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Leaflet **82**

Assessment of Wildlife Damage in Forests

R C Melville L A Tee K Rennolls

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FRONT COVER

Left: Lodgepole pine (80 mm diameter) bark-stripped by red deer. *(33982)*

Right: Norway spruce held in check by red deer browsing. *(19678)*

ASSESSMENT OF WILDLIFE DAMAGE IN FORESTS

R C Melville[1], L A Tee[2] and K Rennolls[3]

Forestry Commission

1. Formerly Forest Officer, Wildlife Branch
2. Chief Forester, Wildlife Branch
3. Biometrician, Statistics and Computing Branch

1. Introduction

It is important that a forest manager should be aware of the scale and extent of animal damage in his forest. Such information will be an aid to making decisions on policy related to wildlife management.

To obtain the exact value of damage it would be necessary to examine every tree. Since this is not practical, except in very small blocks, assessment is usually achieved by the examination of a representative sample. Many different methods of damage assessment in forests have been employed for different circumstances. These include, besides 100 per cent surveys, the use of transects and quadrant sampling using square or circular plots. Whenever quantitative assessments need to be made, whether it be of damage levels, population numbers or diseased individuals in a crop, efficient and reliable techniques must be used. It is difficult to carry out damage assessments visually with any reliability and such visual assessments infringe the important criterion that subjective bias should not influence the data. Two assessors should be able to employ the same method on a given area and obtain estimates which are not significantly different from each other.

Within the context of estimating wildlife damage to a forest, the problem has been to produce not only an accurate and consistent method but, also, one which is simple and quick. The original damage assessment method considered was one of 0.01 ha (10 m × 10 m) square plots laid out at regular intervals throughout the area. This was found to be awkward and time-consuming on a practical basis. Hence a quicker and more manageable system has been developed. This is conveniently described as the **nearest neighbour method** and involves the systematic selection of a number of points throughout the compartment. At each of these points a predetermined number of trees, usually the closest, are examined for damage. The method will be described in detail in the next section and the data recording method, on form NN1, is illustrated in Appendix I.

It is important before carrying out a forest damage assessment, to be clear on what is meant by *damage*. The decision of what to class as damage should depend on the local manager's requirements. When considering browsing, for instance, the survey is usually limited to an assessment of the proportion of trees with current year's *leader* damaged. Side shoot browsing, although it may at times appear serious, does not necessarily have the economic significance of leader browsing. When assessing bark stripping the normal procedure is to record all damaged trees. The nearest neighbour method is suitable for whatever form of damage requires assessment. More than one type of damage or tree species (for example, browsing and fraying by roe deer on a mixture), can be surveyed in the same assessment.

The nearest neighbour method is most suitably applied when a single damage assessment on a particular compartment is needed. In the case of a forest having compartments of different tree species and ages the assessment method may be applied to each compartment separately. The method may be used flexibly to monitor changing damage levels, although in these circumstances fixed monitoring plots might be easier and more efficient. However, such fixed plot assessment may often be ruled out as the assessment procedure can affect the behaviour of deer.

2. The nearest neighbour method

The method involves the selection of a number of points throughout the area, termed *centres*, and about each centre a predetermined number of trees are assessed for damage. The trees around a centre are called a *cluster*. The main practical points to bear in mind are that the centres should cover the whole area in a representative manner and that the trees in a cluster should be chosen objectively and independently of the damage which has occurred. In the next two sections the field method of locating centres and cluster trees will be described. Subsequent sections give details of the calculations that have to be made before, and after, the sampled trees have been assessed.

2.1 Selection of centres

Because of the possibility of the intensity of damage not being homogenous throughout the stand, whether it be by squirrel, deer or rabbit, it is necessary that the whole of an area to be assessed is covered. For this reason the centres should be spaced systematically throughout the stand. This will help to identify regions having different damage intensities, as well as making the assessment easier to carry out.

The centres are chosen to lie upon a set of approximately parallel lines, distance D apart, the centres being spaced D apart along a given line. The value of D is calculated as shown in

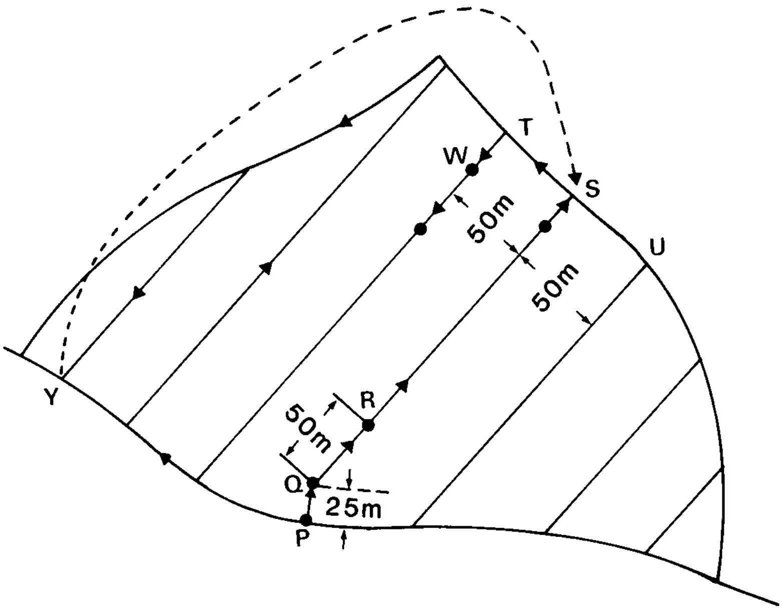

FIGURE 1 Illustration of how to choose centres

Section 2.6 and may be measured in the stand by pacing. For illustration, Figure 1 shows a compartment which is to be assessed. Let us assume that D = 50 m. The initial task is to obtain the first centre. To do this, choose a 'convenient' point P, on the boundary of the stand, and then pace into the stand a distance $\frac{D}{2}$, in this example 25 m.

The point reached, Q, is the first centre. The second centre, R, is then obtained by choosing a convenient direction (across the compartment) and pacing from Q a distance 50 m in this direction. If the compartment rows are clearly visible then the direction QS should be chosen to be along a row. If the rows are not apparent, then P at a compartment corner and QS parallel with the compartment edge is a good choice. A compass will be needed in order to carry out the assessment.

Further centres are obtained by continuing to pace in the same direction until the boundary of the area is reached (S in Figure 1). Mark S and make a note of the number of paces left before the next centre would be reached. The assessor should then move to either point T or U, as is convenient, these points being on the compartment boundary and on lines parallel to QS, at a distance of D (50 m). Suppose the assessor moves to T. He should then continue to pace the remaining number of paces to the next centre W. Further centres are then obtained in the same manner; at each boundary the assessor moves away from QS, until that part of the compartment on the T-side of QS has been covered. Suppose the last centre reached is Y. The assessor should then return to S and then on to U, continuing the assessment in exactly the same manner as from T.

Quite frequently, in practice, the point P can be chosen so that it becomes unnecessary to return to S, particularly when the rows run parallel to an edge of the area.

2.2 Selection of the trees in a cluster

The trees in a cluster need only be selected in an objective manner which is independent of the damage occurring. A very simple method is to choose a predetermined number of trees lying closest to the centre. However, in the case of a stand which is being assessed along rows, it is often more convenient to select those trees occurring in an adjacent row, after the centre has been reached. Even though this method of cluster selection is used we shall still call the assessment method the nearest neighbour method.

2.3 Accuracy required and sample size

The accuracy of the estimate obtained is dependent on the number of trees sampled. The assessor must therefore initially decide on the degree of accuracy he requires, in order to be able to calculate the number of trees to be assessed. In general, the greater the accuracy required of an estimate, the more trees will need to be assessed.

The assessor needs to be clear about what is meant by *accuracy required.* This depends both on the damage level that we might reasonably expect to have occurred and the risks associated with obtaining an inaccurate estimate. If the damage is within either 0–20 per cent or 80–100 per cent then the management decisions will not usually be affected by where in these ranges the estimate falls. However, if the damage is likely to lie somewhere in the range of 40–60 per cent with the value of 50 per cent being critical, then higher accuracy is needed.

The decision as to the degree of accuracy required for an assessment should also depend on the age and value of the crop as well as the size of the compartment being surveyed. Thus a large compartment of an older crop which has a high intrinsic value can justify an assessment with an accuracy of ± 5 per cent; an example would be a mature Norway Spruce stand of 50 ha which has been bark stripped by red deer. On the other hand a 20 ha recently planted compartment suffering from browsing damage need only be surveyed to an accuracy of ± 10 or 15 per cent.

We choose as our criterion of accuracy the 95 per cent confidence limits. Suppose the assessor has chosen his required precision (which we denote by x). He now calculates the number of trees to be assessed from,

$$N = \left(\frac{100}{x}\right)^2 \qquad \textit{Formula 1}$$

where N = total number of trees to be assessed,
and x = accuracy desired (±) at 95 per cent confidence level.

If we were aiming to achieve an accuracy of ± 10 per cent then we might expect our estimate to be, for example, 60 per cent damage with 95 per cent confidence limits encompassing the 50–70 per cent damage levels. In this case we would have to sample at least

$$N = \left(\frac{100}{10}\right)^2 = 100 \text{ trees.}$$

Similarly if we were aiming to achieve an accuracy of ±5 per cent then we would have to sample at least

$$N = \left(\frac{100}{5}\right)^2 = 400 \text{ trees.}$$

Unfortunately, although we might try to achieve a ± 5 per cent accuracy in our assessment, we can never be absolutely certain that this is what we will get. If the damage is approximately random then the precision of the estimate should be close to that aimed for. However, wildlife damage is never completely random; there are many features which may be unexpected. For example, with roe deer browsing on restocked areas, the damage may be concentrated on the edge nearest to more mature crops or, with red deer bark stripping damage, restricted to particular tree species and sizes. It is therefore necessary to calculate the actual accuracy obtained using the data from the assessment and this is explained in Section 2.9.

2.4 Cluster size

The cluster size may be fixed at any value between 4 and 7 (inclusive) with the choice of size being influenced by plantation conditions. We denote the cluster size by c. Normally we would recommend a fixed cluster size of c = 5 trees.

In some circumstances it might be desirable or necessary to choose clusters having a variable number of trees. These circumstances arise when the use of fixed area plots is easier in practice. An example of this situation would be if the assessor was measuring squirrel damage on beech in a mixed hardwood crop with a very low stocking density, where the distance required to be covered from the centre of the cluster in order to measure 5 trees becomes unmanageable. A fixed distance from the centre would then determine the number of trees assessed.

Our account will be restricted to the fixed cluster size, but the necessary amendments to cope with variable size clusters will be found in Appendix II.

2.5 Number of clusters

To calculate the number of clusters, use

$$n = \frac{N}{c} \qquad \textit{Formula 2}$$

where n = the required number of clusters,
N = the total number of trees to be assessed (from Formula 1),
and c = the chosen fixed cluster size.

However, in order to get an adequate representation of the crop at least 20 clusters must be assessed per stand. Thus, to achieve an expected accuracy of ± 10 per cent, which necessitates a sample size of at least 100 trees (from Formula 1), there need be no more than 5 trees per cluster. This would give exactly 20 clusters.

2.6 Distance between clusters

We must establish the distance between each cluster, D. This is calculated using

$$D = \sqrt{\frac{A \times 10{,}000}{n}} \qquad \textit{Formula 3}$$

where D = distance between clusters, in metres,
A = area of the stand, in hectares,
and n = number of clusters to be assessed (from Formula 2).

As an example, if the area of a compartment to be assessed was 10 ha and we require an accuracy of ± 8 per cent using 5 trees per cluster, the calculation would be as follows:

Number of trees to be assessed (using Formula 1) $= \left(\frac{100}{8}\right)^2$ trees

$= 156$ trees.

Number of clusters to be assessed (using Formula 2) $= \frac{156}{5}$

$= 31$ clusters (rounded).

Distance between centres, D

$$= \sqrt{\frac{10 \times 10{,}000}{31}}\ \text{m} = 57 \text{ metres.}$$

The assessment may now be carried out as described in Sections 2.1 and 2.2, the number of damaged trees per cluster being recorded on form NN1, an example of which can be found in Appendix I.

Even if D were measured accurately, only about 31 clusters would be obtained. It is not of major importance that the number of clusters actually obtained differs from 31 (by up to 5 clusters). However, if it is found that at the end of the assessment, far fewer clusters have been assessed than originally desired, (i.e. under 26 in our example), extra clusters can be put in at random throughout the compartment.

2.7 Possible biases

It is possible for bias to creep into the assessment at two points unless the assessor is aware of the danger.

During the pacing of the distance between clusters it may be very tempting to lengthen or shorten the paces so as to finish with a cluster of trees which is either in an area of damage or in an area of no damage. This should never be done, even if the assessor feels that by doing so, he is assessing what is more typical of the area.

Since it is not recommended that the proximity of the nearest neighbour is physically measured, the assessor may subjectively choose either damaged or undamaged specimens in a cluster regardless of their location. Care must be taken that the choice of cluster trees is independent of the damage on the trees.

2.8 Percentage of damage

It has been pointed out above (2.6) that the number of clusters actually assessed might be slightly larger or smaller than the number expected (i.e. n). Let the number of clusters assessed be denoted by n′. Then the percentage of sampled trees damaged is calculated by,

$$\text{percentage damage} = \frac{d}{a} \times 100 \qquad \textit{Formula 4}$$

where d = total number of damaged trees counted,

and a = total number of trees assessed, ($= n'c$).

2.9 Actual accuracy

We can never be absolutely certain that the accuracy obtained is exactly that which we set out to achieve. The actual accuracy obtained from any assessment is determined by the variability of the number of damaged trees recorded at each cluster and could be more or less accurate than had been initially expected. Equal numbers of damaged trees recorded per cluster would give a high degree of accuracy in the estimate, whilst accuracy would be low if the number of damaged trees per cluster varied widely.

To obtain an estimate of the accuracy achieved with any given set of data, the following calculations have to be made:

(i) Square the number of trees damaged in each cluster and add them up to obtain X. That is, if d_i is the number of damaged trees in the i th cluster and there are n′ clusters actually assessed, then

$$X = \sum_{i=1}^{n'} (d_i)^2 \qquad \textit{Formula 5}$$

Example:
If the number of damaged trees in 5 different clusters each of 5 trees is 3,2,4,1 and 3 then:

$$X = (3)^2+(2)^2+(4)^2+(1)^2+(3)^2$$
$$= 39$$

(ii) The actual accuracy, that is the estimated error in terms of the 95 per cent confidence limits, can now be calculated using:

Estimated error

$$= \pm \frac{200\sqrt{X-\left(\frac{d^2}{n'}\right)}}{a}\% \qquad \textit{Formula 6}$$

where d = total number of damaged trees counted,
a = total number of trees assessed,
and n′ = number of clusters assessed.

An example of the use of Formulae 1 to 6 is given in Appendix I.

2.10 Distribution of damage

When the assessments and calculations are completed, the data should be plotted back onto the map of the area surveyed. If, as a result of this it is clear that there is particularly intense damage in one region of the compartment then this might be regarded as a separate region in its own right. The data which has been collected in this region may then be used in Formulae 4, 5 and 6 to calculate the damage estimate in this region, and its accuracy. If the accuracy of this estimate is insufficient then further clusters will be selected at random, or a reassessment made, within this limited area.

3. Crops in mixtures

When mixed crops are being assessed, it is advisable that clusters should consist of an equal number of trees of each species. For example, in a Lodgepole pine / Sitka spruce mixture with 5 trees per cluster, 5 Lodgepole pine and 5 Sitka spruce should be assessed at each centre. If it is found impossible to do so since one of the species has either a very low stocking density or is only sporadically present throughout the compartment, then it may be found necessary to have a variable cluster size throughout the assessment. An example of how to cope with this situation is given in Appendix II.

4. Stocking density

An assessment of an area which gives only the percentage of damage is of limited value without knowledge of the stocking density. If a newly planted crop has 20 per cent deaths, this is obviously not as serious in a fully stocked crop as in one which has less than 1,000 trees per hectare. The fewer trees there are, the less one can afford to accept damage. It is therefore useful to have an estimate of the stocking density. This can be achieved by including some further measurements during the course of the damage assessment. An example is given in Appendix III.

As with damage assessment methods, many types of survey have been employed under different circumstances to estimate stocking density. For the sake of completeness three simple methods are suggested here, one of which should be suitable for the crop being assessed. They are all based upon the use of fixed area plots. It is possible when estimating stocking density to do as was done for damage assessment, i.e. to set a required level of accuracy, and then to determine the number of plots required. For simplicity we shall not do this here, but rather advise that at least twenty plots should be completed for any area assessed. For a fairly irregularly distributed crop having an actual stocking of 1,000 trees/ha, twenty 0.01 ha plots ensure that the estimated 95 per cent confidence interval is 900 to 1,100 trees/ha. Further details and methods relating to stocking density estimation may be found in Forestry Commission Booklet 49 *Timber measurement — a field guide* (Edwards, 1983).

Thus if we were aiming to achieve an accuracy of ± 5 per cent in the damage estimate, requiring a 400 tree sample, or 80 clusters at 5 trees per cluster, then a stocking density plot would have to be completed at every fourth cluster.

In all situations the stocking density is given by dividing the total number of trees counted by the total area of the plots on which they are counted.

4.1 Crops under 1.5 metres in height where no visible rows are present

In this case, the assessor should use a circle of 5.6 metres radius for assessing the stocking density. This gives an area per plot of approximately 0.01 ha. The simplest method is to have a measured 5.6 metres length of string which can be anchored at each centre. By holding the string at its full extension and walking in a circle, all the trees within can be easily counted.

4.2 Crops over 1.5 metres in height where no visible rows are present

For crops over 1.5 metres in height it is more difficult to use a circular plot and it is therefore advocated that square 10 × 10 m plots are laid out.

4.3 Crops in rows

Normally plantation crops are in lines and even after thinning it is often very easy to spot the original rows. It is possible to use these rows to lay out a 1/100 hectare plot, as follows:

Measure the width (in metres) of four rows of trees from the centre line of the first row to the centre line of the fourth row.

Divide this distance into 100 to give the length in metres that has to be measured along a row to provide the side of a 1/100th hectare plot.

Run the tape out along either of the central rows of trees for this distance and count all the trees in that row and in one row on either side.

See Appendix III for diagram and worked example.

5. Summary of method and equipment required

(i) A map of the area to be assessed 1:10,560 (6 inches to 1 mile) or 1:10,000 (metric) is needed, and a compass where difficulty in following tree rows is anticipated. If stratification is required, a separate assessment must be made for each stratum.

(ii) Decide on the accuracy required (Section 2.3).

(iii) Determine the total number of trees to be sampled, N, from Formula 1 (Section 2.3).

(iv) Decide on how many trees should be assessed in each cluster (Section 2.4).

(v) Calculate the number of clusters required from Formula 2, (Section 2.5). If the number is between 20 and 100 proceed to the next step. If the number is less than 20 then take 20 clusters. If the number is greater than 100 then you are either aiming for undue precision, or have made a mistake in your calculations.

(vi) Calculate how far apart the clusters will have to be, i.e. D, to cover the area evenly, using Formula 3 (Section 2.6).

(vii) Choose an arbitrary starting point $\frac{D}{2}$ into the area and walk in a straight line in a convenient direction, usually approximately parallel to the edge of the area or along rows. At the distances D, calculated from Formula 3, stop and record on an assessment sheet NN1 the number of trees damaged in the chosen cluster.

(viii) Measure stocking density (Section 4) if required. Record on assessment sheet.

(ix) At the end of an assessment line, when the boundary of the compartment is reached, note the number of paces from the last cluster. Walk at right angles (to the initial assessment line) for distance D. The new assessment line is parallel, but in the reverse direction to the previous assessment line. From the compartment boundary on this new assessment line, walk the remaining number of paces to the next cluster.

(x) Continue assessment until the area has been fully covered, (see Section 2.1 for details). You are unlikely to have exactly the correct number of clusters.

(xi) Should you have significantly less than the required number, or less than 20, complete the assessment with randomly selected clusters throughout the area. If you have more than the required number, then accuracy should be improved.

(xii) Calculate the percentage damage from Formula 4 (Section 2.8) and the accuracy of the assessment from Formula 6 (Section 2.9).

(xiii) Calculate stocking density. See Section 4 and Appendix III for an illustrative example.

(xiv) If you feel that damage is variable and further stratification may be required, map the damage percentage in each plot onto the map showing plot positions. A pattern of damage may then be discernible which may suggest more intensive assessment in a smaller area.

6. Management implications

As a quick and easy method of assessment the nearest neighbour method is a handy tool for the forest manager to assess wildlife damage as a basis for evaluating management options. An annual assessment of vulnerable compartments will provide him with information on the degree of damage, whether it is increasing, and whether or not he has to consider instigating preventative measures. Deciding the state at which damage levels become unacceptable depends on the forest manager's local knowledge of site and species. For example, when considering browsing pressure on young plantations, the species involved is important; Sitka spruce is able to withstand a much greater degree of leader browsing than Douglas fir, Japanese larch or broadleaves.

The nearest neighbour method can provide data on the severity of damage, how it is spread within a compartment or within the forest, and how it is changing from year to year.

APPENDIX I

EXAMPLE OF THE NEAREST NEIGHBOUR METHOD: FIXED CLUSTER SIZE (Form NN1)

We wished to assess the leader browsing damage which had occurred in a 7.1 ha stand of restocked Sitka spruce, planted in 1977.

(a) *(i) Considerations.* We thought that the damage was about 25 per cent and that net discounted revenue (NDR) calculations would only be affected, in this case, if the damage is 40 per cent or more. We were therefore satisfied with a fairly low 'required accuracy'.

(ii) Pre-assessment calculations. We chose x = 10 per cent as our accuracy target and adopt a cluster size of 5. This leads to 100 trees needing assessment, hence 20 clusters obtained by spacing centres 60 m apart. The necessary calculations are illustrated in the pre-assessment section shown on form NN1(i).

(b) *The assessment.* Figure 2 shows a plan of the compartment and indicates the planting rows. The crop had rows which ran approximately parallel to the forest road shown. Hence entry point P was chosen since we get first centre, Q, which allowed us to traverse the stand along the rows and to cover the whole stand without the need of any backtracking. It will be seen that 22 centres have been obtained, although 20 clusters had been our target.

At each of the 22 centres, 5-tree clusters were assessed and the number damaged at each cluster was recorded on form NN1(ii) which is found at the end of this appendix. These numbers are also shown on Figure 2.

(c) *Post-assessment calculations.* These are shown on form NN1(i) and give the estimated damage as 59 per cent ± 13 per cent. This is much higher than the expected damage level and will clearly affect the NDR calculations for the crop.

If we examine the plan of the stand with damage values at each centre we notice that the stand may be stratified into two regions as indicated in Figure 2. That part of the stand which is 'fairly close' to the adjoining LP70 stand has a much higher damage level than the rest. The centres in this high damage stratum are indicated on form NN1(ii) by an asterisk. There are 14 such centres and 8 centres in the other stratum of low damage. If the damage assessment calculations are carried out for the two strata from the available data, even though there are less than 20 centres in each, we obtain:

DAMAGE (high damage stratum) = 79% ± 7.6%

and

DAMAGE (low damage stratum) = 25% ± 13.7%

(d) *Conclusions.* We conclude that in the stratum having low intensity damage the damage coincides with what was expected and is not up to the critical 40 per cent level. However, it is clear that a large part of the compartment has suffered very great damage and various management options will have to be considered.

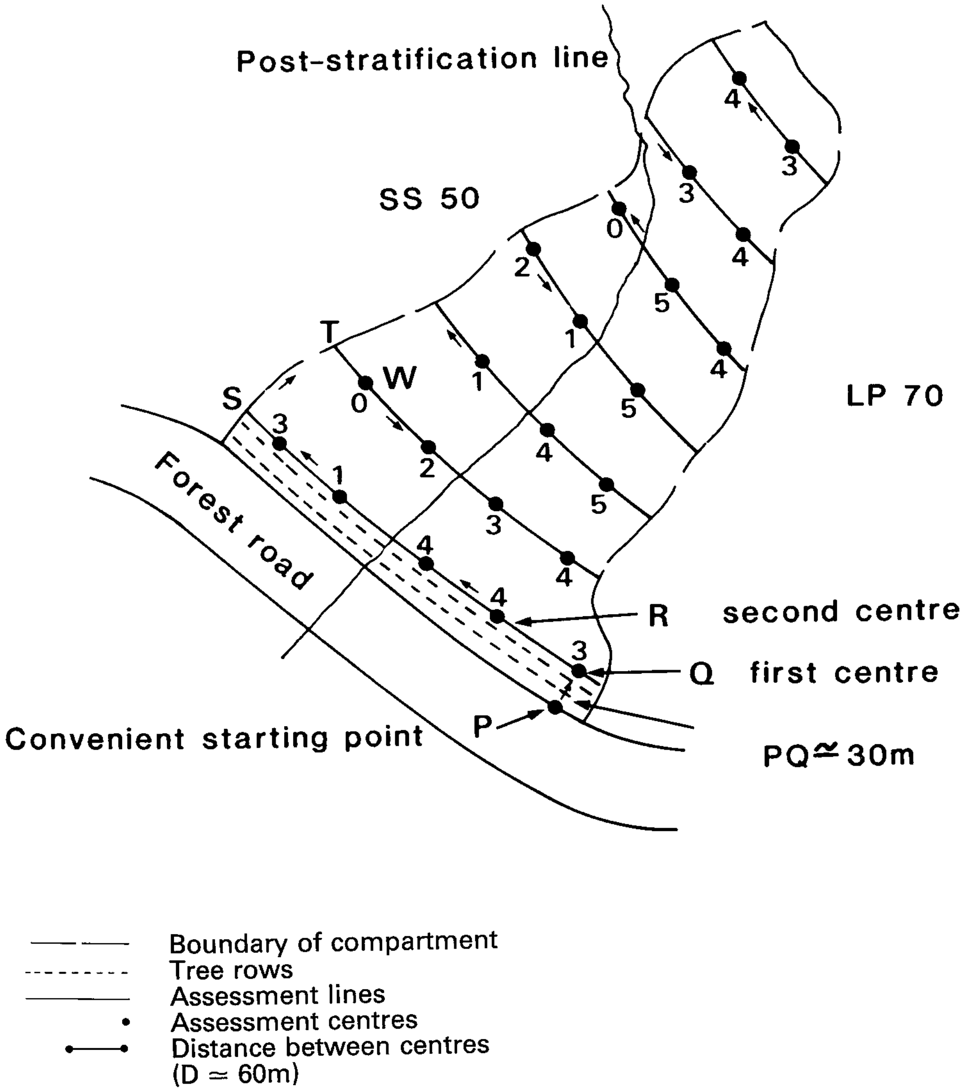

FIGURE 2 A plan of the compartment being assessed (SS 77) with assessment lines, centres and damages superimposed

FORM NN1(i)

Damage assessment (Fixed cluster size)

Crop details

Compartment	10
Species	SS
Planting year	1977
Area(A) ha	7.1
Stocking density	1880/ha
Damage type	Leader browsing in restocked Sitka spruce by Red deer.

Pre-assessment calculations

Accuracy aimed for, x = ± 10 per cent

Number of trees to be assessed,

$$N = \left(\frac{100}{x}\right)^2 = 100 \qquad \textit{(Formula 1)}$$

Number of trees in cluster, c = 5

Number of clusters to be assessed,

$$n = \frac{N}{c} = 20 \qquad \textit{(Formula 2)}$$

Distance between clusters,

$$D = \sqrt{\frac{A \times 10{,}000}{n}} = 60 \text{ m} \qquad \textit{(Formula 3)}$$

Post-assessment calculations

(i) Actual number of clusters assessed,
$n' = 22$

(ii) Total number of damaged trees assessed,
d = 58 + 7 = 65
(i.e. column (2) total + column (6) total)

(iii) Total number of trees assessed,
a = 22 × 5 = 110
(i.e. $n' \times c$)

(iv) Total of squares of numbers of damaged trees,
X = 218 + 25 = 243
(i.e. column (3) + column (7))

Damage = 59% ±13%
from

$$\frac{d}{a} \times 100 \text{ and } \pm \frac{200\sqrt{X - \left(\frac{d^2}{n'}\right)}}{a}$$

(Formula 4) *(Formula 6)*

FORM NN1(ii)

Data sheet: Damage data (fixed cluster size)

(1) Cluster number	(2) Number damaged	(3) [Number damaged]^2	(4) Stocking density count	(5) Cluster number	(6) Number damaged	(7) [Number damaged]^2	(8) Stocking density count
1*	3	9	18	21*	3	9	
2*	4	16	17	22*	4	16	
3*	4	16	12	23			
4	1	1	24	24			
5	3	9	17	25			
6	0	0	19	26			
7	2	4	16	27			
8*	3	9	18	28			
9*	4	16	21	29			
10*	5	25	23	30			
11*	4	16	17	31			
12	1	1	16	32			
13	2	4	21	33			
14	1	1	17	34			
15*	5	25	21	35			
16*	4	16	18	36			
17*	5	25	17	37			
18	0	0	16	38			
19*	3	9	23	39			
20*	4	16	25	40			
Totals	58	218	376	Totals	7	25	

APPENDIX II

NEAREST NEIGHBOUR METHOD : VARIABLE CLUSTER SIZE (FORM NN2)

It may be necessary in some circumstances (see Section 2.4) to vary the number of trees accessed from cluster to cluster. It is still important that the method of selection of the numbers of trees in these clusters should be objective and independent of the damage process. In particular, increasing the size of clusters in regions of high damage will over-estimate the amount of damage.

When we use the variable cluster size to assess damage we still calculate the number of trees to be assessed by using Formula 1. We should have some idea of the average cluster size, and this should be used in Formula 2 instead of the fixed cluster size. The distance between clusters is assessed exactly as in Section 2.6 (Formula 3) and the estimate of percentage damage calculated as in Section 2.8 (Formula 4). The actual accuracy of the assessment must be calculated using Formula 7 given below.

Estimated error =

$$\pm \frac{200\sqrt{X + \left(\frac{d}{a}\right)^2 . Y - 2\left(\frac{d}{a}\right) \cdot Z}}{a} \%$$

Formula 7

where the method of calculating X, Y and Z is indicated in form NN2(ii).

We now give an example based on the data shown in form NN2(ii).

FORM NN2(i)

Damage assessment (Variable cluster size)

Crop details

Compartment	27
Species	LP/SS
Planting year	1960
Area (A) ha	15
Stocking density	1880/ha (LP 495 + SS 1385)
Damage type	Bark stripping on Lodgepole pine by Red deer.

Pre-assessment calculations

Accuracy aimed for, x = ± 10%

Number of trees to be assessed,

$$N = \left(\frac{100}{x}\right)^2 = 100$$ *Formula 1*

Average number of trees in cluster, c = 4

Number of clusters to be assessed,

$$n = \frac{N}{c} = 25$$ *Formula 2*

Distance between clusters,

$$D = \sqrt{\frac{A \times 10{,}000}{n}} = 77\text{m}$$ *Formula 3*

Post-assessment calculations

(i) Actual number of clusters assessed, n′ = 26
(ii) Total number of damaged trees assessed, d = 55
(i.e. column 2 total, NN2(ii))
(iii) Total number of trees assessed, a = 89
(i.e. Column 4 total, NN2(ii))
(iv) X = 153 (Column 3 total, NN2(ii))
(v) Y = 341 (Column 5 total, NN2(ii))
(vi) Z = 218 (Column 6, NN2(ii))

Damage = 61.8% ± 8.3%

from $\frac{d}{a} \times 100$ *(Formula 4)*

and $\pm \dfrac{200\sqrt{X + \left(\frac{d}{a}\right)^2 . Y - 2\left(\frac{d}{a}\right) \cdot Z}}{a}$ %

(Formula 7)

FORM NN2(ii)
Data sheet: Damage data (variable cluster size)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	
Cluster number	Number damaged	$\left[\text{Number damaged}\right]^2$	Size of cluster	$\left[\text{Size of cluster}\right]^2$	Size of cluster × Number damaged	Stocking density count	
						Species	
						SS	LP
1	3	9	5	25	15	12	6
2	2	4	3	9	6	13	4
3	4	16	4	16	16	7	5
4	1	1	2	4	2	19	5
5	3	9	4	16	12	12	6
6	3	9	5	25	15	13	7
7	2	4	3	9	6	11	4
8	1	1	4	16	4	13	5
9	1	1	2	4	2	18	3
10	3	9	5	25	15	14	7
11	2	4	3	9	6	18	5
12	1	1	3	9	3	15	3
13	3	9	4	16	12	10	5
14	1	1	2	4	2	19	3
15	2	4	5	25	10	10	7
16	4	16	5	25	20	13	8
17	2	4	4	16	8	12	5
18	0	0	2	4	0	23	0
19	2	4	3	9	6	11	5
20	4	16	4	16	16	14	6
21	4	16	5	25	20		
22	1	1	2	4	2		
23	3	9	4	16	12		
24	2	4	2	4	4		
25	0	0	1	1	1		
26	1	1	3	9	3		
27							
28							
29							
30							
31							
32							
33							
34							
35							
36							
37							
38							
39							
40							
TOTALS	d = 55	X = 153	a = 89	Y = 341	Z = 218	277	99
						376	

APPENDIX III

MEASUREMENT OF STOCKING DENSITY IN CROPS WITH OBVIOUS ROWS

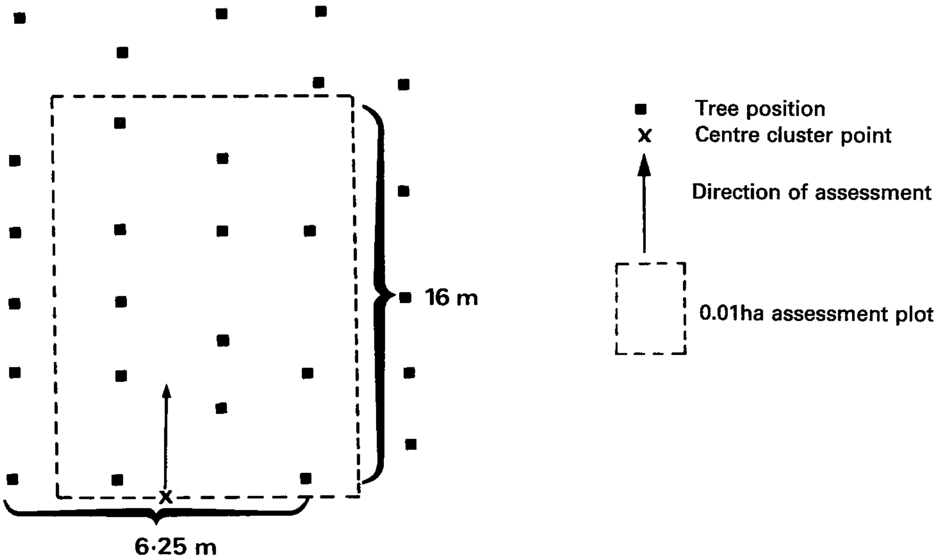

FIGURE 3

Distance between four rows of trees

$= 6.25$ m

$\therefore$ Length of plot to obtain 0.01 ha (100 m^2)

$$= \frac{100}{6.25}$$

$= 16$ m

If twenty stocking density plots sampled when total number of trees counted within these plots is 295, then stocking density

$$= \frac{\text{Total number of trees counted}}{\text{Total area of plots}}$$

$$= \frac{295}{20 \times 0.01}$$

$$= \frac{295}{0.2}$$

$= 1475$ trees/ha

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