Cirsium palustre
Cirsium vulgare
Clematis vitalba
Conopodium majus
Convallaria majalis
Cystopteris fragilis
Cytisus scoparis
Dactylis glomerata
Deschampsia caesppitosa
Deschampsia flexuosa
Dianthus spp.
Dicranum spp.
Dicranella spp
Digitalis purpurea
Dryopteris spp.
Dryopteris affinis
Dryopteris carthusiana
Dryopteris dilatata
Dryopteris filix-mas
Empetrum nigrum
Epilobium augustifolium
Epilobium hirsutum
Epilobium montanum
Equisetum arvense
Equisetum sylvaticum
Erica cinerea
Erica tetralix
Eriophorum agustifolium
Eriophorum spp.
Eriophorum vaginatum
Eupatorium cannabinum
Euphorbia amygdaloides
Euphorbia spp.
Festuca altissima
Festuca heterophylla
Festuca ovina
Festuca ruba
Filipendula ulmaria
Fragaria spp.
Fragaria vesca
Fuchsia magellanica
Funaria hygrometrica
Fuscia spp.
Galanthus nivalis
Galeobdolon spp.
Galeopsis tetrahit
Galium aparine
Galium odoratum
Galium saxatile
Galium vernum
Geranium pratense
Geranium robertianum
Geranium sanguineum

Geranium spp.
Geranium sylvaticum
Geum urbanum
Glechoma hederacea
Grimmia pulvinata (moss)
Gymnocarpium dryopteris
Hedera helix
Heracleum spphondylium
Hieracium spp.
Holcus lanatus
Holcus mollis
Homalothecium sericeum
Hordelymus europaeus
Hyacinthoides non-scripta
Hymenophyllum tunbrigense
Hymenophyllum wilsonii
Hypericum perforatum
Hypnum jutlandicum
Hypericum pulchrum
Hypnum cupressiforme
Hypochoeris radicata
Hypochoeris glabra
Impatiens grandulifera
Impatiens parviflora
Iris pseudacorus
Isothecium myosuroides
Juncus acutiflorus
Juncus articulatus
Juncus bulbosus
Juncus conglomeratus
Juncus effusus
Juncus inflexus
Juncus spp.
Juncus squarrosus
Koeleria glauca
Lamiastrum galeobdolon
Lamium purpureum
Lathyrus pratensis
Lathyrus montanus
Leucobryum glaucum
Lilium martagon
Lobelia dortmanna
Lolium multiflorum
Lolium perenne
Lonicera periclymenum
Lotus corniculatus
Lotus pedunculatus
Luzula campestris
Luzula luzuloides
Luzula multiflora
Luzula pilosa
Luzula sylvatica
Lycopodium spp.

Lysimachia nemorum
Lysimachia spp.
Lysimachia vulgaris
Maianthenum bifolium
Matteuccia struthiopteris
Melampyrum pratense
Melampyrum spp.
Melica uniflora
Mercurialis perennis
Milium effusum
Mnium spp. (moss)
Molinia caerulea
Mycelis spp.
Myosotis arvensis
Myrica gale
Nardus stricta
Oenanthe crocata
Osmunda regalis
Oxalis acetosella
Papaver rhoeas
Papaver dubium
Pedicularis sylvatica
Petasites albus
Phalaris arundinacea
Phegopteris connectilis
Phleum pratense
Phyllitis scolopendrium
Pleurozium schreberi
Poa annua
Poa nemoralis
Poa pratensis
Poa spp.
Poa trivialis
Polygonatum multiflorum
Polygonum spp.
Polypodium spp.
Polystichum aculeatum
Polystichum setiferum
Polytrichum spp. (moss)
Potentillia erecta
Primula veris
Primula vulgaris
Pteridium aquilinum
Pulmonaria spp.
Ranunculus ficaria
Ranunculus flammula
Ranunculus repense
Ranunculus spp.
Rhodendron ponticum
Rhytidiadelphus spp.
Rosa arvensis
Rubus caesius
Rubus fruticosus
Rubus idaeus
Rubus spp.

Rumex acetosa
Rumex acetosella
Rumex obtusifolius
Rumex spp.
Sanicula europaea
Schistidium apocarpum
Scirpus sylvaticus
Senecio jacobea
Sesleria albicans
Sesleria spp.
Schoenus nigricans
Silena spp.
Silene dioica
Silybum marianum
Solidago virgaurea
Spphagnum spp. (moss)
Stachys sylvatica
Stellaria holostea
Stellaria media
Succisa pratensis
Symphytum officinale
Teucrium scorodonia
Teucrium spp.
Thuidium tamariscinum
Tortula muralis (moss)
Trichomanes sppeciosum
Tricophorum cesppitosium
Trifolium pratense
Trifolium repens
Trifolium spp.
Typha spp.
Ulex europaeus
Ulex galia
Umbilicus rupestris
Urtica dioica
Urtica urens
Vaccinium myrtillus
Vaccinium oxycoccos
Vaccinium vitis-idaea
Valeriana officinalis
Veronica chamaedrys
Veronica montana
Veronica spp.
Vicia sativa
Vicia sepium
Vicia spp.
Vinca minor
Viola riviniana
Viola spp.
Aethusa cynapium
Aspplenium adiantum-nigrum
Bellis perennis
Cerastium holosteoides
Cirsium acaule
Cynosurus cristatus

Deschampsia setacea
Drosera rotundifolia
Elymus caninus
Equistium fluviatile
Hydrocyte vulgaris
Lapsana communis
Mentha arvensis
Menyanthes trifoliata
Narthecium ossifragum
Phragmites communis
Pinguicula lusitanica
Plantago lanceolata
Plantago major
Polygala serpyllifolia
Polygala vulgaris
Polygonum hydropiper
Potentilla anserina
Potentilla palustris
Potentilla reptans
Potentilla sterillis
Prunella vulgaris
Ranunculus acris
Rhamnus catharticus
Rumex sanguineus
Saxifraga sppathularis
Scabiosa succisa
Scrophularia nodosa
Taraxacum officinale
Veronica serpyllifolia
Pulicaria dysenterica
Centaurea nigra
Dactylorhiza maculata
Dactylorhiza fuchsii
Galium palustre
Senecio aquaticus
Spparganium erectum
Sonchus arvensis
Sonchus oleraceus
Lyththrum salicaria
Solanum nigrum
Carex paniculata
Plagiothecium undulatum
Campylopus introflexus
Dicranum scoparium
Dicrenella heteromalla
Rhytidiadelphus loreus
Bazzania spp
Kindbergia praelonga
Crocosmia crocosmiiflora
Hypericum androsaemum
Solanum dulcamara
Lychnis flos-cuculi

APPENDIX 4 SHRUB SPECIES

Alnus viridis
Amelanchier ovalis
Berberis sp.
Betula nana
Buxus sempervirens
Calluna vulgaris
Clematis vitalba
Cornus mas
Cornus sanguinea
Corylus avellana
Cotoneaster integerrima
Crataegus monogyna
Crataegus. sp.
Daphne mezereum
Escallonia sp.
Euonymus europaea
Euonymus verrucosa
Frangula alnus
Hedera helix
Humulus lupulus
Ilex aquilifolium
Juniperus sp.
Ligustrum sp.

Lonicera periclymenum
Malnus sylvestris
Prunus laurocerasus
Prunus mahaleb.
Prunus padus
Prunus spinosa
Rhamnus cathartica
Rhamnus frangula
Rhamnus sp.
Ribes sp.
Ribes uva-crispa
Rhodendron ponticum
Rosa sp.
Salix sp.
Salix caprea
Sambucus nigra
Sambucus racemosa
Solanum sp.
Staphylea pinnata
Syringa vulgaris
Tamaris communis (Yam)
Viburnum lantana
Viburnum opulus

APPENDIX 5 LIST OF TREE SPECIES USED IN THE NFI

Abies alba	Pinus contorta v. NC	other hard broadleaves
Abies concolor	Pinus contorta v. SC	other soft broadleaves
Abies grandis	Pinus mugo var. mughus	
Abies nordmanniana	Pinus mugo var. uncinata	
Abies procera	Pinus nigra v. maritima	
Abies sp.	Pinus radiata	
Acer campestre	Pinus silvestris	
Acer negundo	Pinus strobus	
Acer platanoides	Pinus sp.	
Acer pseudoplatanus	Platanus acerifolia	
Acer sp.	Populus alba	
Aesculus hippocastanum	Populus canescens	
Ailantus altissima	Populus cultivated	
Alnus glutinosa	Populus balsamifera	
Alnus incana	Populus nigra	
Alnus viridis	Populus tremula	
Arbutus unedo	Prunus avium	
Betula pendula	Prunus serotina	
Betula pubescens	Prunus spinosa	
Betula sp.	Pseudotsuga menziesii	
Carpinus betulus	Pseudotsuga taxifolia	
Castanea sativa	Pyrus communis	
Cedar libani	Quercus cerris	
Cupresus macrocarpa	Quercus palustris	
Fagus silvatica	Quercus petraea	
Fraxinus americana	Quercus pubescens	
Fraxinus excelsior	Quercus robur	
Fraxinus sp.	Quercus robur f. slavonica	
Chamaecyparis lawsonia	Quercus rubra	
Ilex aquifolium	Quercus sp.	
Juglans nigra	Robinia pseudoacacia	
Juglans regia	Salix caprea	
Juniperus communis	salix alba	
Larix decidua	Salix sp.	
Larix kaempferi	Sequoia sempervirens	
Larix x eurolepis	Sorbus aria	
Larix sp.	Sorbus aucuparia	
Malus silvestris	Sorbus torminalis	
Notofagus procera	Taxus baccata	
Picea abies	Thuja plicata	
Picea engelmanni	Tilia cordata	
Picea glauca	Tilia platyphylla	
Picea mariana	Tilia tomentosa	
Picea omorika	Tsuga heterophylla	
Picea pungens	Ulmus carpinifolia	
Picea sitchensis	Ulmus glabra	
Picea sp.	Ulmus laevis	
Pinus banksiana	Ulmus procera	
Pinus cembra	Ulmus scabra	
Pinus contorta v. inland	Corylus avellana	
Pinus contorta v. lulu	other conifers	

APPENDIX 6 NO THIN CLASSIFICATION

Conifer

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 assessment of whether a forest 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[9]). An example of the process is outlined below:

Species: Sitka spruce Top **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 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.

Table 15. Threshold basal areas (m^2) for fully stocked stands.

	Top Height										
Species	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**
Sitka spruce	33	34	34	35	35	36	37	38	39	40	42
Norway spruce	33	33	34	35	36	38	40	42	44	46	49
Lodgepole pine	33	31	31	30	30	31	31	32	33	34	-
Scots pine	26	26	27	30	32	35	38	40	43	46	-
Douglas fir	28	28	28	29	30	31	32	34	35	37	40
Japanese larch	22	22	23	23	24	24	25	27	28	29	-
European larch	23	22	22	22	23	24	25	27	28	30	-
Western red cedar	-	49	50	51	53	55	57	60	63	66	70
Western hemlock	32	34	35	36	36	36	37	38	38	39	40
Noble fir	-	45	46	46	47	48	49	51	52	54	-
Corsican pine	34	34	33	33	33	34	35	36	37	39	-

Broadleaf

Tending is carried out at different times depending on the species concerned and growth rate. It is normally carried out when the average height of broadleaves reaches approximately 8 m. Thinning should be carried out when canopy competition occurs between trees. This can begin at different times depending on species, initial stocking and growth rates (Teagasc 2008[10]).

Table 16. Minimum average heights (m) for tending and thinning broadleaves.

Species	Tending	Thinning
Ash/ Sycamore/ Norway/ Maple	8	12-15
Oak	8-10	10-12
Oak mixture	8-10	10-12
Beech	7-8	12-15
Beech mixture	7-8	12-15

[9] 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.

[10] Teagasc. 2008. Silvicultural guidelines for the tending and thinning of broadleaves.

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TABLE OF PERSONNEL

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