



**NFI:
Mensuration protocol
for the
National Forest Inventory**

June 2010

E. D. Mackie, R. W. Matthews and A. Brewer¹

FR Biometrics Division

¹ IFOS, Forestry Commission

NFI mensuration protocol

An aerial photo/map (likely GIS-based on a laptop) of the 1 ha NFI sample square which has been stratified/differentiated into provisional sections should be available on the laptop. It is assumed that, prior to carrying out mensuration assessments, the surveyor will 'walk through' the 1 ha sample square, in the process confirming the demarcation of sections. It is also assumed that the broad characteristics of each section will be assessed and recorded including, for example, tree species present within each section. The details of these procedures are not specified here.

The mensuration protocol involves plot-based assessments, usually in each section containing woodland. The definition of woodland is a cover of trees with a canopy of at least 20% of the area.

All surveying/ground-truthing of each section will be carried out prior to the plot-based assessments in that section. This includes a determination of the number of storeys and the modification and verification of the mapped representation of section boundaries within the sample square.

Determining of number of storeys in each section

- a. The surveyor should pick up a sense of the number of storeys in each section as they walk through the sample square.
- b. The criteria to be used to determine what is a storey are given in Appendix 1, along with several examples.
- c. The storey must be 'measurable', defined here as the population of trees forming the storey having a mean dbh of at least 4 cm. The number of measurable trees within this population must represent at least 5% of the total number of measurable trees forming the section, as judged by visual assessment.
- d. Record the number of storeys in the section. Permitted classes of storey are upper, middle, lower and complex.

Note:

As a basic convention the NFI survey defines strata at low heights relevant to the assessment of vegetation and regeneration. These are not considered as part of this protocol.

Plot-based assessments

All plot-based assessments will be carried out in each section of the sample square (subject to exceptional circumstances as described in Figure 1).

Normally, these assessments will involve laying out two or three circular 0.01 ha sample plots at non-overlapping, random locations in each section. The number of plots will depend on the section area. The laptop will automatically select the locations of the plot centres. Plot centres will sometimes be located such that the plot boundary intersects the section or square boundary. In the case of a section

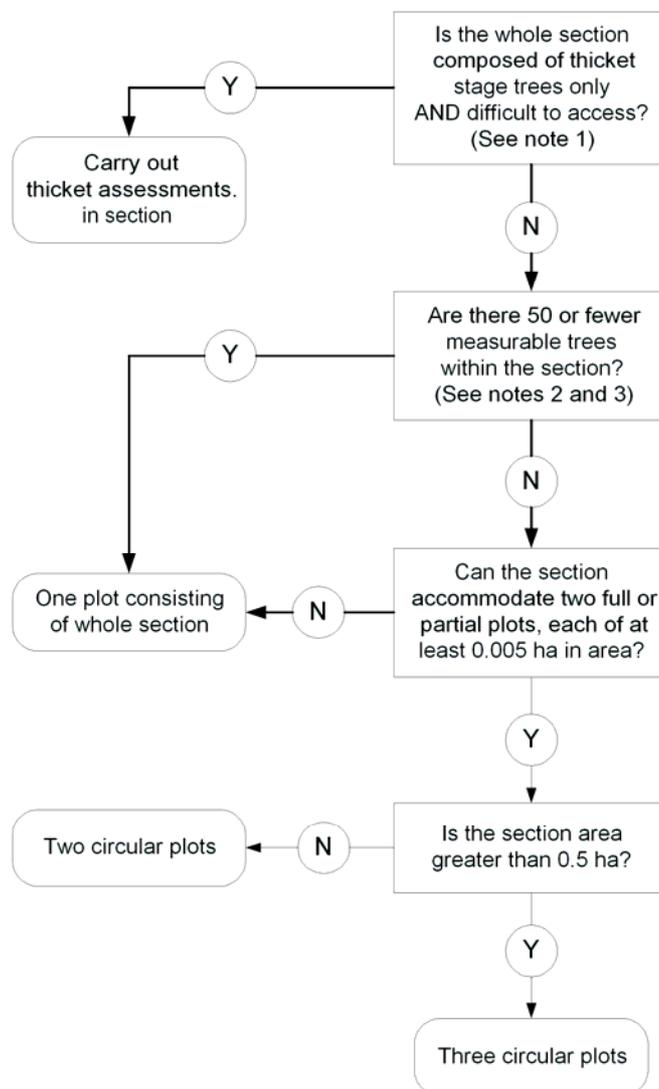
boundary, this will result in a 'partial assessment plot'. When this situation arises, provision is made for appropriate adjustments to plot assessments (see section on assessments in circular plots). Care will also need to be exercised in identifying the centres of partial assessment plots. Guidance is given in Appendix 2.

In exceptional cases, assessments will be taken in a single plot consisting of the entire area of the section. These exceptional cases occur when:

- The section cannot accommodate two non-overlapping full or partial plots, each of at least 0.005ha. in area.
- The surveyor judges that there are no more than 50 measurable trees in the section.

The decision tree in Figure 1 can be used to decide what type of plot-based assessment should be made.

Figure 1. Decision tree for selecting plot-based assessment procedures (see accompanying notes).



Notes for Figure 1

1. For the purposes of this protocol trees are considered to form a thicket when:
 - The bases of the live crowns of the trees are below 2m height.
 - The live crowns of the trees overlap so tightly that access is very difficult.
2. For the purposes of plot-based assessments, a measurable tree is defined as being alive or dead and having a dbh of at least 4 cm.
3. Judging the number of measurable trees in the section will not always be easy. As a guide, Table 1 gives the average spacing between trees that would be expected if a section of given area contained 50 trees.

Table 1. Approximate average spacing between trees for sections of different area equivalent to a total of 50 trees per section

Section area (ha)	Average spacing between trees (m)
0.05	3.2
0.1	4.5
0.2	6.5
0.3	7.5
0.4	9
0.5	10
0.6	11
0.7	12
0.8	12.5
0.9	13.5
1.0	14

4. A circular plot with area 0.01 ha will have a diameter of 11.2 m. When laying out two or more plots, the plot boundaries must not overlap but their boundaries do not need to fall entirely within the section or sample square.

Assessments in circular plots

In each plot:

- a. If a storey within the plot consists of thicket, this should be treated separately from other storeys using the thicket assessment method (see note 1 to Figure 1 and Section on assessment of thickets). Other storeys are assessed using steps b to f.
- b. All trees of height at least 1.3 m should be registered. Of these, trees with dbh less than 4 cm are counted but not assessed further. If a tree has a dbh of at least 4 cm then the dbh should also be measured and recorded. The stool of a coppice is defined as a tree, in this case the coppice is counted as one tree and stems are counted and recorded separately. A girthing tape to an accuracy of 1 cm diameter should be used to take these measurements. A small tree gauge is used for measuring dbh between 4 cm and 7 cm. The dbh values should be recorded along with:
 - The species of each tree

- The status of each tree (dead or alive)
 - The storey within the section to which the tree most closely belongs (see section on determination of storeys).
- c. For each storey for which one or more trees are present within the sample plot, identify within the plot the tree belonging to the storey with the largest dbh. This is the "dominant height sample tree" of the storey and also the "first sample tree". From this tree, find the third nearest tree belonging to the same storey. This is the second sample tree. From the second sample tree, find the third nearest tree of the same storey, but ignoring and therefore not reselecting the original first sample tree in this selection procedure. This is the third sample tree. All selections are made solely with reference to the storey the trees belong to and without reference to their species. The second and third sample trees (referred to as "stand height sample trees") may fall outside the sample plot and/or sample square, but not outside the section. In the unlikely event that the section does not contain enough trees of the storey then abandon the assessment of individual stand height trees where relevant and make a comment to this effect. If the stand comprising the section continues beyond the boundaries of the square, trees beyond the square boundary may be counted as stand height sample trees.
- d. For the first sample tree (dominant height sample tree), measure and record its dbh in the appropriate data field/cell on the laptop. Also measure and record its total height using a Vertex III/IV hypsometer. Place the Transponder on the tree(s) ensuring a good line of sight to the top of the tree when standing 1 to 1.5 times the height away from the tree.
- e. For the second sample tree, measure and record its dbh and its total height in the same manner as for the first sample tree. Also measure and record the upper and lower crown heights and the crown diameter at two perpendicular points - at the widest point and at 90° to this - (see Figures in Appendix 3 for guidance).
- f. For the third sample tree, measure and record its dbh, total height and its crown diameter at two perpendicular points in the same manner as for the second sample tree. (Upper and lower crown heights are not required to be measured for the third sample tree).

Assessments in partial circular plots and plots intersecting the boundary of the square

When laying out circular plots at random within a section, the boundary of a plot may intersect the boundary of a section or the sample square.

When a plot boundary intersects a square boundary, it is possible that the trees in the area of the plot outside the square belong to the same stand as those within the section (i.e. the area of trees forming the section continues beyond the square boundary). In these situations, assessments should include that part of the stand within the plot that falls outside the square i.e. as though the plot falls entirely within the square. The surveyor will need to record that the section / stand extends beyond the square boundary by making a simple map of the full extent of the stand.

If some of the trees in the area of the plot outside the square belong to a different stand to those within the section, this indicates that the plot intersects a section boundary outside of the sample square. Using the GIS, the surveyor will draw a polygon to represent the extent of the relevant and valid stand that continues outwith

the square, that contains the part of the plot that spans the square boundary. The procedure for assessment of partial circular plots, taking account of this section boundary, should then be followed.

When a plot boundary intersects a section boundary, the procedure for assessment of partial circular plots should always be followed.

After the plot centre has been successfully located and the section boundary is fairly represented on the map (see Appendix 2), the GIS software will estimate the area of the partial circular plot. This should be recorded.

An adapted version of the procedure for 'assessments in circular plots' is performed in partial circular plots. Assessments a and b of this procedure should be confined to the plot area falling within the section, while assessment c uses only trees within the partial assessment plot to identify the dominant height sample tree for each storey. Assessments d to f are followed as for full assessment plots.

Assessments where the whole section is the plot

Within the section:

- a. If a storey within the section consists of thicket, this should be treated separately from other storeys using the thicket assessment method (see note 1 to Figure 1 and Section on assessment of thickets). Other storeys are assessed using steps b to f.
- b. All trees of height at least 1.3 m should be registered. Of these, trees with dbh less than 4 cm are counted but not assessed further. If a tree has a dbh of at least 4 cm then the dbh should also be measured and recorded. The stool of a coppice is defined as a tree, in this case the coppice is counted as one tree and stems are counted and recorded separately. A girthing tape to an accuracy of 1 cm diameter should be used to take these measurements. A small tree gauge is used for measuring dbh between 4 cm and 7 cm. The dbh values should be recorded along with:
 - The species of each tree
 - The status of each tree (dead or alive)
 - The storey within the section to which the tree most closely belongs (see section on determination of storeys).
- c. Randomly locate 3 sample points within the section. (This may be assigned automatically by the laptop.)
- d. For each storey, at each location, select the closest tree (regardless of species) to the sample point; this tree is the first sample tree of the storey. From this tree, find the third nearest tree belonging to the same storey. This is the second sample tree. From the second sample tree, find the third nearest tree of the same storey, but ignoring and therefore not reselecting the original first sample tree in this selection procedure. This is the third sample tree. All selections are made solely with reference to the storey the trees belong to and without reference to their species. The second and third sample trees may fall outside the sample square, but not outside the section. In the unlikely event that the section does not contain enough trees of the storey for the successful selection of a third sample tree, or of both the second and third sample trees, then abandon the assessment of the relevant sample trees and make a comment to this effect. If the stand comprising the section continues beyond the boundaries of the square, trees beyond the square boundary may be counted as sample trees.
- e. For the first sample tree, measure and record its dbh in the appropriate data field/cell on the laptop. Also measure and record its total height using a Vertex III/IV hypsometer. Place the Transponder on the tree(s) ensuring a good line of sight to the top of the tree when standing 1 to 1.5 times the height away from the tree.
- f. For the second sample tree, measure and record its dbh and its total height in the same manner as for the first sample tree. Also measure and record the upper and lower crown heights and the crown diameter at two perpendicular points - at the widest point and at 90° to this - (see Figures in Appendix 3 for guidance).
- g. For the third sample tree, measure and record its dbh, total height and its crown diameter at two perpendicular points in the same manner as for the

second sample tree. (Upper and lower crown heights are not required to be measured for the third sample tree).

Assessment of thickets

A thicket assessment consists of a qualitative, visual assessment of the stocking density of the trees forming the thicket and an assessment of mean height.

- a. The stocking density of the thicket should be assessed visually as either 'high', 'medium' or 'low' as indicated in Table 2.
- b. Identify an accessible tree in the thicket which is representative of the mean height of the trees forming the thicket. Measure and record the total height of this tree. When the assessment is for a thicket in a 0.01 ha circular plot, it is acceptable for the accessible tree not to be within the plot.

Table 2. Qualitative stocking density classes for thickets

Class	Approximate stems per ha	Approximate spacing between trees
High density	Greater than 2500	Less than 2 m
Medium density	1000 – 2500	Between 2 m and 3 m
Low density	Less than 1000	Greater than 3 m

Appendix 1. Determining storeys within a section

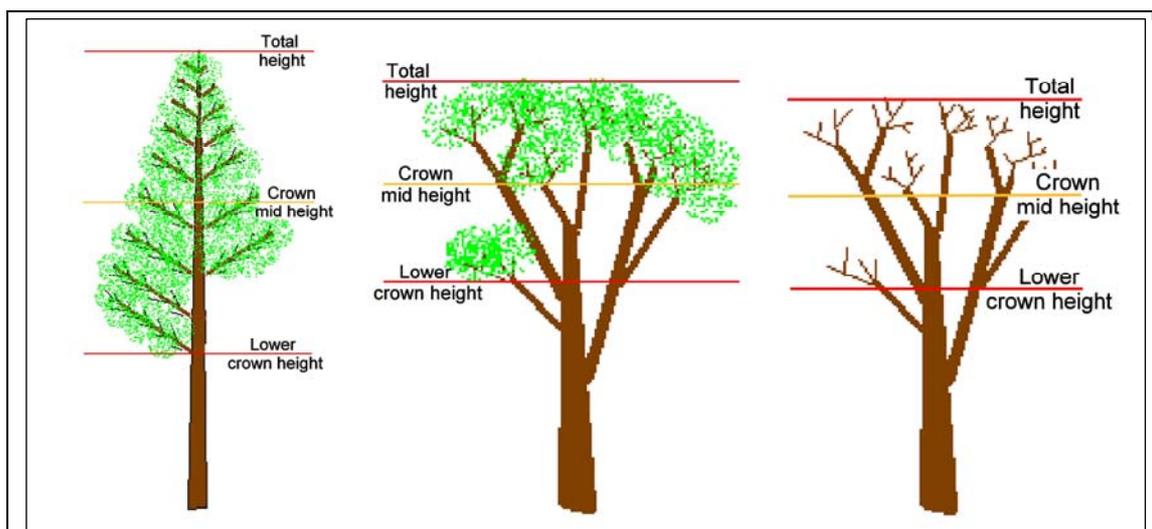
In assessing stand structure within a section for the presence of distinct storeys, it will often be the case that there is some variation in the heights of the trees but that it is difficult to determine from a simple visual assessment whether the trees of various sizes naturally group into different canopies and therefore into distinct identifiable storeys.

This appendix describes a procedure for the assessment of a section which will help in the decision about whether different storeys are present in the stand and, if such separate storeys can be identified, the means of identifying the members of a storey. Due to the complexity of stand structure in many situations, there is still likely to be a certain amount of subjectivity and dependence on the skill of surveyors in the identification of storeys within a section. Following the procedures described here will help to ensure some degree of consistency in the definition of storeys across stands of differing structures and across surveyors.

Before attempting to group trees into separate storeys according to their general vertical stature, it is first necessary to identify a definitive concept of the height of any particular tree for this purpose. Ultimately, a storey is defined by the similarity of the vertical positioning of the canopies of the trees belonging to that storey, and since tree canopies can vary considerably in general shape and form, the overall height of a tree will not always be the best representation of its vertical 'presence'. A better representation of the general vertical positioning in the canopy of a tree would be the mid-point between the bottom and top of the crown, which is here named the 'mid-crown' height.

The mid-crown height is then defined as the midway point between the lower crown height and the total height of the tree. The following diagrams illustrate three examples of the positioning of the lower crown, total and mid-crown heights of conifer and broadleaf species.

This is a formal definition of the mid-crown height. In practice it represents the height which is 'half way up' the crown of a tree.



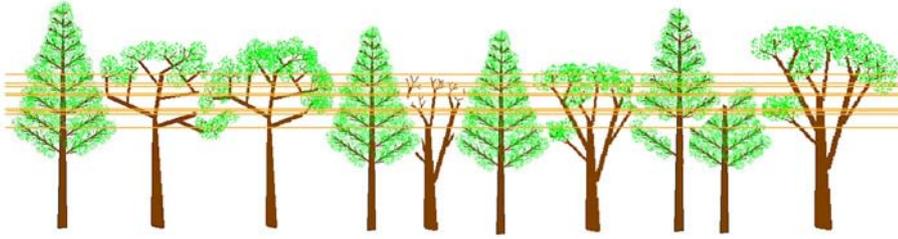
In first deciding whether an identifiable multi-storey structure exists within a section, consideration is given to the vertical distribution of the mid-crown heights of trees within the section. The essential question to ask is whether these mid-crown heights cluster into two or more groups on the vertical scale?

The convention to be used in answering this question is to visualize the mid-crown heights of the trees within the section and to decide, in the first instance, whether an upper storey exists in the section. This is the case if there is a distinguishable cluster of mid-crown heights in which the lowest member of that group is at least 4 metres higher than most of the rest of the trees within the section. This is described as 'most' rather than 'all' because there are likely to be situations in which there is a well-defined highest group and one or more lower groups but also an occasional tree whose height is spanning the vertical 'gap' between the highest group and the others. As a guideline, the tallest group can be identified as a distinct storey (the upper storey) if the number of trees that have mid-crown heights that are less than 4 metres lower than this tallest grouping do not represent more than 5% of the number of trees in the tallest group.

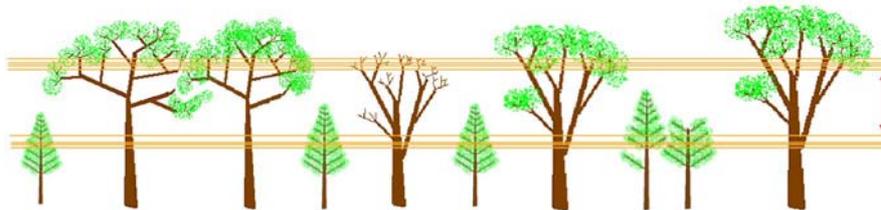
If these conditions exist in the section, the stand within the section can be considered to be a multi-storey stand and the trees in the identified tallest group (on the basis of mid-crown heights) form a stratum of the section which will be separately assessed and sampled. Any occasional trees that are less than 4 metres lower than the lowest in this tallest grouping are assigned to the lower strata. In turn, the mid-crown heights of the remainder of the trees in the section are also assessed for a clustering pattern and if a distinguishable second tallest grouping can be identified on the same basis (with mid-crown heights at least 4 metres higher than most of the remainder of the trees) then this second tier also forms a separate storey which will be treated as a separate stratum of the stand. The remainder of the trees of measurable height, including any which are less than 4 metres lower than the identified second tallest grouping, then belong to a third stratum of the stand. (In theory, there is no limit to the number of distinct storeys that could be identified in this manner, but in practice it is unlikely that stands with more than three distinguishable storeys will be encountered. Any woodland section may therefore be sub-divided into one, two or three separate storeys on the basis of canopy heights).

If it is not possible to identify a distinct upper storey using the guidelines described above, the height distribution of the trees within the section is too complex to be described as having a multi-storey structure. In these situations, in common with stands of a simple structure with a single storey of nearly uniform height, the section is regarded as possessing a single storey and is assessed and sampled accordingly.

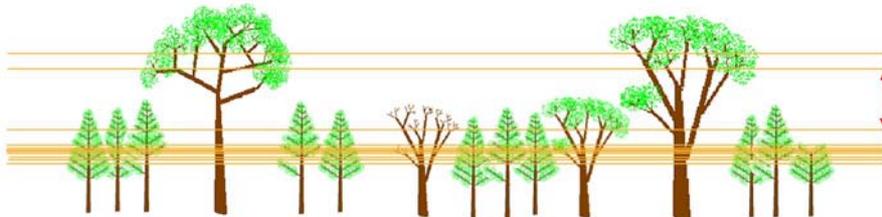
The following diagrams give a visual representation of different examples of stands which would be identified as multi-storey and those which would not, and would consequently be treated as single storey stands.



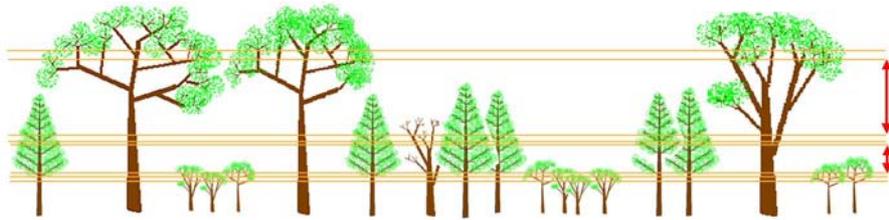
In this example it can be seen that the projected mid-crown heights of the trees form an obvious band. The stand has a single-storey.



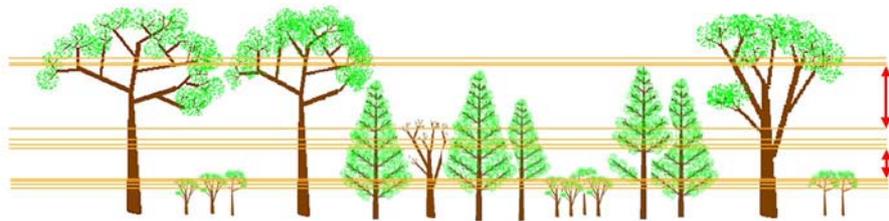
The projected mid-crown heights of the trees in this example fall into two bands with a clear gap between the two bands, greater than 4 metres (vertical arrow). The stand has a distinct upper storey and lower storey. A section containing such a stand would possess two storeys.



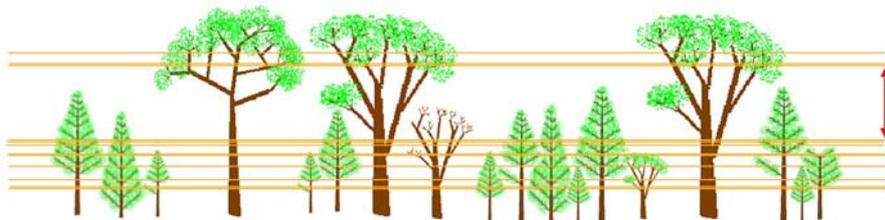
This example also shows two bands of projected crown mid-heights, although in this instance the members of the upper storey are widely spaced and therefore sparse. This storey is still treated as a separate storey.



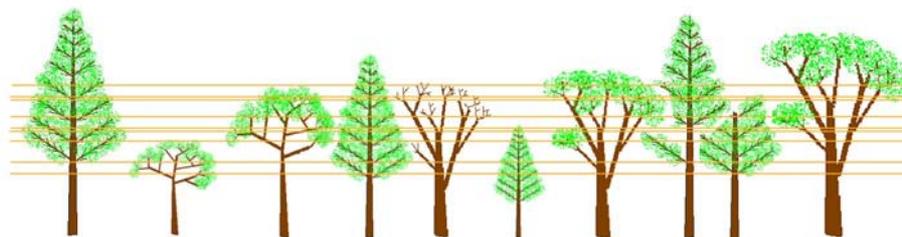
The projected mid-crown heights of the trees in this example fall into three bands with clear gaps between each of the bands, greater than 4 metres (vertical arrows). The stand has three distinct storeys - upper, middle and lower.



In this example, there are conifer trees with total heights similar to the upper storey. However, the trees have long crowns and by looking at the projected mid-crown heights it is clear that these trees belong to a lower storey (vertical arrows). This is another example of a three-storey stand.



The heights of the trees in this example are variable, but there is still a distinct upper storey. The band for the lower storey is wide, reflecting the complex structure, but there is a clear gap of greater than 4 m between the projected mid-crown heights for these trees and those forming the upper storey (vertical arrow). A section with a stand of this structure would therefore contain two storeys.



In this example the heights of the trees are very variable, reflecting a complex stand structure. It is not possible to distinguish obvious storeys (i.e. no bands in the projected mid-crown heights of trees). The test for a difference in mid-crown height of 4 metres is based on groups of trees forming distinct bands, not individual trees. A section containing such a stand would therefore be considered to possess a single (complex) storey.

It should be noted that storeys within a section may have very different lateral distributions. Some may be uniformly spread over the whole area of the section while others may occur in patches and do not cover the whole area of the section. Where such patterns give rise to separately identifiable areas of sufficient size during the mapping stage of the sample square, these may be accommodated in the partitioning of the sample square into separately identified sections. This will often not be the case, however, and it is expected that individual storeys within a section may often occupy only parts of a section, or vary greatly in density in different areas of the section. It may sometimes be found that sample plots laid out in a section will capture little or no trees belonging to a particular storey being assessed, while others capture a dense part of the storey. This is to be expected, dependent upon the structure of the stand within a section, and adjustment or rejection of a sampling point should not be made on this basis.

Appendix 2. Locating on the ground and verifying the location of the centre point of a partial circular plot

After the surveyor has ground-truthed, and where necessary modified, the plan of the sections and section boundaries within the square, the field assessment software will generate two or three randomly located points representing plot centres within each NFI wooded section that is to be assessed with the use of circular mensuration plots.

In some instances the random locations selected by the software will result in circular plots that intersect with section boundaries such that the whole of the plot is not contained within the section. When this occurs, it is especially important that the section boundary is well represented on the map, and that the centre point of the plot in relation to the intersecting section boundary(s) is located on the ground to an acceptable level of accuracy.

The surveyor should first go to the approximate location of the centre point of the partial plot, using absolute GPS references or a distance and direction relative to an identifiable feature on the map that can be located on the ground. The surveyor should then inspect that part of the section boundary (or boundaries) that intersect and therefore fall inside the circular plot, as shown on the map, and check that the map representation of this part of the boundary is a fair representation of the shape of the boundary as it passes through the plot. If necessary, the surveyor should redraw the boundary on the map to reflect the shape of the boundary seen on the ground in this vicinity.

The surveyor should then select a point on the intersecting section boundary that can be closely identified on the map, again if necessary fixing its position relative to an identifiable mapped feature (which can be a kink or curve in the boundary itself). This position on the section boundary should be marked on the map, and then the map can be interrogated to obtain the direction and distance from this boundary reference point to the centre of the plot. The surveyor then proceeds to locate and mark the plot centre on the ground with reference to this direction and distance.

Once the centre point is located, its position relative to the section boundary can then be verified. The map will provide the relative direction from the plot centre to each of the intersection points with the section boundary. The surveyor, facing in each of these directions, should measure out a distance equal to the plot radius (5.6m) from the plot centre and check that in each case the located point falls on the section boundary to an accepted level of tolerance of +/- 0.5m. If such tolerance levels are exceeded the surveyor must recheck the validity of the procedure to locate the plot centre on the ground, and, if this is reconfirmed, the surveyor should make adjustments to the mapped representation of the section boundary such that it intersects the radii from the plot centre at the physically observed distances.

Appendix 3. Crown and storey definitions. Including excerpt from FR SOP 0232 (May 2008).

Lower Crown Height The height of the **lowest live branch** on the main stem (excluding epicormics and forks), recorded to the nearest 0.1 m. on hardwoods this is the lowest level of fine branching.

Upper Crown Height. The height on the main stem where the **lowest complete whorl** of branches occurs, recorded to the nearest 0.1 m.

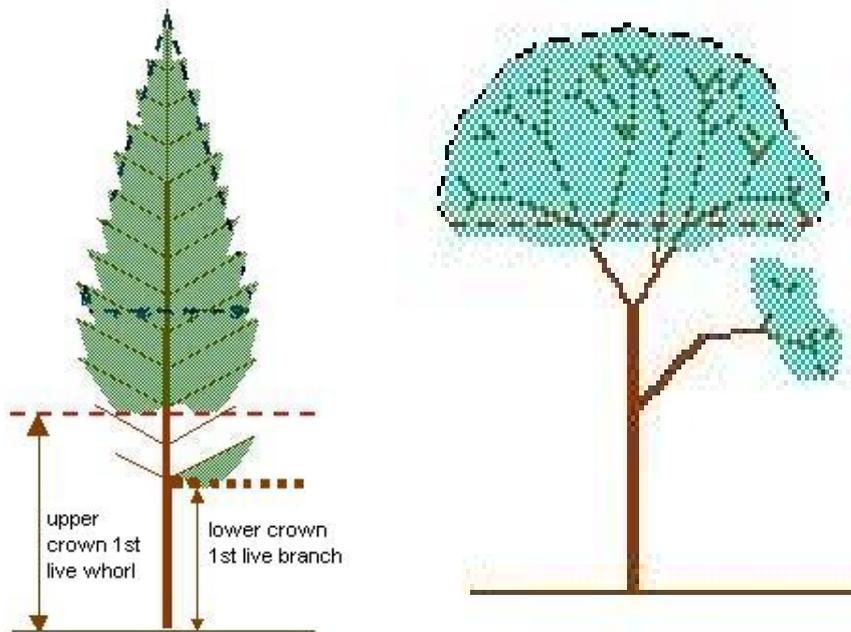


Diagram of tree crown diameter projection measurement

PLAN VIEW

