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

Ireland's National Forest Inventory 2017

Field Procedures and Methodology

Ireland's National Forest Inventory 2017 – Field Procedures and Methodology

Covering the National Forest Inventory, 2015 to 2017

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Spatial Data

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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 770,020ha or 11% of the national land area in 2017. 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 50.8% of Irish forests are in public ownership while 49.2% 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.

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. The third NFI fieldwork began in 2015 and was completed in 2017.

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.

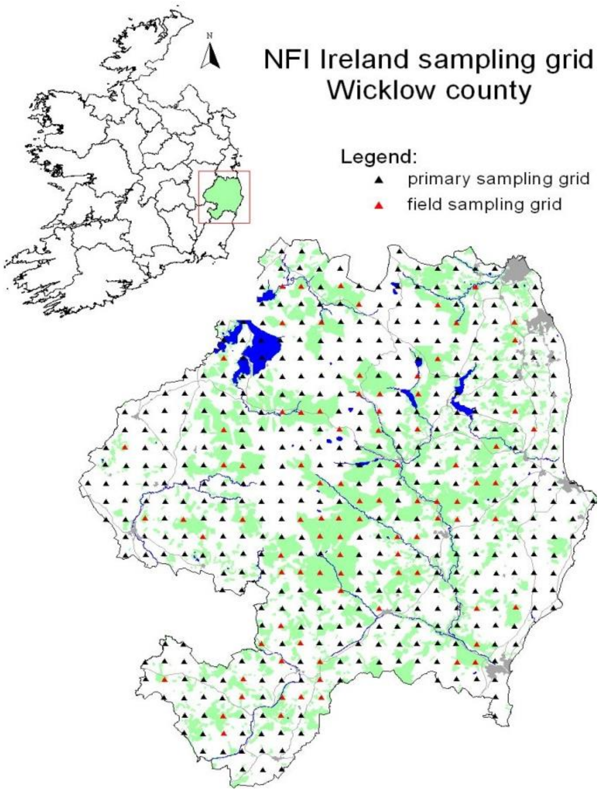

Figure 2. Primary sampling grid (© Ordnance Survey Ireland 2018)

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. Within each sample plot a variety of primary attributes is assessed, including information 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. By the time of the third NFI in 2017, a total of 1,932 forest plots were assessed. 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 2018.

1.5 Methodological Changes

This section outlines the primary methodological changes that were introduced between the second and third cycle.

1.5.1 Assessment of Ground Vegetation

In advance of the 3rd NFI, a review of NFI field procedures and methodologies for the assessment of ground vegetation was undertaken (Devaney, 2015). A series of recommendations were made based on a review of international practice for NFI vegetation assessment, national studies of forest vegetation diversity, and operational experience of NFI field survey.

In general, the report found that existing Irish NFI procedures provide a sound basis for the assessment of ground vegetation attributes in Irish forests. However, key recommendations for the modification of sampling procedures and methodologies include:

- detailed vegetation sampling should only be carried out between May 1st and September 31st each year
- species cover information should be recorded on a 154m² vegetation subplot (7m radius circle)
- all vascular plants should be recorded to species level
- bryophyte data should not be recorded to species level due to lack of recorder expertise
- the DOMIN cover/abundance scale should be used for assessment % cover
- relevant training courses should be attended by field teams
- the "Fossitt" habitat classification scheme should be used to describe habitats of NFI plots
- Adoption of clear definitions for species groups and updated species lists and supplementary identification guides were also provided.

All of the above recommendations outlined above were adopted, which will enhance the scope, accuracy, and communication of vegetation diversity data in future Irish NFI cycles.

1.5.2 Plot Sampling Design

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 three concentric circles. Trees of different dimensions are mapped and described on each particular plot. The decision about which trees qualify is based on their position, with respect to distance from the plot centre and their Dbh. Within the 12.62m circle all trees with a Dbh greater than 200mm are mapped and assessed. All trees greater than or equal to 120mm Dbh and within the 7m circle are mapped and assessed.

During the first and second NFI cycle, trees with a Dbh of less than 120mm and greater were assessed on a 3m circle. In the third cycle, the radius of the 3m (28m²) was increased to 4m (50m²). The increase in sampling intensity was undertaken to increase the accuracy of estimates derived from trees less than 120mm in Dbh.

1.5.3 Forest Health

Prior to the commencement of the 3rd cycle a complete review of those attributes describing the health of the forest estate was undertaken based on a review of international practice and operational experience of NFI field survey. A completely new set of attributes were established that described biotic and abiotic forest damage. Also, the extent of both biotic and abiotic damage is assessed in terms of tree mortality and the severity of the damage.

1.6 Layout of Field Procedures and Methodology

The primary purpose of this methodology publication is to give the background to the NFI, 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 4, 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 5 to 13. In Section C, a summary of the field-work validation and data analysis procedures are presented in chapters 14 and 15.

1.7 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 2km x 2km 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 100m 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 the national mapping agency; Ordnance Survey Ireland (OSi). The aerial photographs used in the third cycle were of much higher resolution (sub-metre) than those in previous NFI's, enabling the identification of pre-existing forests for the first time in this third NFI cycle. Furthermore, as the imagery was predominantly captured in the dormant season, it allowed for an accurate assessment of other land-use types. The acquisition years of the imagery that was used in the aerial photograph interpretation exercise is detailed in Figure 4.

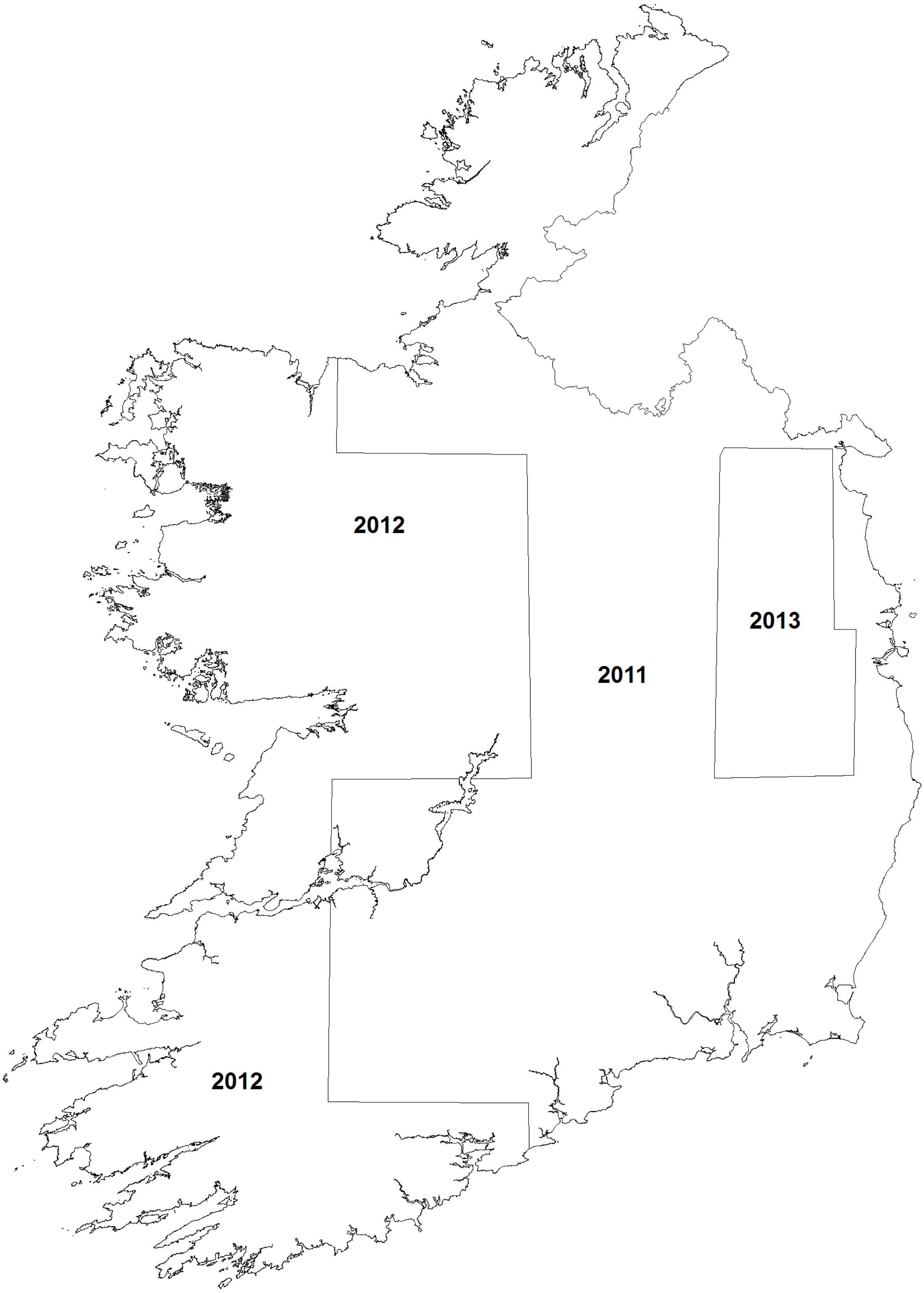

Figure 4. Acquisition date of the imagery used in 3rd NFI cycle aerial photograph interpretation.

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 Geographic Information System (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 2km x 2km grid into Forest, Non-Forest or 'Check Plot' **land-use types** (Figure 5).

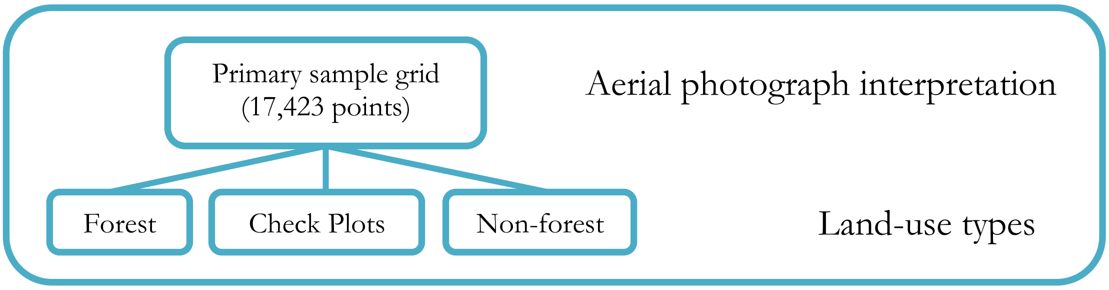

Figure 5. Overview of NFI land-use classification.

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. From 2012 onwards 30cm resolution DigitalGlobe aerial photography became available which greatly enhanced aerial interpretation over the previously used 1m resolution air photos.

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 Intergovernmental Panel on Climate Change (IPCC) guidelines and with the requirements of Land use, land-use change and forestry (LULUCF), 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 Wooded Land
Sea and coastal complex	Quarry
Cropland	Road (Paved)
Cutaway Peat (Domestic)	Track (Unpaved)
Cutaway Peat (Industrial)	Water Body
Bare Rock	
Grassland	

1. **Forest**

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

   Explanatory notes

   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 0.1ha and a minimum width of 20m.
   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 5m 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 1m from the position of the pith-line[1] 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 utilised for agricultural crop production e.g. corn. This class excludes 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.

---

[1] 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.

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. **Bare Rock**
   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.

10. **Grassland**
    Land predominantly under grass species, excluding bog and heath.

11. **Green Space (Rural)**
    Green spaces located in rural areas such as parks, gardens and sports fields.

12. **Green Space (Urban)**
    Green spaces located in urban areas such as parks, gardens and sports fields.

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

14. **Other Wooded Land**
    Land not classified as Forest, spanning more than 0.5 hectares; with trees higher than 5 meters and a canopy cover of 5-10 percent, or trees able to reach these thresholds in situ; or with a combined cover of shrubs, bushes and trees above 10 percent. It does not include land that is predominantly under agricultural or urban land use.

15. **Quarry**
    Man-made sand, gravel or stone quarries.

16. **Road (Paved)**
    Any public or private paved road.

17. **Track (Unpaved)**
    Any unpaved public or private road.

18. **Water Body**
    Any inland water including rivers, canals, reservoirs and lakes.

Chapter 3 ESTABLISHING THE PLOT CENTRE

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

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 6)
3. Colour aerial photographs at 1:15,000 scale also aids this process (Figure 7).
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 8).

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Figure 6. Example of general plot location on OSi discovery series map.

Figure 7. Example of plot location on aerial photograph.

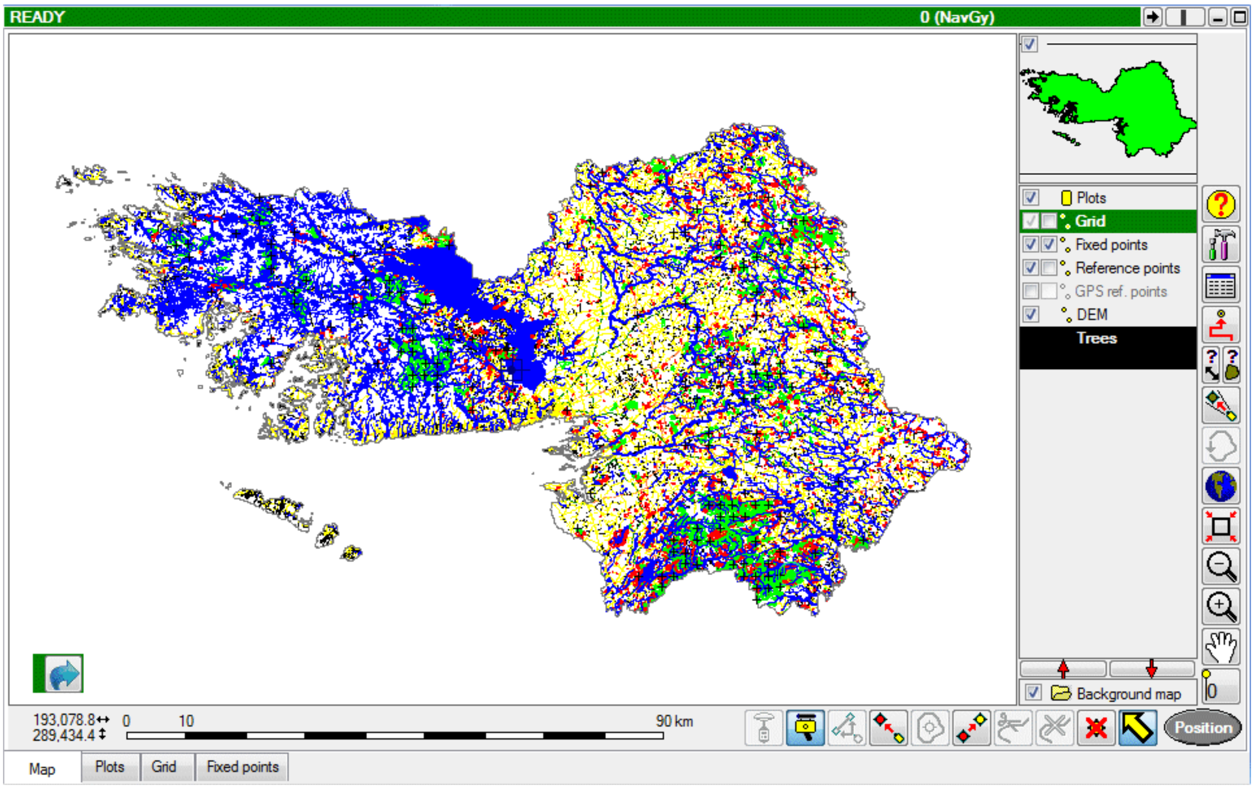


Figure 8. Example of digital map on the field computer at county level.

3.2 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[2] coordinate system to which all the measured entities are referenced, such as tree positions. 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 original plot centre.

3.3 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 9). The total forest area includes both Forest and Forest Open Area.

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.

[2] 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.

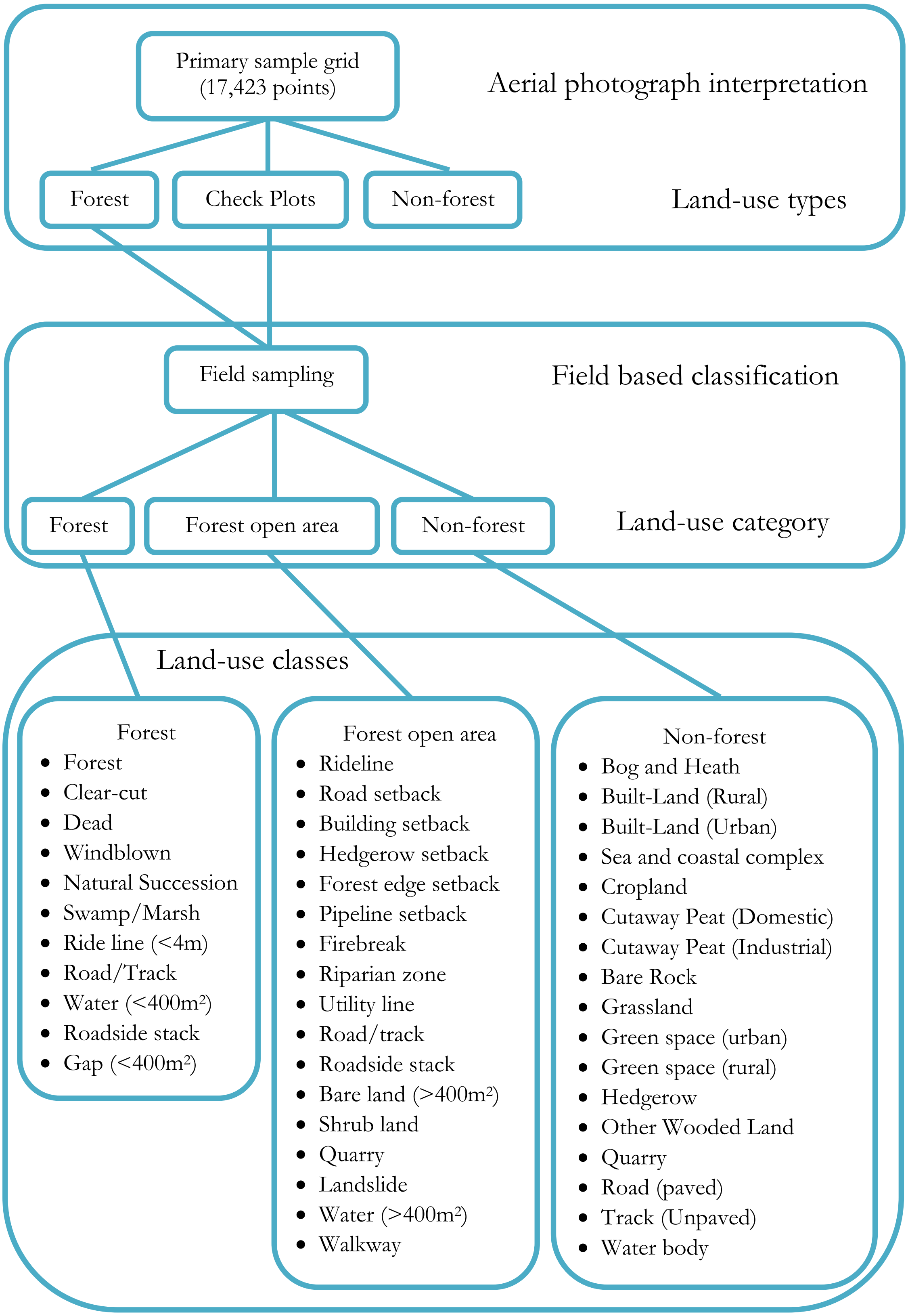


Figure 9. NFI land classification overview.

3.4 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 1m 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 1m from the position of the pith-line of the outermost trees (Figure 10).
3. All areas where the boundary feature is ≥5m and ≤20m from the pith-line are classified as Forest Open Area.
4. All areas where the boundary feature is <5m from the pith-line are classified as Forest.
5. Outlier trees ≥20m from the nearest tree in the main body of trees will not be included in the forest (Figure 11). This scenario usually occurs in natural succession land.
6. In the context of semi-natural forests the pithline of the trees should take precedence over a fence-line. Other man-made boundaries such as hedgerows or stone still retain precedence over the pithline.

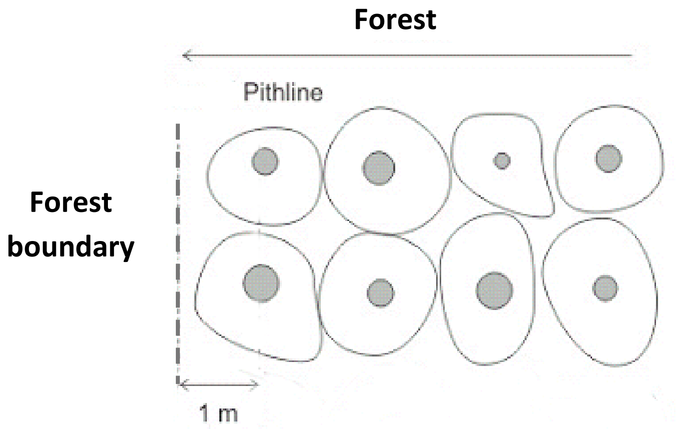


Figure 10. Establishing the forest boundary where there is no boundary feature.

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 12. 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.

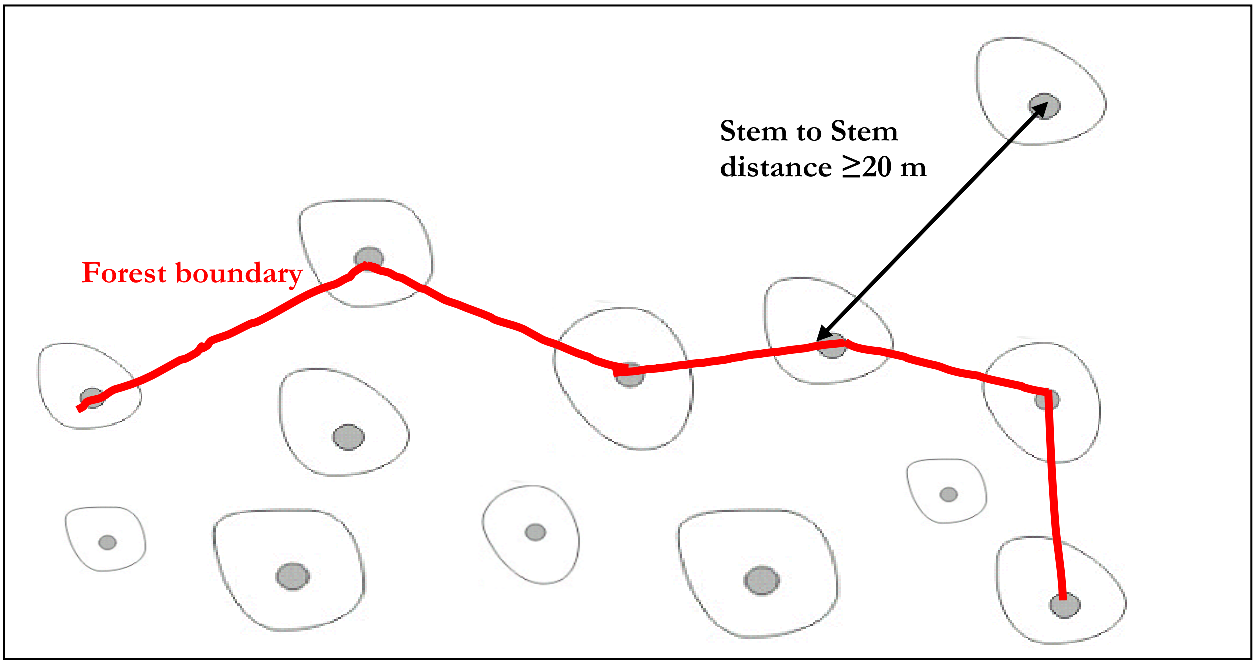


Figure 11. Identifying outlier trees.

Figure 12. Forest boundary, survey pole marks the plot centre in grassland.

3.4.1 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 considered a more permanent feature than the fence line (Figure 13). The set-back from the pith-line to the hedgerow is wider than 5m and narrower than 20m, thereby conforming to the Forest Open Area classification. If the set-back was wider than 20m it would be classified as Non-Forest.

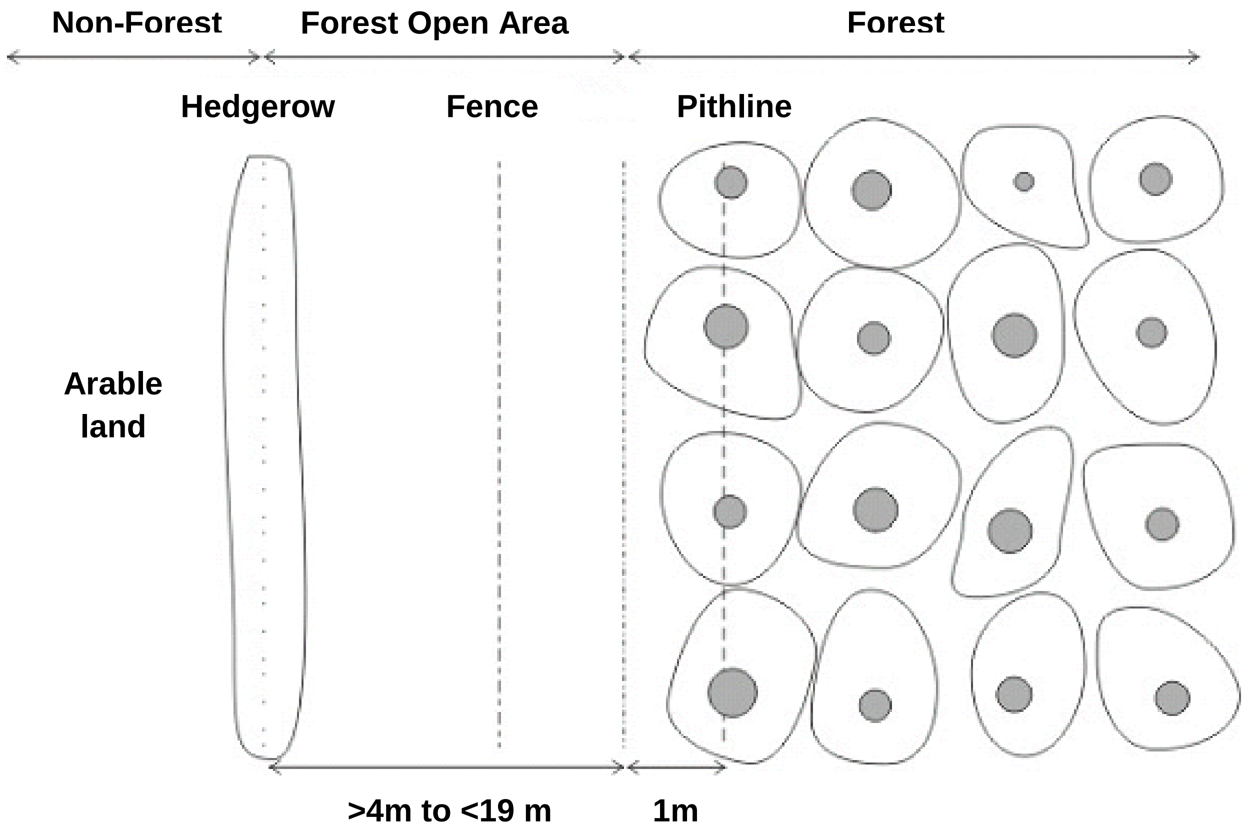


Figure 13. Identifying the forest boundary, example 1.

Example 2

Where a portion of an enclosed fieild is afforested a fence is typically erected to stock proof the forest (Figure 14). 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 ≥5m and ≤20m in order to constitute Forest Open Area.

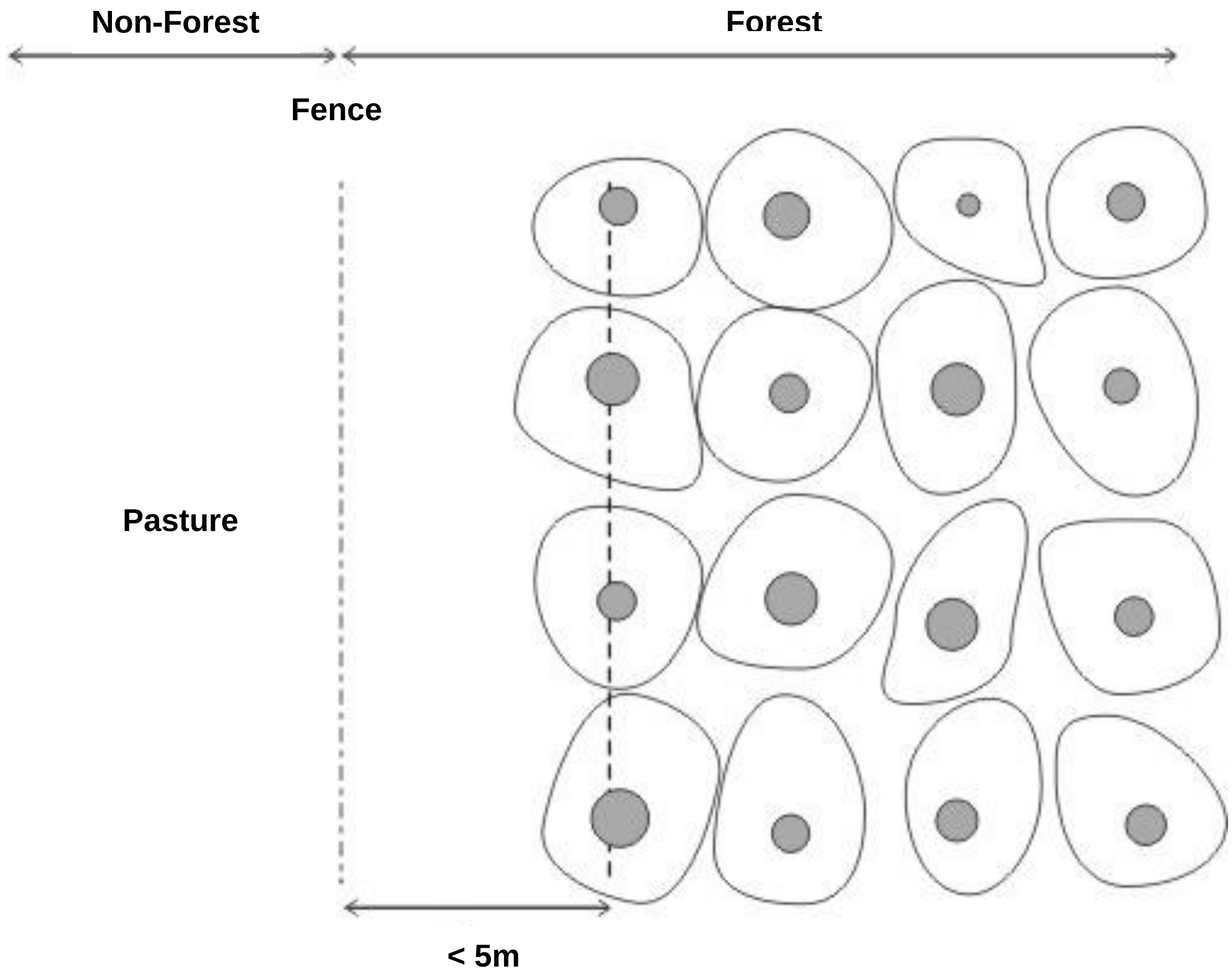


Figure 14. Identifying the forest boundary, example 2.

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 1m from the pith-line (Figure 15). 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 19m it would be classified as Non-Forest.

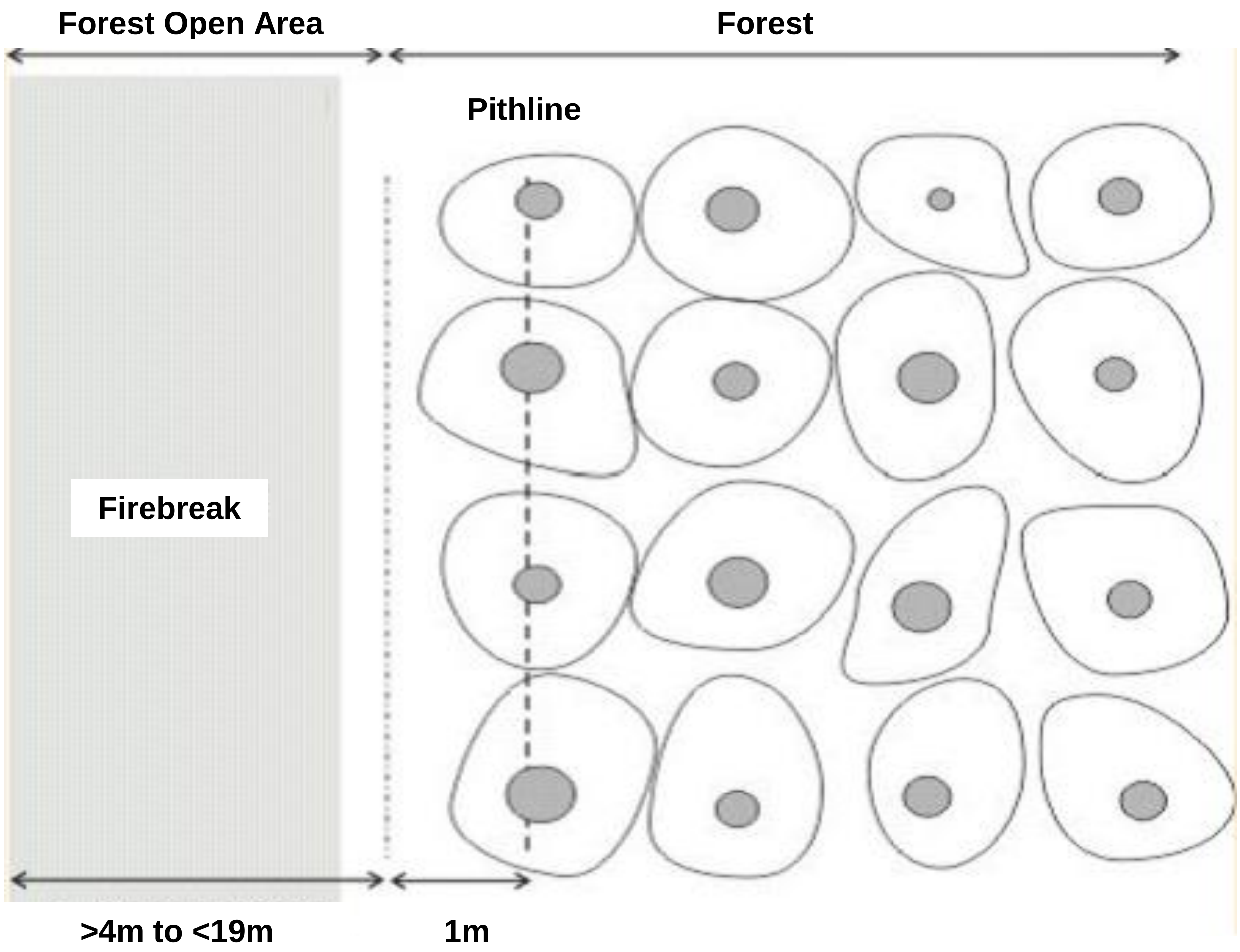


Figure 15. Identifying the forest boundary, example 3.

Example 4

The road in this example (Figure 16) 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 6m wide from pith-line to pith-line.

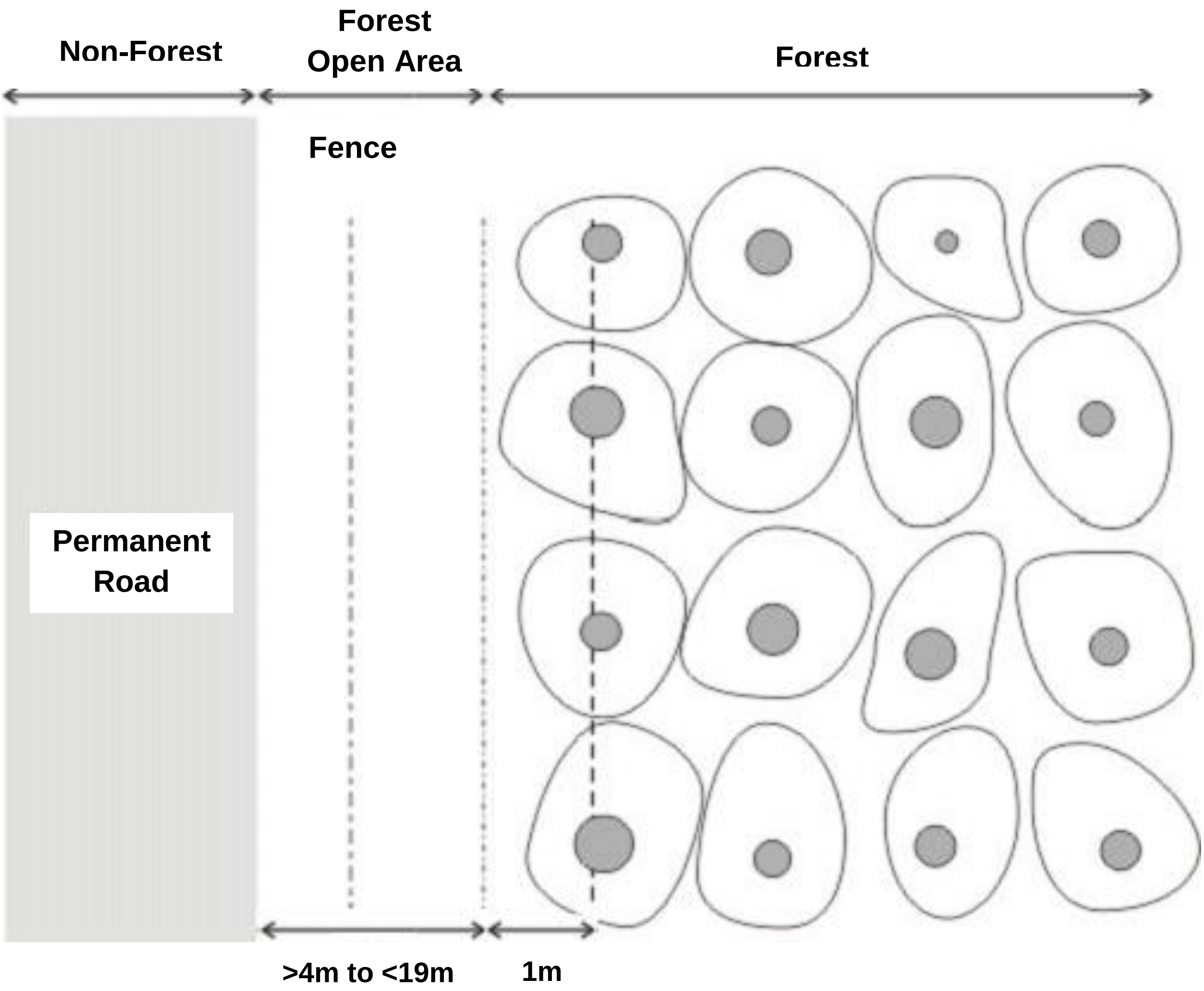


Figure 16. Identifying the forest boundary, example 4.

In Figure 17 below the original field boundary has been eroded by livestock trespass. 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 17. Identifying the forest boundary, example 5.

In Figure 18 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 >5m.

Figure 18. Identifying the forest boundary, example 6.

3.5 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 19 aids in the decision making process.

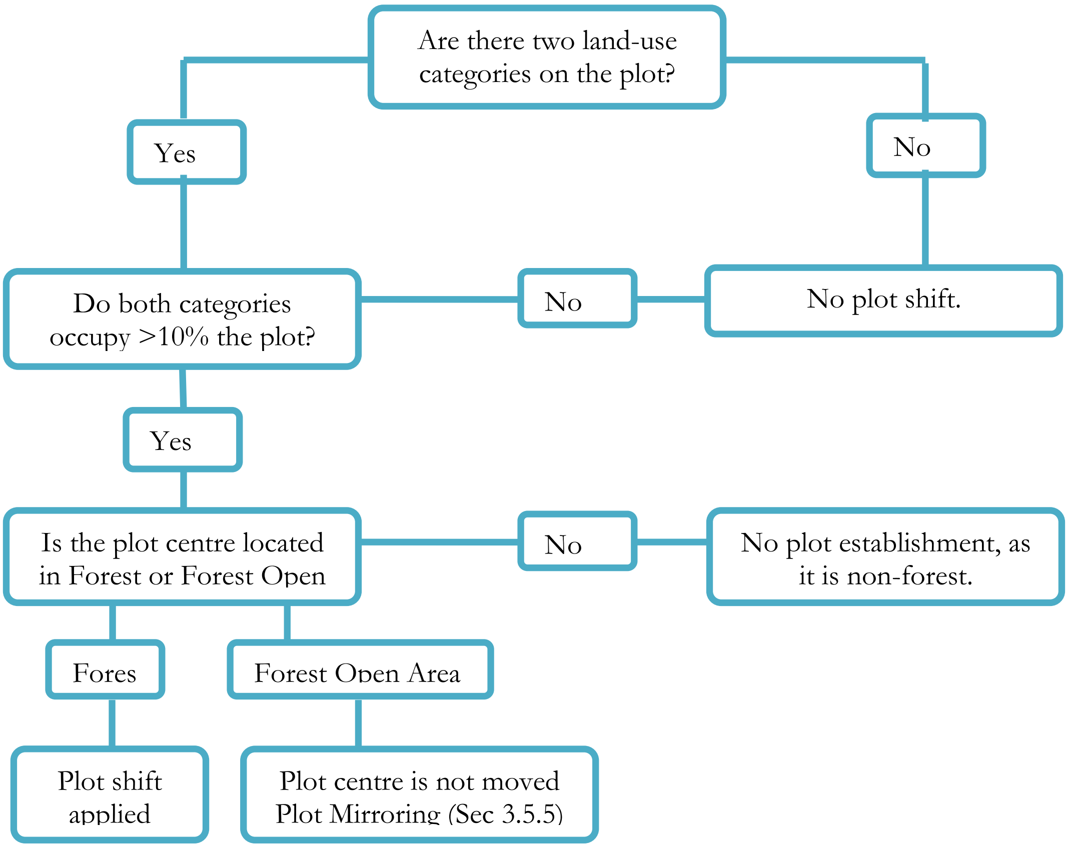
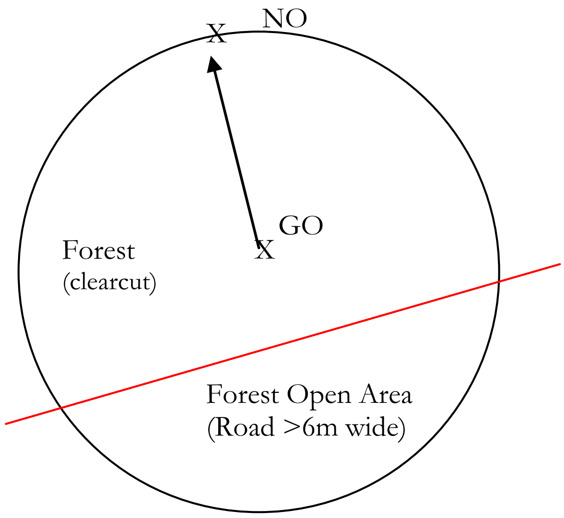


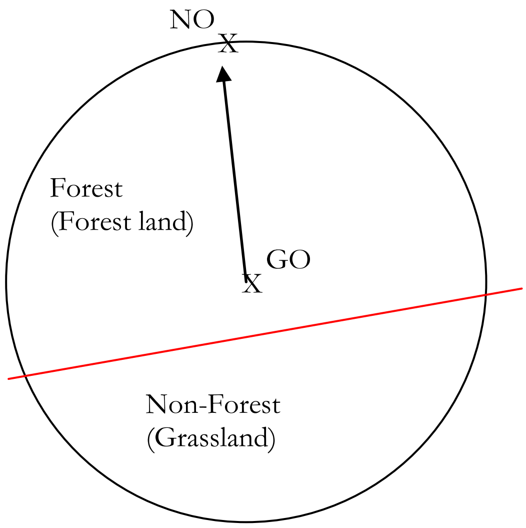
Figure 19. Plot shift decision diagram.

3.5.1 New plot establishment

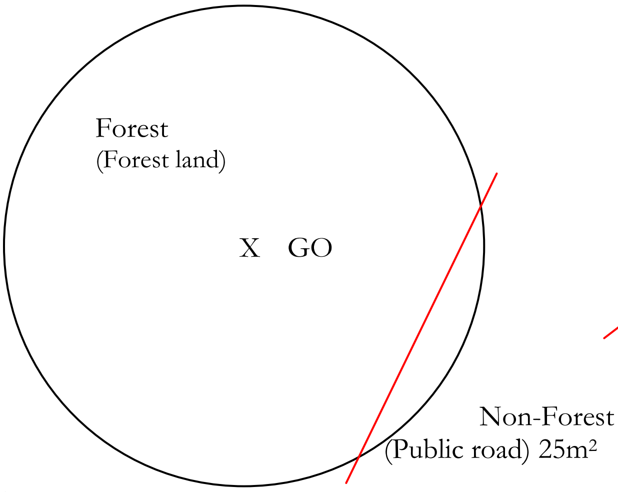
Where plot shifting is necessary, the new plot centre is moved by the length of the plot radius (12.62 m) from the original position perpendicular to the boundary between the two land-use classes. The positions of the generated and new origin are recorded, which may be checked later during validation. For examples see Figure 20.



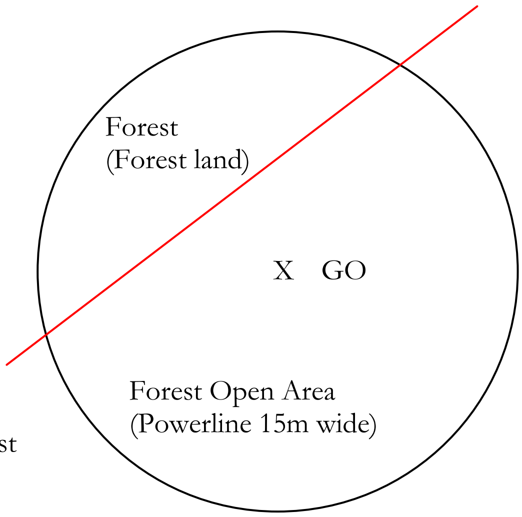
Plot shift



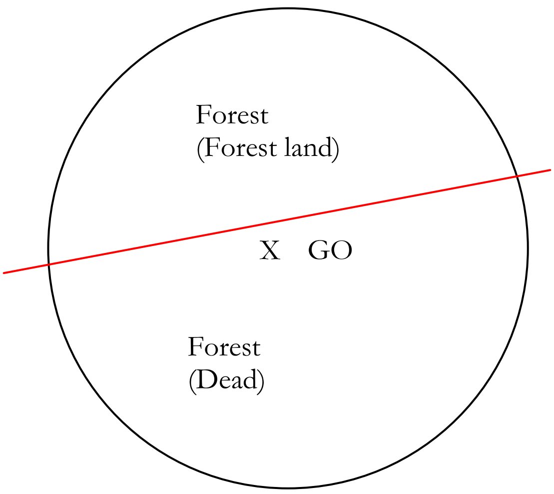
Plot shift



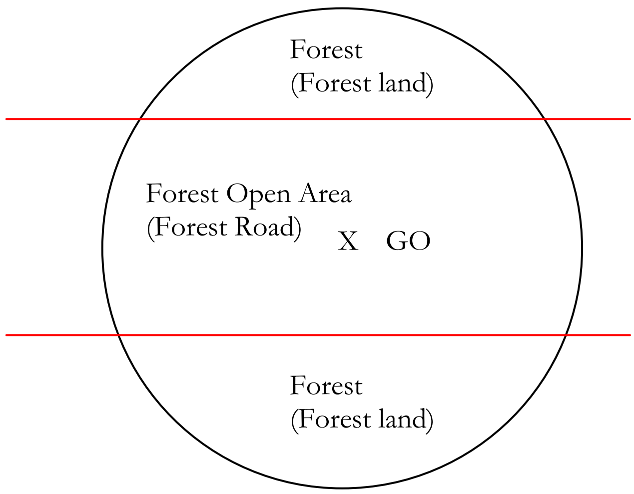
Subplot smaller than 10% of the whole plot area, no plot shift.



Forest open area, no plot shift.



No plot shift as only one land-use category present



Forest open area, no plot shift.

Figure 20. Plot shift examples (where GO=generated origin NO=new origin).

3.5.2 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 category. As in the previous section, the new plot centre is moved 12.62m from the original position perpendicular to the boundary between the two land-use classes.

In Figure 21 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% Non-forest (Grassland) 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 public road, no shift would have been required.

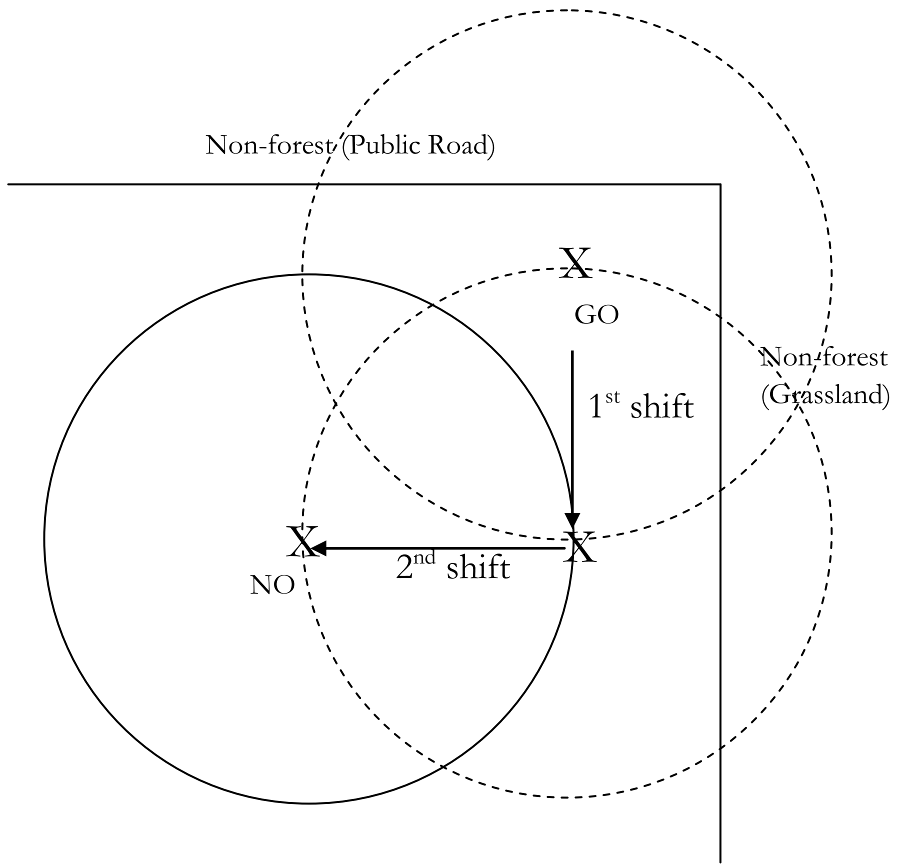


Figure 21. More than one plot shift.

3.5.3 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 22 describes how to handle this situation the field.

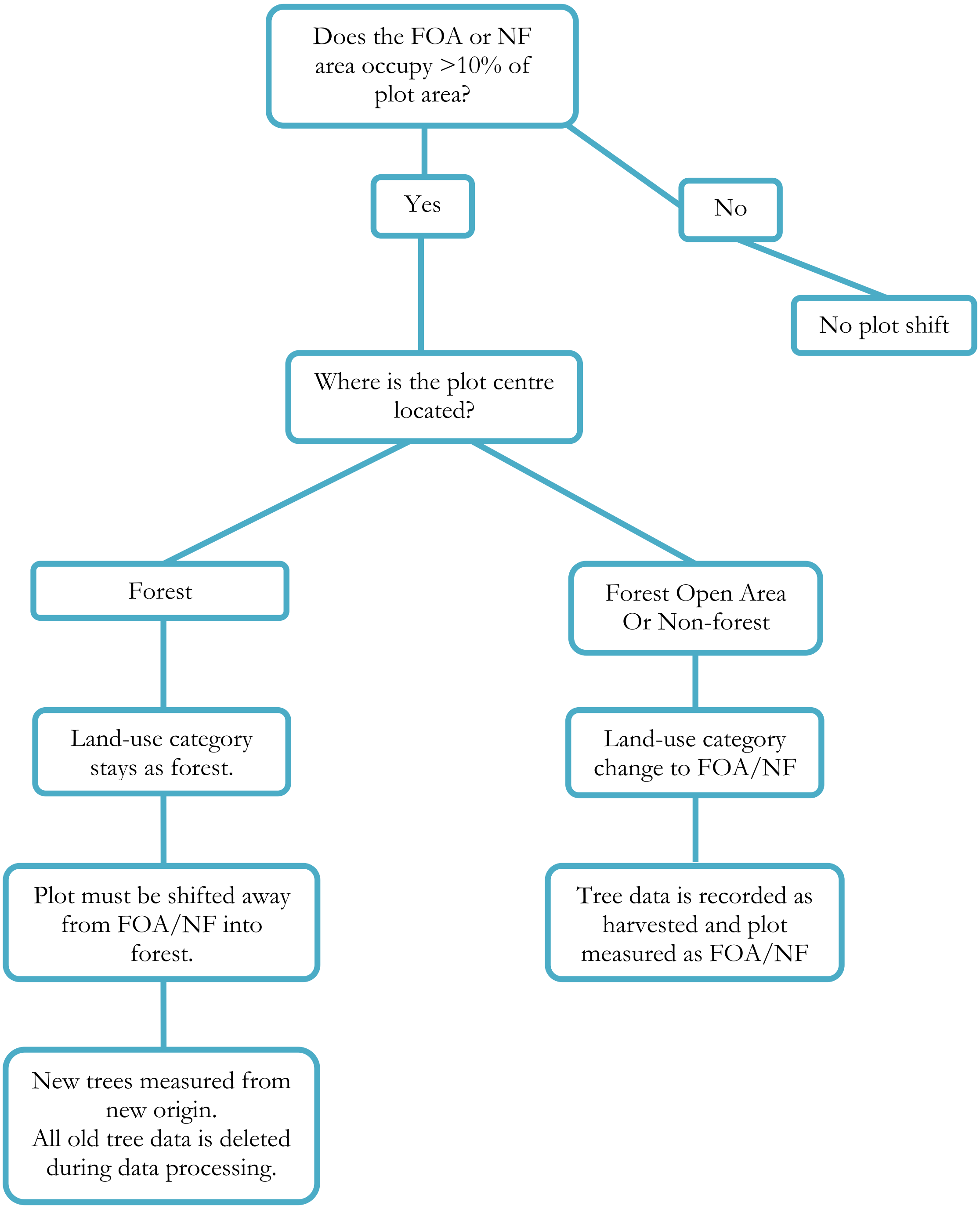


Figure 22. Land-use change on established plots.

3.5.4 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 presented in Figure 23 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.

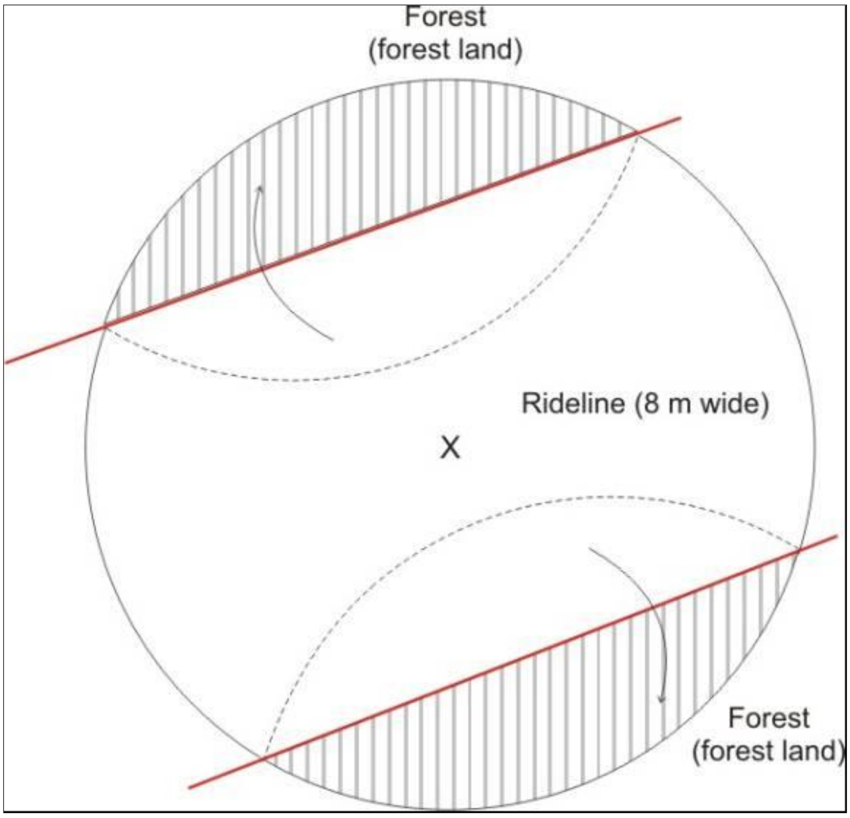


Figure 23. Plot mirroring.

Chapter 4 DATA COLLECTION OVERVIEW

4.1 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 the main hardware components are presented in Appendix 2.

The underlying technology used in the NFI is an integrated system of hardware and software developed by Institute of Forest Ecosystem Research (IFER[3]). 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 data storage devices.

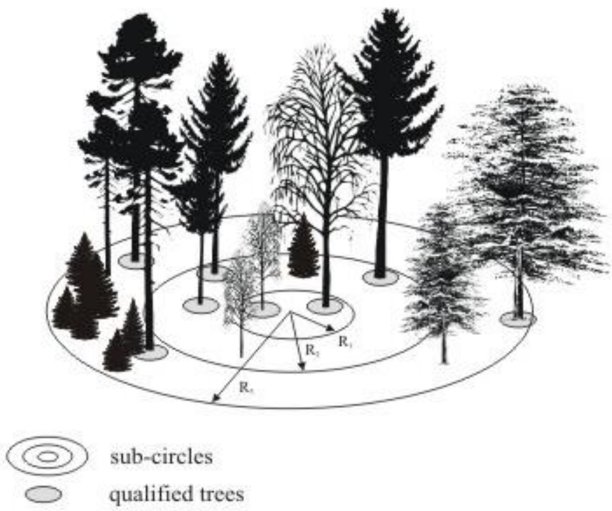
The NFI database is a full relational database with a spatial map component, which is a layer containing the locations of field plots and ancillary background map data used for navigation to field plots. Selected layers (e.g. trees) have a spatial reference (i.e. position relative to the plot centre).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

4.2 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 500m² (i.e. 25.24m 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 three concentric circles. Trees of different dimensions are mapped and described on each particular plot (Figure 24). The decision about which trees qualify is based on their position, with respect to distance from the plot centre and their Dbh. Within the 12.62m circle all trees with a Dbh greater than 200mm are mapped and assessed. All trees greater than or equal to 120mm Dbh and within the 7m circle are mapped and assessed. Within the 4m circle all trees with a Dbh of 70mm and greater are mapped and assessed. All small trees with a Dbh of less than 70mm and height >20cm are assessed on the 4m circle also, but not mapped.



	R_1	R_2	R_3
Sub-circle radius (m)	4	7	12.62
Sub-circle area (m²)	50.3	153.9	500
Threshold Dbh (mm)	70	120	200

Figure 24. Tree mapping concentric plot design.

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

4.3 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 25). An upper stem and base diameter were also measured for a maximum of five trees (Dbh≥200mm) 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).

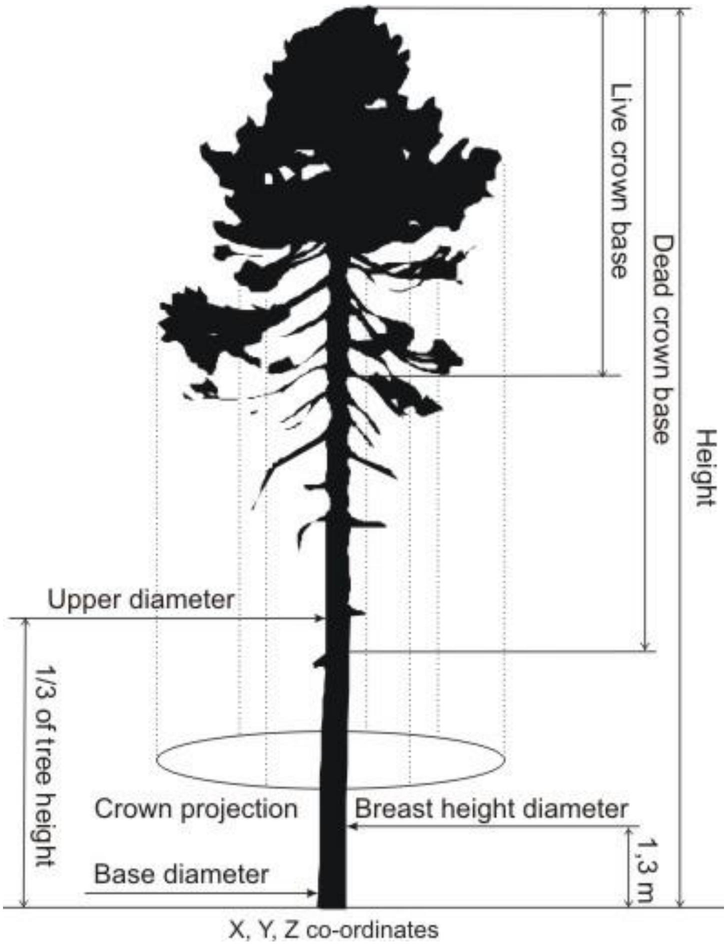


Figure 25. Visual representation of tree data collected.

A description of the forest stand in the 12.62m 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 20cm and within the 7m 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. Shrub vegetation over the whole plot is identified and quantified as a percentage cover on the plot. Other ground vegetation species cover information is assessed on the vegetation subplot, i.e. 7m radius 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 Plot id Plot area Land-use category Accessibility **Forest structure** Stand layer type Canopy closure pecies composition Stocking **Individual trees** Tree status (dead or alive) Species Dbh Upper diameter Upper diameter height Tree height Live crown base Dead crown base Stem quality (straightness, forking) Social status Fork **Forest Health** Abiotic & Biotic Damage Damage agent, Extent and Severity Age of tree damage Stem rot Tree break Defoliation Discoloration Broadleaf damage **Ecosystem** Lichens presence and type Shrub species and cover Grass, Rush, Sedge species and cover Herb species and cover Bryophyte cover Fern species and cover Shrub species and cover	**Deadwood** Stump presence Stump diameter, height and decay status Dead logs presence Dead logs distribution Dead log mid-diameter, length and decay status **Site** Altitude Aspect Slope Humus form Soil condition Group soil Soil sub-group Peat texture Soil texture Drainage Moisture Soil depth Peat depth Litter description **Regeneration** Origin Species, Dbh and age Height Tree number **Forest management** Ownership Forest type Forest naturalness Cultivation type Development stage Thin status Establishemnt type

4.4 PLOT WORKFLOW OVERVIEW

This 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 range-finder 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.

4.4.1 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 26). The distance from plot centre is checked using a loggers tape, while tree Dbh is checked using a Dbh tape.

Figure 26. 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 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 12.62m 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.

4.4.2 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.

4.4.3 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 sample 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 ≥20cm Dbh. Tree vitality is then described for each of the Height trees

4.4.4 Stage 4: Finishing the plot

The Dbh and height of small trees present in the 4m 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 7m 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 5 PLOT

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

5.1 ACCESSIBILITY

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

Application: Inaccessible plots may have to be 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.

5.2 LAND USE CATEGORY

Definition: Broad classification of land-use 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 0.1ha, a minimum width of 20m, trees present higher than 5m 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 (>400m^2 and <0.5ha) enclosed within the forest boundary.
3. **Non-Forest**: Areas that do not conform to the Forest or Forest Open Area definitions.

5.3 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 >3m and <6m wide, from pith-line to pith-line.
8. **Road**: This is a forest road within the forest boundary that is >3m and <6m wide, from pith-line to pith-line.
9. **Water**: A water body that is located within the forest boundary and that is <400m^2 in area. This sub-category also includes streams that are <3m wide, from pith-line to pith-line.
10. **Roadside stack**: This area is <400m^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 (<400m^2)**: A gap in the canopy that is <400m^2 and contains shrub species.
12. **Gap without shrubs (<400m^2)**: An unplanted gap in the canopy that is <400m^2 and does not contain shrub species.
13. **Parks and Gardens**: An area of trees within the curtilage of a domestic dwelling or public park which conforms to the forest definition.

Forest Open Area

1. **Rideline**: An unplanted strip used to sub-divide large forest areas and facilitate access for forest management. It must be >6m wide from pith-line to pith-line.
2. **Road setback**: An area that is >5m and <20m wide from pith-line to road edge.
3. **Building setback**: An area that is >5m and <20m wide from pith-line to boundary feature.
4. **Hedgerow setback**: An area that is >5m and <20m wide from pith-line to hedgerow.
5. **Forest edge setback**: An area that is >5m and <20m wide from pith-line to boundary feature.
6. **Pipeline setback**: An area that is >5m and <40m wide from pith-line to pith-line or boundary feature.
7. **Firebreak**: An unplanted area for the purpose of forest protection, that is >5m and <20m 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 >6m and <40m wide from pith-line to pith-line when situated within the forest. At the forest edge, it should be >5m and <20m 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 <40m from pith-line to pith-line when situated within the forest stand. When situated at the forest edge, the unplanted area should be <20m. 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 >6m wide from pith-line to pith-line.
11. **Roadside stack**: These areas must be >400m^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 (>400m^2)**: These are gaps in the canopy that are >400m^2 and less than 0.5ha 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 20m.
16. **Water**: Water body that is <1000m^2 in size or consisting of a stream/river >3m and <6m 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 >6m wide from pith-line to pith-line.

Non-Forest

1. **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.
2. **Built Land (Rural):** Land occupied by houses, farm buildings and other buildings in rural areas with an area >400m^2 that has buildings present.
3. **Built Land (Urban):** Land occupied by buildings, within towns and cities with an area >400m^2 that has buildings present.
4. **Sea and Coastal Complex:** Occurs in coastal areas and is usually a mixture of sea, sand, grass, shrub and rock.
5. **Cropland:** Land currently under agricultural crops or temporarily unplanted land, excluding grassland.
6. **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.
7. **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.
8. **Bare Rock:** An area of outcropping rock that is situated outside the forest boundary, 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.
9. **Grassland** Land predominantly under grass species, excluding bog and heath.
10. **Green Space (Rural):** Green spaces located in rural areas such as parks, gardens and sports fields.
11. **Green Space (Urban):** Green spaces located in urban areas such as parks, gardens and sports fields.
12. **Hedgerow:** Linear features (<20m wide) that may or may not have tree and/or shrub species present.
13. **Other Wooded Land:** Land not classified as Forest, spanning more than 0.5ha; with trees higher than 5 meters and a canopy cover of 5-10%, or trees able to reach these thresholds in situ; or with a combined cover of shrubs, bushes and trees above 10%. It does not include land that is predominantly under agricultural or urban land use.
14. **Quarry:** Man-made sand, gravel or stone quarries.
15. **Road (Paved):** Any public or private paved road.
16. **Track (Unpaved):** Any unpaved public or private road.
17. **Water Body:** Water body that is >0.1ha in size or consisting of a stream/river >6m wide from pith-line to pith-line.

5.4 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 latitude and longitude information is obtained from the GPS and entered into a specific programme to provide magnetic declination.

Attribute **Magnetic Declination**

1. The magnetic declination is recorded in degrees.

5.5 County

Definition: A sub-national geographic division.

Application: Facilitates regionalisation of results.

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

5.6 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.

5.7 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

5.8 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.

5.9 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 ≥7cm Dbh present on the 12.62m plot.
2. **Small trees present**: Trees <7cm Dbh present on the 12.62m plot.
3. **No trees present**: No trees are present on the 12.62m plot.

4. **All trees harvested**: Trees were present previously, now all trees have been removed.

5.10 SMALL TREES

Definition: Identifies those plots with trees <70mm Dbh, within the 4m plot.

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

Measurement and Description: Dbh and height of trees on the 4m plot is assessed.

Attribute **Small trees**

1. **Small trees present**: Trees <70mm Dbh present on the 4m plot.
2. **No small trees present**: No trees <70mm Dbh are present on the 4m plot.

5.11 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 12.62m plot for dead branches, stumps and/or logs.

Attribute **Deadwood**

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

5.12 FOREST HEALTH

Definition: Describes whether a health issue affecting the normal growth of the trees is present or absent.

Application: Records whther damage affecting tree health is present or absent.

Measurement and Description: Assessed visually by looking on the 12.62m plot for signs and symptons of forest damage.

Attribute **Forest Health**

1. **No forest damage present**: Trees present on the plot show no signs or symptons of damage.
2. **Abiotic damage present**: Trees on the plot show signs of abiotic damage.
3. **Biotic damage present**: Trees on the plot show signs of biotic damage present.
4. **Both abiotic and biotic damage present:** Trees on the plot show signs of both biotic and abiotic damage present.

5.13 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.

5.14 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.

5.15 OWNER DETAILS

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

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

Measurement and Description: Text entered by field team.

Chapter 6 INVENTORY CYCLE

This chapter details the information relating to the inventory cycle.

6.1 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.
3. **3rd cycle**. Plot established between 2015 and 2017

6.2 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. **No change**: 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 new forest road constructed since previous cycle.
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. rideline replanted following clearfelling.
4. **New plot**: A new plot centre is established, due to afforestation or natural-succession.
5. **New plot, forest missed in previous NFI**: A new plot centre is established, due to afforestation or natural-succession. However, this forest was present during a previous cycle, but excluded in error at that time.
6. **GO moved in forest, due to new OA**: Plot centre from a previous cycle is relocated, due to presence of a new land use category, e.g. GO moved away from new forest road.
7. **GO move error previous cycle NFI, return to GO**: Plot centre was moved in the last cycle in error. Plot is relocated to the Generated Origin (GO) in 3rd cycle.
8. **GO should have moved in previous NFI, move GO**: Plot centre was established at GO in the last cycle, but should have been moved at that time due to the presence of another land use type. GO moved in current cycle to New Origin (NO).
9. **FOA in previous NFI, should have been Forest**: Plot was classified as FOA in the last cycle in error, should have been forest.
10. **Forest in previous NFI, should have been FOA**: Plot was classified as Forest in last cycle in error, should have been FOA.
11. **Forest or FOA in previous NFI, should have been NF**: Plot was classified as Forest or FOA in the last cycle in error, should have been Non-Forest.
12. **Deforestation**: There has been a change of land use category on the plot from Forest (last cycle) to Non-Forest (current cycle).
13. **Inaccessible**: Forest plot was field visited in a previous cycle, but field data collection was not undertaken in the current cycle due to restrictions on access.

6.3 Date

Definition: Date of plot assessment.

Application: Identify date of plot assessment.

Measurement and Description: Date is entered for each cycle.

6.4 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: The first team member (Tm 1) inputs the data into the computer and operates the laser range-finder 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.

6.5 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 7 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.

7.1 PLANTING YEAR

Definition: Details the year when the forest 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.

7.2 STOCKING STATUS

Definition: Specifies the presence of trees on the plot.

Application: Stocking is primarily used during data processing to identify plots that have tree cover information.

Measurement and Description: The assessment of stocking status takes place over the 12.62m plot.

Attribute **Stocking status**

1. **Stocked forest area**: Forest estate with trees present on site.
2. **Unstocked felled area**: Recently felled forest area with no trees present.
3. **Unstocked forest gap**: No small or mapped tree data was recorded on the plot. However there are trees present on the plot, but none were recorded due to the concentric plot sampling design.

7.3 OWNERSHIP

Definition: Specifies land ownership.

Application: Forest ownership is an important attribute in terms of resource availability.

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. **Bord na Mona**: Forest land owned by Bord na Mona
7. **Other**: Not belonging to any of the above, e.g. Electricity Supply Board, Department of Defence or any local authority.

7.4 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 12.62m plot. Temporaily unstocked and forest open area categories are also assigned an EFT type.

Attribute **European forest type**

1. **Conifer**: More than 75% of coniferous tree species.
2. **Broadleaf**: More than 75% of broadleaf tree species.
3. **Mixed**: A forest composed of broadleaved and conifer species, the minor category making up at least 25% of the canopy.

7.5 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 12.62m plot. The classification of forest subtype is based on canopy cover (Table 3).

Table 3. Examples of forest subtype.

Forest subtype	Example species	Mix Ratio
Pure	Sitka spruce	None
Mixed	Sitka spruce: Hybrid larch	70:30
Pure	Oak	None
Mixed	Oak: Beech	80:20
Mixed	Oak: Scots pine	50:50

Attribute **Forest Subtype**

1. **Pure**: The dominant species occupies 80% or more of the canopy.
2. **Mixed**: The dominant species occupies between 20-80% of the canopy.

7.6 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 12.62m 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.

7.7 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 12.62m plot.

Figure 28. Regular tree distribution.

Attribute **Tree distribution**

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

7.8 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 12.62m 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. At least 80% or more 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.

7.9 ESTABLISHMENT TYPE

Definition: Establishment type describes the land type on which the forest has been established and how the forest 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 12.62m 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 land 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.

7.10 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 development stage of a forest is primarily by assessing the developement of the forest canopy. The assessment of development stage takes place on the 12.62m plot.

Attribute **Development 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.

7.11 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 per ha of the stand is calculated to determine if the forest is ready to be thinned (see Appendix 3).

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 12.62m 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 3 for further details on the classification of no thinning.
7. **Not applicable**: Not suitable for thinning/undeveloped due to low stocking or semi-natural species predominating.

7.12 NATIVENESS

Definition: Species that have arrived and inhabited an area naturally, without deliberate assistance by man. In Ireland usually taken to mean those trees 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 12.62m plot.

Attribute **Nativeness**

1. **Native**: Native species occupy 80% or more of the canopy.
2. **Mixed**: Native species occupy between 20-80% of the canopy.
3. **Non-native**: Exotic species occupy more than 80% of the canopy.

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*

Common Name	**Botanical Name**
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*

7.13 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 12.62m plot.

Attribute **Pruning or Shaping**

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

7.14 Forest 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: Factors affecting wood supply are assessed on the 12.62m plot.

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:
   - Non-commercial broadleaves – Plots classified as Semi-natural in the Establishment Type attribute (Forest table).
   - Nutrient Deficient Conifers - Plots classified as having Critical Nutrient deficiency in the Overall severity of damage on plot attribute (Abiotic Damage table);
   - Very poorly drained – Plots classified as Very poorly drained in the Drainage attribute (Site table).
   - Recreation – Plot is located in a forest area that is heavily used for recreation. Recreation is the primary objective and is likely to have an impact on wood mobilisation.
   - Excessive slope (≥30 degrees).
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 8 STAND LAYERS

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

8.1 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 12.62m 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.

8.2 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 12.62m plot.

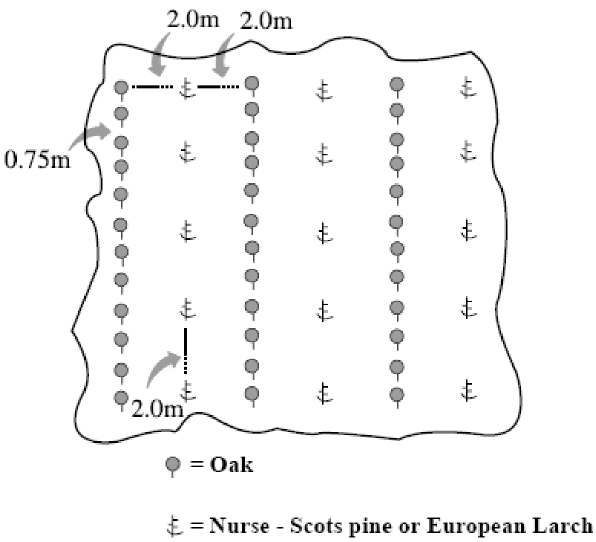


Figure 29. Canopy cover in a mixture (Anon. 2003).

8.3 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 12.62m plot are recorded. The species of naturally regenerated trees that are greater than 20cm in height are also recorded. A full list of tree species used in the NFI is given in Appendix 4.

8.4 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 individual planted trees within the 7m plot and all individual natural regenerated trees ≥20cm in height within the 7m plot are counted. Trees occurring in clusters which are <7cm Dbh are grouped together and counted as single stems e.g. hazel or willow. All dead trees are excluded.

8.5 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.

8.5.1 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 12.62m 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 9 TREES

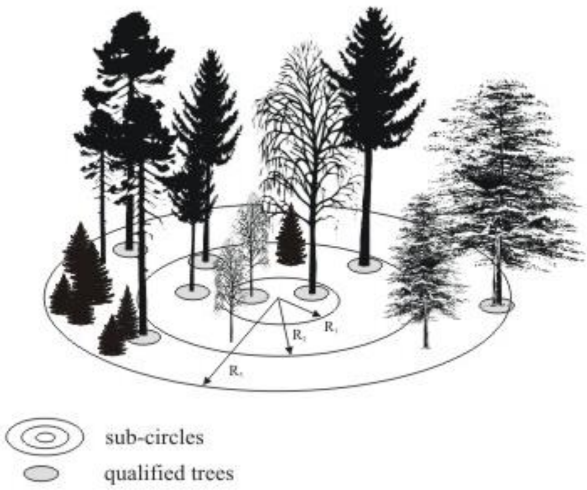
This chapter details the information that is collected on the individually mapped trees within the plot.

9.1 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. Information collected at individual tree level also facilitates the estimation of secondary attributes such as tree volume.

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.



	R_1	R_2	R_3
Sub-circle radius (m)	4	7	12.62
Sub-circle area (m^2)	50.3	153.9	500
Threshold Dbh (mm)	70	120	200

Figure 30. Concentric plot design.

9.2 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. Standing trees that were dead in the previous and current cycle are included.
3. **Felled 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 the inclusion thresholds. Tree Dbh is now large enough for tree to be included.
5. **Living to standing dead**: Tree was living and is now dead standing. The tree is mapped in the current cycle. 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.

9.3 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.

9.4 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.

9.5 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 4.

9.6 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.

9.7 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 8.5.1.

9.8 DIAMETER AT BREAST HEIGHT

Definition: The diameter at breast height (Dbh) of a tree is the stem diameter at 1.3m 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 in Figure 31 was adapted from the Forest Mensuration: a handbook for practitioners[4] (Matthews and Mackie 2006):

1. The Dbh of a tree is measured at 1.3m from ground level. In order to retain consistency a pole of 1.3m 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 following measurement convention must be adhered to when measuring Dbh:
   a) On sloping ground, measure the diameter at 1.3m from ground level on the upper side of the tree.
   b) On uneven or ploughed ground, measure the diameter at 1.3m from the ground level at the base of the tree.

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c) Where a swelling occurs at 1.3m above ground level, measure the diameter above and below the swelling at an equal distance from the 1.3m 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 1.3m 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 1.3m from ground level and not stool level.

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

h) On trees that fork at 1.3m, 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 1.3m, measure the diameter below 1.3m where it is smallest.

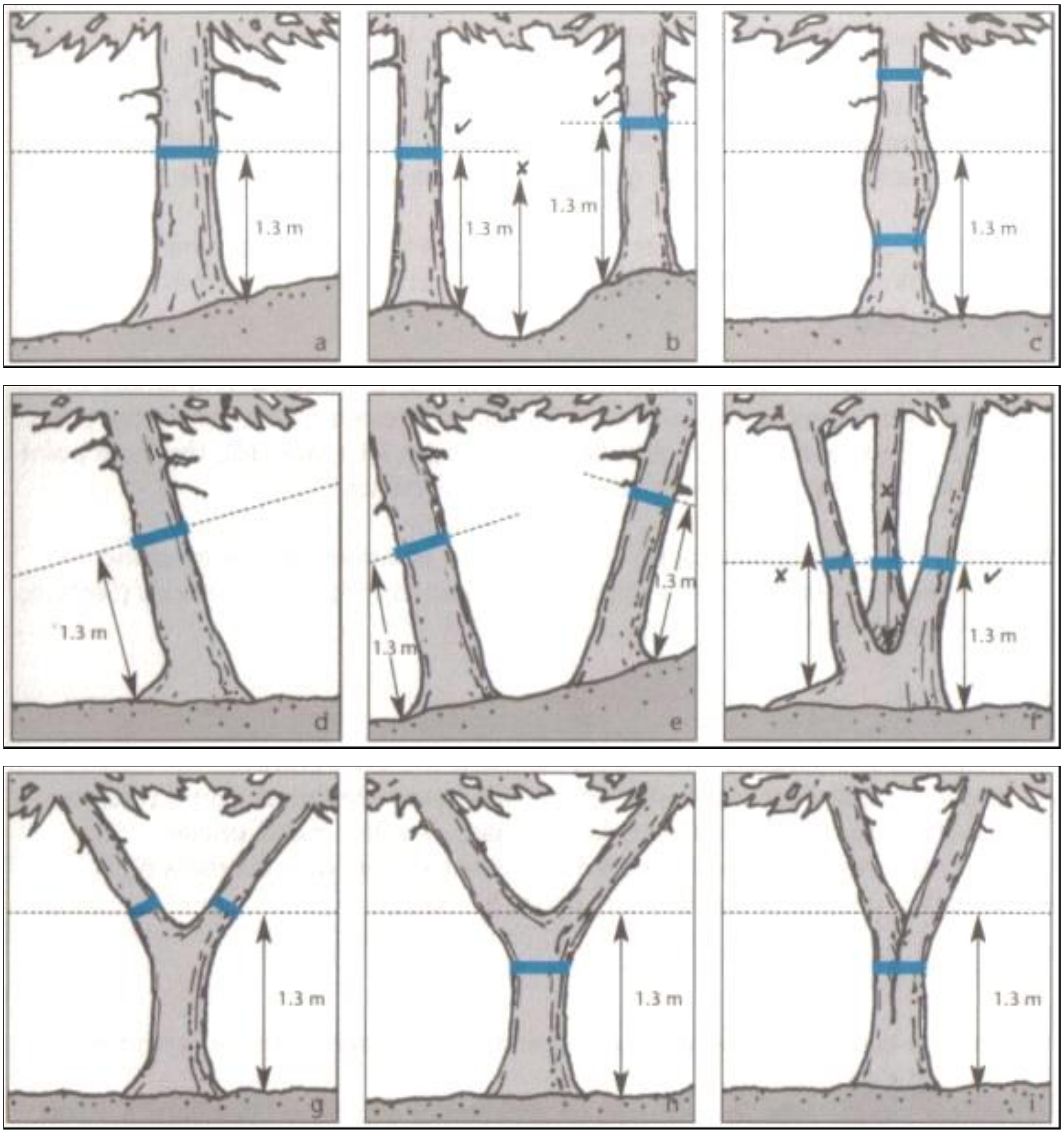

Figure 31. Dbh measurement convention.

9.9 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 32, it is permissible to record the diameter at another height, provided that the height at which the diameter was measured is recorded.

9.10 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 nearestcm using a laser rangefinder equipped with clinometer.

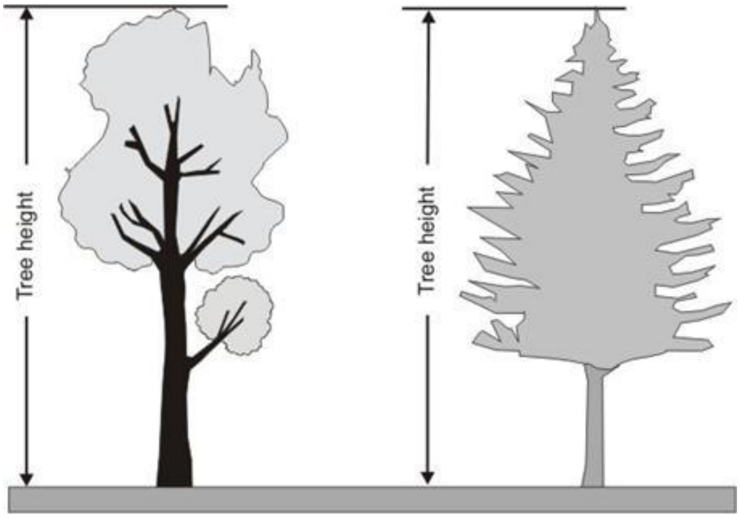

Figure 32. Tree height.

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.

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.

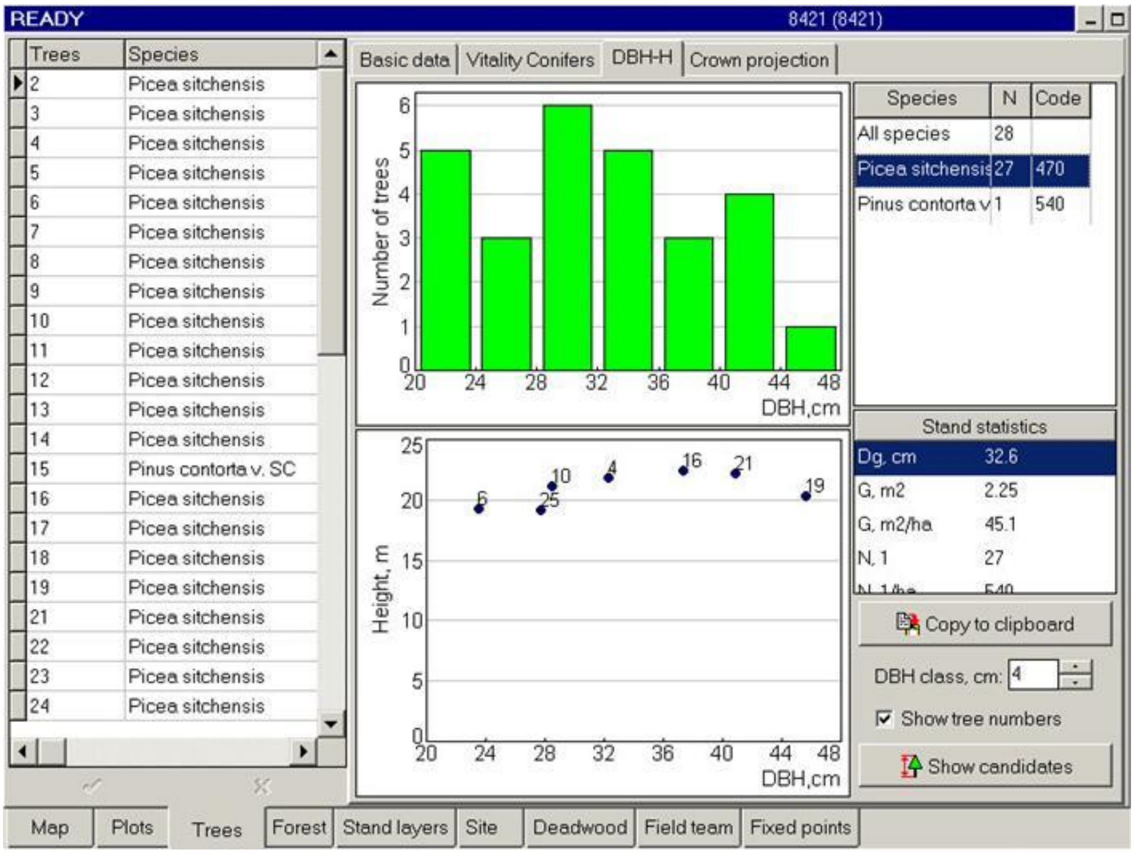

Figure 33. Representation of Dbh classes and sample height trees in the Field-Map™ software.

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, 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 detailed 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.

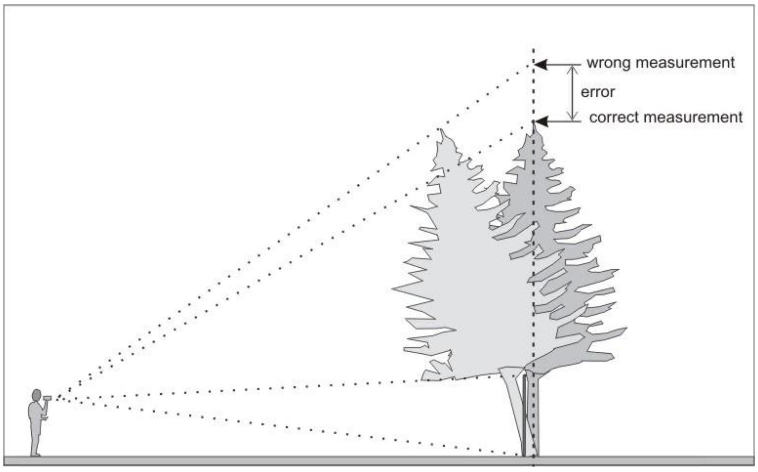

Figure 34. Height measurement error on leaning trees.

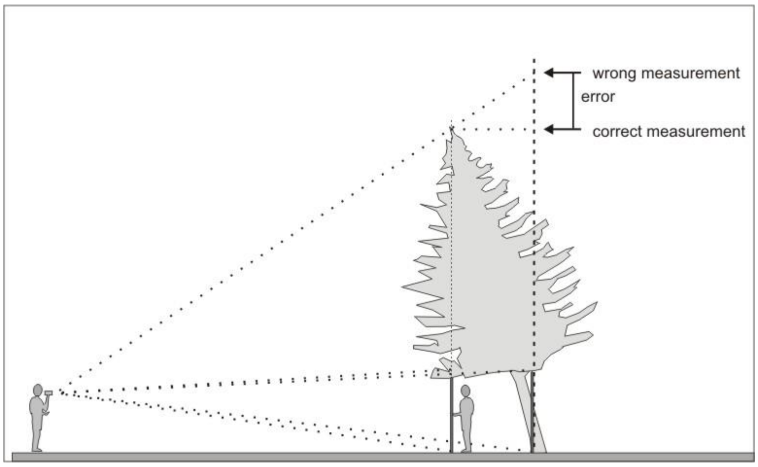

Figure 35. Height measurement on slanted trees.

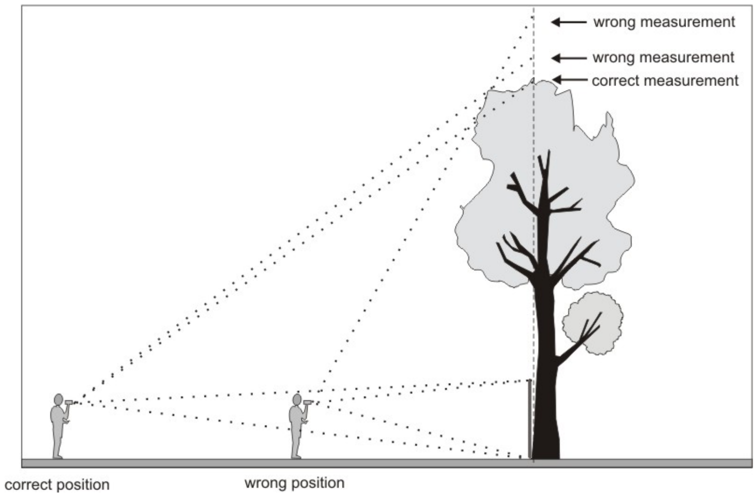

Figure 36. Height measurement on trees.

9.11 Crown measurement

This section details the tree crown attributes recorded: living and dead crown base and crown projection.

9.11.1 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.

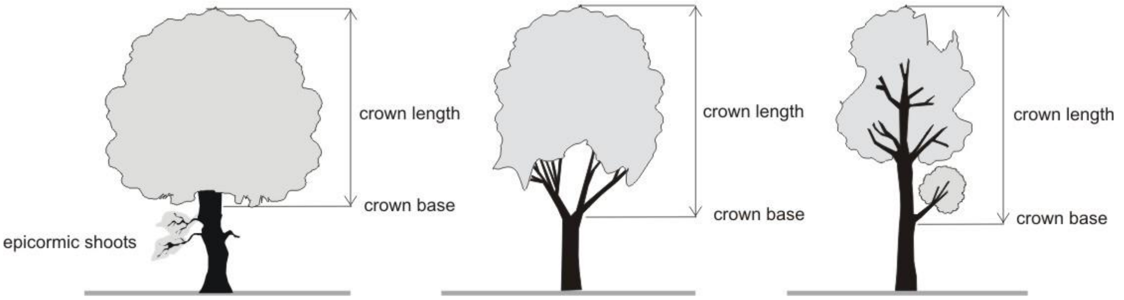

Figure 37. Crown base measurement on broadleaf trees.

9.11.2 Crown projection

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

Application: The measurement of the distribution of the crown around the stem of the tree allows for 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 (Figure 38). 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. The position of the points are recorded on a local Cartesian coordinate system.

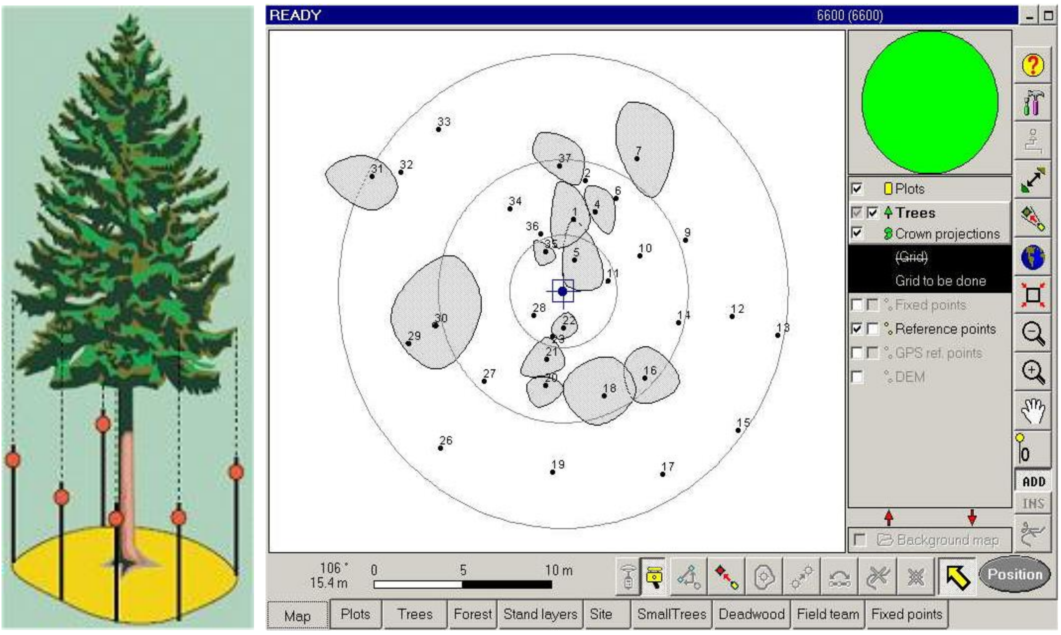

Figure 38. Representation of crown projections taken on a plot.

9.12 Other stem diameter measurements

This section describes the upper stem and base diameter attributes.

9.12.1 Upper stem diameter

Definition: The diameter of a tree stem, recorded at a height equal to one-third 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≥200mm. 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 one-third 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 (mm) is recorded.
2. **Height**: The height (m), at which the upper stem diameter is measured, is recorded.

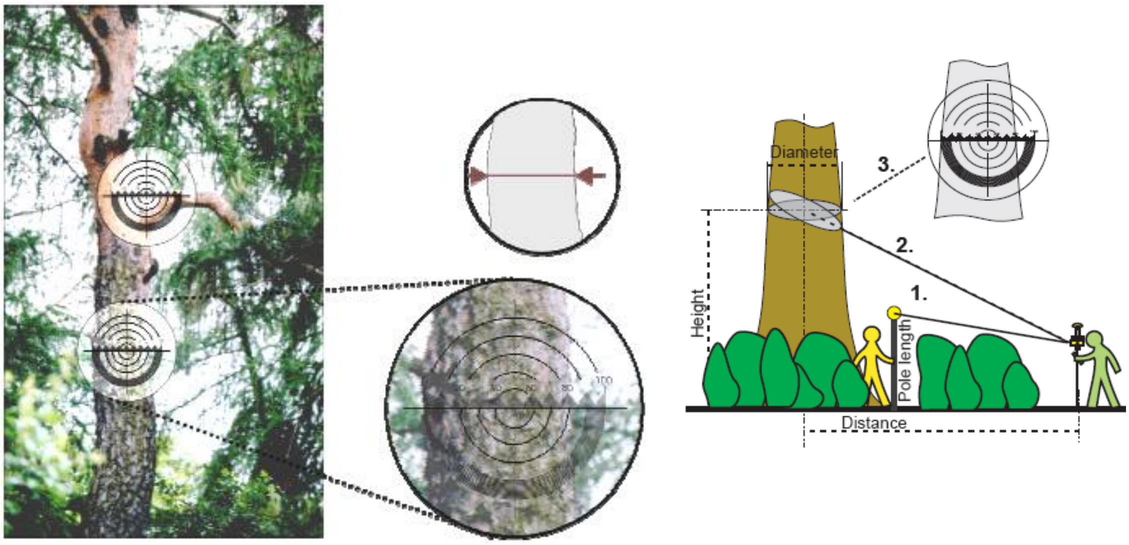

Figure 39. Diameter measurement at one third of the tree height.

9.12.2 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 66cm then the base diameter is measured at a height of 22cm from ground level. Base diameter is measured using a diameter tape and is recorded in mm.

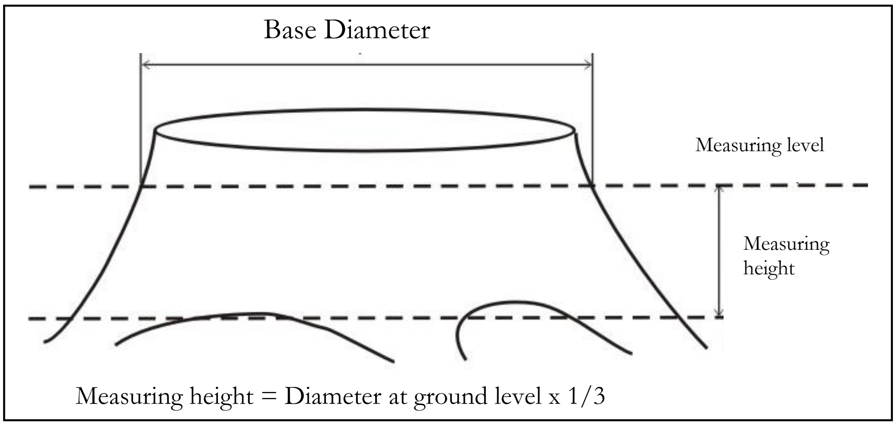

Figure 40. Base diameter.

9.12.3 Social status

Definition: Social status 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 forest, trees can be differentiated into crown classes as competition for light, nutrients and moisture sets in (Figure 41). 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. The social status of each mapped tree is recorded.

Attribute **Social Status (modified Kraft (1884))**

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. **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.
7. **Other**: Trees that cannot be accurately described by the above categories e.g. windblow trees.

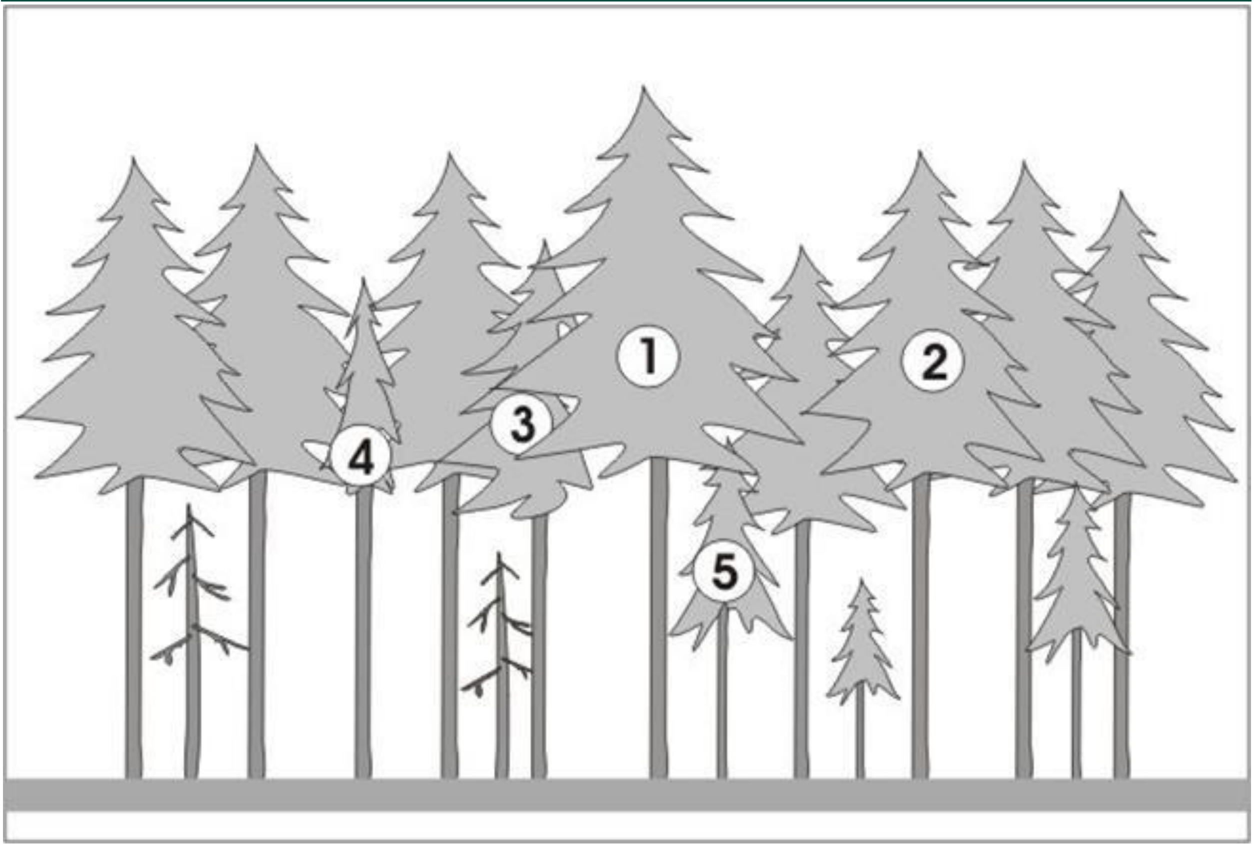

Figure 41. Social status (Kraft).

9.13 TREE FORM

The tree form is described in terms of: tree fork, stem straightness and rot affecting recovery of potential end products from the stem.

9.13.1 Tree fork

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

Application: The presence or absence of a fork starting below 5m 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 5m, where the diameter of one stem is at least half the diameter of the other (Figure 42). 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 5m.
2. **Fork below 1.3m**: Forking present on the tree below 1.3m.
3. **Fork 1.3-3m**: Fork present between 1.3m and 3m.
4. **Fork 3-5m**: Fork present between 3m and 5m.

Figure 42. Forked tree.

9.13.2 Stem straightness

Definition: Describes the straightness of the first 6m 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 6m 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 43, which is an adaptation of a figure presented in MacDonald *et al.* (2001).

Attribute **Stem Straightness**

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

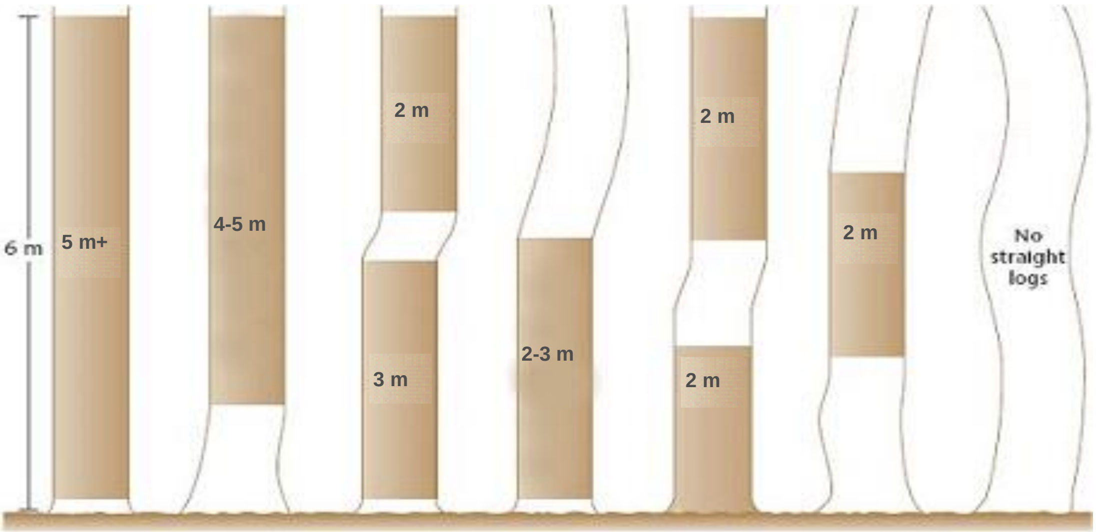

Figure 43. Assessment of stem straightness.

9.13.3 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 44.

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

9.14 Damage Type

Definition: A categorisation of damage to individual trees caused by biotic (e.g. deer) and abiotic (e.g. wind) agents according to tree component affected and damage agent.

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: Damage type comprises stem damage, leader damage, bark damage and root damage. Wind is the primary cause of stem and leader damage, while animals and harvesting machinery are the primary cause of bark and root damage.

Attribute **Damage Type**

1. **No damage**: Damage is not present on the tree.
2. **Leader**: Leader damage on the tree, such as dieback, forking, or grazing.
3. **Stem surface**: Damage to the bark or cambium.
4. **Stem**: Damage to the bole of the stem.
5. **Root**: Damage to roots by animals or machinery.

9.14.1 Leader Damage

Attribute **Leader Damage**

1. **Leader break**: Less than two year's leader growth has been broken.
2. **Substitute tree**: The tree top was damaged and replaced with a new leader, resulting in a kink in the stem otherwise described as a 'bayonet' feature.
3. **Replicated tree top**: The presence of a fork in the upper crown produces an additional competing tree top.

9.14.2 Stem Surface Damage

Attribute **Surface Damage**

1. **Bark stripping**: Bark stripping damage reduces timber quality through staining (due to fungal infection) and structural defects and ultimately reduces timber value and yield.
2. **Fraying**: Male deer mark their territories and clean the velvet off their newly-grown antlers by rubbing or fraying them on young, whippy trees.
3. **Mechanical abrasion:** Abrasion of the bark/cambium/wood resulting in a loss of bark/vascular cambium/wood from the stem surface.

9.14.3 Stem Damage

Attribute **Stem Damage**

1. **Crown break**: The crown of the tree is broken, more severe than tree top break, but still occurring in the live crown.
2. **Stem break**: The stem below the live crown is broken. Note that the remaining stem must be greater than 1.3m in height to be a tree, otherwise it is a stump.
3. **Bent 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.

9.14.4 Root Damage

Attribute **Root Damage**

Refers to a root system injury or severance on a living tree due to abiotic (mechanical) forces (Figure 45) or biotic agents (e.g. deer). Root damage occurs below the root collar and within 1m of the central pith of the tree. Roots of less than 20mm in diameter are not assessed

Figure 45. Harvesting machinery root damage.

9.14.5 Damage age

Attribute **Damage age**

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 two or more growing seasons ago.
3. **Repeated damage**: There is a mixture of old and new damage.

9.14.6 Damage severity

Attribute **Damage Severity**

1. **Low:** damage agent appears to have minimal impact on tree growth or vitality.
2. **Moderate:** damage agent has some obvious impact on tree growth or vitality, but the impact is limited.
3. **High:** damage agent has an obvious impact on tree growth or with evidence of decay or suppression of tree growth evident
4. **Critical:** damage agent has critically impacted and killed the tree or the damage agent is expected to kill the tree in the near future.

9.15 Tree vitality

Tree vitality is described using the following five attributes: vitality, growth tendency, defoliation, discolouration and broadleaf vitality. It is assessed on height trees. 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).

9.15.1 Growth tendency

Definition: Growth tendency describes the annual height increment in the two 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.

9.15.2 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 46). 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 46. 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.

9.15.3 Tree defoliation

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

Application: Defoliation is an important indicator of forest health.

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 47).

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 47. Defoliation on Sitka spruce.

9.15.4 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.

Chapter 10 FOREST HEALTH

This chapter outlines the forest health data collected at plot level. A summary table of damage agents is presented in Table 5 below. Damage to forest health is an alteration of the normal growth pattern of the trees. Damage may be present on the plot, or may have occurred since the last inventory cycle, but no longer present. In both scenarios damage is recorded.

Table 5. Summary of damage attributes recorded.

Damage Type	Damage Agent Type	Agent
Abiotic	Nutrition Deficiency	N/P deficiency
		K deficiency
		Lime-induced chlorosis
	Climate	Frost
		Endemic Windthrow
		Catastrophic Windthrow
		Exposure
		Waterlogging
		Sea salt
		Drought
	Anthropogenic	Fire
		Poor tree establishment
Biotic	Disease	Heterobasidion annosum
		Armillaria spp.
		Rhizina undulata
		Chlara Ash Dieback
		Phytophtera Ramorum
		Phytophtera alni
		Dothistroma
	Insects	Large Pine Weevil
		Green Spruce Aphid
		Pine Shoot Moth
	Animal	Livestock & Deer
		Rabbit & Hare
		Feral Goat
		Grey Squirrel
		Bank Vole
	Vegetation	Shrub (Gorse & Briar)
		Invasive shrub (Rhodo & Laurel)
		Grass & Herbs
		Bracken
		Heather
	Harvesting	Harvesting operation/machines

10.1 BIOTIC DAMAGE

10.1.1 Biotic Damage Agent Type

Definition: Classification of the type of biotic agent damaging the trees.

Application: To assess health and vitality of the forest.

Measurement and description: Assessment is carried out on the tree canopy of the 12.62m plot.

Attribute: Damage Agent Type

1. **Disease:** Damage as a result of disease infection.
2. **Insect:** Damage as a result of insect attack.
3. **Animal:** Damage as a result of animal.
4. **Vegetation:** Damage as a result of competing vegetation.
5. **Harvesting Operations:** Damage as a result of harvesting operations.

10.1.2 Biotic Damage Agent

Definition: Name of agent damaging the trees.

Application: To assess health and vitality of the forest.

Measurement and description: Assessment is carried out on the tree canopy of the 12.62m plot.

Attribute: Biotic Damage Agent

Table 6. Biotic Damage Agent.

Animal	Disease	Vegetation	Insect	Harvesting machines
Deer	hetrobasidian annossum	Shrub (Gorse & Briar)	Large pine weevil	Harvesting machines
Cattle	armellaria sp.	Invasive shrub (Rhodo & Laurel)	Green spruce aphid	
Sheep	rhizina undulata	Grass & Herbs	Pine shoot moth	
Goat	chalara	Bracken		
Rabbit/Hare	phytophera ramorum	Heather		
Squirrel	phyophtera alni			
Horse	Dosthistroma sp.			
Bank vole				

10.1.3 Biotic Damage type

Definition: Description of the type of damage present.

Application: To assess health and vitality of the forest.

Measurement and description: Assessment is carried out on the tree canopy of the 12.62m plot.

Attribute: Biotic Damage type

Table 7. Biotic Damage Type.

Disease	Insect	Animal	Harvesting machines	Vegetation
resin bleeding	resin bleeding	bark stripping	stem damage	vegetation competition
wilting	wilting	fraying	root damage	
dieback	dieback	browsing		
defoliation	defoliation	overgrazing		
discolouration	discolouration	tree top break		
deformity	deformity			

10.2 Abiotic Damage

10.2.1 Abiotic Damage Agent Type

Definition: Classification of the abiotic type of agent damaging the trees.

Application: To assess health and vitality of the forest.

Measurement and description: Assessment is carried out on the tree canopy of the 12.62m plot.

Attribute: Abiotic Damage Agent Type

1. **Climate:** Damage caused by climatic variables.
2. **Nutritient Deficiency:** Damage caused by nutrient deficiency.
3. **Anthropogenic:** Damage as a result of human activity.

10.2.2 Abiotic Damage Agent

Definition: Name of agent damaging the trees.

Application: To assess health and vitality of the forest.

Measurement and description: Assessment is carried out on the tree canopy of the 12.62m plot.

Attribute: **Abiotic Damage Agent**

Table 8. Abiotic Damage Agent.

Climate	**Nutrition Deficiency**	**Anthropogenic**
Frost	N or P deficiency	poor tree establishment
Exposure	k deficiency	fire
Waterlogging	Lime chlorosis	
Drought		
Sea salt		
Endemic windblow		
Catastrophic windblow		

10.3 Assessment of damage

The extent of biotic and abiotic damage is assessed in terms of mortality and the extent of the damage.

10.3.1 Extent of damage

Definition: Percentage of tree plot canopy damaged.

Application: To assess health and vitality of the forest.

Measurement and description: Assessment is carried out on the tree canopy of the 12.62m plot.

Attribute: **Extent of plot canopy damaged (%)**

1. **<4% few individuals**: tree canopy of a few individual trees is damaged.
2. **<4% several individuals**: tree canopy of a several trees is damaged.
3. **<4% many individuals**: tree canopy of many trees is damaged.
4. **5-10%**: between 5 and 10% of the tree canopy area is damaged.
5. **11-25%**: between 11 and 25% of the tree canopy area is damaged.
6. **26-33%**: between 26 and 33% of the tree canopy area is damaged.
7. **34-50%**: between 34 and 50% of the tree canopy area is damaged.
8. **51-75%**: between 51 and 75% of the tree canopy area is damaged.
9. **76-90%**: between 76 and 90% of the tree canopy area is damaged.
10. **91-100%**: between 91 and 100% of the tree canopy area is damaged.

10.3.2 Tree Mortality

Definition: Percentage of tree canopy that has died.

Application: To assess health and vitality of the forest.

Measurement and description: Assessment is carried out on the tree canopy of the 12.62m plot.

Attribute: **Extent of Tree Mortality (%)**

1. **<4% few individuals**: tree mortality extends to few individual trees.
2. **<4% several individuals**: tree mortality extends to several individual trees.
3. **<4% many individuals**: tree mortality extends to many trees.
4. **5-10%**: tree mortality extends to between 5 and 10% of the tree canopy area.
5. **11-25%**: tree mortality extends to between 11 and 25% of the tree canopy area.
6. **26-33%**: tree mortality extends to between 26 and 33% of the tree canopy area.
7. **34-50%**: tree mortality extends to between 34 and 50% of the tree canopy area.
8. **51-75%**: tree mortality extends to between 51 and 75% of the tree canopy area.
9. **76-90%**: tree mortality extends to between 76 and 90% of the tree canopy area.
10. **91-100%**: tree mortality extends to between 91 and 100% of the tree canopy area.

10.3.3 Damage severity

Definition: Classification of the overall severity of damage on the plot.

Application: To assess health and vitality of the forest.

Measurement and description: Assessment is carried out on the tree canopy of the 12.62m plot.

Attribute: **Damage Severity**

1. **Low:** damage agent appears to have minimal impact on tree growth or vitality.
2. **Moderate:** damage agent has some obvious impact on tree growth or vitality, but the impact is limited.
3. **High:** damage agent has an obvious impact on tree growth or with evidence of decay or suppression of tree growth evident
4. **Critical:** damage agent has critically impacted and killed trees or the damage agent is expected to kill trees in the future.

10.4 Abiotic Damage Agents

Definition: This includes any non-living factors which cause damage to trees.

Application: Damage/disorder which impacts on tree growth.

Measurement and Description: If there is abiotic damage/disorder evident on individual trees present in the plot, determine the primary cause and classify accordingly. Assessment is carried out on the 12.62m plot. More than one abiotic damage factor may be entered for each plot.

10.4.1 Frost Injury

Definition: Bud damage in late spring/early summer, shrivelling/browning in conifer shoots and "tasseling" in broadleaves as a result of frost.

Application: Frost injury is a common health problems affecting Sitka spruce in Ireland and locally can result in significant damage (Figure 48). Recovery is usually vigorous but form may suffer and rotation length may be extended, both of which incur financial penalties. Trees are vulnerable while their height is less than, or only slightly above, the depth of the accumulation of cold air; usually 1-2m.

Measurement and Description: If there is damage to individual trees present in the 12.62m plot due to frost injury, classify accordingly.

Figure 48. Frost injury and associated tree deformity.

10.4.2 Windthrow

Definition: The uprooting/snapping of trees within the plot.

Application: Windthrow damage may lead to increased harvesting costs, downgrading of assortments and shortened rotation lengths. Shatter greatly reduces the value of logs.

Measurement and Description: Recording the occurrence of windthrow on the 12.62m plot.

Attribute: **Windthrow damage type**

1. **Catastrophic:** Catastrophic windthrow arises as a result of storm conditions of unusual severity with the damage usually occurring over large areas of forest (Figure 49). The amount of damage is influenced more by wind speed, wind direction and local topographic features than by soil conditions or silvicultural treatment. Catastrophic storms can cause serious damage to plantations on both unstable and windfirm sites, if trees are not uprooted, stems are snapped.

Figure 49. Catastrophic windthrow.

2. **Endemic:** Endemic windthrow occurs usually at the edge of stands or breaks in the canopy. It is a feature of mostly upland forests each year caused by normal winter gales (Figure 50). Very little stem breakage occurs, uprooting of trees on unstable sites being the predominant effect. Damage is normally confined to sites that are inherently unstable due to soil type or topography, and usually affects stands at a particular top height. Endemic windthrow comprises either single trees or groups of trees, and it can spread progressively over several years, resulting in a significant threat to forestry.

Figure 50. Endemic windthrow.

10.4.3 Lime-induced Chlorosis

Definition: On soils with a high limestone/shell marl content lime-induced chlorosis is a disorder linked to iron or manganese deficiency and is potentially fatal.

Application: Symptoms often do not develop until canopy closure or later and include yellowing and thinning of foliage, stunting and die-back. Marl and Calcareous Soils Deposits of marl and calcareous mud in flat areas surrounded by limestone are often found beneath midland peats. Marl is recognised when moist by its olive to pale olive colour, ranging through light grey to white, and its softness. When it is dry it is whitish in colour, of friable consistency and powdery (Figure 51).

Measurement and Description: Marls have pH values in the region of 8.0. Where marl occurs within 70cm of the soil surface, the site is classed as unplantable. Marl may not always be detectable by means of the standard peat sampler, particularly where it occurs in the form of intra-peat layers, but is easily seen and identified in stream-banks, drains or other excavations. If there is damage to individual trees present in the plot due to lime-induced chlorosis, classify accordingly.

Figure 51. Fen marl.

10.4.4 Nutrition deficiencies

Definition: Elements required for healthy tree growth are absent, which can be manifested by chlorotic foliage and a poor growth rate.

Application: Site nutrition factors affecting tree growth. Nutrition deficiencies is the most serious health problem affecting commercial plantations in Ireland.

Measurement and Description: Ocular assessment of tree colouration, tree shape, tree form, growth rate, needle size, associated vegetation.

Attribute **Nutrition deficiencies:**

1. **Nitrogen/Phosphorous deficiency**: Nitrogen/phosphorous deficiency can occur typically on infertile sites such as podsols & peats and is often associated with unenclosed land. These deficiencies can arise individually or in combination. Nitrogen deficiency is most apparent on sites where heather is the dominant vegetation, but Nitrogen deficiency can also arise in association with extreme Phosphorous deficiency. In practice these individual deficiency types are difficult to distinguish through ocular assessment alone without foliar analysis, and are therefore grouped into Nitrogen/Phosphorous deficiency (Figure 52). Deficiency symptoms in conifers include:
   - Uniform light green or yellow colour which occurs the strongest discolouration on young needles, (in contrast to potassium deficiency)
   - Thin and spindly leading shoot
   - Severely limited growth, particularly height growth.
   - Shortening of needles (In contrast to potassium deficiency)
   - Nitrogen deficiency can also arise in association with extreme phosphorus deficiency on some organic soils.
   - Shoot length reduction, die-back occurs in severe cases.

Figure 52. Phosphorous/Nitrogen deficiency.

2. **Potassium deficiency:** Potassium deficiency is only likely to develop on peaty soils, typically fen peats and peaty podsols, commonly with grass/rush vegetation. The deficiency produces a distinctive straw coloured needles on older foliage and yellowing of needles at the tips of shoots on current growth. At its most developed Potassium deficiency can lead to die-back that is characteristically confined towards the centre of the tree (Figure 53).

Figure 53. Potassium deficiency.

10.4.5 Exposure

Definition: Constant winds reduce tree growth; in these conditions "wind shaping" in crowns, browning and dieback of windward shoots, basal sweep along with thick branches contribute towards reduced timber quality. Wind may desiccate needles and also subject soft young shoots to bending, twisting and abrasion that create permanent deformities. Gales early in the growing season on fast growing crops can also cause leaders to break .Mainly affects conifers.

Application: Damage varies with exposure and elevation but can be serious, especially in fast growing crops.

Measurement and Description: Record the occurrence of exposure/wind directional damage on the plot.

10.4.6 Fire

Definition: A fire that has caused the death of trees.

Application: Fire damage may lead to reduced tree growth, tree mortality and forest destruction (Figure 54).

Measurement and Description: Recording the occurrence of fire damage on the 12.62m plot.

Figure 54. Fire damage.

10.5 Biotic Damage Agents

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

Application: Biotic agents causing damage/disorder which impacts on tree growth outside of those described in the trees chapter.

Measurement and Description: If there is biotic damage/disorder evident on individual trees present in the plot, determine the primary cause and classify accordingly. Assessment is carried out on the 12.62m plot. More than one biotic damage factor may be entered for each plot.

10.5.1 Common Root Diseases

Definition: The three common fungi root diseases primarily affecting conifers in Ireland: *Armillaria* (honey fungus), *Heterobasidion annosum* (Fomes) and *Rhizina undulata*.

Application: Both *Armillaria* and *Heterobasidion annosum* can kill large trees, though fatal attacks are more commonly seen on young trees; both also cause root- and butt-rot in live trees. *Rhizina* also kills sizeable trees but is unable to cause decay.

Measurement and Description: If one of the three common fungi root diseases is evident on the plot, determine the type and classify accordingly. Assessment is carried out on the 12.62m plot.

Attribute: **Conifer Root diseases:**

1. ***Armillaria spp.*** (Honey fungus)
2. ***Heterobasidion annosum*** (Fomes)
3. ***Rhizina undulata.*** (Pine fire fungus)

10.5.2 Vegetation Competition

Definition: Competing vegetation that smothers, overshadows or whips smaller trees results in tree death or delayed establishment.

Application: Competition by vegetation for nutrients and moisture may inhibit the growth of young broadleaf trees in particular. Heavy grass growth may prolong the period during which trees are susceptible to damage from spring frost by raising the level of cold air relative to the trees. Competitrion from Calluma sp. for nutrients can lead to a reduction in leader growth and stunting in some cases (Figure 55).Grass or dense vegetation around the tree may give shelter to bank voles. Dense growth of furze, bracken or rhododendron can prevent natural regeneration or impact on the establishment of young forests (Figure 56).

Measurement and Description: If there is vegetation competition evident on individual trees present in the plot, classify accordingly. Assessment is carried out on the 12.62m plot.

Figure 55. Competition from *Calluna sp.*

Figure 56. Competition from Rhododenron, gorse and bracken.

10.5.3 Harvesting Damage

Definition: Abrasion resulting in a loss of the bark/ vascular cambium/wood.

Application: harvesting damage can result in the degradation of timber quality and also lead as en entry point for diseases to enter a tree (Figure 57).

Measurement and Description: If damage is evident on the plot, its presence should be noted accordingly. Assessment is carried out on the 12.62m plot.

Figure 57. Machine bark/cambium damage

10.5.4 Large animal

Definition: Animals raised in an agricultural setting (e.g. cattle), as well as wild mammals (e.g. deer or goats).

Application: Livestock/deer within a forest will browse, trample and strip bark from trees. Tree damage and death will result. Sheep may uproot newly planted trees. Cattle may also poach and compact soil. All animal traffic can destroy drainage. Fencing may be damaged.

Measurement and Description: If there is livestock damage/disorder evident on individual trees present in the plot, determine the primary cause and classify accordingly. Assessment is carried out on the 12.62m plot.

Attribute: **Damage type:**

1. ***Browsing:*** All species of deer eat tender tree and plant shoots and leaves. Most trees are eaten but broadleaves, especially cherry, ash, willow, hazel and rowan are strongly preferred. A ragged end to a shoot suggests deer or sheep; a clean, angled cut is produced by hares or rabbits.
   - **Deer:** Browse line up to 1.8m (Figure 58)
   - **Sheep:** Other signs usually present e.g. wool, droppings etc. (Figure 59 and 60)
   - **Goat:** Coarse browsing of foliage to 1.5m. Newly planted trees pulled out of ground
2. ***Bark stripping***

- **Deer:** As deer have no upper incisor teeth they leave broad teeth marks running up the peeled stem with torn or broken bark hanging at the top (Figure 61).
- **Sheep:** Damage by sheep leaves diagonal teeth marks.
- **Goat:** Severe bark stripping to 1.5 m, often leading to tree death. Incisor marks diagonal (Figure 62).

3. ***Tree Fraying (Deer)*** Male deer mark their territories and clean the velvet off their newly-grown antlers by rubbing or fraying them on young, whippy trees.
4. ***Vegetation overgrazing*** Herb layer and tree natural regeneration removed due to livestock and deer overgrazing.

Figure 58. Browsing by deer.

Figure 59. Bark stripping by sheep.

Figure 60. Bark stripping by sheep (Rooney and Hayden, 2002).

Figure 61. Bark stripping by deer (teethmarks more or less vertical).

Figure 62. Bark stripping by goats; note the teethmarks (Rooney and Hayden, 2002).

10.5.5 Rabbit and Hare

Definition: European Rabbit (*Oryctolagus cuniculus*) and the Irish hare (*Lepus timidus hibernicus*).

Application Browsing and stripping of the bark of trees result in damage and tree death from rabbits and hares. Hares tend to browse and cut shoots in localised patches and along lines of trees. Hare damage is rarely as significant as rabbit damage. Browsing is the most common form of damage caused by rabbits and hares to young trees (Figure 63).

Measurement and Description: If there is rabbit or hare damage evident on individual trees present in the plot, determine the primary cause and classify accordingly. Assessment is carried out on the 12.62m plot.

Attribute: **Damage type:**

1. ***Browsing:*** a clean, angled cut is produced by hares or rabbits.
   - **Rabbit:** browse up to 0.54m, removed portion often eaten
   - **Hare:** browse up to 0.70m along a line of trees, removed portion often left behind.

Figure 63. Rabbit browsing (Rooney and Hayden, 2002).

2. ***Bark stripping***

   Rabbit: Bark stripping can occur to a height of 540mm (higher in snow). Incisor marks are 3 to 4mm wide, in pairs, usually running diagonally across the stem. Beech is particularly vulnerable.

10.5.6 Grey Squirrel

Definition: Grey Squirrel (*Sciurus carolinensis*)

Application: Greys are capable of causing much damage, mainly through bark stripping, to growing broadleaved trees.

Measurement and Description: If there is grey squirrel damage evident on individual trees present in the plot, record same. Assessment is carried out on the 12.62m plot. Grey squirrels are predominately located east of the Shannon (Figure 64).

Damage can include bark tree top break and bark stripping (Figure 65). Bark stripping is marked by the incisor marks 1.5mm wide in pairs, usually running parallel with stem or branch. Sycamore, beech, oak and pine most at risk.

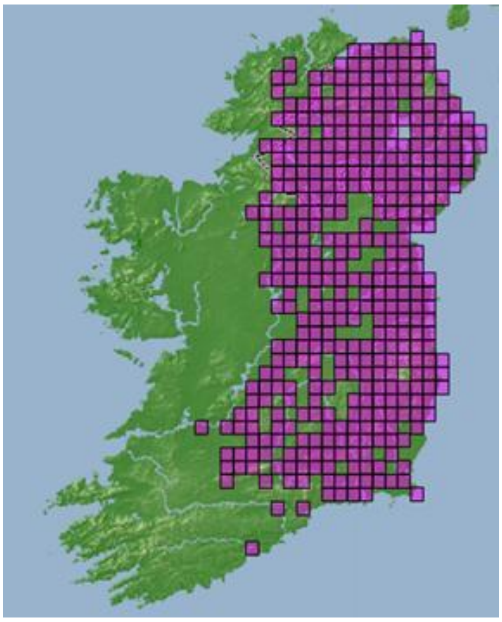

Figure 64. Grey Squirrel distribution. (National Biodiversity Data Centre.)

Figure 65. Grey squirrel damage.

10.5.7 Bank Vole

Definition: Bank vole (*Myodes glareolus*).

Application: Bank voles have the capacity to damage newly planted and young trees by stripping bark and gnawing at the stem, sometimes ring barking the entire base and killing the tree.

Measurement and Description: Bank voles climb, so damage can occur up to 4m, with young sitka spruce (>5yrs) is the species most affected. If there is bank vole damage evident on individual trees present in the plot, record same. Bank vole runs are visible in long grass when the latter is removed. Assessment is carried out on the 12.62m plot. Bark is removed in short, irregular strips 5 to 10mm wide, with incisor marks 1mm wide in pairs (Figure 66).

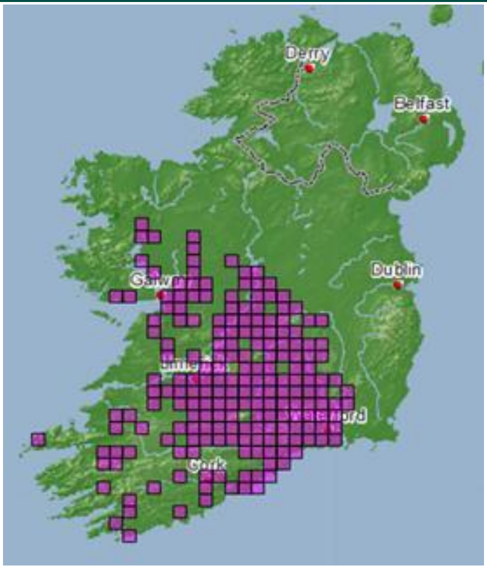

Figure 66. Bank vole bark stripping and distribution map (National Biodiversity Data Centre).

10.5.8 Large Pine Weevil

Definition: The large pine weevil (*Hylobius abietis*) is a beetle and the most important pest of replanted conifer sites in Ireland.

Application: Young transplants can withstand a small amount of feeding, but extensive feeding causes needle loss, reduces plant growth, and can lead to death when plants are completely ring-barked (Figure 67). In the absence of control measures, up to 100% of transplants can be killed.

Measurement and Description: All conifer sites felled within the last 3 year should be checked for weevil. At least 5 stumps should be sampled across the 12.62m radius plot.

Figure 67. Pine weevil damage (Dillion and Griffin 2008).

10.5.9 Green Spruce Aphid

Definition: These aphids are 1.0 to 1.5mm long, olive to dull green with red eyes and are generally wingless (Figure 68). It is different from other aphids in that it is active during the winter months, usually from October through to March and not during the summer.

Application: The aphid causes major discoloration and loss of spruce foliage and a reduction in timber production during the forest rotation.

Measurement and Description: If there is Green Spruce Aphid damage evident on individual trees present in the plot, record same. Assessment is carried out on the 12.62m plot.

Figure 68. Green spruce aphids present on Sitka spruce.

10.5.10 Red Band Needle Blight

Definition: Red band needle blight is is caused by the pathogen known as *Dothistroma septosporum*.

Application: Red Band Needle Blight is an economically important wilt disease affecting a number of coniferous trees, in particular pines throughout Scotland. It was officially recorded in Northern Ireland in 2011 and in September 2016 was found in Ireland for the first time. Red band needle blight causes premature needle defoliation which results in the loss of timber yield and, in severe cases, tree mortality (Figure 69).

Measurement and Description: If there is Red Band Needle Blight evident on individual trees present in the plot, record same. Assessment is carried out on the 12.62m plot.

Attribute: **Red Band Needle Blight**

Figure 69. Red Band Needle Blight, signs and symptoms.

10.5.11 Phytophtera Ramorum

Definition: The disease caused by the pathogen *Phytophthora ramorum* a fungus like organism, can damage and kill plants and trees it infects.

Application: Japanese larch appears to be particularly susceptible to the disease, affecting all age classes and causing significant dieback and deaths. Thes disease has also been found on beech and Noble fir in Ireland. Symptoms of the disease include (Figure 70):

- Partial or whole crown discolouration: reddish brown or grey brown depending on degree of infection
- Crown partially flushed (in needle) or not at all
- Crown dieback
- Wilt and dieback of fresh needles with blackening of needles.
- Shoot dieback from tip back along shoot.
- Resin bleeding on branches and trunk.
- Excessive side shoot/epicormic growth and heavy cone production may be observed.
- Excessive external resin bleeding in upper crown.

Measurement and Description: If there is Phytophtera ramorum evident on individual trees present in the plot, record same. Assessment is carried out on the 12.62m plot.

Figure 70. Phytophtera ramorum signs and symptoms.

10.5.12 Chalara Ash Dieback

Definition: Chalara ash dieback disease is a relatively new serious disease of ash caused by the fungal pathogen *Chalara fraxinea* (*Hymenoscyphus pseudoalbidus*).

Application: Common ash (*Fraxinus excelsior*) is susceptible to Chalara ash dieback disease, as are a number of other species of ash. The disease can affect ash trees of any age and in any setting. Mortalities can occur, with younger trees (less than 10 years old) succumbing more rapidly. Symptoms associated with Chalara ash dieback disease includes (Figure 71):

- Necrotic lesions and cankers along the bark of branches or main stem.
- Foliage wilt.
- Foliage discolouration (brown / black discolouration at the base and midrib of leaves).
- Dieback of shoots, twigs or main stem resulting in crown dieback.
- Epicormic branching or excessive side shoots along the main stem.
- Brown / orange discolouration of bark.

Measurement and Description: If there is Chlara Ash Dieback evident on individual trees present in the plot, record same. Assessment is carried out on the 12.62m plot.

Figure 71. Chalara Ash Dieback signs and symptoms.

10.5.13 Phytophtera Alni

Definition: The disease caused by the pathogen *Phytophthora alni* a fungus like organism, can damage and kill Alder trees, with Alnus glutinosa most susceptible.

Application: In the UK more than 15% of surveyed alder have been affected or killed by Phytophtera alni. From a distance, diseased alders attract attention in mid to late summer because the leaves are frequently abnormally small, yellow and sparse. The leaves often fall prematurely, leaving the branches bare. In a tree with severe crown symptoms, the lower part of the stem is often marked with a black or rusty coloured exudate known as 'tarry spots' which can sometimes occur at 2–3m from ground level.

Measurement and Description: If there is Phytophtera alni evident on individual trees present in the plot, record same. Assessment is carried out on the 12.62m plot.

10.5.14 Pine Shoot Moth

Definition: Pine shoot moth can be a pest in pine plantations, due to the habit of its larvae burrowing into the needles and feeding inside developing buds.

Application: The larvae will burrow or mine into the base of pine needles, feeding and over-wintering in the lateral buds and shoots and destroying their interior and resulting in the deformation or death of leading shoots. Terminal and/or lateral buds will also fail to flush on infected shoots. Where a leading shoot survives it will usually be bent (like a Dutch pipe) and where they do not, multiple leaders will form. Either way significant stem deformities will occur. In Ireland, pine shoot moth is a problem with lodgepole pine stands and notable outbreaks have occurred in forests on the midland bogs and the Ballyhouras in the south west.

Measurement and Description: If there is Pine Shoot Moth damage evident on individual trees present in the plot, record same. Assessment is carried out on the 12.62m plot.

Chapter 11 SMALL TREES

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

11.1 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 72).

Measurement and Description: Assessment is carried out at tree level.

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 72. Regeneration below forest stand and afforestation.

11.2 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 at tree level.

Attribute **Origin of Regeneration**

1. **Planted**: Trees canopy, is the result of planting.
2. **Natural**: Trees canopy, is the result of natural regeneration.

11.3 Small tree measurements

Definition: Attributes assessed on individual small trees: age, height, Dbh and number.

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 4m plot are assessed.

Measurement and Description: The age, height, number and Dbh (if tree is above 1.3m in height) of each small tree is recorded if occurring as individual stems. Small trees may be grouped on the basis of 0.5m height differences and/or if occurring in clusters e.g. hazel and willow. The same age, Dbh and height measurement conventions used in the previous chapter are used for the small tree measurements.

11.4 Small tree damage

11.4.1 Small tree damage type

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 type**

1. **No damage**: Damage is not present on the tree.
2. **Leader**: Leader damage on the tree, such as dieback, forking, or grazing.
3. **Stem surface**: damage to the bark or cambium.
4. **Stem**: damage to the bole of the stem.
5. **Root**: damage to roots by animals or machinery.

11.4.2 Small tree damage agent

Attribute **Small Tree Damage Agent**

1. Deer
2. Cattle
3. Sheep
4. Goat
5. Squirrel
6. Rabbit
7. Hare
8. Horse.

11.4.3 Small tree damage age

Attribute **Small Tree Damage Age**

1. **New:** damage occurred within the last year
2. **Old:** damage is more than 1 year old
3. **Repeated**: Damage has been repeated over time.

11.4.4 Small tree damage severity

Attribute **Damage Severity**

1. **Low:** damage agent appears to have minimal impact on tree growth or vitality.
2. **Moderate:** damage agent has some obvious impact on tree growth or vitality, but the impact is limited.
3. **High:** damage agent has an obvious impact on tree growth or with evidence of decay or suppression of tree growth evident
4. **Critical:** damage agent has critically impacted and killed trees or the damage agent is expected to kill trees in the near future.

Chapter 12 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.

12.1 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 7cm and a minimum length of 1m. Only the portion of the log occurring within the plot is included. Assessment of the log length stops at 7cm top diameter (Figure 73). The mid diameter and length of the log is recorded.

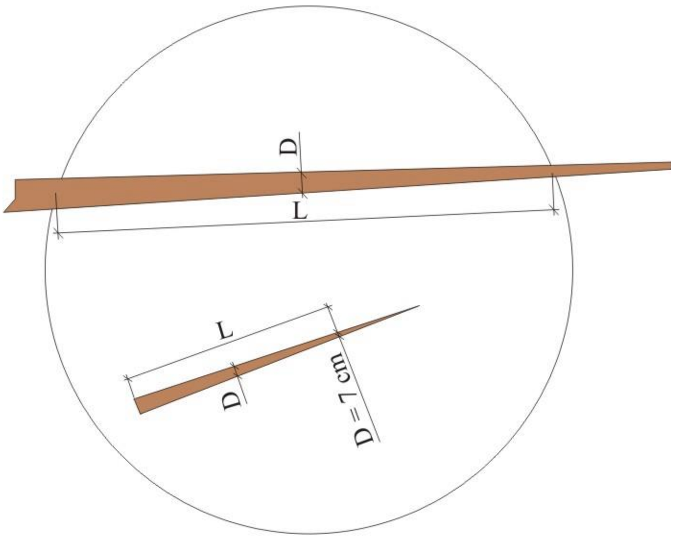

Figure 73. Dead log measurement.

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 74, 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.

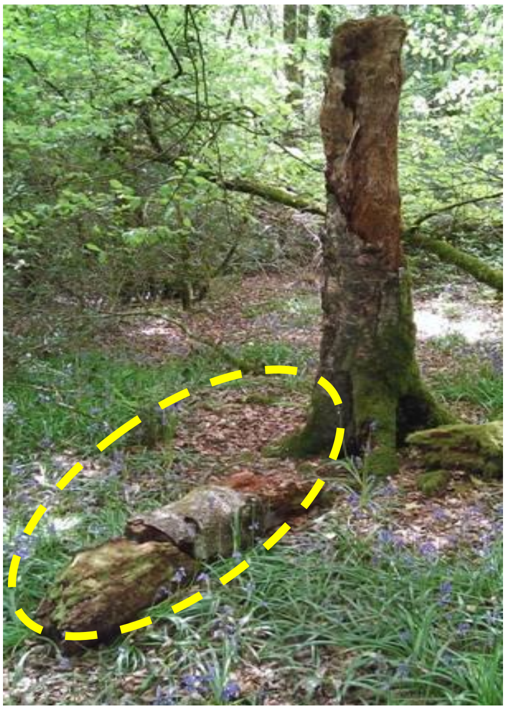

Figure 74. Standing dead tree.

12.1.1 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 12.62m 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 7cm and/or they are less than 1m in length.
3. **Dead logs present**: Logs are present with a minimum mid diameter of 7cm and a minimum length of 1m.

12.1.2 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 76).

Measurement and Description: The assessment of dead log distribution is on the 12.62m 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 75. Dead logs randomly distributed and dead logs in windrows.

12.1.3 Deadlog decay status

Definition: Deadlog decay status describes the level of decomposition of the deadlog 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.

Measurement and description: The decay status of all deadlogs recorded on the 12.62m plot is assessed.

Attribute **Deadlog Decay Status** (Olajuyigbe, 2011)

1. **Fresh:** Freshly felled logs

2. **Intact:** Log whole and hard, with bark intact (±100%), some signs of decay in places
3. **Sapwood soft:** Sapwood soft in patches, fragmentation evident, bark ≥50%, all branch knots flush with log surface or can be seen
4. **Advanced decay:** Large blocky pieces missing. Log frame is deformed. Portions of sapwood missing. Branch knots prominent. Little bark present
5. **Largely diminished:** Well decayed and deformed. Humification is advanced. Collapses when moved.

12.2 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 76).

Measurement and Description: Stumps occurring on the 12.62m plot are included in the assessment. A stump must have a minimum top diameter of 10cm and height of less than 1.3m. A stump with a height of greater than 1.3m is considered a standing dead tree. The stump top diameter and height is recorded in cm.

Figure 76. Stump deadwood.

12.2.1 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 12.62m 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 10 cm.
3. **Stumps present**: Stumps are present with a minimum top diameter of 10 cm.

12.2.2 Stump decay status

Definition: Stump decay status describes the level of decomposition of the stump 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.

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

Attribute **Stump Decay Status** (Olajuyigbe, 2011)

1. **Fresh:** Freshly created or live sapwood (from root grafts to adjoining live trees).
2. **Intact:** Stump is dead, inner wood intact and hard, decay barely commenced, bark is soft or peeling off, sapwood is hard, knife cannot be inserted.

3. **Sapwood soft:** Sapwood is very soft, fragmentation is evident and knife penetrates sapwood, bark missing in places, other areas hollow, decay commencing in the heartwood. In some cases invading roots in the sapwood.
4. **Advanced decay:** Decay in advanced stage, stump reduced in size with large pieces missing. Heartwood is soft. In some cases invading roots found growing in the heartwood.
5. **Largely diminished:** Stump largely diminished. Top surface merging into the ground, heartwood disintegrating. Little force breaks up the stump.

12.3 Deadwood species group

Definition: Deadwood species group 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 12.62m plot is assessed.

Attribute **Deadwood Species Group**

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

Chapter 13 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.

13.1 WOODLAND HABITAT

Definition: A standardised schema for classifying woodland habitat.

Application: Habitats are recorded, described and mapped for a variety of different reasons. It is important, therefore, that a standard approach is used when recording habitat information. This hierarchical classification scheme is intended to facilitate habitat identification and differentiation at a general level. This scheme has been widely used to standardise data collection on habitats, thereby enhancing compatibility and the potential value of data collected. It should also facilitate baseline surveys of sites and habitat resources at local, regional or national scales (Fossitt, 2000).

Measurement and Description: The assessment of Woodland Habitat is based on the 12.62m plot.

Attributes **Woodland Habitat Type and sub-type** (Fossitt, 2000)

1. **Semi-natural woodland**

   i. Oak-birch-holly woodland

   These woods occur on acid or base-poor, reasonably well drained soils. They are usually dominated by *Quercus petraea* (sometimes with *Quercus robur* or their hybrids). The field layer typically includes *Vaccinium myrtillus, Blechnum spicant* and *Luzula sylvatica.*

   ii. Oak-ash-hazel woodland

   These woods occur on reasonably well-drained, base-rich soils or on rocky limestone terrain. They are typically dominated by some combination of *Quercus robur*, *Fraxinus excelsior* and *Corylus avellana*. The field layer often includes *Circaea lutetiana, Polystichum setiferum, Viola riviniana, Arum maculatum, Fragaria vesca, Allium ursinum* and *Potentilla sterilis.*

   iii. Yew woodland

   These are stands dominated by *Taxus baccata*. This woodland type is very rare in Ireland and is found on shallow, rocky limestone soils. The field layer is characteristically sparse.

   iv. Wet pedunculate oak-ash woodland

   These are woods occurring on ground that is subject to winter flooding or waterlogging but which dries out in summer. It is typical on poorly drained, heavy clay soils and is usually dominated by some combination of *Quercus robur* and *Fraxinus excelsior*. *Alnus glutinosa* can be locally abundant. The field layer typically includes *Filipendula ulmaria, Circaea lutetiana, Rubus fruticosus* and *Chrysosplenium oppositifolium.*

   v. Riparian woodland woodland

   These are wet woodlands that are subject to regular flooding along river margins or on low-lying river islands. The canopy is dominated by a mixture of native and non-native willows (*Salix* spp.), and *Alnus glutinosa* may be occasional. The field layer typically includes *Urtica dioica*, *Angelica sylvestris*, *Oenanthe crocata*, *Calystegia sepium* and *Phalaris arundinacea.*

   vi. Wet willow-alder-ash woodland

   These are wet woodlands of permanently waterlogged sites. They are usually dominated by some combination of *Salix cinerea, Alnus glutinosa* and *Fraxinus excelsior.* Included here are lakeside woods, woods on fen peat (carr) and woods on spring-fed or flushed sites. Field layer species include *Agrostis stolonifera, Galium palustre* and *Filipendula ulmaria.*

vii. Bog woodland

These are woods on ombrotrophic bogs, including cutover bogs and bog margins and hence are usually found on deep acidic peat. They are dominated by *Betula pubescens* with a field layer often comprising *Calluna vulgaris, Vaccinium myrtillus, Pteridium aquilinum, Molinia caerulea* and *Rubus fruticosus.*

2. **Highly modified/non-native woodland**

i. (Mixed) broadleaved woodland

This is a modified woodland type with 0-25% conifers and 75-100% broadleaves which may contain native and / or non-native species. It should be used in situations where woodland stands cannot be classified as semi-natural on the basis of the criteria outlined above. Trees may include native and non-native species. Plantations of broadleaved trees are included if the canopy height is greater than 5 m, or 4m in the case of wetland areas.

ii. Mixed broadleaf/conifer woodland

This is a modified woodland type where both conifer and broadleaved species have a minimum cover of 25%, and a maximum of 75%. Trees may be either native or non-native species. Mixed broadleaved/conifer plantations are included if the canopy height is greater than 5 m, or 4m in the case of wetland areas.

iii. (Mixed) Conifer woodland

This general category includes woodland areas with 75-100% cover of conifers, **other than conifer plantation**. The broadleaved component should be less than 25%. Woodlands that belong in this category are most likely to be found in parks or gardens, or in the grounds of old estates and institutions where there has been a history of planting. Non-native trees usually dominate. The term 'mixed' should be used in the habitat title if woodland stands comprise a number of different conifer species.

iv. Conifer plantation

This category is used for areas that support dense stands of planted conifers where the broadleaved component is less than 25% and the overriding interest is commercial timber production. Conifer plantations are characterised by even-aged stands of trees that are usually planted in regular rows, frequently within angular blocks. Species diversity is low and single species stands are common. The majority of planted conifers are non-native species such as Sitka Spruce *(Picea sitchensis)*, Lodgepole Pine *(Pinus contorta)*, Norway Spruce *(Picea abies)* and larches (*Larix* spp.). Conifer plantations may be fringed with narrow bands of broadleaved trees, most of which are also planted. Any distinct blocks of broadleaved trees should be recorded separately in the appropriate woodland category.

3. **Scrub/transitional woodland**

i. Scrub

This broad category includes areas that are dominated by at least 50% cover of shrubs, stunted trees or brambles. The canopy height is generally less than 5 m, or 4m in the case of wetland areas. Scrub frequently develops as a precursor to woodland and is often found in inaccessible locations, or on abandoned or marginal farmland. In the absence of grazing and mowing, scrub can expand to replace grassland or heath vegetation. Trees are included as components of scrub if their growth is stunted as a result of exposure, poor soils or waterlogging. If tall trees are present, these should have a scattered distribution and should not form a distinct canopy. This category does not include areas that are dominated by young or sapling trees (<5 or 4m in height) or young conifer plantations. Scrub can be either open, or dense and impenetrable, and it can occur on areas of dry, damp or waterlogged ground. Common components include spinose plants such as Hawthorn *(Crataegus monogyna)*, Blackthorn *(Prunus spinosa)*, Gorse *(Ulex europaeus)*, Juniper *(Juniperus communis)*, Bramble (*Rubus fruticosus* agg.) and erect or scrambling roses (*Rosa* spp.), in addition to a number of willows (*Salix* spp.), small birches (*Betula* spp.) and stunted Hazel *(Corylus avellana)*. Scrub may also contain Bog-myrtle *(Myrica gale)* and Broom *(Cytisus scoparius)*. The field layer is often impoverished and poorly-developed but, in some situations, may be similar to that of woodland. Lowgrowing Western Gorse *(Ulex gallii)* and prostrate Juniper *(Juniperus communis)* can also be components of heath. Note that any areas that are dominated by non-native shrubs should be excluded.

ii. Immature woodland

Immature woodland includes areas that are dominated by young or sapling trees that have not yet reached the threshold heights (5 m, or 4m in the case of wetland areas) for inclusion in the woodland categories previously described. Recently planted areas and young plantations should also be included here, with the exception of **conifer plantations**. Any areas that are dominated by shrubs or stunted trees should be considered under **scrub**.

iii. Recently-felled woodland

Temporary unstocked foresst area following recent felling.

13.2 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 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 and range of the vegetation present will also be indicative of the insect diversity.

Measurement and Description:

1. 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 6 detail the list of species recorded.
2. Shrub species and cover may be recorded throughout the year. Other vegetation sampling should only be carried out between May 1st and September 31st each year.
3. Shrub species and cover should be recorded on the 12.62m plot. Other ground vegetation species cover information is done on the 7m plot.
4. Where practicable, vegetation sampling should be carried out immediately on the plot.
5. Total bryophyte cover should be recorded. It is not necessary to assess bryophytes to species level.
6. All vascular plants should be recorded to species level.
7. If a species cannot be identified on the plot, a sample of that species, preferably taken from outside the plot, should be taken for identification that evening. A list of species that are protected (Flora Protection Order 1999, Habitats Directive) and cannot be removed is provided in Appendix 5.

13.2.1 Vegetation Type

Definition: All non-epiphytic vegetation life-forms living under the canopy layer.

Attribute **Vegetation Type**

1. **Herb**: Vascular herbs, excluding graminoids and ferns. See Appendix 6 for a species list.
2. **Grasses**: All grasses, rushes and sedges. See Appendix 7 for a species list.
3. **Bryophytes**: Nonvascular, terrestrial green plants, including mosses and liverworts.
4. **Shrub**: Woody perennial plants, generally more than 0.5 meters and less than 5 meters in height at maturity and without a definite crown. Note, if climbing, the lianas *Hedera helix* and *Lonicera periclymenum* can be included in the shrub layer. If hazel *Corylus avellana* does not meet the height

threshold requirements to be considered a tree (the ability to reach 5m in height) it can be included in the shrub layer. See Appendix 8 for a species list.

5. **Fern**: True ferns and horsetails but excluding clubmosses and spikemosses. See Appendix 9 for a species list.

13.2.2 Vegetation Cover Class

Definition: All non-epiphytic vegetation life-forms living under the canopy layer.

Measurement and Description: Vegetation cover is assessed on the 7m plot into percentage classes (Figure 77).

Attribute **Vegetation Cover**

1. **No presence**: No vegetation cover.
2. **<4% few individuals**: Total vegetation cover is less than <4% few individual plants present.
3. **<4% several individuals**: Total vegetation cover is less than <4% several few individual plants present.
4. **<4% many individuals**: Total vegetation cover is less than <4% many individual plants present.
5. **5-10%**: Total vegetation cover is between 5 and 10% of the plot area.
6. **11-25%**: Total vegetation cover is between 11 and 25% of the plot area.
7. **26-33%**: Total vegetation cover is between 26 and 33% of the plot area.
8. **34-50%**: Total vegetation cover is between 34 and 50% of the plot area.
9. **51-75%**: Total vegetation cover is between 51 and 75% of the plot area.
10. **76-90%**: Total vegetation cover is between 76 and 90% of the plot area.
11. **91-100%**: Total vegetation cover on the plot is between 91 and 100% of the plot area.

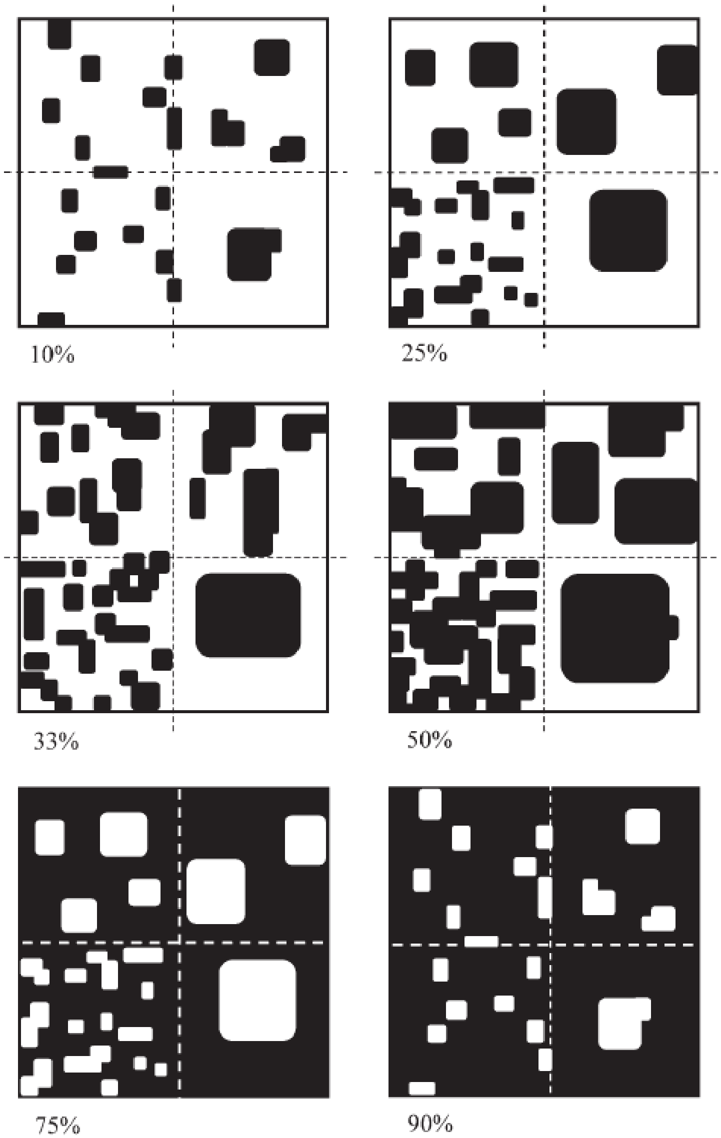

Figure 77. Visual interpretation of vegetation cover (Rodwell, 2006).

13.3 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 78). 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 78. 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**

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

13.4 LITTER AND HUMUS

The litter layer and humus are described in this section.

13.4.1 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 12.62m 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

13.4.2 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.

13.5 Soil Description

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

13.5.1 Soil Description

Definition: Broad classification into peat and mineral soil.

Application: Soil description 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 description is assessed when the soil pit is dug. Peat and soil depth are measured to the nearest cm.

Attribute **Soil Description**

1. **Peat (>40cm):** Peat soil greater than 40cm of peat.
2. **Mineral soil (<30cm):** Mineral soil less than 30cm in depth.
3. **Mineral soil (>30cm):** Mineral soil greater than 30cm in depth.

13.5.2 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 NFI classifies soil into eleven great soil groups which were presented by Simo *et al.* (2008).

Attribute **Soil Group**

1. Brown earth
2. Brown podzolic
3. Luvisol
4. Podzol
5. Groundwater Gley
6. Surface Water Gley
7. Rendzina
8. Lithosol
9. Alluvial
10. Ombrotrophic
11. Minerotrophic

Each soil group is briefly described in the following section. The photographs used in this section were copied from the Irish Soils Information System Website (Teagasc and EPA, 2015).

Brown earth

Relatively mature, well-drained mineral soils, derived from parent materials of acidic or basic status (Figure 79). 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 (Simo *et al.*, 2008). They have not been extensively leached or degraded (i.e. they lack argillic (Bt) or podzolic B (Bs, Bh) horizons) although some leaching has resulted in the translocation of calcium (Jones et al., 2011).

Figure 79. Typical Brown Earth (left and middle) and Humic Calcareous Brown Earth (Right)

Obmbrotrophic Peats

Ombrotrophic peat soils are rain-fed peat soils in lowland (raised bog) and upland positions (blanket peat). They are an organic-rich soils with an O horizon >40 cm, found within the upper 80 cm. Ombrotrophic soils are oligotrophic with a pH <4.0 throughout the Reference Section (Simo *et al.*, 2008).

Obmbrotrophic Peats

Minerotrophic Peat soils are an organic-rich soils with an O horizon of more than 40cm within the upper 80cm and are ground water-fed peat systems occurring in river valleys, inter-drumlin hollows and on the periphery of raised bogs. They are eutrophic and have a pH >4.0 in at least some part of the Reference Section (Simo *et al.*, 2008).

Brown podzolic

Well-drained, acid mineral soils, derived mainly from acidic parent materials such as shale, granite or sandstone (Figure 80). 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.

Brown Podzolic Soils show features of incipient podzolic processes but are not sufficiently expressed to classify them as Podzols. They have a podzolic B horizon (Bs) but lack an albic (E) horizon. This Great Group includes weak developed soils which are difficult to classify as Podzols, primarily through cultivation or land improvement and in some cases there may also be a thin discontinuous iron pan present (Simo *et al.*, 2008).

Figure 80. Brown podzolic.

Podzol

These soils are subject to intense leaching of minerals, particularly iron and aluminium, and are formed from acidic parent materials (Figures 81). Podzols have a dark, humose or peaty surface horizon and an albic horizon (E) overlying a podzolic B horizon (Bs). If the topsoil is peaty it should be <40cm thick. The albic horizon has a moist colour value >4. Due to severe leaching of iron and cementation, some podzols may develop a thin impervious 'iron pan' in the B horizon. Gleying can also occur within the profile (Jones et al., 2011).

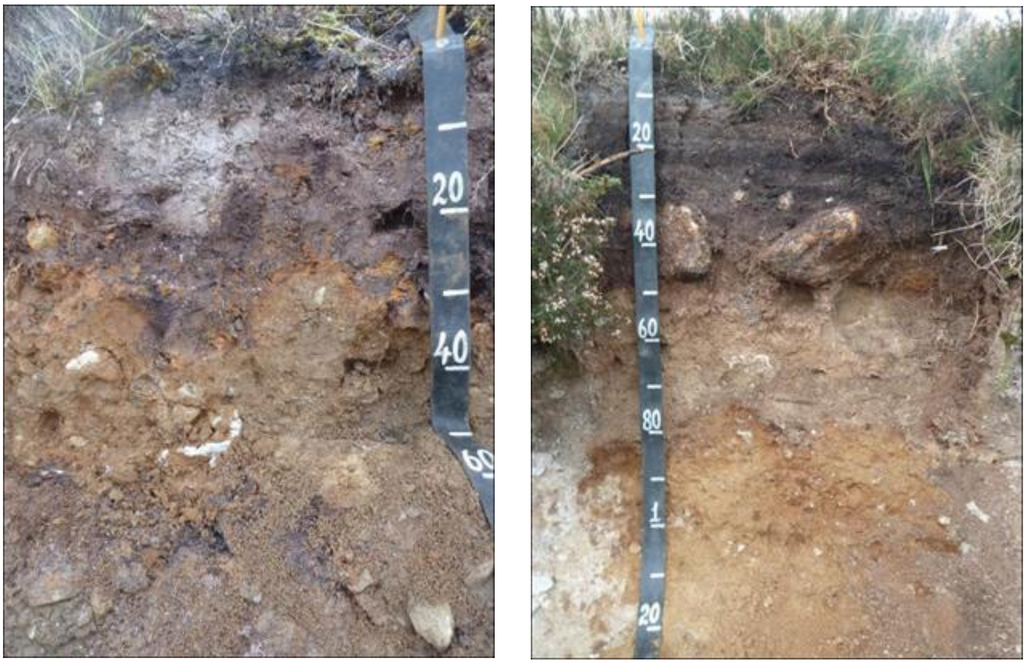

Figure 81. HumoFerric Podzol (left) Ferric Podzol (right).

Surface Water Gley

Surface-water gleys have a gleyed sub-surface horizon and a slowly permeable sub-surface horizon (Figure 82). The slowly permeable sub-surface horizon impedes downward water movement from in situ precipitation and/or lateral run off from upslope positions resulting in seasonal waterlogging. These soils attend tohave fine texture (fine loamy or clayey) in the lower subsoil horizons. These soils show prominently mottling above 40cm (Jones et al., 2011).

Figure 82. Typical Surface Water Gley (left), Humic Surface Water Gley (middle and right).

Ground Water Gley

These soils have gleyed sub-surface horizons, displayed by prominent mottling or uniformly grey subsoils within 40cm depth (Figure 83). The gleying is caused by periodic waterlogging resulting from a shallow fluctuating groundwater table. The gleyed sub-surface horizons and the substratum are permeable. In Groundwater Gley soils, the lower subsoil horizons generally have grey matrix colours. These soils attend to have coarse texture (coarse loamy or sandy) on the lower subsoil horizons (Simo *et al.*, 2008). They used to be associated to river banks or interdrumlins locations (Figure 84).

Figure 83. Typical Ground Water Gley (left) and Humic Ground Water Gley (middle and right).

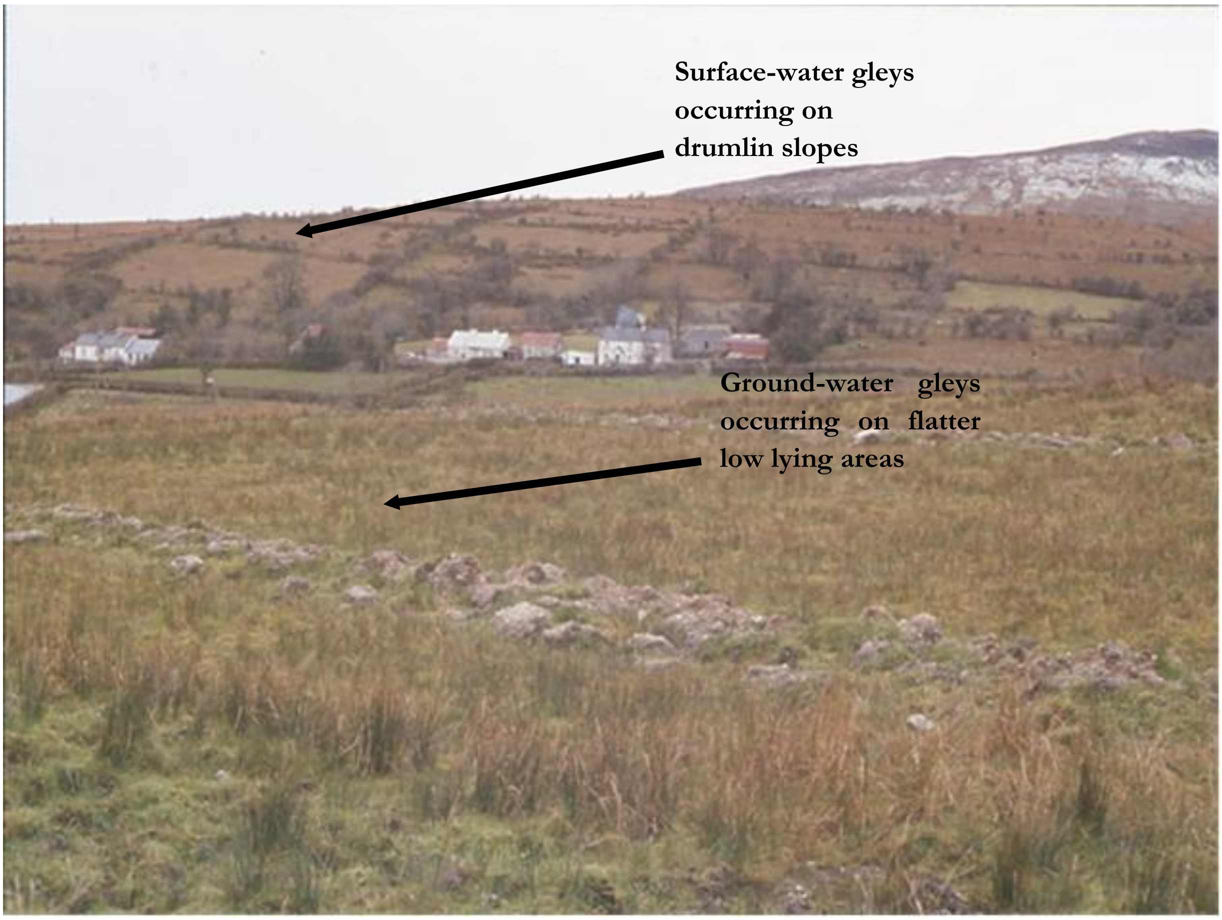

Figure 84. Position of gleyed soils in the landscape (Teagasc, 2007).

Rendzina

These are well-drained, shallow mineral soils (Figure 85). Rendzinas are shallow (<30cm depth) calcareous soils with hard rock or skeletal material comprising >80% coarse fragments at or above 30cm (Jones et al., 2011).

Figure 85. Rendzina (Left) and Histic Rendzina (Right).

Luvisol

These soils have eluvial horizons from which clay has been leached and illuvial horizons in which clay has been deposited lower down (Figure 86). These clay illuviation result in a Bt horizon with significant increase of clay (argillic B horizon) compared to the overlying horizons. An albic E horizon may be present between the A and Bt horizons. These soils are decalcified, thus soils that are calcareous do not have argillic B horizons, unless soils were formed before carbonate source (Simo et al., 2008).

Figure 86. Typical Luvisol (middle) and stagnic luvisol (left and right).

Lithosol

Very shallow and stony mineral soils, usually overlying solid or shattered bedrock (Figure 87). 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. These are shallow (<30cm depth) non-calcareous soils, commonly overlying hard rock or skeletal and gravelly material made up of >80% coarse material. They tend to be stony soils, or with shattered bedrock and are associated with frequent rock outcrops (Jones et al., 2011).

Figure 87. Humic Lithosol (Top left),Typical Lithosol (Top Right) and Histic Lithosol (Bottom)

Alluvial

Alluvial soils are formed in deposits of river, lake, estuarine or marine alluvium (Figure 88). The majority of series described are associated with recent rivers and streams. The lake alluviums found in Ireland are mostly associated with depressions at the sites of glacial or post-glacial lakes. Alluvial soils have present gleyic or stagnic properties, on sequencing profile are reduced. They can have loamy or clayey B horizons that may overlie coarse substratum. There are two main groups of alluvial soils found in Ireland (Simo et al., 2008):

1. Alluvial soils which are formed in alluvial deposits and remain poorly drained due to the influence of shallow ground water.
2. Drained Alluvial soils are formed on alluvial deposits but have been drained but are well to moderately drained. These soils are formed on alluvial deposits and are well to imperfectly drained.

Figure 88. Typical Brown Alluvial Soils (Top), Typical Alluvial Gley (Bottom Left) and Humic Alluvial Gley (Bottom Right).

13.5.3 Soil sub-group

Definition: Soil sub-group categorises the soil groups into more descriptive classes.

Application: In order to further describe the inherent physical characteristics of a soil.

Measurement and Description: Soil is assessed when the soil pit is dug.

Attribute **Soil sub-group**

Table 9. Soil sub-group.

Great Group Name	Sub-group name
Ombrotrophic	Natural Ombrotrophic Peat Soils
	Drained Ombrotrophic Peat Soils
	Cut-over Ombrotrophic Peat Soils
	Industrial Ombrotrophic Peat Soils
Minerotrophic	Natural Minerotrophic Peat Soils
	Drained Minerotrophic Peat Soils
	Cut-over Minerotrophic Peat Soils
Rendzina	Typical Rendzinas
	Histic Rendzinas
	Humic Rendzinas
Lithosol	Typical Lithosols
	Histic Lithosols
	Humic Lithosols
Alluvial	Typical Alluvial Gleys
	Histic Alluvial Soils
	Typical Calacareous Alluvial Gleys
	Histic Calcareous Alluvial Soils
	Humic Calcareous Alluvial Gleys
	Humic Alluvial Gleys
	Typical Brown Alluvial Soils
	Gleyic Brown Alluvial Soils
Groundwater Gley	Typical Groundwater Gleys
	Histic Groundwater Gleys
	Typical Undifferentiated Gleys
	Humic Undifferentiated Gleys
	Calcareous Groundwater Gleys
	Histic Calcareous Groundwater Gleys
	Humic Calcareous Groundwater Gleys
	Humic Groundwater Gleys
	Anthric Groundwater Gleys
Surface Water Gley	Typical Surface-water Gleys
	Humic Surface-water Gleys
	Anthric Surface-water Gleys

Great Group Name	Sub-group name
Podzol	Ferric Podzols
	Typical Gley Podzols
	Stagno-Gley Podzols
	Iron-pan Stagno Podzols
	HumoFerric Podzols
	Anthric Podzols
Brown Podzolic	Typical Brown Podzolics
	Gleyic Brown Podzolics
	Stagnic Brown Podzolics
	Humic-stagnic Brown Podzolics
	Humic Brown Podzolics
	Anthric Brown Podzolics
Luvisol	Typical Luvisols
	Gleyic Luvisols
	Humic-gleyic Luvisols
	Stagnic Luvisols
	Humic-stagnic Luvisols
	Humic Luvisols
	Anthropic Luvisols
Brown Earth	Typical Brown Earths
	Gleyic Brown Earths
	Humic-gleyic Brown Earths
	Stagnic Brown Earths
	Humic-stagnic Brown Earths
	Typical Calcareous Brown Earths
	Gleyic Calcareous Brown Earths
	Stagnic Calcareous Brown Earths
	Humic Calcareous Brown Earths
	Anthric Calcareous Brown Earths
	Humic Brown Earths
	Anthric Brown Earths
	Anthric - Humic Brown Earths

13.6 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.

13.6.1 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.

13.6.2 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 89). 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.

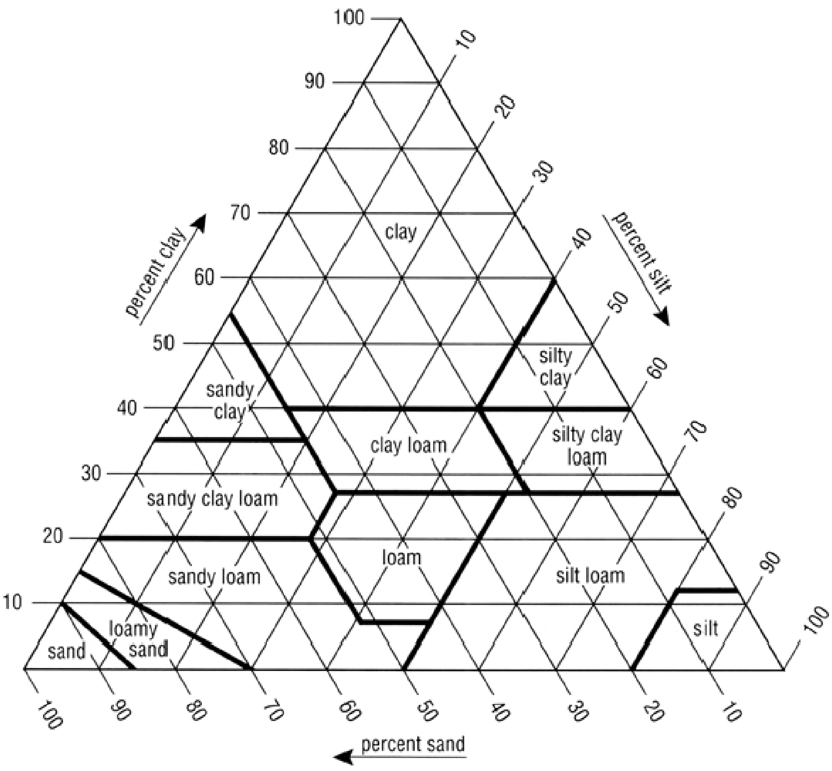

Figure 89. Percentages of clay, silt and sand in the basic textural classes (Anon. 1993).

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 90) to get the texture class:

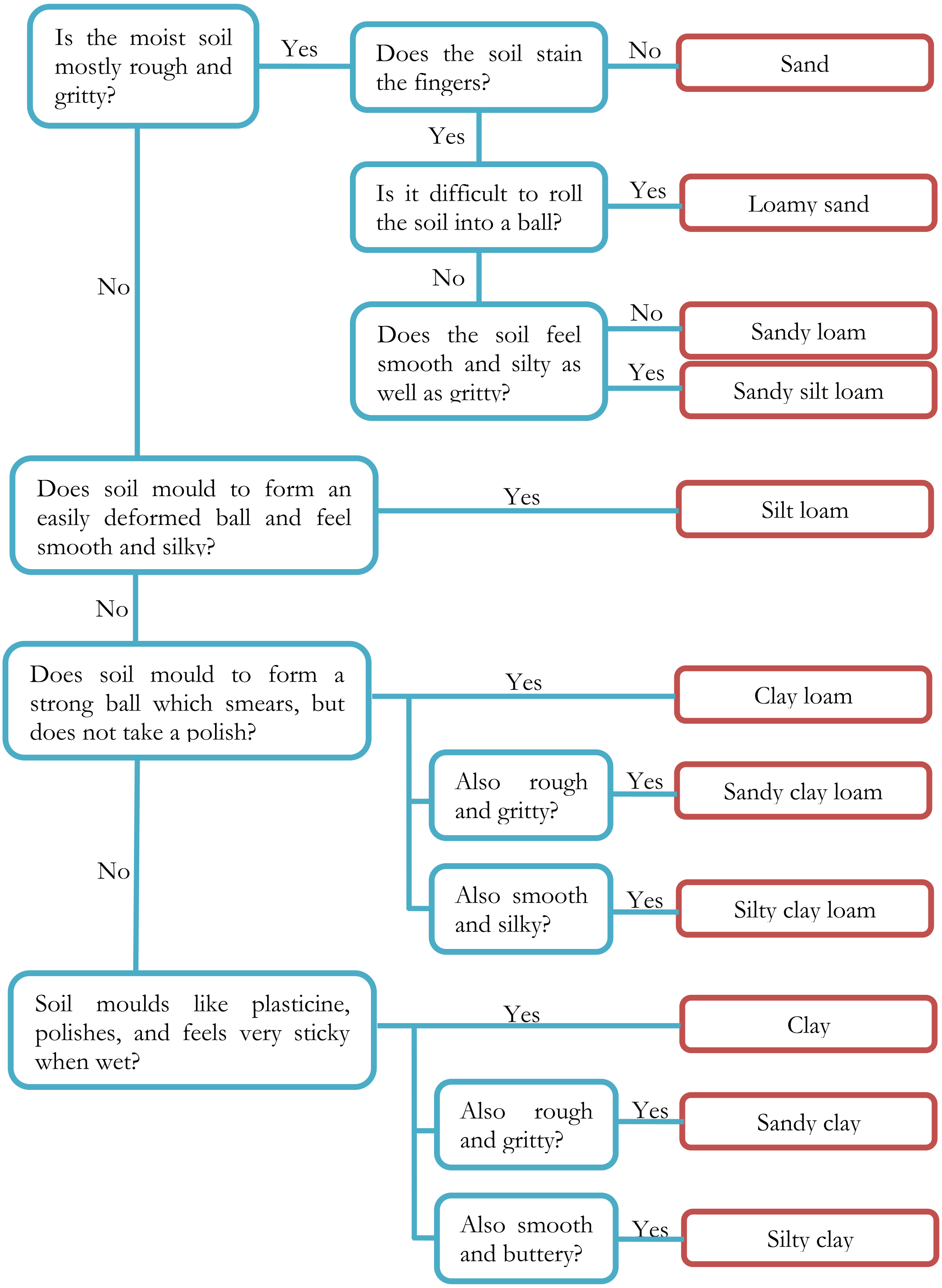

Figure 90. Assessment of soil texture (Anon. 2005).

13.6.3 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 100cm. In the case where both soil and peat are present (e.g. a peaty gley), the maximum combined recording depth is also 1m.

13.7 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 and management of a forest 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.

Measurement and Description: Assessment of the cultivation type present is made on the 12.62m 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 91).
2. **Ripping**: A vertical steel plate, with horizontal tines attached, is pulled through the soil at a depth of 30-60cm 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 92).
6. **Double mould board ploughing (DMD)**: A plough with two large boards facing in opposite directions turns two sods, leaving a deep drain in between the two plough ribbons (Figure 93).
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 94).
8. **No cultivation**: There was no soil cultivation, the trees regenerated naturally.

Figure 91. Mounding.

Figure 92. Single mould board ploughing (Hart 1991).

Figure 93. Double mould board ploughing (Hart 1991).

Figure 94. Soil cultivation: mechanical planting.

13.8 Terrain classification

This section describes attributes that are used to assess terrain.

13.8.1 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 12.62m 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.

13.8.2 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, which is 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 12.62m 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.

13.8.3 Ground conditions

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 10). 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 12.62m 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 10. 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 (<5cm 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 5-45cm)	Average	Poor
	Peaty gleys and humic gleys (peat 5-45cm)	Poor	Very poor
	Hill peat (relatively firm, not too wet, >45cm)	Poor	Very poor
	Other deep peats (soft, wet, >45cm)	Very poor	Very poor

SECTION C
VALIDATION
AND
DATA ANALYSIS

Chapter 14 VALIDATION OF FIELDWORK

14.1 BACKGROUND

The field data collection element of the third cycle National Forest Inventory (NFI) commenced in December 2015 and finished by July 2017. To ascertain the quality of field data collection, 98 plots or 5.2% of the 1,923 plots visited in the field, were completely re-measured in four separate validation stages between 2016 and 2017. These validation stages were carried out jointly between the Forest Service, Department of Agriculture, Food and the Marine and IFER – Monitoring and Mapping Solutions. 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.

14.2 FIELD DATA COLLECTION STAFF

The third cycle NFI field data collection was carried out six full time field staff on temporary contracts. Staffing was more stable in the third NFI than in the two previous cycles, contributing 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. Table 11 below summarises the field data collection attributes for the NFI cycle 1 to 3.

Table 11. Summary NFI field data collection.

	1st Cycle	2nd Cycle	3rd Cycle
No. of forest plots	1,742	1,827	1,923
Data Collection Period	Oct 2004 to Dec 2006	20% - Oct 2009 to Jan 2011 80% - Jan 2011 to Dec 2012	Dec 2015 to July 2017
Time period	27 months	38 months	20 months
Revisit Interval	-	5.95	4.66
Staff	6 staff on temporary contracts. Three 2-person teams High staff turnover of 12.	20% - Permanent NFI staff. 80% - 3 forestry inspectors redeployed plus 2 staff on temp contracts and 1 other funded by Environmental Protection Agency (EPA).	6 staff on temporary contracts. Three 2-person teams.
Other comment	Approx. 250 check plots visited.	Majority of FOA plots not revisited, approximately 10 FOA plots that may have changed were visited.	20 FOA plots that may have changed to forest were revisited. 5 previous defor plots visited 124 check plots visited.

14.3 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 April 2016 the first stage covered 24 plots; the second started in August 2016 covered 25 plots; the third stage in February 2017 covered 25 plots and the fourth in June 2017 covered 24 plots. A total of 98 plots were jointly assessed (Figure 95).

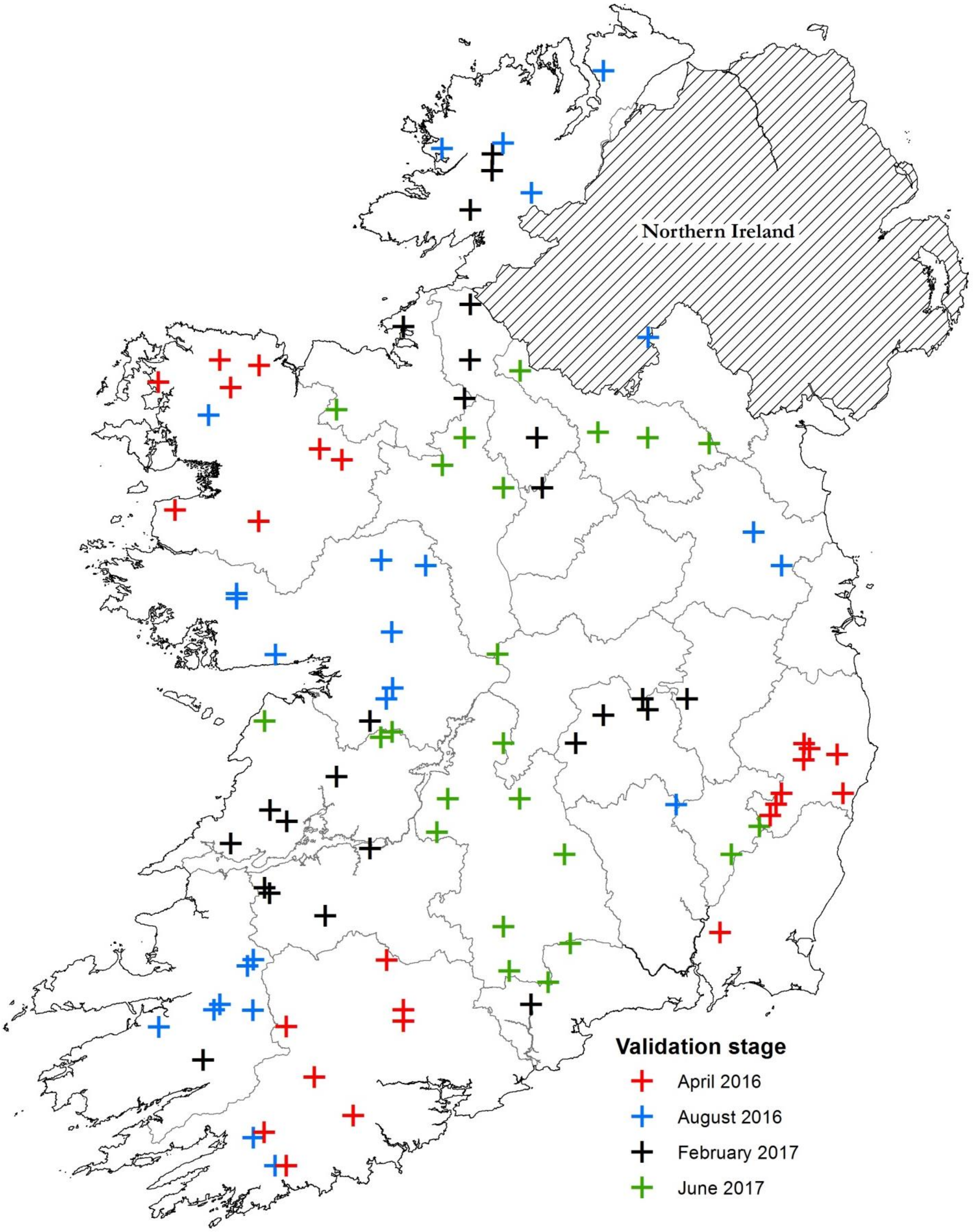

Figure 95. Distribution of plots selected for validation.

14.4 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.

14.5 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.

14.5.1 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.

14.5.2 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.

14.5.3 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 detailed in Table 12.

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 detailed in Table 12.

Table 12. Weighting of mistakes

Type of mistake	Forest plots (trees present above threshold Dbh)	Forest plots (trees present under threshold Dbh), Forest (no trees present) and Forest Open Area plots.
Dendrometric and equipment measurement	X 3	X 1
Trees and forest layers description	X 2	X 2
Site description	X 1	X 3

14.5.4 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.

14.6 Summary Results

Out of the 99 jointly assessed plots the number to be re-measured was 7 (7.1%), the number categorized as "acceptable" was 29 (29.2%) and those termed "Good" was 67 (63.6%). The summary results, along with previous NFI validation results, are shown in Table 13. These figures show high quality data was collected in the third cycle, on a par with the quality of data collected in the second cycle.

Table 13. Summary of validation results

Rating	% Plots Validated		
	1st Cycle	2nd cycle	3rd cycle
Good	58	69	64
Acceptable	32	25	29
Remeasure	10	6	7
Total	100	100	100

14.7 Re-measurement plots/errors commentary

In total seven re-measure plots (7%) were identified during the entire validation exercise. 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 landuse misclassification. The results of each validation were communicated to the NFI teams through feedback meetings, helping to minimise errors and standardise approach throughout field data collection. Trees omitted from mapping is an area that requires constant vigilance, due to its high potential impact on NFI results.

The data quality in this third cycle NFI remained high; the validation results can be attributed to:

1. Extensive training at the start of the project.
2. On site support for 4 weeks with all teams following training.
3. Validation initiated as soon as possible after field data collection.
4. Awareness of field staff that a comprehensive assessment of their work is being carried out.
5. A clear, written field methodology is available to all teams.
6. Well-resourced training materials and maps.
7. Data quality spot checks.

8. Good technical support availability to all field teams.
9. Good equipment backup and availability.

14.7.1 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.

14.7.2 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.

14.8 Recommendations

It is a strong recommendation to continue the approach of hiring full time staff on temporary contracts for all future NFI's. The results from the validation show that data quality is very good and forms a reliable basis for results generation.

Chapter 15 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).

15.1 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, 11,539 (i.e. 31.6%) of the 36,738 mapped trees have been measured for height in the 3rd cycle. In the first NFI cycle, 7,559 (i.e. 33.6%) of the 22,477 mapped trees were measured for height and in the second NFI 9,437 (i.e. 31.6%) of the 29,822 were measured for height. Only living and undamaged trees were selected to assess tree height.

15.1.1 Modelling tree height in the 3rd 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:

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

where h is the tree height, dbh is the diameter at breast height, and P_1, P_2 are the parameters of the models.

For each tree species a global Dbh-height model was generated (Figure 96). 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 97). 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 98).

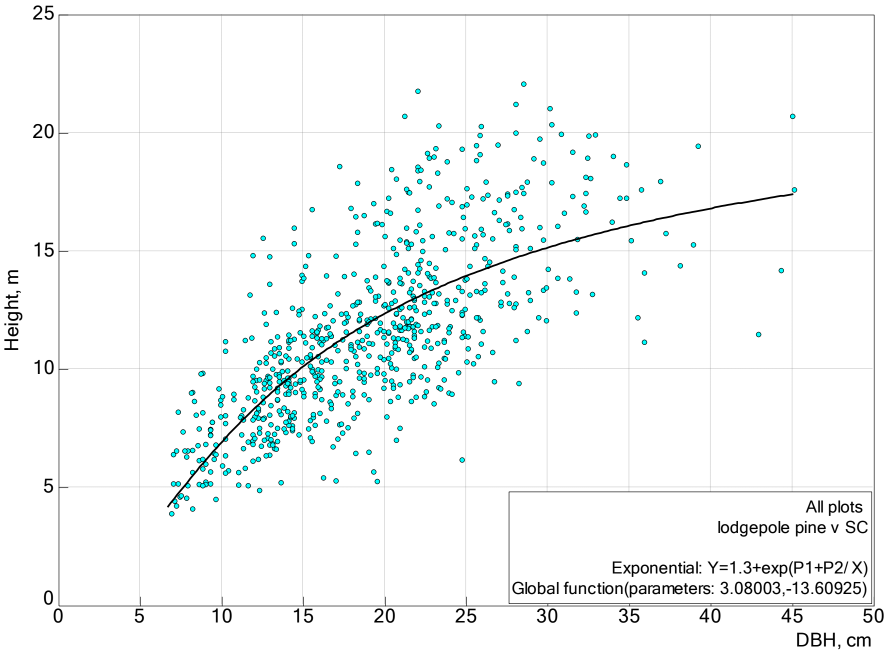

Figure 96. Example of a global Dbh-height model (Lodgepole pine).

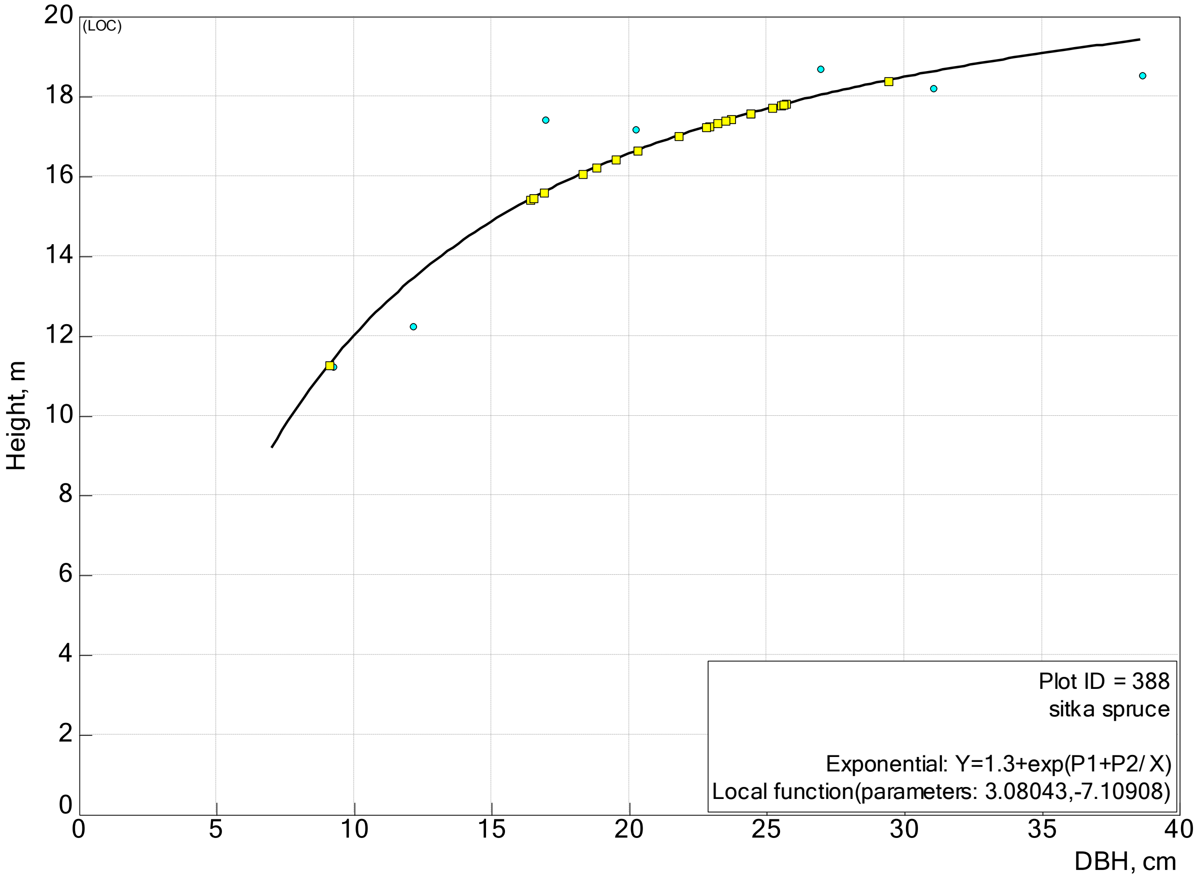

Figure 97. Example of species Dbh-height model for an individual plot.

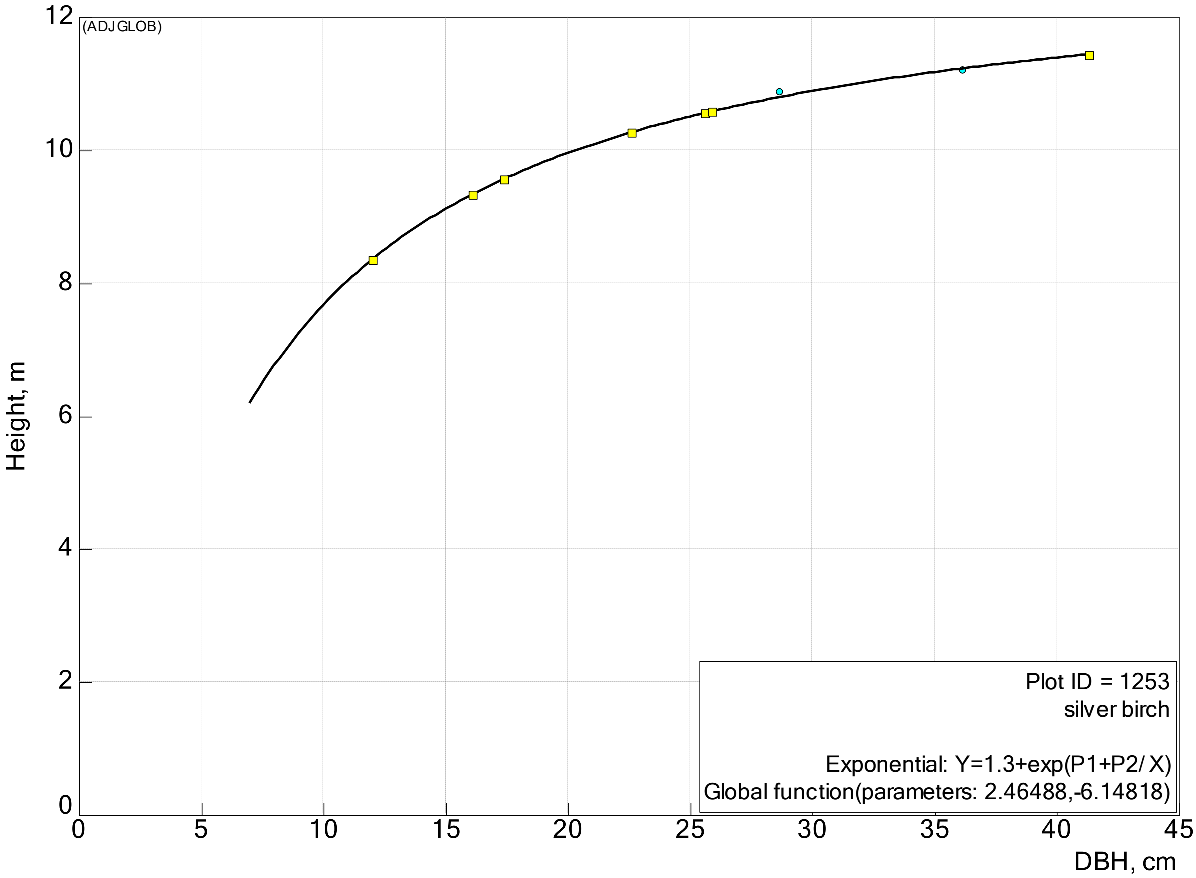

Figure 98. Global species Dbh-height model; adjusted using trees measured on the plot.

15.1.2 Modelling tree height on plots assessed for height in 2^{nd} 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 99). 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.

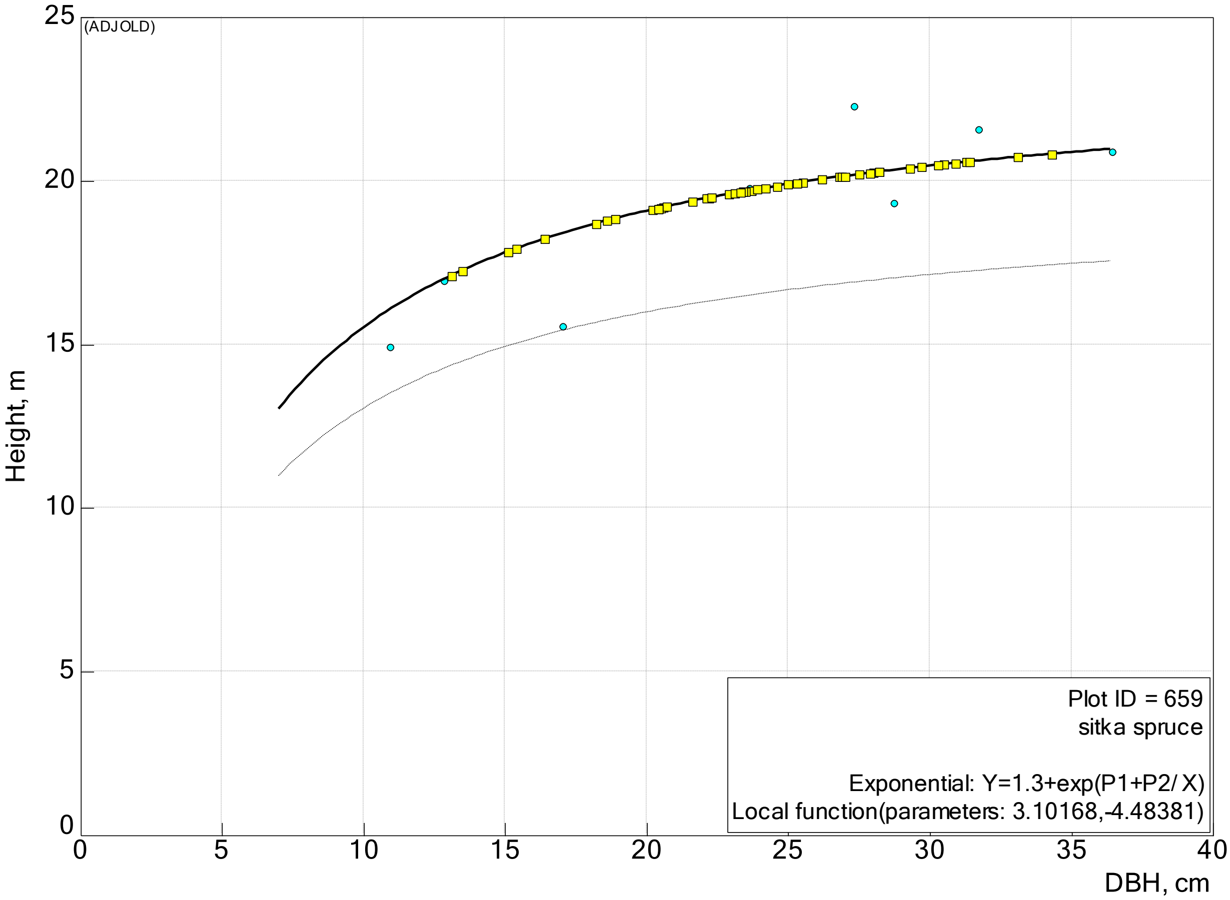

Figure 99. Plot Ht – Dbh model, continuous line is new model, dashed line old model.

15.1.3 Evaluation of Dbh-height modelling

The overall model fit is demonstrated using the chart of predicted versus observed heights (Figure 100). The standard deviation of 1.1m and correlation coefficient 0.98 displays a good fit.

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. As the Dbh-height model was parameterised using NFI data, there is very little difference when using measured or modelled height. 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 (e.g. from 2^{nd} cycle) and modelled value (e.g. from 3^{rd} 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.

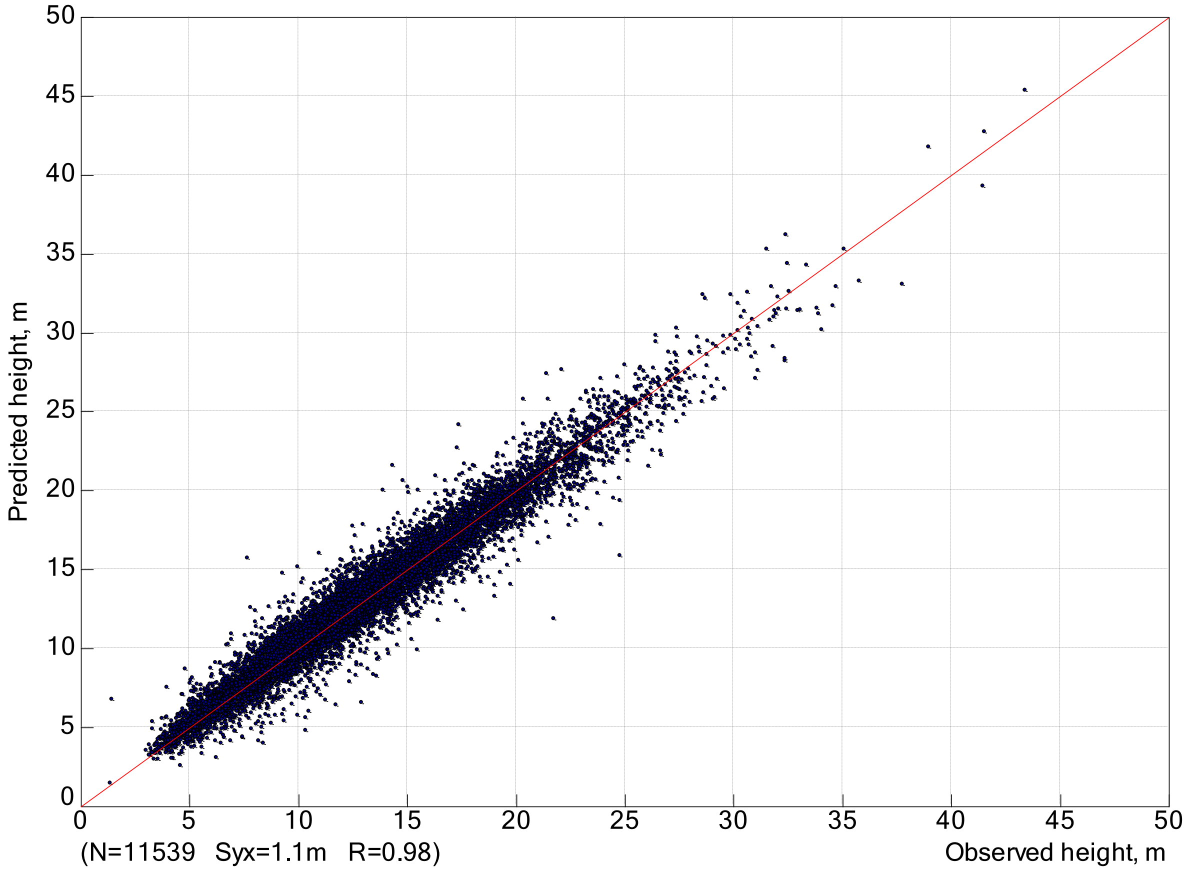

Figure 100. Predicted versus observed tree height.

15.2 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.

15.2.1 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 14.

Table 14. Tree category and type assessed in the NFI.

Tree Category	Tree Category	Relevant for increment?	Number of Trees	
			Per Category	Sub-total
Dbh/Ht Unknown in previous cycle	new plot tree	Yes	957	13,047
	ingrowth	Yes	11,763	
	omitted by mistake	Yes	327	
Dbh/Ht Unknown in current cycle	living to lying dead	Yes	284	5,950
	harvested tree	Yes	5,139	
	deforestation (living last cycle)	Yes	64	
	deforestation (dead last cycle)	No	13	
	standing dead tree cut	No	218	
	measured by mistake	No	134	
	standing dead to lying dead	No	98	
Dbh/Ht known in both cycles	no change	Yes	23,873	24,554
	standing dead to living (Lazarus tree)	Yes	3	
	living to standing dead	Yes	340	
	standing dead current and previous cycle	No	338	
		Total Number of Trees		43,553

15.2.2 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 15). For example Plot ID may be considered important as all trees present on the same plot will be growing under similar conditions.

Table 15. Attributes used in the kNN modelling.

Attribute Name	**Definition**
IDPlots	Plot ID
Species	Tree species
Species Group	Trees are grouped into broad species categories
DBH	Tree Dbh
Basal area (G)	Tree basal area (BA)
Height	Height (modelled)
Age	Tree age
GMeanTree	Quadratic mean DBH (mm)
PlotG	Basal area, m²/ha (excluding small trees)
DPLOTG	Diff. of basal area, m²/ha/yr
DOMHEIGHT	Dominant height of larger trees, m
NTREE	Tree count, 1/ha
DPLOTN	Diff. of tree number, 1/ha/yr
RANKDBH	Rank of tree by DBH, i.e. the position of the tree on the plot sorted by increasing Dbh
PLOTGA	Sum of basal area of larger trees, m²/ha
AVGDBH	Average DBH2, mm
MEANBA	Mean basal area, m²
AVGAGE	Average age, yr
AVGVOLUME	Average volume, m³
DOMSPEC	Dominant species (i.e. tree species with the greatest proportion of BA)
RELPLOTDEN	Plot representative tree number divided by plot Average volume
RELTREESIZE	Relative tree size (i.e. DBH_mm / GMEANTREE)

15.2.3 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 core 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 2.24mm.

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 RANKDBH with the core five parameters, performed best in the modelling process, having a RMSE of 2.154mm.

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 2.146mm.

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, 2.122mm.

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 to be one for each attribute.

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 13 nearest neighbours performed best in the modelling process, having a RMSE of 2.115mm.

15.2.4 Evaluating the Dbh increment model

The RMSE of the final model was 2.1 mm, while the the poorest performing model had a RMSE of 3.1mm. 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 overall model fit is demonstrated using the chart of modelled versus measured Dbh increment (Figure 101). The standard deviation was 2.11mm and correlation coefficient of 0.65.

Graphical analysis shows where the model displayed bias in two areas for those trees that had (Figure 102):

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

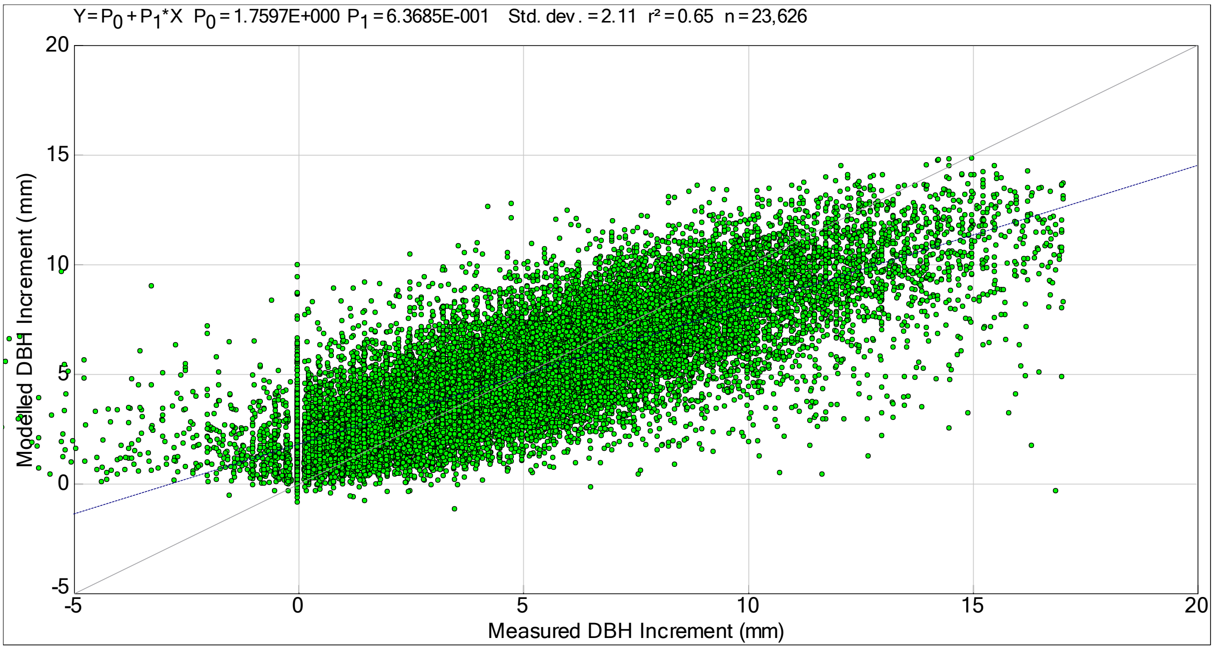

Figure 101. Comparison of modelled Dbh increment versus observed increment

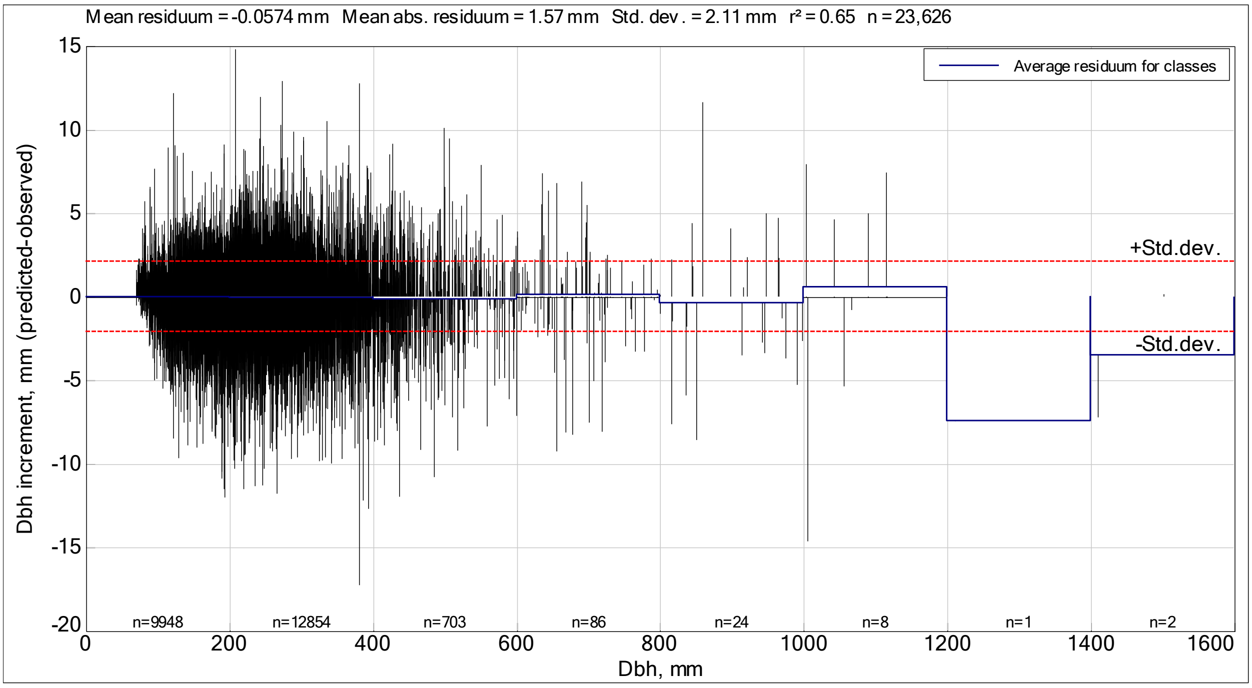

Figure 102. Assessment of residuals, modelled Dbh increment versus observed increment.

15.3 VOLUME ESTIMATION

This section details the estimation of standing volume for conifer and broadleaf species. In the first NFI cycle, the British Forestry Commission (BFC) single tree volume equations (Matthews and Mackie 2006) were used to estimate the standing tree volume.

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[5] 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.

Following the completion of the second cycle field-work, single tree stem profile models were developed for four broadleaf species Birch, Beech, Oak and Ash.

15.3.1 Volume model components

For the modeling of stem profile of individual trees the exponential model of Riemer et al. (1995) was used:

$$d_h = 2\left(\frac{i}{1-e^{q(1.3-H)}} + \left(\frac{d_{1.3}}{2} - i\right)\left(1 - \frac{1}{1-e^{p(1.3-H)}}\right) + \frac{\left(\frac{d_{1.3}}{2} - i\right)e^{1.3p}}{1-e^{p(1.3-H)}} e^{-ph} - \frac{ie^{-qH}}{1-e^{q(1.3-H)}} e^{qh} \right) \quad \text{(Eq. 1)}$$

where d_h – stem diameter at height h
H – total height
$d_{1.3}$ – diameter at breast height
i, p, q – model parameters

The model is robust and can be parameterized if required to reflect regional and site specific requirements. The model parameters can be described logically as follows; parameter i represents the common asymptote of lower and upper parts of the stem, p is the parameter characterizing the lower part of the stem, and q is the parameter characterizing the upper part of the stem. Initially, the model was parameterized individually for each sample stems using the non-linear least squares method. This procedure resulted in the set of parameters of stem profile (Eq. 1) for every sample tree. A species specific generalization of the model was then created out by relating stem profile parameters to dbh and height.

$$i = p_1 d_{1.3}^{p_2} H^{p_3} \quad \text{(Eq. 2)}$$

$$q = p_1 d_{1.3}^{p_2} H^{p_3} \quad \text{(Eq. 3)}$$

Parameter p does not have a clear relation to dbh and height and therefore it was modeled indirectly by the diameter at stump height (d_{stump}):

$$d_{stump} = p_1 d_{1.3}^{p_2} \quad \text{(Eq. 4)}$$

By default the stump height was assumed to be 1 % of the tree height.

The parameterization of the above models (Eqs. 2, 3, 4) was carried out using the non-linear least squares method. The parameters of the generalized stem profile models (Eqs. 2, 3 and 4) for individual species are presented in Table 16.

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

Allometric models were developed for direct volume calculation and represent a simple alternative to stem profile models. Such models are particularly suitable for those cases where an easy computation is required and the spatial distribution of the stem volume along the vertical stem axis or when local calibration of models is not required. See appendix 10 for more details.

Table 16. Parameters of the generalized stem profile model (Eq. 1) for individual tree species.

Species	Parameter	Equation	P_1	P_2	P_3
Japanese larch	i	2	4.514989E-01	1.010443E+00	5.659603E-03
	q	3	1.833184E+00	-8.821236E-01	-7.895097E-02
	d_{stump}	4	1.222935E+00	9.813170E-01	
Norway spruce	i	2	4.457229E-01	8.540887E-01	1.723236E-01
	q	3	2.136199E+00	-7.243262E-01	-2.163123E-01
	d_{stump}	4	1.718203E+00	8.959732E-01	
Sitka spruce	i	2	4.903530E-01	6.281807E-01	3.975268E-01
	q	3	2.852190E+00	-8.135345E-02	-1.076931E+00
	d_{stump}	4	1.176701E+00	1.014001E+00	
Lodgepole pine	i	2	6.402757E-01	1.163579E+00	-3.231529E-01
	q	3	6.756219E-01	-1.644166E+00	1.295646E+00
	d_{stump}	4	1.627271E+00	9.036579E-01	
Scots pine	i	2	3.831201E-01	1.132899E+00	-1.145653E-01
	q	3	3.864707E-01	-2.027362E-03	-1.086332E-02
	d_{stump}	4	1.355459E+00	9.490704E-01	
Douglas fir	i	2	6.515489E-01	1.116365E+00	-2.530735E-01
	q	3	5.068554E+00	4.212538E-01	-1.838219E+00
	d_{stump}	4	1.155988E+00	9.981836E-01	
Oak	i	2	4.514989E-01	1.010443E+00	5.659603E-03
	q	3	1.833184E+00	-8.821236E-01	-7.895097E-02
	d_{stump}	4	1.222935E+00	9.813170E-01	
Beech	i	2	4.457229E-01	8.540887E-01	1.723236E-01
	q	3	2.136199E+00	-7.243262E-01	-2.163123E-01
	d_{stump}	4	1.718203E+00	8.959732E-01	
Ash	i	2	4.903530E-01	6.281807E-01	3.975268E-01
	q	3	2.852190E+00	-8.135345E-02	-1.076931E+00
	d_{stump}	4	1.176701E+00	1.014001E+00	
	i	2	6.402757E-01	1.163579E+00	-3.231529E-01
	q	3	6.756219E-01	-1.644166E+00	1.295646E+00
Birch	d_{stump}	4	1.627271E+00	9.036579E-01	

15.4 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.

15.4.1 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 103.

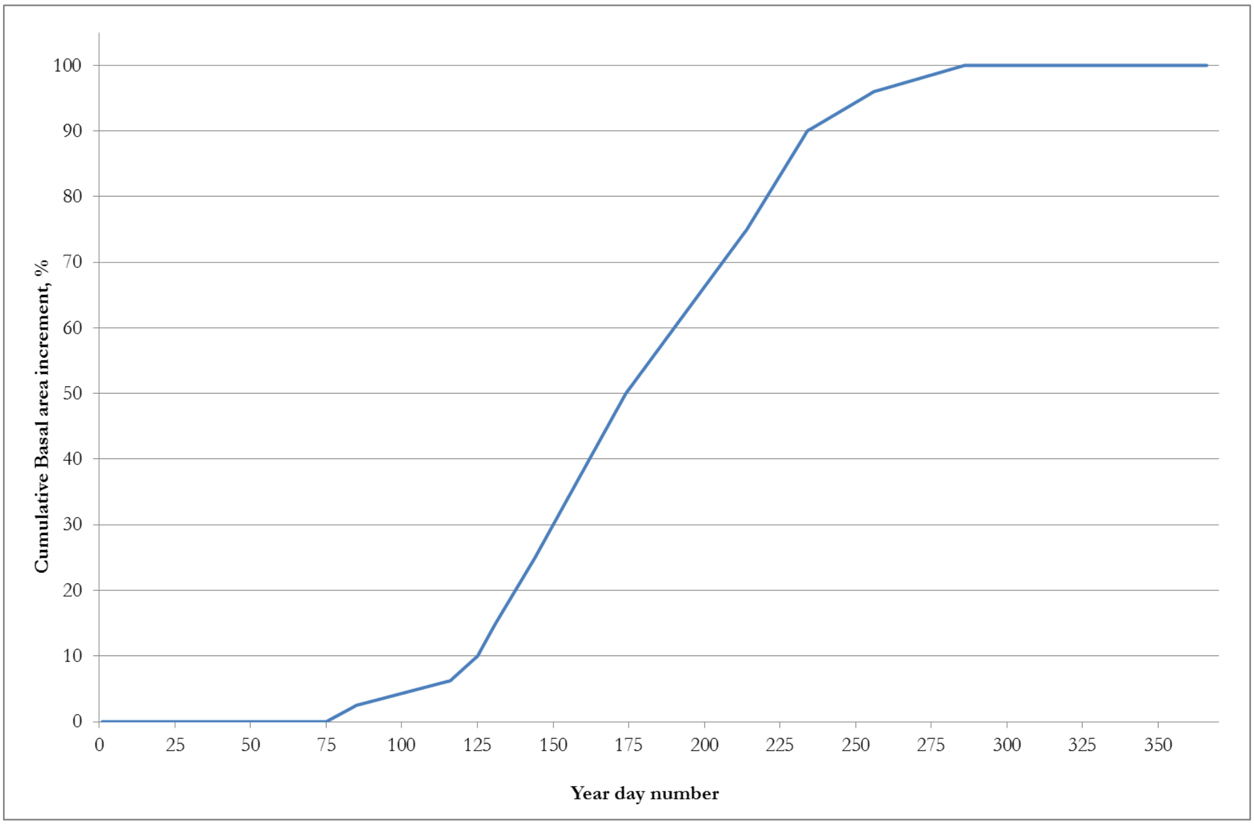

Figure 103. Cumulative basal area growth over the calendar year (O'Muirgheasa 1970).

15.4.2 Calculating increment period

Using the average daily increment data detailed in the above Figure, the proportion of cumulative increment was assigned to each plot for both the 2nd and 3rd cycle assessment dates. The cumulative increment for the 3rd cycle was then subtracted from the cumulative increment for the 1st cycle, to calculate the difference in increment between the sampling months. Finally, the cumulative growth difference is subtracted from the sample year difference to calculate the increment period in years. Table 17 below outlines for a number of plots the calculation process.

Table 17. Calculating the increment period for individual NFI plots.

Plot ID	1st Cycle Date	2nd Cycle Date	1st Cycle Cumulative Growth	2nd Cycle Cumulative Growth	Cumulative Growth 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

15.5 CARBON ESTIMATIMATION

The amount of carbon (C) present in forests (i.e. the C stock) provides an estimate of the total accumulation of C to a specific point in time. The NFI measures C stocks in the forest pool, which include aboveground biomass (stems, leaves and branches), belowground biomass (Stumps and roots to a minimum diameter of 5mm), litter (fallen needles/leaves and branches >7cm diameter), deadwood (harvest residue, dead trees) and soils.

The estimates of C stock for each plot were calculated using Ireland's carbon reporting system, CARBWARE (Duffy et al., 2017, Black, 2016). This system was developed to meet reporting requirements to the United Nations Framework Convention on Climate Change (UNFCCC).

Since the first NFI changes have arisen in the NFI methodology and, biomass estimation techniques. More accurate biomass equations, new classification systems and associated C stock values were introduced for soil and deadwood.

15.5.1 CARBWARE

The CARBWARE model (Black, 2016) is used to estimate carbon stock changes for biomass, litter deadwood and soils (see Duffy et al., 2017 for model details).

Data from the NFI, such as individual tree information, soils, deadwood, amount of harvest removed and area deforested, has been incorporated into the CARBWARE model software to produce annual estimates of greenhouse gas (GHG) emissions/removals since 2006 (Figure 104). The annual estimates are used to report Ireland's national forest emission removals to the UNFCCC and the Kyoto protocol (Duffy et al., 2017). The estimates include emissions for fires, organic soils, fertilisation, harvest mortality, and decomposition of litter and deadwood and removals due to biomass growth and accumulation of litter and deadwood. Removals by harvested wood products (HWP) are derived using FAO and EUROSTAT data, but these results are not presented in this report (for full description of GHG estimates see Duffy et al., 2017).

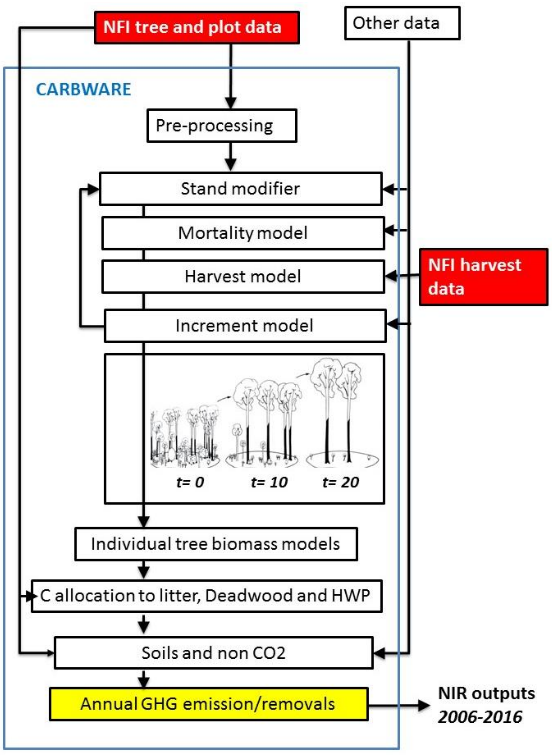

Figure 104. Description of the CARBWARE model inputs from the NFI and outputs from the software for annual estimation of forest GHG emissions/removals (Adapted from Black, 2016).

15.5.2 Tree Above- and Below-Ground stocks

Single tree biomass C stock are based on species cohort allometric equations shown in Table 18 and a C fraction of 50% of dry matter. These are used to estimate both C stocks and C stock changes.

Similar species are grouped into six different cohorts based on available research information (Spruces, Pines, Larches, Other conifers, fast growing broadleaves and slow growing broadleaves). Abbreviations: AB-above ground, TB-total biomass, BB-below ground = (TB-AB), FB-foliage, SB-stem (i.e. timber >7cm diameter), L_{HR}= lop and top from harvest residues, Dbh diameter at breast height (1.3 m) in cm, H –height in m.

Table 18. Allometric equations used to calculate biomass component for individual trees (kg d.wt tree-1).

Sp	Eq	Tree Part	Range	Equation	Coefficients a	b	c	d	r^2	RMSE	Slope	Source*
Spruce	1	AB	H>4m	$a \times DBH^b + c \times H^d$	0.23877	2.12	5 x 10^7	4.99	0.91	0.29	1.01	i, ii
	2	AB	H<4m	$a \times H^b \times c$	1.32	1.7	1.38		0.86	0.2	1.1	i, ii
	3	TB		$\exp[Ln(a) + b \times Ln(AG)]$	1.02	1.033			0.91	0.08	1.03	ii, iii
	4	BB		TB-AB								
	5	FB		$AB \times a + b \times \exp[-c \times AB]$	0.025	0.089	0.003		0.68	3.4	0.98	i, ii
	6	SB		$\exp[Ln(a) + b \times Ln(AG)]$	0.405	1.09			0.99	2.99	1.03	ii, iii
	7	L_{HR}		AB-SB								
Pines	8	AB	H>3.8m	$a \times DBH^b + c \times H^d$	0.07	2.42	0.039	2.51	0.93	0.13	0.94	ii, iii
	9	AB	H<3.8m	$a \times H^b$	0.12	3.91			0.95	0.74	0.95	i, ii
	10	TB		$\exp[Ln(a) + b \times Ln(AG)]$	1.15	1.01			0.96	0.4	1.01	ii, iii
	4	BB		TB-AB								
	5	FB		$AB \times a + b \times \exp[-c \times AB]$	0.025	0.089	0.003		0.68	3.4	0.98	i, ii
	11	SB		$\exp[Ln(a) + b \times Ln(AG)]$	0.71	1.005			0.97	0.27	0.96	ii, iii
	7	L_{HR}		AB-SB								
Larch	12	AB	H>2m	$a \times DBH^b + c \times H^d$	0.11	2.31	0.001	3.29	0.94	0.27	0.94	ii, iii
	13	AB	H<2m	$a \times H^b$	0.03	1.91			0.67	0.44	1.2	i, ii
	14	TB		$\exp[Ln(a) + b \times Ln(AG)]$	1.43	0.98			0.99	0.25	0.99	ii, iii
	4	BB		TB-AB								
	5	FB		$AB \times a + b \times \exp[-c \times AB]$	0.025	0.089	0.003		0.68	3.4	0.98	i, ii
	15	SB		$\exp[Ln(a) + b \times Ln(AG)]$	0.903	0.972			0.98	0.28	0.96	ii, iii
	7	L_{HR}		AB-SB								
Other conifers	16	AB	H>3.8m	$a \times DBH^b + c \times H^d$	0.022	2.73	0.19	2.06	0.96	0.46	1.008	ii, iii
	17	AB	H<3.8m	$a \times H^b \times c$	0.005	1.58	1.12		0.86	0.28	1.02	i, ii
	18	TB		$\exp[Ln(a) + b \times Ln(AG)]$	1.59	0.96			0.99	0.28	1.005	ii, iii
	4	BB		TB-AB								
	5	FB		$AB \times a + b \times \exp[-c \times AB]$	0.025	0.089	0.003		0.68	3.4	0.98	i, ii
	19	SB		$\exp[Ln(a) + b \times Ln(AG)]$	0.89	0.96			0.98	0.57	1.055	ii, iii
	7	L_{HR}		AB-SB								
Slow growing broadleaves	20	AB	H>3.0m	$a + \left[\frac{b \times DBH^c}{DBH^c + 246872}\right]$	0.08	25000	2.5					iv
	21	AB	H<3.0m	$a \times H^b$	0.031	1.72			0.84	0.88	0.91	i, ii
	22	TB		$\exp(-a + Ln(DBH) + b)$	1.509	0.284						iv
	23	FB	Dbh>10cm	$a \times (DBH \times 10)^b$	0.009	1.47			0.96			v
	24	FB	Dbh<10cm	$AB \times 0.3$					0.78	1.2	0.79	i, ii
	25	SB	Dbh>19cm	$a \times (DBH \times 10)^b$	0.0002	2.5			0.97			v
	26	SB	Dbh<9cm	$(AB + BB)/1.4$								BEF
	7	L_{HR}		AB-SB								
Fast growing broadleaves	20	AB	H>3.0m	$a + \left[\frac{b \times DBH^c}{DBH^c + 246872}\right]$	0.06	25000	2.5					iv
	21	AB	H<3.0m	$a \times H^b$	0.031	1.72			0.84	0.88	0.91	i, ii
	22	TB		$\exp(-a + Ln(DBH) + b)$	1.509	0.284						iv
	27	FB	Dbh>3cm	$a + b \times DBH^c$	0.375	0.0024	2.517		0.90			vi
	28	FB	Dbh<3cm	$AB \times 0.3$					0.78	1.2	0.79	i, ii
	29	SB	Dbh>35cm	$a \times DBH^b$	0.0001	2.535			0.97			v
	30	SB	Dbh<9cm	$(AB + BB)/1.4$								BEF, vii
	7	L_{HR}		AB-SB								

Explanation of source column in above table:

- **i** National research harvested tree database (COFORD funded project CARBiFOR)
- **ii** Black et al., (2009) Carbon stock and stock changes across a Sitka spruce chronosequence on surface water gley soils. *Forestry,* 85(3), 255-271
- **iii** Forest Research pulled tree database (Brice Nicholl, NRS, Forest Research, UK)
- **iv** Brown S (2002) . Measuring carbon in forests: current status and future challenges. Environmental Pollution 116: 363-372.
- **v** Johansson, T. (1999). Dry matter amounts and increment in 21-to 91-year-old common alder and grey alder some practical implicatons. Canadian Journal of Forest Research 29 1679-1690.
- **vi** Bartelink, H.H. (1997). Allometric relationship for biomass and leaf area of beech (Fagus sylvatica L). Annals of Forest Science. 54: p. 39-50.
- **vii** Black K., Tobin B., Saiz G., Byrne K. & Osborne B. (2004). Improved estimates of biomass expansion factors for Sitka spruce. Irish Forestry 61:50-65.

15.5.3 Deadwood C stocks

During the third NFI a new decay status attribute was introduced to describe the decay staus of stumps and logs which was based on coarse woody debris reseach in managed Sitka spruce forests in Ireland (Olajuyigbe 2011). The factors used to covert deadwood volume to biomass/carbon in the second and third cycle are presented in Table 19 and 20.

Table 19. Factors to covert lying and stump deadwood volume to biomass and carbon in the 2nd cycle.

Decay status	Lying		Stump	
	Density	Cfraction	Density	Cfraction
solid wood	0.402	0.4739	0.399	0.4804
rotten sapwood, solid heartwood	0.365	0.4768	0.317	0.4907
rotten heartwood, solid sapwood	0.263	0.4829	0.266	0.4754
rotten wood	0.201	0.4766	0.251	0.4801

Table 20. Factors to covert lying and stump deadwood volume to biomass and carbon in the 3rd cycle.

Decay Status	Lying		Stump	
	Density	Cfraction	Density	Cfraction
Fresh	0.277	0.46	0.398	0.47
Intact	0.269	0.46	0.391	0.47
Sapwood soft	0.196	0.46	0.208	0.47
Advanced decay	0.191	0.46	0.167	0.47
Largely diminished	0.148	0.46	0.172	0.47

15.5.4 Soil

Soil C stocks are derived based on the SIS soil descriptions and soil depth, but soils are generalised into six groups based on avaialbe unpublished research information (Table 21).

Table 21. Referece Soil C stock values upto 30 cm.

Soil group	tC/ha (30cm)
Drained Ombrotrophic Peat Soil	157.6
Drained Minerotrophic Peat Soil	132.7
Brown podsolics	104.8
Brown earths	91. 7
Gleys	119.9
Other mireal	73.8

The the soil C stock (Csoil) is calculated using the above refernce soil C stock, plot area and the soil depth.

$$Csoil = A_j \times C_{ref(i)} \times SD$$

and

$$SD = \frac{soil\ depth\ (cm)}{30cm}$$

For organo mineral soils, the C stock is calculated for each horizon.The area (A_i) of the 0.05ha plots with peat soils is multiplied by 20 to scale the measurement up to 1ha.

15.5.5 Litter C Stock

The litter C stock includes needles, leaves and branches up to a diameter of 7cm. Litter fall reflects the transfer of carbon from the above-ground biomass pool to the litter pool. Stocks are derived using the CARBWARE growth model, which is based on nationally derived leaf/needle biomass and the foliage turnover rates (Tobin et al., 2006).

15.6 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 400ha. For example, one plot classified as being privately owned will represent 400ha 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 500m². 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.

15.7 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. An overview of equations applied in the Inventory Analyst statistical calculations for individual inventory plots and for the whole dataset is presented in Table 22.

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 22. Overview of equations applied 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.

15.8 STATISTICAL METHODS

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

15.8.1 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.

15.8.2 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 $\mathrm{var}(\hat{\tau}_h)$ denote the variance of $\hat{\tau}_h$, and suppose that one has an unbiased estimator $\widehat{\mathrm{var}}(\hat{\tau}_h)$ 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:

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

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

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

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

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

where

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

is the finite population variance from stratum *h*.

An unbiased estimator of the variance of $\hat{\tau}_{st}$ is

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

where

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

is the sample variance from stratum *h*.

15.8.3 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

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

with unbiased estimator of variance

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

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

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

An unbiased estimator of this variance is

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

15.8.4 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

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

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

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

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

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

15.8.5 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:

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

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

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 $w_i \cdot N/W$.

15.8.6 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
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

Impulse™ TruPulse 360R Rangefinder
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 1m 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

iSXBlue II GNSS and charger

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' 5m tape
- 2 x 500mm Dbh tape
- 1 x 800mm Dbh tape
- 2 x silky hand saws
- 1 x slash hook
- 1 x 15m loggers tape
- Centre poles
- Thumb-tacks (Plastic topped)
- Marking paint
- 2 x mobile phones
- 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 105). 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 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 105. Hammerhead XRT™ field computer.

Global Positioning System (GPS)

The purpose of the GPS is to aid navigation to the plot centre. In the first and second cycle the Trimble Pro XR series of GPS units use differential correction (DGPS) were used, where the 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.

For the third NFI we are using the iSXBlue II GNSS, which receives both GLONASS and GPS satellite signals simultaneously and receive free correction by SBAS (EGNOS, WAAS, MSAS, GAGAN) that delivers an accuracy of 30cm RMS (Figure 106). With GLONASS, iSXBlue II GNSS further access to 24 satellites in addition to GPS satellites (total 55 pcs) which results in much better precision and are even more susceptible to such hilly terrain and forest.

Figure 106. iSXBlue II GNSS.

Laser Range Finder and Electronic Compass

In the first and second cycle the Impulse™ laser range finder, with built in inclinometer and Mapstar™ electronic compass were used. For the third cycle the TruPulse 360 R Laser Rangefinder replaced the previous Laser Tech equipment (Figure 107). The equipment is 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 107. TruPulse 360 R Laser Rangefinder.

Remote Diameter Scope

A magnified remote diameter scope is fitted to the TruPulse 360 R 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 (+/-10mm).

Configuration of the Field Equipment

The laser rangefinder is mounted on a carbon monopod. GPS, Laser and compass are connected to the field computer via bluetooth. 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.

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 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. An example of the process is outlined below:

Species: Sitka spruce **Top Height**: 10m **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 23. Threshold basal areas (m^2) for fully stocked stands (Coillte 1998[6]).

	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 8m. 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 (Table 24.)

Table 24. Minimum average heights (m) for tending and thinning broadleaves (Teagasc 2008[7]).

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

[6] 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.

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

APPENDIX 4 LIST OF NFI TREE SPECIES

Abies alba
Abies concolor
Abies grandis
Abies nordmanniana
Abies procera
Abies sp.
Acer campestre
Acer negundo
Acer platanoides
Acer pseudoplatanus
Acer sp.
Aesculus hippocastanum
Ailantus altissima
Alnus glutinosa
Alnus incana
Alnus viridis
Arbutus unedo
Betula pendula
Betula pubescens
Betula sp.
Carpinus betulus
Castanea sativa
Cedar libani
Cupresus macrocarpa
Fagus silvatica
Fraxinus americana
Fraxinus excelsior
Fraxinus sp.
Chamaecyparis lawsonia
Ilex aquifolium
Juglans nigra
Juglans regia
Juniperus communis
Larix decidua
Larix kaempferi
Larix x eurolepis
Larix sp.
Malus silvestris
Notofagus procera
Picea abies
Picea engelmanni
Picea glauca
Picea mariana
Picea omorika
Picea pungens
Picea sitchensis
Picea sp.
Pinus banksiana
Pinus cembra
Pinus contorta v. inland
Pinus contorta v. lulu
Pinus contorta v. NC
Pinus contorta v. SC

Pinus mugo var. mughus
Pinus mugo var. uncinata
Pinus nigra v. maritima
Pinus radiata
Pinus silvestris
Pinus strobus
Pinus sp.
Platanus acerifolia
Populus alba
Populus canescens
Populus cultivated
Populus balsamifera
Populus nigra
Populus tremula
Prunus avium
Prunus serotina
Prunus spinosa
Pseudotsuga menziesii
Pseudotsuga taxifolia
Pyrus communis
Quercus cerris
Quercus palustris
Quercus petraea
Quercus pubescens
Quercus robur
Quercus robur f. slavonica
Quercus rubra
Quercus sp.
Robinia pseudoacacia
Salix caprea
salix alba
Salix sp.
Sequoia sempervirens
Sorbus aria
Sorbus aucuparia
Sorbus torminalis
Taxus baccata
Thuja plicata
Tilia cordata
Tilia platyphylla
Tilia tomentosa
Tsuga heterophylla
Ulmus carpinifolia
Ulmus glabra
Ulmus laevis
Ulmus procera
Ulmus scabra
Corylus avellana
other conifers
other hard broadleaves
other soft broadleaves

APPENDIX 5 PROTECTED VASCULAR PLANT SPECIES

Latin name	Common name
Achillea maritima	Cottonweed
Allium schoenoprasus	Chives
Alopecurus aequalis	Orange Foxtail
Arabidopsis petraea	Northern Rock-cress
Arenaria ciliata	Fringed Sandwort
Asparagus officinalis	Asparagus
Asplenium obovatum	Lanceolate Spleenwort
Astragalus danicus	Purple Milk-vetch
Betonica officinalis	Betony
Calamagrostis epigejos	Wood Small-reed
Callitriche truncata	Short-leaved Water-starwort
Cardamine impatiens	Narrow-leaved Bitter-cress
Carex depauperata	Starved Wood-sedge
Carex divisa	Divided Sedge
Centaurium pulchellum	Lesser Centaury
Cephalanthera longifolia	Narrow-leaved Helleborine
Clinopodium acinos	Basil Thyme
Colchicum autumnale	Meadow Saffron
Cryptogramma crispa	Parsley Fern
Deschampsia setacea	Bog Hair-grass
Epilobium alsinifolium	Chickweed Willowherb
Equisetum × moorei	Moore's horsetail
Eriophorum gracile	Slender Cottongrass
Filago minima	Small Cudweed
Galeopsis angustifolia	Red Hemp-nettle
Gnaphalium sylvaticum	Heath Cudweed
Groenlandia densa	Opposite-leaved Pondweed
Gymnocarpium robertianum	Limestone Fern
Hammarbya paludosa	Bog Orchid
Helianthemum nummularium	Common Rock-rose
Hordeum secalinum	Meadow Barley
Hydrilla verticillata	Hydrilla
Hypericum canadense	Irish St John's-wort
Hypericum hirsutum	Hairy St John's-wort
Inula salicina	Irish Fleabane
Lathyrus japonicus	Pea
Limosella aquatica	Mudwort
Lotus subbiflorus	Hairy Bird's-foot-trefoil
Lycopodiella inundata	Marsh Clubmoss

Common name	Latin name
Pennyroyal	Mentha pulegium
Oysterplant	Mertensia maritima
Recurved Sandwort	Minuartia recurva
Weasel's-snout	Misopates orontium
Slender Naiad	Najas flexilis
Rough Poppy	Papaver hybridum
Alpine Bistort	Persicaria vivipara
Pillwort	Pilularia globulifera
Small-white Orchid	Pseudorchis albida
Borrer's Saltmarsh-grass	Puccinellia fasciculata
Round-leaved Wintergreen	Pyrola rotundifolia
Great Burnet	Sanguisorba officinalis
Perennial Glasswort	Sarcocornia perennis
Meadow Saxifrage	Saxifraga granulata
Hart's saxifrage	Saxifraga hartii
Marsh Saxifrage	Saxifraga hirculus
Alpine Saxifrage	Saxifraga nivalis
Schoenoplectus triqueter	Triangular Club-rush
Annual Knawel	Scleranthus annuus
Kerry Lily	Simethis mattiazzii
Irish Lady's-tresses	Spiranthes romanzoffiana
Killarney Fern	Trichomanes speciosum
Clustered Clover	Trifolium glomeratum
Subterranean Clover	Trifolium subterraneum
Globeflower	Trollius europaeus
Wood Bitter-vetch	Vicia orobus
Hairy Violet	Viola hirta
Pale Dog-violet	Viola lactea

APPENDIX 6 HERB SPECIES

Achillea millefolium (Yarrow)
Aegopodium podagraria (Ground elder)
Aethusa cynapium (Fool's parsely)
Ajuga reptans (Bugle)
Alisma plantago-aquatica (Common water plantain)
Alliaria petiolata (Garlic mustard)
Allium ursinum (Ramsons)
Anagallis arvensis (Scarlet pimpernel)
Andromeda polifolia (Bog rosemary)
Anemone nemorosa (Wood anenome)
Anemone ranunculoides (Yellow anenome)
Angelica sylvestris (Angelica)
Antennaria dioica (Cat's foot)
Anthriscus sylvestris (Cow parsely)
Apium nodiflorum (Fools Watercress)
Aquilegia vulgaris (Columbine)
Arctium minus (Lesser burdock)
Arum maculatum (Lords and Ladies)
Atropa bella-donna (Deadly nightshade)
Bellis perennis (Daisy)
Berula erecta (Water parsnip)
Betonica officinalis (Betony)
Buglossoides purpurocoerulea (Purple gromwell)
Callitriche stagnalis (Pond water-starwort)
Caltha palustris (Marsh marigold)
Calystegia sepium (Bindweed)
Campanula sp.
Capsella bursa-pastoris (Sheperd's purse)
Cardamine flexuosa (Wavy bittercress)
Cardamine hirsuta (Hairy bittercress)
Cardamine pratensis (Cuckoo flower)
Cardamine sp.
Centaurea nigra (Knapweed)
Cerastium fontanum (Mouse-ear chickweed)
Cerastium holosteoides (Common mouse-ear)
Chamerion angustifolium (Rosebay willow herb)
Chelidonium majus (Greater celandine)
Chenopodium album (Lamb's quarter)
Chrysosplenium oppositifolia (Golden saxifrage)
Circaea lutetiana (Enchanter's nightshade)
Cirsium acaule (Dwarf thistle)
Cirsium arvense (Creeping thistle)
Cirsium dissectum (Meadow thistle)
Cirsium palustre (Swamp thistle)
Cirsium vulgare (Spear thistle)
Clematis vitalba (Traveller's Joy)
Conopodium majus (Pignut)
Convallaria majalis (Lily of the valley)
Crepis paludosa (Marsh hawksbeard)
Crocosmia crocosmiiflora (Montbretia)
Dactylorhiza fuchsii (Common spotted orchid)

Dactylorhiza maculata (Heath spotted orchid)
Dianthus sp.
Digitalis purpurea (Foxglove)
Drosera rotundifolia (Sundew)
Epilobium hirsutum (Willowherb)
Epilobium montanum (Broadleaved willow herb)
Epipactis helleborine (Broadleaved Helleborine)
Eupatorium cannabinum (Hemp agrimony)
Euphorbia amygdaloides (Wood spurge)
Euphorbia sp.
Fallopia japonica (Japanese knotweed)
Filipendula ulmaria (Meadowsweet)
Fragaria sp.
Fragaria vesca (Wild strawberry)
Galanthus nivalis (Snowdrop)
Galeobdolon sp.
Galeopsis tetrahit (Hemp nettle)
Galium aparine (Gleavers)
Galium odoratum (Sweet wood ruff)
Galium palustre (Marsh bedstraw)
Galium saxatile (Heath bedstraw)
Galium uliginosum (Fen bedstraw)
Galium vernum (Lady's bedstraw)
Geranium pratense (Cranesbill)
Geranium robertianum (Herb Robert)
Geranium sanguineum (Bloody cranesbilll)
Geranium sp.
Geranium sylvaticum (Wood carnesbill)
Geum rivale (Water avens)
Geum urbanum (Wood avens)
Glechoma hederacea (Ground ivy)
Hedera helix (Ivy)
Heracleum mantegazzianum (Giant hogweed)
Heracleum sphondylium (Hogweed)
Hieracium sp.
Hyacinthoides non-scripta (Blue-bell)
Hydrocyte vulgaris (Marsh pennywort)
Hypericum androsaemum (Tutsan)
Hypericum perforatum (Perforate St John's wort)
Hypericum pulchrum (Slender St John's wort)
Hypochoeris glabra (Smooth Cat's ear)
Hypochoeris radicata (Cat's ear)
Impatiens grandulifera (Himalyan balsam)
Impatiens parviflora (Small Balsam)
Iris pseudacorus (Yellow iris)
Lamiastrum galeobdolon (Yellow archangel)
Lamium purpureum (Purple deadnettle)
Lapsana communis (Nipplewort)
Lathyrus montanus (Bitter vetch)
Lathyrus pratensis (Meadow vetchling)

Leucanthemum vulgare (Oxeye daisy)
Leycesteria formosa (Himalayan honeysuckle)
Lilium martagon (Turk's cap lily)
Listera ovata (Twayblade)
Lobelia dortmanna (Water lobelia)
Lonicera periclymenum (Honeysuckle)
Lotus corniculatus (Bird's foot trefoil)
Lotus pedunculatus (Greater bird's foot trefoil)
Lychnis flos-cuculi (Ragged robin)
Lycopus europaeus (Gypsywort)
Lysimachia nemorum (Yellow pimpernel)
Lysimachia sp.
Lysimachia vulgaris (Yellow loosestrife)
Lythrum salicaria (Purple loosestife)
Maianthenum bifolium (False lily of the valley)
Melampyrum pratense (Cow wheat)
Melampyrum sp.
Mentha arvensis (Field mint)
Menyanthes trifoliata (Bogbean)
Mercurialis perennis (Dog's mercury)
Moehringia trinervia (Three nerved Sandwort)
Mycelis muralis (Wall lettuce)
Mycelis sp.
Myosotis arvensis (Field forget-me-not)
Myosotis scorpioides (Water forget-me-not)
Narthecium ossifragum (Bog aspholdel)
Neottia nidus-avis (Bird's nest orchid)
Odontites vernus (Red bartsia)
Oenanthe crocata (Water dropwort)
Orobanche hederae (Ivy broomrape)
Oxalis acetosella (Wood sorrell)
Papaver dubium (Long-headed poppy)
Papaver rhoeas (Poppy)
Pedicularis sylvatica (Lousewort)
Persicaria maculosa (Lady's thumb)
Petasites albus (White butterbur)
Petasites fragrans (Winter Heliotrope)
Pilosella officinarum (Mouse-ear hawkweed)
Pinguicula lusitanica (Pale butterwort)
Plantago lanceolata (Ribwort plantain)
Plantago major (Greater plantain)
Polygala serpyllifolia (Heath milkwort)
Polygala vulgaris (Common milkwort)
Polygonatum multiflorum (Solomon's seal)
Polygonum hydropiper (Water peppar)
Polygonum sp.
Potentilla anserina (Silverweed)
Potentilla palustris (Marsh cinquefoil)
Potentilla reptans (Creeping cinquefoil)
Potentilla sterillis (Barren strawberry)
Potentillia erecta (Tormentil)
Primula veris (Cowslip)
Primula vulgaris (Primrose)
Prunella vulgaris (Self heal)

Pulicaria dysenterica (Fleabane)
Pulmonaria sp.
Ranunculus acris (Meadow buttercup)
Ranunculus ficaria (Lesser celendine)
Ranunculus flammula (Lesser spearwort)
Ranunculus repens (Creeping buttercup)
Ranunculus sp.
Rorippa nasturtium-aquaticum (Watercress)
Rumex acetosa (Sorrell)
Rumex acetosella (Sheep's sorrell)
Rumex obtusifolius (Broad leaved dock)
Rumex sanguineus (Bloody dock)
Rumex sp.
Sanicula europaea (Wood sanicle)
Saxifraga spathularis (St Patrick's cabbage)
Scrophularia nodosa (Figwort)
Senecio aquaticus (Marsh ragwort)
Senecio jacobea (Roagwort)
Silena sp.
Silene dioica (Red campion)
Silybum marianum (Milk thistle)
Solanum dulcamara (Bittersweet)
Solanum nigrum (Black nightshade)
Solidago virgaurea (Goldenrod)
Sonchus arvensis (Field sow thistle)
Sonchus oleraceus (Sow thistle)
Stachys sylvatica (Hedge woundwort)
Stellaria graminea (Lesserstichwort)
Stellaria holostea (Greater stitchwort)
Stellaria media (Chickweed)
Stellaria uliginosa (Bog stichwort)
Succisa pratensis (Devil's bit scabious)
Symphytum officinale (Comfrey)
Taraxacum officinale (Dandelion)
Teucrium scorodonia (Wood sage)
Teucrium sp.
Trifolium pratense (Red clover)
Trifolium repens (White clover)
Trifolium sp.
Typha sp.
Umbilicus rupestris (Wall pennywort)
Urtica dioica (Nettle)
Urtica urens (Dwarf nettle)
Valeriana officinalis (Valerian)
Veronica chamaedrys (Germander speedwell)
Veronica montana (Mountain speedwell)
Veronica serpyllifolia (Thyme-leaved Speedwell)
Veronica sp.
Vicia sativa (Vetch)
Vicia sepium (Bush vetch)
Vicia sp.
Vinca minor (Lesser periwinkle)
Viola riviniana (Common dog-violet)
Viola sp.

APPENDIX 7 GRASS SPECIES

Agrostis capillaris (Common Bent)
Agrostis gigantea (Redtop bent grass)
Agrostis sp.
Agrostis stolonifera (Creeping bent)
Alopecurus pratensis (Foxtail)
Anthoxanthum odoratum (Sweet vernal grass)
Arrhenatherum elatius (False oat-grass)
Brachypodium pinnatum (Tor grass)
Brachypodium sylvaticum (False broome)
Bromopsis ramosa (Hairy Brome)
Bromus sp.
Calamagrostis epigeios (Wood small reed)
Calamagrostis sp.
Carex binervis (Green ribbed sedge)
Carex echinata (Star sedge)
Carex flacca (Glaucous sedge)
Carex paniculata (Greater tussock sedge)
Carex pendula (Pendulous sedge)
Carex pilulifera (Pill sedge)
Carex remota (Remote sedge)
Carex rostrata (Bottle sedge)
Carex sp.
Carex sylvatica (Wood sedge)
Cynosurus cristatus (Crested dog's tail)
Dactylis glomerata (Cock's foot)
Deschampsia caespitosa (Tufted hair grass)
Deschampsia flexuosa (Wavy hair grass)
Deschampsia setacea (Bog hair grass)
Elymus caninus (Bearded Couch Grass)
Elytrigia repens (Couch grass)
Eriophorum agustifolium (Bog cotton)
Eriophorum sp.
Eriophorum vaginatum (Hare's tail Cottongrass)
Festuca altissima (wood fescue)
Festuca heterophylla (Various leaved fescue)
Festuca ovina (Sheep's fescue)

Festuca ruba (Red fescue)
Glyceria fluitans (Floating Sweet grass)
Holcus lanatus (Yorkshire fog)
Holcus mollis (Creeping soft grass)
Hordelymus europaeus (Wood barley)
Juncus acutiflorus (Sharp flowered rush)
Juncus articulatus (Jointed rush)
Juncus bufonius (Toad rush)
Juncus bulbosus (Bulbus rush)
Juncus conglomeratus (Compact rush)
Juncus effusus (Soft rush)
Juncus inflexus (Hard rush)
Juncus sp.
Juncus squarrosus (Heath rush)
Koeleria glauca (Blue hair grass)
Lolium multiflorum (Italian rye-grass)
Lolium perenne (Perennial rye-grass)
Luzula campestris (Field wood rush)
Luzula luzuloides (White wood rush)
Luzula multiflora (Heath wood rush)
Luzula pilosa (Hairy wood rush)
Luzula sylvatica (Great wood rush)
Melica uniflora (Wood melick)
Milium effusum (Aureum)
Molinia caerulea (Purple moor grass)
Nardus stricta (Mat grass)
Phalaris arundinacea (Reed canary grass)
Phleum pratense (Timothy)
Phragmites communis (Common reed)
Poa annua (Annual meadow grass)
Poa nemoralis (Wood blue grass)
Poa pratensis (Smooth meadow grass)
Poa sp.
Poa trivialis (Rough blue grass)
Schoenus nigricans (Black bog rush)
Scirpus sylvaticus (Wood club rush)
Sesleria sp.
Sparganium erectum (Branched bur-reed)
Tricophorum cespitosium (Deer grass)

APPENDIX 8 SHRUB SPECIES

Alnus viridis (Green Alder)
Amelanchier ovalis (Serviceberry)
Arctostaphylos uva-ursi (Bearberry)
Berberis sp. (Berberis)
Betula nana (Dwarf birch)
Buxus sempervirens (Box)
Calluna vulgaris (Ling heather)
Clematis vitalba (Traveller's Joy)
Cornus mas (Dogwood)
Cornus sanguinea (Dogwood)
Cornus sericea (Red-osier dogwood)
Corylus avellana (Hazel)
Cotoneaster integerrima
Crataegus monogyna (Hawthorn)
Crataegus. sp. (Hawthorn sp.)
Cytisus scoparius (Broom)
Daboecia cantabrica (St Dabioc's heath)
Daphne mezereum (Spurge laurel)
Empetrum nigrum (Crowberry)
Erica cinerea (Bell Heather)
Erica tetralix (Cross leaved heather)
Escallonia sp.
Euonymus europaea (Spindle)
Euonymus verrucosus (warted spindle tree)
Fuchsia magellanica
Hedera helix (Ivy)
Humulus lupulus (Hop)
Ilex aquilifolium (Holly)
Juniperus sp.
Leycesteria formosa (Himalayan honeysuckle)
Ligustrum sp.
Ligustrum vulgare (Privet)
Lonicera periclymenum (Honeysuckle)
Mahonia aquifolium (Oregon grape)
Malus sylvestris (Crab apple)

Myrica gale (Bog myrtle)
Prunus laurocerasus (Cherry laurel)
Prunus mahaleb (Mahaleb cherry)
Prunus padus (Bird cherry)
Prunus spinosa (Blackthorn)
Rhamnus catharticus (Buckthorn)
Rhamnus frangula (Alder buckthorn)
Rhamnus sp.
Rhodendron ponticum
Ribes nigrum (Blackcurrant)
Ribes sp.
Ribes uva-crispa (Gooseberry)
Rosa arvensis (Field Rose)
Rosa canina (Dog rose)
Rosa pimpinellifolia (Burnet rose)
Rosa sp.
Rubus caesius (Dewberry)
Rubus fruticosus agg. (Bramble)
Rubus idaeus (Wild raspberry)
Rubus sp.
Salix caprea (Goat willow)
Salix sp.
Sambucus nigra (Elder)
Sambucus racemosa (Red elderberry)
Solanum sp.
Staphylea pinnata (European bladdernut)
Symphoricarpos albus (Snowberry)
Syringa vulgaris (Lilac)
Tamaris communis (Yam)
Ulex europaeus (Gorse)
Ulex gallia (Autumn gorse)
Vaccinium myrtillus (Bilberry)
Vaccinium oxycoccos (Cranberry)
Vaccinium vitis-idaea (Cowberry)
Viburnum lantana (Guelder rose)
Viburnum opulus (Wayfaring tree)

APPENDIX 9 FERN SPECIES

Aspelium scolopendrium (Hart's tongue fern)
Aspelium tricohomanes (Maidenhair Spleenwort)
Asplenium adiantum-nigrum (Black spleenwort)
Asplenium ceterach (Rustyback)
Asplenium sp.
Asplenium viride (Green spleenwort)
Athyrium filix-femina (Lasy-fern)
Blechnum spicant (Hard fern)
Cystopteris fragilis (brittle bladder-fern)
Dryopteris affinis (Scaly male fern)
Dryopteris carthusiana (Narrow buckler fern)
Dryopteris dilatata (Broad buckler fern)
Dryopteris filix-mas (Male-fern)
Dryopteris sp.
Equisetum arvense (Field horsetail)
Equisetum palustre (Marsh horsetail)
Equisetum sylvaticum (Wood horsetail)
Equistium fluviatile (Water horsetail)
Gymnocarpium dryopteris (Oak fern)
Hymenophyllum tunbrigense (Tunbridge filmy fern)
Hymenophyllum wilsonii (Wilson's filmy fern)
Matteuccia struthiopteris (Ostrich fern)
Oreopteris limbosperma (Mountain fern)
Osmunda regalis (Royal fern)
Phegopteris connectilis (Beech fern)
Polypodium sp.
Polystichum setiferum (Soft shield fern)
Pteridium aquilinum (Bracken)
Trichomanes speciosum (Killarney fern)

APPENDIX 10 ALLOMETRIC VOLUME MODELS

Allometric models were developed for direct volume calculation and represent a simple alternative to stem profile models. Such models are particularly suitable for those cases where an easy computation is required and the spatial distribution of the stem volume along the vertical stem axis or when local calibration of models is not required. The following equation was used:

$$v = p_0 + p_1 d_{1.3}^{p_2} H^{p_3} \qquad \text{(Eq. 1)}$$

where v is volume (m³), $d_{1.3}$ - diameter at breast height, p_0, p_1, p_2, p_3 - species specific model parameters, H - total height

In order to cater for alternative stem volume conventions, three basic volume types were parameterized using empirical data and the above equation 1. The volume types include:

a) The volume of the whole stem ($v_{ground\text{-}to\text{-}tip}$)
b) The volume of the stump ($v_{ground\text{-}to\text{-}stump}$)
c) The volume of the upper part of the stem from 7cm diameter to the stem tip ($v_{7cm\ diameter\text{-}to\text{-}tip}$).

All other commonly used volume types can be derived from the basic allometric models:

$$v_{stump-to-tip} = v_{ground-to-tip} - v_{ground-to\ stump} \qquad \text{(Eq. 2)}$$

$$v_{ground-to-7cm\ top\ diameter} = v_{ground-to-tip} - v_{7cm\ top\ diameter-to-tip} \qquad \text{(Eq. 3)}$$

$$v_{stump-to-7cm\ top\ diameter} = v_{ground-to-tip} - v_{ground-to\ stump} - v_{7cm\ top\ diameter-to-tip} \qquad \text{(Eq. 4)}$$

In order to improve the accuracy of the regression models, two separate sets of parameters were estimated for trees with diameter at breast height less than 14cm and for larger trees equal to or greater than 14 cm. In order to smooth the model for the full diameter range, a transition zone between 14 and 18cm was used. Within this zone the resultant volume was interpolated between both models. The parameters used in the allometric equations are shown for broadleaves in Table 25 and conifers in Table 26.

Table 25. Parameters of the allometric volume equations (Eq. 1) for broadleaf tree species groups.

Species	Volume type	$d_{1.3}$, cm	p_0	p_1	p_2	p_3
Birch	ground-to-tip	<14	0.000000E+00	5.580268E-05	2.108553E+00	7.412689E-01
		14+	-4.261875E-02	1.998528E-04	1.628252E+00	8.523137E-01
	7cm diameter-to-tip	<14	0.000000E+00	1.719781E-03	-5.660189E-02	6.966616E-01
		14+	2.012603E-03	1.077569E-02	-1.859951E+00	1.601221E+00
	ground-to-stump	<14	0.000000E+00	1.704804E-06	1.937433E+00	1.105778E+00
		14+	-9.029826E-04	3.489431E-06	1.685903E+00	1.147471E+00
Beech	ground-to-tip	<14	0.000000E+00	7.121573E-05	2.020042E+00	7.415426E-01
		14+	-3.053104E-01	3.423552E-04	1.632153E+00	7.97028E-01
	7cm diameter-to-tip	<14	0.000000E+00	2.503554E-03	-5.193252E-01	9.891872E-01
		14+	6.691411E-04	1.304299E-02	-1.296206E+00	1.026332E+00
	ground-to-stump	<14	0.000000E+00	2.760556E-06	1.675449E+00	1.111786E+00
		14+	9.626997E-03	1.072989E-07	2.098219E+00	1.720581E+00
Ash	ground-to-tip	<14	0.000000E+00	5.520908E-05	1.815545E+00	1.050189E+00
		14+	-1.093401E-02	8.795257E-05	1.914365E+00	8.288379E-01
	7cm diameter-to-tip	<14	0.000000E+00	2.923930E-02	-1.538138E+00	9.651901E-01
		14+	3.148136E-04	1.971154E-02	-1.105184E+00	6.706110E-01
	ground-to-stump	<14	0.000000E+00	1.549715E-06	2.561864E+00	4.34142E-01
		14+	1.197470E-04	5.302685E-07	1.943901E+00	1.452710E+00
Oak	ground-to-tip	<14	0.000000E+00	7.685929E-05	2.008474E+00	7.207937E-01
		14+	-1.216346E-02	8.859487E-05	1.909422E+00	8.489018E-01
	7cm diameter-to-tip	<14	0.000000E+00	2.819067E-03	-5.169345E-01	9.214043E-01
		14+	3.207919E-04	1.626711E-02	-1.199180E+00	8.260644E-01
	ground-to-stump	<14	0.000000E+00	2.854759E-06	2.229411E+00	4.916870E-01
		14+	3.203328E-03	2.337958E-06	2.082604E+00	7.877461E-01

Table 26. Parameters of the allometric volume equations (Eq. 1) for conifer tree species groups ypes.

Species	Volume type	$d_{1.3}$, cm	p_0	p_1	p_2	p_3
Japanese larch	ground-to-tip	<14	0.000000E+00	4.689068E-05	2.2338669E+00	7.186728E-01
		14+	-1.319847E-02	7.462121E-05	1.742102E+00	1.061732E+00
	7cm diameter-to-tip	<14	0.000000E+00	3.201459E-02	-1.906923E+00	1.266639E+00
		14+	2.585690E-03	2.560663E-02	-2.233088E+00	1.487608E+00
	ground-to-stump	<14	0.000000E+00	1.668791E-05	1.420655E+00	4.931299E-01
		14+	-1.722235E-04	1.720961E-06	2.019893E+00	8.267337E-01
Norway spruce	ground-to-tip	<14	0.000000E+00	6.674246E-05	1.891171E+00	9.318898E-01
		14+	-4.835030E-03	8.387114E-05	1.699090E+00	1.070422E+00
	7cm diameter-to-tip	<14	0.000000E+00	6.312910E-02	-2.063982E+00	1.124044E+00
		14+	2.600243-03	2,529122E-02	-2.495886E+00	1.690149E+00
	ground-to-stump	<14	0.000000E+00	1.459761E-06	1.947316E+00	9.856047E-01
		14+	-5.166593E-04	3.512256E-06	1.648623E+00	1.062864E+00
Sitka spruce	ground-to-tip	<14	0.000000E+00	5.275761E-05	1.956165E+00	9.529312E-01
		14+	-2.508143E-02	1.320439E-04	1.622112E+00	1.022816E+00
	7cm diameter-to-tip	<14	0.000000E+00	4.197016E-02	-1.850675E+00	1.097233E+00
		14+	2.748275E-03	3.145480E-02	-2.718377E+00	1.832010E+00
	ground-to-stump	<14	0.000000E+00	1.413894E-06	2.280823E+00	6.406977E-01
		14+	4.292907E-04	6.101248E-07	1.902294E+00	1.346098E+00
Lodgepole pine	ground-to-tip	<14	0.000000E+00	6.921817E-05	1.919190E+00	8.846675E-01
		14+	1.519302E-03	7.669112E-05	1.827239E+00	9.372965E-01
	7cm diameter-to-tip	<14	0.000000E+00	4.263883E-02	-1.938347E+00	1.176486E+00
		14+	1.618827E-03	1.050722E-02	-1.724288E+00	1.384023E+00
	ground-to-stump	<14	0.000000E+00	1.973888E-06	2.091059E+00	7.091858E-01
		14+	-1.762187E-04	3.002487E-06	1.998789E+00	6.664901E-01
Scots pine	ground-to-tip	<14	0.000000E+00	5.314210E-05	1.936612E+00	9.498913E-01
		14+	-9.049616E-03	9.944734E-05	1.863076E+00	8.179097E-01
	7cm diameter-to-tip	<14	0.000000E+00	2.404621E-02	-1.770231E+00	1.294410E+00
		14+	2.325565E-03	6.462273E-02	-2.758394E+00	1.683393E+00
	ground-to-stump	<14	0.000000E+00	3.029297E-06	1.689774E+00	8.994627E-01
		14+	-4.124476E-04	2.175148E-06	1.870392E+00	9.124144E-01
Douglas fir	ground-to-tip	<14	0.000000E+00	6.193637E-05	1.893085E+00	9.432626E-01
		14+	-5.132084E-03	1.008348E-04	1.861738E+00	8.073406E-01
	7cm diameter-to-tip	<14	0.000000+00	4.785848E-02	-1.989235E+00	1.170558E+00
		14+	1.988496E-03	7.055136E-03	-1.998482E+00	1.801436E+00
	ground-to-stump	<14	0.000000E+00	1.144930E-06	2.109822E+00	8.526327E-01
		14+	1.131918E-04	9.973821E-07	2.081449E+00	9.377287E-01

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