Forestry Commission

Bulletin 108

Monitoring Vegetation Changes in Conservation Management of Forests

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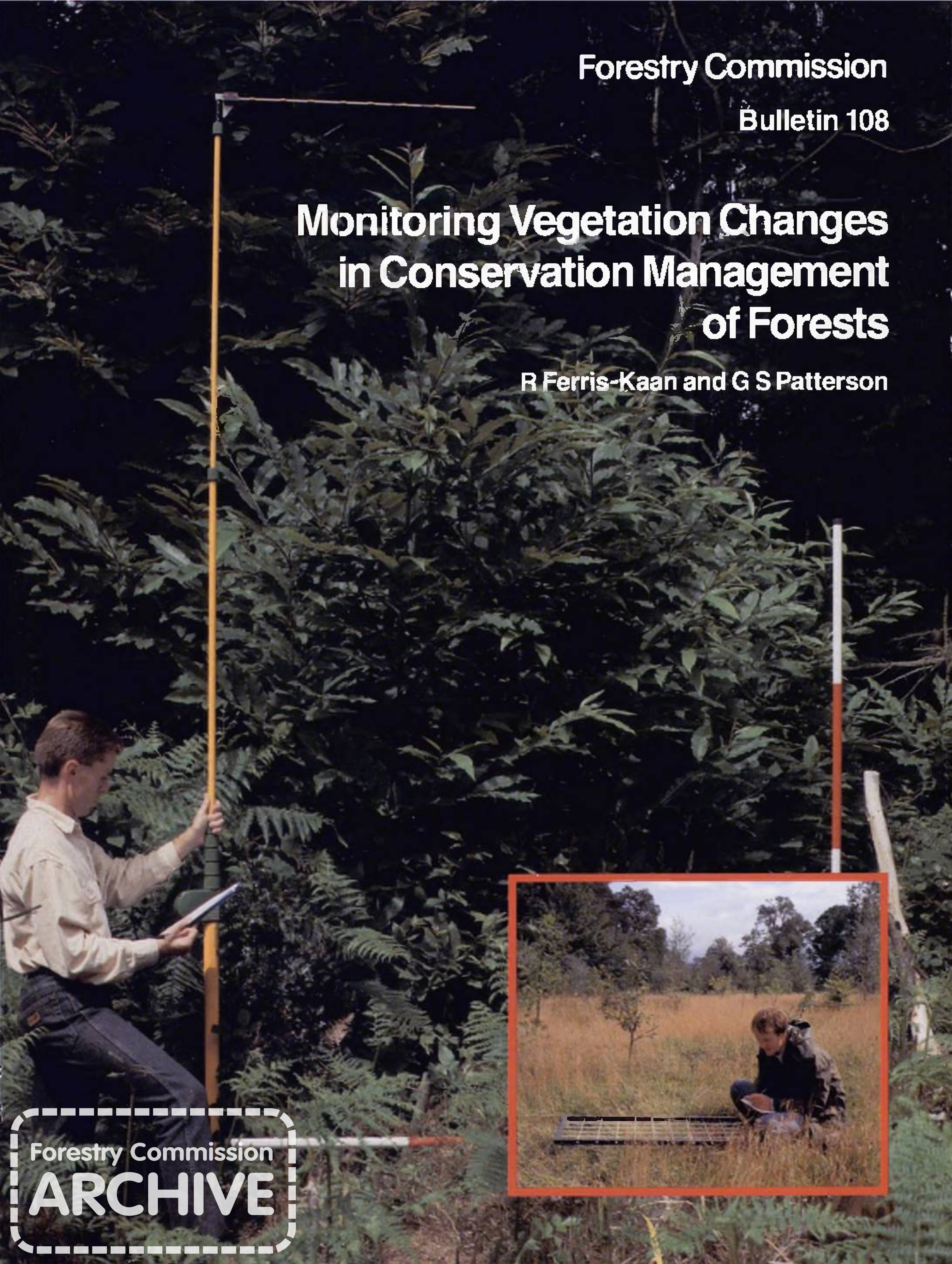

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Monitoring Vegetation Changes in Conservation Management of Forests

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Front cover: Measurement of vegetation structure and height using a vertical quadrat and measuring pole. *(40503)*
Inset: Assessing changes in plant species frequency and cover in a grassland area of a young farm woodland.

Contents

Monitoring Vegetation Changes in Conservation Management of Forests

Summary

Monitoring should be an integral part of conservation management in forests. It provides managers with information on the status and trend of species or habitats, and indicates whether specific goals have been achieved.

Vegetation assessments can be used to monitor habitat quality as well as plant and species composition. Plants can be more easily monitored than many animals.

This Bulletin provides advice on setting objectives and selecting appropriate parameters for measurement when monitoring vegetation. The need for sufficiently rigorous sampling is discussed, and measurement methods are outlined. Techniques for data interpretation are given and approaches to monitoring in different situations are described.

Analyse des Changements de Végétation dans la Gestion Forestière

Résumé

Le suivi devrait faire partie intégrant de la gestion de nos forêts. Il donne aux ingénieurs des eaux et forêts des renseignements sur l'état et l'évolution des espèces ou habitats, et permet de déterminer si des objectifs spécifiques ont été atteints.

Les analyses de végétation permettent de déterminer la qualité de l'habitat, ainsi que la composition des plantes et des espèces. Les plantes sont plus faciles à étudier que de nombreux animaux.

Ce Bulletin présente des conseils sur la fixation d'objectifs et la sélection de paramètres de mesure appropriés pour l'analyse de la végétation. Il évoque la nécessité d'un échantillonnage rigoureux suffisant, et présente dans leurs grandes lignes les méthodes de mesure. Il décrit également des techniques d'interprétation des données et des approches à adopter pour l'analyse de diverses situations.

Beobachtungen von Vegetationsänderungen innerhalb der Naturschutzverwaltung in Wäldern

Zusammenfassung

Beobachtung sollte ein wesentlicher Bestandteil der Naturschutzverwaltung in Wäldern sein. Sie liefert Verwaltern Informationen über den Zustand und die Entwicklung von Arten oder Lebensräumen, und sie zeigt an, ob spezifische Ziele erreicht wurden.

Vegetationsbewertung kann sowohl zur Beobachtung der Lebensraumqualität, als auch der Pflanzen und Artenzusammenstellung, benutzt werden. Pflanzen lassen sich leichter beobachten als viele Tiere.

Dieses Bulletin gibt Hinweise zur Zielsetzung und zur Wahl angebrachter Rahmen zur Messung der Beobachtungen von Vegetationsänderungen. Die Notwendigkeit von ausreichenden, rigorosen Stichproben wird diskutiert und Meßmethoden werden beschrieben. Es werden Techniken zur Datendarstellung angegeben und Verfahren zur Beobachtung in verschiedenen Situationen werden beschrieben.

Control de los Cambios de Vegetación en la Gestión para la Preservación de los Bosques

Resumen

La actividad de control debería ser una parte integral de la gestión para la preservación de los bosques. Proporciona a las personas responsables información sobre el estado y la orientación de especies y hábitats, e indica si se han logrado objetivos concretos.

La inspección de la vegetación puede servir para controlar la calidad del hábitat y la composición de plantas y especies. Las plantas son más fáciles de controlar que muchos animales.

Este Boletín ofrece asesoramiento para fijar objetivos y seleccionar parámetros adecuados de medición para el control de la vegetación. Se discute la necesidad de tomas de muestras suficientemente rigurosas y se perfilan métodos para la medición. Se dan técnicas para la interpretación de datos y se describen maneras de enfocar la cuestión del control en diferentes situaciones.

Chapter 1

Monitoring: an Introduction

Monitoring is a process of detecting whether change has occurred, establishing its direction and measuring its extent. This should be accompanied by an assessment of the significance of the changes detected (Hellawell, 1991).

Monitoring should be a part of normal management, providing information to managers to assist in decision-making. Conservation management is no exception to this rule. The 1985 Amendment to the Wildlife and Countryside Act 1981 (Anon., 1985) places a statutory duty on the Forestry Commissioners to seek to

> achieve a reasonable balance between the interests of forestry and the conservation and enhancement of the countryside and conservation of wildlife.

Since then conservation management has increased in importance throughout forests and woodlands. However, monitoring of the effects of managing forests for wildlife has lagged behind this increase in activity and expenditure.

Vegetation is often suitable for monitoring changes in wildlife conservation values, because it provides shelter and food for animals, it is relatively permanent and easy to record, and it reflects soil, climate and management practices (Goldsmith, 1991).

This Bulletin suggests strategies and describes methods for vegetation monitoring in forests. It is not intended as an exhaustive account of all available techniques. It attempts to make forest managers aware of the choices of approach which are available and to introduce methods which are easy to use in the field and sufficiently reliable to provide useful information. Readers requiring more detailed, specific information should refer to the References and Further reading.

An attempt is made to distinguish methods that can be employed by forest staff with basic botanical field skills from those which would normally require specialist ecological and data-handling skills, e.g. ecological consultants. If changes in abundance above or below a preset level or shifts in distribution into or out of a particular area are to be detected, it is unlikely that any complex statistical analyses are required. This being the case, such monitoring and interpretation can be undertaken by local rangers and foresters. Situations likely to require professional help include:

- those in which difficult-to-identify plant groups are the subject of monitoring (e.g. mosses, liverworts, lichens);
- those where fine scale or complex vegetation changes are to be monitored (e.g. where a number of environmental variables are known or anticipated to be driving changes in the vegetation);
- those where the monitoring programme covers a large area and is likely to require more time than is available to local staff.

For detailed monitoring requiring complex statistical analysis and interpretation, ecological consultants, university departments or government-funded research establishments may be appropriate. Areas of expertise and costs are likely to vary. It is important to realise that monitoring can be an expensive operation.

Managers need to set the objectives of the monitoring programme and assess available resources. If this planning stage is carried out thoroughly, then it becomes easier to target the resources effectively and to assign the work to the most suitable people.

Chapter 2

Planning a Monitoring Scheme

Setting objectives

It is vital to define objectives as precisely as possible at the beginning of any monitoring scheme. Collection of data with no well-defined purpose is liable to be expensive and yield inconclusive results.

The three main types of objective that are likely to arise in monitoring forest vegetation for wildlife conservation management purposes are:

1. To assess the outcome of management practices designed to maintain or enhance some aspect of conservation value. An example is the management of rides to provide plant and insect diversity.
2. To assess compliance with standards or targets which may be derived from legislation or from codes of practice. For example, the *Forests and Water Guidelines* (Forestry Commission, 1992) specify minimum distances of river bank which should be vegetated in order to minimise erosion and conserve riparian wildlife.
3. To detect changes in the vegetation of a site, which may be variable in extent and direction and may be due to various causes, both natural and man-made. Here the purpose is to detect early warnings of adverse changes in the value of the site to wildlife. This can be called surveillance monitoring, and is most appropriate to high value sites such as nature reserves.

Monitoring should not be used to determine the relative effects of various treatments and the causes of changes. Despite this, type 1 monitoring is often undertaken with this aim. A management treatment, e.g. mowing of ride verges, is undertaken and the observed changes in plant diversity are attributed to the treatment. This cannot be done without untreated control areas being built into the monitoring scheme. Control areas often yield useful information which helps to interpret the observed changes, especially when a number of examples can be compared. However, properly replicated experiments would be needed to determine the relative effects of treatments with confidence.

Monitoring should therefore be considered as a means of measuring the outcome of management rather than a way of comparing the effects of alternative treatments, which is research.

Wherever possible, monitoring should be concerned with measurements with respect to predetermined standards or targets which the manager has set as objectives. Setting such targets will help to define what should be measured and how measurements should be taken (Figure 2.1(a)). The targets, standards or signals of significant change are selected for the key features to be monitored *before* monitoring starts. Monitoring then assesses values in comparison with these 'yardsticks'.

Monitoring schemes with no clear objectives or targets often give inconclusive results. Excessive data may be collected, which increases expense and complexity, while in other situations inappropriate data may be collected (Figure 2.1(b)). For example, a manager may wish to manage his or her forest roadsides by felling edge trees and periodic coppicing or grass cutting with the objective of increasing the abundance and species richness of flowering plants, to act as a food supply to butterflies and moths.

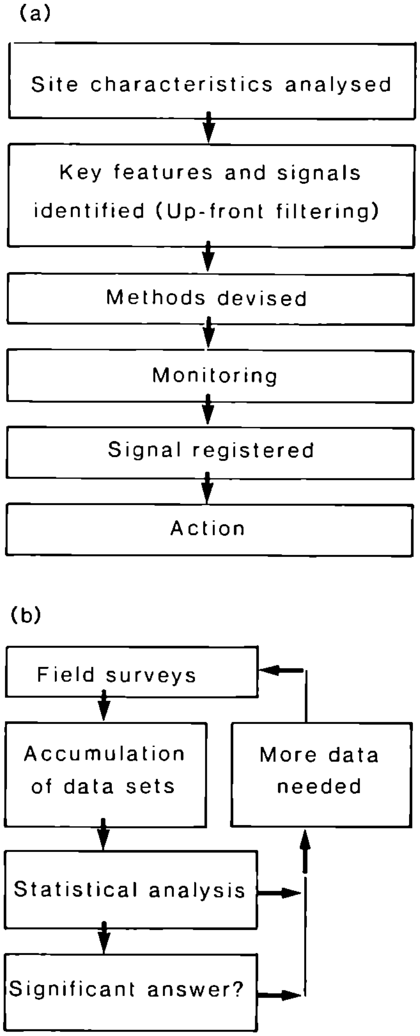

Figure 2.1 Monitoring strategies: (a) the ideal strategy, (b) the incorrect strategy (from Hellawell, 1991).

The objective should be precisely set at the beginning, e.g.

- to achieve a mean value of (for example) five flowering plant species per m^2 on road verges;
- to achieve a mean cover of at least 20% of flowering plant species on road verges.

The targets set should depend upon some prior knowledge of the site, perhaps derived from survey information, plus an appreciation of what is likely to result from the intended management and a definition of what is desirable. The targets can be changed in the light of experience if necessary. In this example, the manager has decided that species richness and cover of flowering plants are the important criteria, and this suggests the methods of monitoring which could be used.

What to monitor

Once objectives have been set for the management and monitoring of a site, the choice of what to monitor will become clearer. The manager may be concerned with a number of attributes of vegetation.

The abundance of selected species

There are likely to be some plant species which assume importance for their conservation value, e.g. rarities. Examples include one-flowered wintergreen, *Moneses uniflora*, a rare plant of Caledonian pinewoods; and the military orchid, *Orchis militaris*, now found only in Buckinghamshire and Suffolk.

Other species are indicators of site conditions, or the likely presence of other plants normally associated with them. For instance, on a mire system, increases in the mosses *Pleurozium schreberi* and *Hypnum cupressiforme* suggest drying out of the surface, while *Sphagnum* spp. indicate wetter conditions.

Many plant species are important as foodplants or hosts to animal species in which the manager is interested. For example, the purple emperor butterfly, *Apatura iris*, lays its eggs on the broad- and narrow-leaved sallows, *Salix caprea* and *S. cinerea*; and the orange-tip butterfly, *Anthocaris cardamines*, lays its eggs on lady's smock, *Cardamine pratensis* (Thomas, 1989). Broadleaved shrubs and trees along woodland edges support large numbers of invertebrates, which provide good foraging habitat for bats (Mayle, 1990) and birds (Fuller, 1991).

Abundance can be measured by absolute measures which do not depend on plot or quadrat size (e.g. cover, density or basal area) and non-absolute measures (mainly frequency) which do. Measures of performance of individual plants may also be used, especially for small populations of rare plants or for key indicator species (Hutchings, 1991).

Species composition

Conservation or expansion of plant communities are likely to be common management objectives, particularly for semi-natural habitats such as ancient semi-natural woods, lowland heaths and raised mires. In such cases, the species composition of the vegetation (i.e. the distribution and abundance of all the species present) is of interest, and the manager may be aiming to maintain the relative proportions of plant species that make up the community. The recent increased planting of 'native' woodlands provides an opportunity for an expansion of characteristic plant communities. The development of these ought to be monitored.

Where the objective of management is to maintain or develop a specified community composition, monitoring may be done by calculating an index of 'closeness of fit' to a specified community. The recent development of the *National Vegetation Classification (NVC)* has provided reference communities which enable this type of monitoring to be done (Rodwell, 1991). The closeness of fit can be calculated by computer software packages, given data from one or more sample quadrats for the presence and cover of each plant species (Malloch, 1990; Hill, 1989; Wallace *et al.*, 1992).

If the manager wishes to increase the variety of species present on a site, irrespective of their nature (e.g. whether or not they are rare or characteristic of the site), then he or she may use *species richness*, which is the number of species per unit area, or *species diversity*, which measures both the number of species and the spread of abundance between them by means of an index. Species richness only requires information on the presence of species, while species diversity requires a measure of abundance as well. Many diversity indices have been devised (Pielou, 1975). The most widely used index is the Shannon-Weaver Index (H^1):

$$H^1 = -\sum_{i=l}^{S} p_i \ln p_i$$

where H^1 = diversity, p_i = proportion of the ith species, ln = natural logarithm, and $\sum_{i=l}^{S}$ is the sum of the calculations made for all the S species present.

For example, if a sample quadrat contains 100% cover of three species, A, B and C, which have 45%, 35% and 20% cover, respectively, the diversity value (H^1) would be:

$$H^1 = (-0.45 \ln 0.45) + (-0.35 \ln 0.35) + (-0.20 \ln 0.20)$$

$$\text{So } H^1 = 0.36 + 0.37 + 0.32 = 1.05$$

If the same quadrat were more heavily dominated by species A, with 90% cover, while B and C had 5% cover each, the diversity would be less:

$$H^1 = (-0.90 \ln 0.90) + (-0.05 \ln 0.05) + (-0.05 \ln 0.05)$$

$$\text{So } H^1 = 0.09 + 0.15 + 0.15 = 0.39$$

Because of the inclusion of information on relative abundance, species diversity is generally a more useful measure than species richness, but it does require more information to be collected.

Vegetation structure

Managers are often interested in plants as a habitat for animal species and communities that they are hoping to conserve. Monitoring of vegetation can be a useful way of appraising the habitat quality for animals, because it is often cheaper and easier than assessing animal populations, especially communities.

For animals, and particularly vertebrates, the species of plants present is often of secondary importance to vegetation structure in determining habitat quality. For example, the species richness and abundance of songbirds have often been found to be related to the complexity of the *vertical structure* in woodland, so that woods with several overlapping layers (field, shrub, lower and upper canopy) have a richer bird population. For example, Moss (1978) and French *et al.* (1986) used the Shannon-Weaver formula described earlier to calculate *foliage height diversity (FHD)* indices, which correlated well with songbird diversity. However, some caution is necessary when interpreting bare FHD indices, as many different vegetation structures can generate the same FHD index (Petty and Avery, 1990). Additionally, many vegetation measures are intercorrelated and it might be that some other

Table 2.1 Attributes of vegetation structure which influence diversity of animals.

Type of structural feature	*What to measure*	*Notes*
Vertical layering (stand structure)	a. Number of layers b. Cover of each layer c. Calculate a FHD from a. and b.	Define layers according to objectives (see Figure 2.2)
Horizontal patchiness (habitat structure)	a. Number of patches per unit area b. Percentage area of each patch type c. Number of patches of each type d. Calculate mean patch size from b. and c. e. Calculate patch size diversity from b. and c.	Define minimum patch diameter and select relevant patch type
Quantity of edge	a. Edge: area ratio b. Length of edge (total for each type of patch interface)	

vegetation measure, correlated with FHD, could be the causal factor in any relationship with animal species diversity (Erdelen, 1984). Simple measures such as the number of vegetation layers present within a defined plot size can also be used to give an index of vertical complexity when used for monitoring (Table 2.1).

The *horizontal structure* or patchiness of vegetation is also important to animals. Deer, for example, are more abundant where patches of open pre-thicket forest used for feeding are interspersed with older stages used for shelter and cover. This has been used to predict future populations of deer at a forest scale, given information on age-class structure (Ratcliffe *et al.*, 1986).

Different scales of patchiness are important for different animals. For example, grassland invertebrates will relate to patchiness at a scale of individual tussocks, which can be greatly influenced by cutting or grazing. Birds such as black grouse, *Lyrurus tetrix*, will relate to larger patches of various vegetation types, e.g. flushed grassland which is rich in invertebrates for feeding young chicks, and ericaceous heath for adult food and nesting cover. At a still larger scale, large restocking coupes may be required to attract moorland wading birds and raptors such as the hen harrier, *Circus cyaneus*.

A manager who is considering monitoring vegetation as animal habitat should first define the target animal species or group and take advice to determine what attributes of vegetation structure are important to them. This will suggest what to monitor. As described in Chapter 1 it will be useful to set a target or minimum standard value in terms of those attributes, and then monitor achievement of that target.

It will be easier to identify the attributes required by individual species than whole groups of animals. However, because of the general importance of vertical layering and horizontal patchiness to animals, and given that a common management objective is likely to be to increase species diversity in the forest as a whole, some simple measures of vegetation structure are worth considering as a means of monitoring trends in animal habitat quality.

The choice of thresholds to define vegetation layers should depend upon the animals of interest. Different studies have used different numbers of layers and also different heights to form the boundaries of the layers. In many cases the divisions may have been selected according to subjective impressions about the layering of the vegetation (Petty and Avery, 1990). However, Figure 2.2 suggests layers which are likely to be important to most animal groups, and could therefore be useful to monitor general habitat quality.

Similarly, horizontal patches can be defined, indicating distribution of distinct structural types of vegetation. Figure 2.3 suggests how woodland could be divided on the basis of minimum height differences between adjacent stands (using layers as defined in Figure 2.2) in

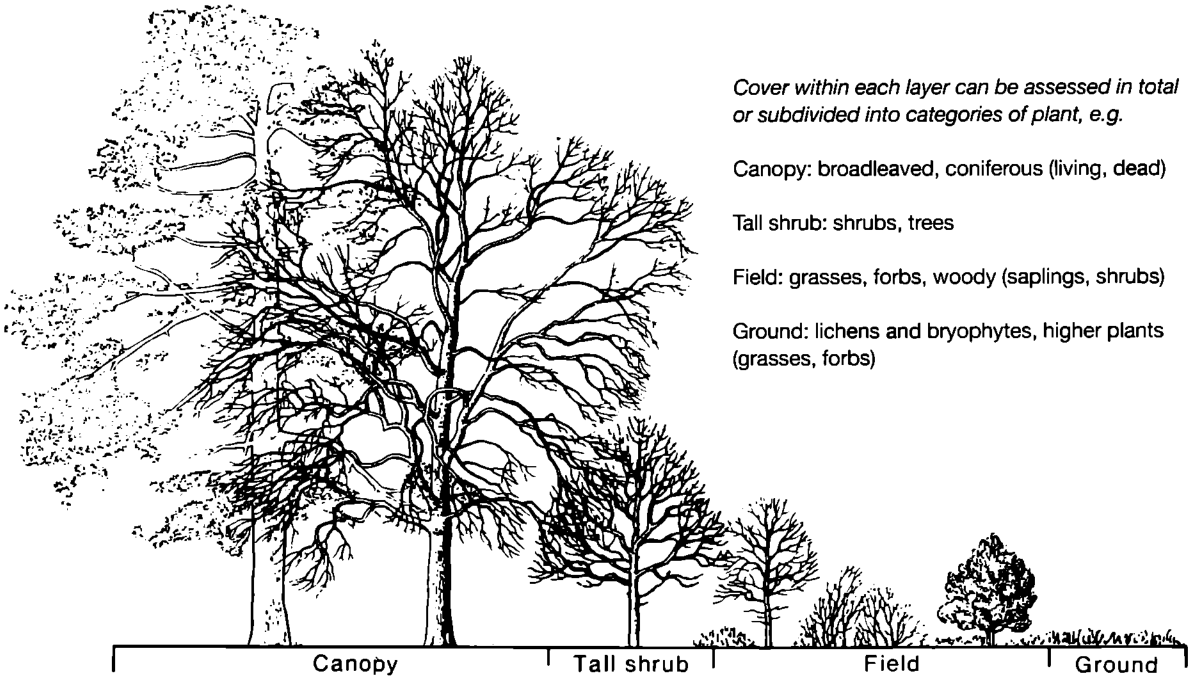

Figure 2.2 Layers for monitoring vegetation structure.

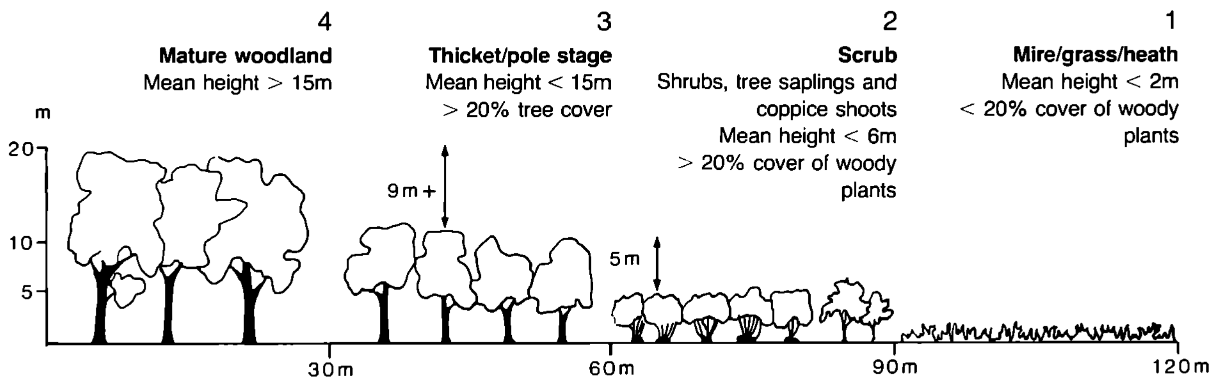

Figure 2.3 The division of woodland into patches, showing definitions and minimum mean height differences between layers and minimum patch diameters recognised. The minimum defined patch diameter in this example is 30 metres. (See text for explanation.)

order to define separate patches. These patches may be mapped as shown in Figure 2.4.

In order to be defined as a patch, a certain minimum diameter needs to be set. This may vary, and depends upon the objective of the monitoring programme. For example, habitat patches may be perceived on a much smaller scale by relatively immobile animal species, such as certain invertebrates, than those utilised by species with larger home ranges, such as some bird species. At this larger scale, coarse-grained variation between habitat types may define patches, thus incorporating non-woodland areas. In this case, other patch types could be defined, according to habitat categories, for example:

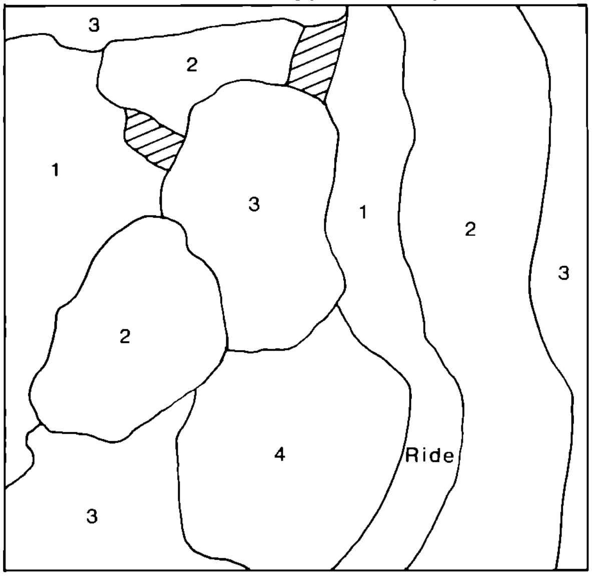

Figure 2.4 A hypothetical distribution of woodland patches, shown in map form. Hatched area: not recognised (below minimum diameter and size threshold); 1: grass-dominated (<20% tree/shrub cover); 2: scrub (20% tree/shrub cover); 3: thicket/pole stage woodland; 4: mature woodland.

- Grassland (acid, neutral, base-rich)
- Heathland
- Bogs or mires
- Linear features (above a specified minimum width): roads, rides, streamsides
- Water bodies

For diversity of a wide range of vertebrate animals, and also plants and invertebrates, a minimum patch diameter of 30 m (i.e. just over one mature tree height) is probably a good general threshold to choose because, for example, gaps in a tree canopy of this size will contrast more strongly with adjacent stands of trees than smaller gaps in terms of physical conditions. Similarly, a patch of heather or flushed meadow vegetation at this scale has more chance of developing a wide range of associated plants and animals than do very small fragments.

This approach to monitoring could be used where managers have defined targets in terms of structure. Examples of such targets might be:

- To achieve at least three vegetation layers over a minimum of 30% of the site, with the tall shrub layer occupying between 20% and 50% cover (see Figure 2.5). This could be appropriate to increase songbird diversity and abundance, for example.
- To increase the number of patches in a forest block by 20% over the next 20 years. This could help to produce a varied mosaic of habitat patches of different-aged growth, thus increasing the amount of edge habitat available.

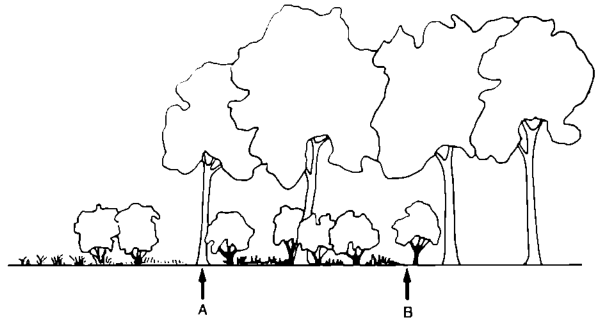

Figure 2.5 Achieving a target in terms of vegetation structure in woodland: the objective of developing three structural layers over 30% of the site is met between points A and B, with the shrub layer occupying 20-30% of the site.

Alternatively, monitoring of this sort could only seek to assess the direction and scale of changes in structure as an indication of habitat trend.

Summary of Chapter 2

1. The initial planning of a monitoring scheme requires:
   (a) A precise statement of the management objectives relevant to conservation. As far as possible, these should be expressed in terms of specific attributes and stated targets or standards which should be met.
   (b) Selection of appropriate vegetation attributes to be monitored to assess achievement of the objectives.
2. Although monitoring of treated and control areas will often yield useful insights into the

effects of management, monitoring cannot determine the reasons for observed changes.

3. The main attributes of vegetation which will be useful in monitoring are:

(a) Abundance, distribution and performance of individual species, selected for various reasons, e.g. indicators of ecological status, rarity, etc.

(b) Plant community features:

- species richness
- diversity
- community composition.

These parameters are derived from information on distribution and/or abundance of individual species.

(c) Vegetation structure:

- vertical layering (stand structure)
- horizontal patchiness (woodland structure).

These features are important to animals and may often be useful as a measure of habitat quality which is simpler and less costly to monitor than animal populations themselves.

Chapter 3

Sampling

When the methods of sampling are being decided, it is important to consider the precision of measurement which is required as well as the precision of the sampling scheme.

The precision of measurement should be related to the degree of change which one wishes to detect. For example, if a rare species is being monitored, a change of its percentage frequency value from 20% to 15% might be regarded as a significant decline, while the same change for a common species might not be important. Similarly, when indicator species are being monitored, small changes may have considerable significance in signalling ecological changes. In these cases, a very precise form of measurement is required.

In other cases it may be acceptable to detect large-scale changes only, and so measurements need not be so precise. For example, if a manager set out an objective of management as the maintenance of the cover of heather, *Calluna vulgaris*, in an unplanted glade at between 25 and 75%, then the Domin Scale of cover-abundance could be used (Table 4.1), with values in the range 6-8 indicating that the objective is met.

Seldom will it be practicable to monitor changes over an entire site, unless the population under consideration is small both in number and area. Therefore, it is necessary to take a sample of the population concerned. Approaches to sampling are all based on common sense, and can be easily devised by prior knowledge and careful thought about the subject to be monitored. Only a basic knowledge of statistical methods is required. The number of samples and their size are interconnected, and it is not possible to make a general rule to suit all situations.

If a sample of the population is being taken, the mean value of the sample is an estimate of the true population mean, and a measure of its reliability is therefore required.

The reliability of the sample mean (m) as an estimate of the true mean (μ) increases as sample size (n) increases. However, increasing sample size clearly increases the cost and length of the monitoring process, and so it is desirable to reach a compromise between reliability and cost. Once the acceptable level of reliability of the sample mean value is decided by the manager, the number of samples that are required can be calculated, provided that an estimate of the variability of the population is available. Such an estimate can be obtained from a preliminary sample.

If the desired reliability or *confidence limit* is set so that there is a 95% probability that the true mean value will be within a range ± 5% of the sample mean value, then the required sample size can be shown to be:

$$n = 1600\,(s/m)^2$$

where s = the standard deviation (a measure of variability) of the sample values, and m = the sample mean. Appendix 1 gives a worked example of appropriate sample size, using this formula. In order to calculate the required sample size in this way, it is clearly important to have reasonably accurate advance estimates of the mean (m) and standard deviation (s).

Table 3.1 shows how increasing the sample size of a population with a fixed level of variability reduces the confidence limits. It needs to be recognised that although greater precision can be obtained by taking very large samples, the benefits tail off and the cost of taking and

Table 3.1 The 95% confidence limits for samples of varying size, assuming a standard deviation of one (s = 1) and a Student's *t* distribution (from Usher, 1991).

Sample size	95% confidence limits	Percentage decrease
2	± 8.984	
4	± 1.591	82
8	± 0.836	47
16	± 0.533	36
32	± 0.361	32
64	± 0.250	31
128	± 0.175	30

analysing the samples increases. There are very great benefits to taking more than eight samples, but much beyond $n = 16$ the benefits will depend upon the degree of variability.

If very slight differences are suspected to be of ecological significance (e.g. the decline or expansion in range of a sensitive 'indicator' plant species), then a large sample may be unavoidable. However, careful choice of the species or other attributes to be monitored should minimise this potential problem, e.g. by choosing indicator species which are quite common and yet are responsive to ecological change.

Sampling methods can be broadly divided into two categories: those which use plots, usually termed quadrats, and plotless methods such as the nearest neighbour method, used in the assessment of wildlife damage in forests (Melville *et al.*, 1983). Whichever method is adopted, there are a number of ways in which sampling can be undertaken. An outline is given below, and readers may wish to refer to a fuller account given in the *Forest Mensuration Handbook* (Hamilton, 1975).

A number of approaches can be taken to selecting the position of sample plots or points.

Subjective sampling

As the name suggests, subjective sampling simply involves locating sampling units according to the recorder's subjective assessment of the area to be monitored. It may be useful where only a single site or a small area is being monitored, and the chance of selecting a representative portion is high. Results cannot be applied with certainty to a larger area. Poor repeatability through time or with different surveyors is a drawback, unless permanent quadrats are used, which in any case have certain disadvantages (see p. 11).

Generally, subjective sampling is not advisable and other methods should be used wherever practical.

Random sampling

With random sampling, every point in the study area has an equal probability of being sampled, and so the data are not biased and can be subjected to a wide range of statistical tests.

Randomness can be achieved by using a grid over a map of the site, and then selecting grid coordinates from a table of random numbers. Random sampling is best suited to relatively uniform areas which are easily accessible. However, it is sometimes not easy to achieve a truly random distribution, and plot relocation can be difficult, especially in woods. There is also one theoretical problem with the random allocation of quadrats: sources of variation affecting the abundance and distribution of the plant species or community may be known beforehand,and these are ignored by the random allocation (Usher, 1991).

Systematic sampling

The sample points are based on a grid or on transect lines, which prevents all the sample positions from being clumped. It is more efficient than random sampling for detecting species and for use in areas of heterogeneous vegetation, and is very useful in mapping and monitoring work. Plots are more easily located and relocated in woodland when using this method. However, there is a risk of bias if used on sites with regularly spaced features, such as tree rows, drains or plough furrows.

Whereas results for random sampling are independent of the nature of the population, the properties of estimates based on systematic sampling depend heavily on whether the population is effectively randomly ordered, or shows linear or cyclic trends, etc.

If the population is in random order, the same tests and formulae for sampling variances are available as for simple random sampling. This is a reasonable assumption in most cases, but does not always apply. For further information see Cochran (1977).

Combinations of random and systematic methods

Two methods include elements of the advantages of both the above systems without their main disadvantages.

1. *Restricted random sampling*. This can be used where the habitat appears to be heterogeneous and yet no clear strata exist. In this case, the site is divided into a convenient number of equal sized areas, within which random samples are taken. It ensures good coverage of the area.
2. *Stratified sampling*. Stratification can be applied to areas where it is possible to recognise different strata (zones) based upon topography, soil type, broad vegetation communities, etc. It may produce a gain in precision in the estimates of characteristics of the whole population. Stratified sampling is generally recommended for monitoring work, because it reduces sample variability, the result of which is that a precise estimate of any stratum mean can be obtained from a small sample in that stratum (Cochran, 1977). This makes sampling more convenient from an administrative point of view, greatly simplifying a heterogeneous population into internally homogeneous subpopulations.

The quadrat locations within each stratum may be selected by random allocation of grid coordinates (*stratified random*) or by a systematic approach (*stratified systematic*). The number of samples per stratum is related to its area or the apparent variability within the strata. High variability will tend to require greater sample size (see p. 10). Stratified systematic sampling is suitable if separate estimates are wanted for each stratum, or if unequal sampling fractions are to be used. The cost of sampling may also be reduced by allowing effort to be concentrated on the strata which are of most interest.

Permanent or temporary plots?

Permanent plots are often used in order to eliminate sampling errors due to spatial differences, and allow comparisons between two or more sampling periods in a monitoring scheme.

However, the comparison of data for the same plot through time is subject to some problems. Change occurring between sampling episodes is likely to influence what happens when a third sampling is undertaken (i.e. the change between the second and third sampling episodes is not completely independent of the change between the first and second in an individual plot). This phenomenon is known as *auto-correlation*. It is possible to plan a monitoring scheme so that such auto-correlation is avoided (Greig-Smith, 1983). Plots should be randomly selected and recorded on date one. They are recorded for a second time on date two, and that is the last time that this particular selection of plots is used. In the second sampling period a new set of an equal number of random plots is selected. On date three, the second set of plots is re-recorded and a third set of plots is recorded for the first time, and so on (Usher, 1991). By this means, all sets of plots are recorded twice only, avoiding dependence of a current observation on a previous one. The disadvantage of such a scheme is that, except on the first and last sampling dates, the monitoring intensity is doubled. However, the data are likely to be more reliable, and so these considerations need to be weighed up against each other.

Permanent plots are probably best confined to situations where replacement plots are impractical (e.g. exclosure plots designed to detect the effect of removing grazing animals over a long period), or where statistical analysis is not intended and interpretation will rely on ecological judgement and perhaps the small size or uniformity of the sample site.

If permanent plots are being used, they must be precisely and readily located, using some form of permanent marker pegs, e.g. steel rods driven into the ground, to indicate the corner points of plots. The location of sampling points should always be recorded on a scale map of the site, using grid references wherever possible.

Quadrat size

Plot-based methods of sampling use *quadrats*, which can be square, rectangular or circular in shape, depending on convenience. The appropriate quadrat size depends largely upon the vegetation type and the measurement method to be used. For monitoring trees and shrubs, it is necessary to ensure that a reasonable number of individuals are sampled. With the development of the *National Vegetation Classification (NVC)*, much woodland recording has used a large quadrat size, i.e. 50 × 50 m. Field layer vegetation may be recorded within a 10 × 10 m quadrat. However, this is not suitably precise for monitoring ground layer, for which a quadrat size of 2 × 2 m may often be sufficient. In some situations, a small unit is desirable and a 1 × 1 m quadrat, subdivided into 25 units, may be ideal for continuous grassy swards.

It is difficult to determine the optimum quadrat size for a range of habitats, and usually only one size is practical, necessitating some compromise (Goldsmith, 1991). The quadrat should be small enough to be assessed easily. Smaller sized quadrats require less time per quadrat, permitting more quadrats to be used and so increasing the accuracy of the estimates. Quadrats should be large enough for most of them to include one or more of the largest individuals or patches. Once a monitoring project is under way, the quadrat size must not be changed.

Where it is important to record a high proportion of the species present, a simple procedure for identifying an appropriate quadrat size involves recording the number of plant species present in quadrats of increasing size, up to a point where the number of species levels off (Kershaw and Looney, 1985). Any further increase in quadrat size beyond this point is likely to involve considerable recording effort, with little return in terms of information.

Where frequency of presence of species is the method of measurement, the quadrat size will influence the results obtained (the larger the quadrat, the more often a given species will be recorded). This is described in more detail in Chapter 4.

Summary of Chapter 3

1. Sampling of a fraction of the monitoring site will usually be necessary because of limited resources.
2. The number of samples required can be determined given prior knowledge of the variability of the attribute to be sampled and given a desired level of precision of the results. Preliminary sampling is the ideal method of assessing variability.
3. In most monitoring schemes the target level of precision should be that the true mean lies within 5% of the sample mean with 95% probability (or confidence limits). This will often require the minimum number of samples to be between 10 and 20.
4. A number of methods exist for selecting sampling positions. Stratified sampling is recommended for monitoring work. Systematic sampling points or plots have the advantage over random locations in that they are easier to relocate. Achieving a truly random distribution of plots may not be easy. Unless there are marked strata within the site, systematic sampling is sufficiently precise in terms of providing unbiased estimates of population parameters.
5. Careful thought is required before permanent plots are used because of statistical and practical considerations, but they are suitable in some circumstances.
6. The appropriate quadrat size depends upon the vegetation type and the attribute to be sampled. Preliminary sampling will help to determine the ideal size.

Chapter 4
Measurement Methods

Species abundance

Abundance can be measured in many ways using non-absolute and absolute parameters. The most widely used non-absolute measure is frequency which is in widespread use in both description and monitoring of vegetation. Absolute measures include cover, density, biomass and basal area.

Frequency

The presence or absence of a plant species or distinct structural type (e.g. vegetation within a defined height range, such as dwarf shrub communities) is assessed by sampling in quadrats or at points (see p. 15). By recording the proportion or percentage of quadrats occupied, a value of frequency can be obtained. At a very simple level, if species X is present in 5 quadrats out of a total sample of 20, then it has a percentage frequency of $5/20 \times 100 = 25\%$. Changes in frequency can be used for monitoring. Recording only plants with rooted shoots within the sampling unit (*rooted frequency*) is normally preferable to recording all occasions when any part of the plant falls within the quadrat (*shooted frequency*), because it is easier to decide whether plants are truly within the quadrat.

Because the value of frequency depends on quadrat size (Figure 4.1), it is important to state the size of quadrat used in any estimate of percentage frequency (Kershaw and Looney, 1985; Goldsmith, 1991). It follows that if data are to be compared from different sample plots, it is essential to use the same quadrat size on each sampling occasion. The size of the sampling unit should be chosen to ensure that the species of interest lie initially within the range of 20–70% frequency, as far as possible (Goldsmith, 1991).

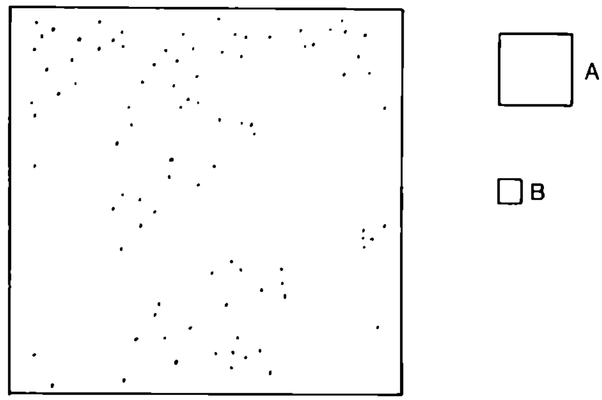

Figure 4.1 The dependence of percentage frequency on quadrat size. The two sizes of quadrat (A and B) will give widely differing percentage frequency values from the same diagrammatic community (from Kershaw and Looney, 1985).

Frequency is well suited for monitoring work because it is simple, allowing a large number of quadrats to be recorded in a short period, and because it is less prone to observer error or bias than are visual estimates of abundance based on cover (see p. 15). However, frequency estimates are essentially assessing distribution rather than amount of a species, so that supplementary field notes may be valuable.

Other methods: cover, density, biomass and basal area

Cover is defined as the area of ground occupied by the vertical projection of plant material growing above it onto a horizontal plane. Cover is the commonest parameter used.

Density is the number of individuals per unit area. It is widely used for animals, which are usually discrete units and are therefore easily counted. It has uses in monitoring plant species with units that are easily defined, e.g. individual plants or tillers of a rhizomatous grass, bulbs, orchids, annuals and trees. Because plants often spread vegetatively density can be a difficult measure to use.

Biomass is the quantity or weight of living plant material in a unit area. Biomass is time consuming to estimate directly and, although accurate, is destructive and therefore not repeatable (Goldsmith, 1991). If relationships with more readily measured variables are known, biomass may be estimated indirectly. An example is the relationship between tree biomass and diameter at breast height, dbh (see Tritton and Hornbeck, 1982), and between stem and/or crown diameter and biomass for shrubs.

Basal area is defined as the area outline of a plant near or at ground level. It is appropriate to trees or plants with a tussocky growth form. Basal area measurements have practical application on permanent plots where vegetation changes are to be monitored for several years.

Cover

Cover can be measured in several ways. The main approaches are:

- visual estimates within quadrats;
- point quadrats, using narrow-diameter pins or vertically arranged pairs of cross-wires for sighting (Figure 4.2);
- line intercept methods;
- plotless methods, where the distance from a series of predetermined points (e.g. on a transect) to the nearest plant of the species concerned is used, together with a measurement of its diameter;
- photographic methods.

The most suitable methods for monitoring depend on the vegetation type and the level of precision required. Generally, visual estimates of cover are not recommended, unless the required precision is low (e.g. when large changes in cover are expected, and the detection of smaller changes is not important).

Visual estimates

Estimates of cover are often placed in ranges of value. The *Domin Scale* and *Braun-Blanquet Scale* of cover (Table 4.1) are very commonly used for vegetation survey, where they are sufficiently precise to characterise communities, but should not be used for monitoring without careful thought about the precision required. In addition, because of the unequal class widths in such scales, it is difficult to use the data in subsequent statistical analyses.

The Domin Scale is useful for description in forest communities, where differences in abundance among rarer species are often quite noticeable. The Braun-Blanquet scale may be easier to work with since the recognition of a

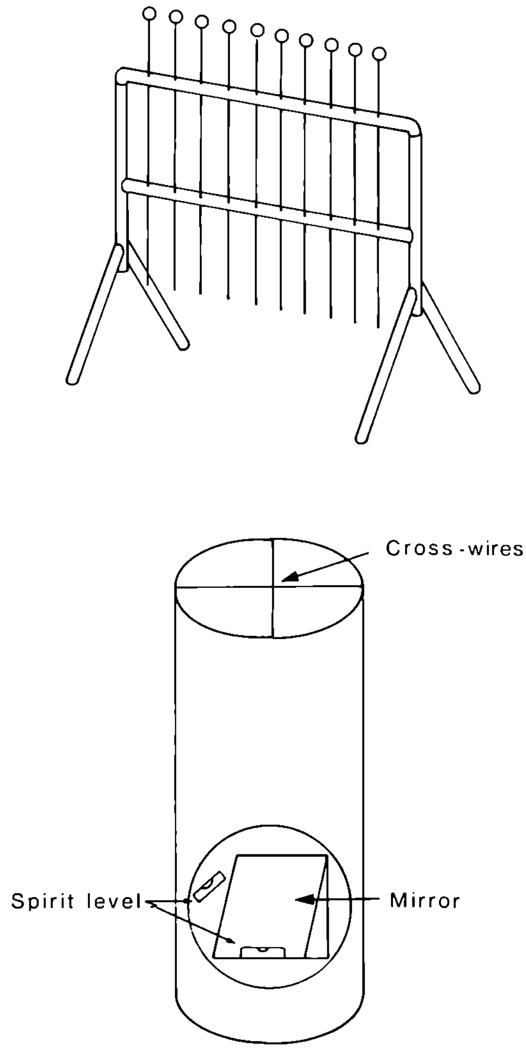

Figure 4.2 Point quadrats using pins and cross-wire sighting devices for estimating cover.

Table 4.1 Cover-abundance scales commonly used in estimating species abundance during vegetation survey and classification projects.

Subjective assessment	*Domin scale*	*Braun-Blanquet scale*
Cover 100%	10	5
Cover above 75%	9	
Cover 50–75%	8	4
Cover 33–50%	7	
Cover 25–33%	6	3
Abundant, cover about 20%	5	2
Abundant, cover about 5%	4	
Scattered, cover small	3	
Very scattered, cover small	2	1
Scarce, cover small	1	

smaller number of cover classes requires less familiarity with the vegetation. The use of such scales for monitoring will only allow the detection of substantial changes, and any attempt to increase their precision by increased sampling intensity would be constrained by the sampling error associated with visual estimates.

Studies have shown that using the same observer for successive samplings will reduce the amount of error. However, despite this, change of less than around 20 percentage points cannot be expected to be distinguished from differences due to error (Sykes *et al.*, 1983). In a series of woodland surveys using subjective visual methods, Kirby *et al.* (1986) demonstrated differences in the frequency with which particular species were recorded both between observers and between seasons.

The Domin scale has, however, some value in monitoring changes in community composition. The computer software package MATCH (Malloch, 1990) uses the maximum Domin score for each species, from a number of samples, to compare with the NVC community composition.

When the whole community is being assessed in this way, errors in individual species cover estimates do not matter so much, assuming that no overall bias towards under- or overestimating cover develops between successive samplings.

Point quadrats

Point quadrats are more objective and precise, although slower than visual estimates. However, they are difficult to use in tall field layer vegetation or windy conditions. Single points, or an array of ten pins, placed along a transect, are efficient methods for use in short vegetation. Pins are lowered one at a time, and the species touched by each pin in turn recorded. The final number of 'hits' from a number of sample 'frames' is then expressed as a percentage of the total number of pins (Figure 4.2). It should be noted that the total percentage cover for all species in an area will nearly always exceed 100%, due to layering of the vegetation (i.e. leaf overlap), and so this method gives an impression of the vegetation structure. It is known as *cover repetition*.

Line intercept methods

Line intercept methods are more suitable for compact, sizeable and distinct growth forms such as tussock grasses, heather, shrubs and trees, rather than single shoots or complex mixtures of species as in a grass sward. If plant groups are being monitored (e.g. grasses), they become easier to use.

The principle used is that cover is proportional to the length of the sample line (effectively a linear quadrat composed of a tape) which is intercepted by a vertical projection of the plant (Figure 4.3).

Line intercept methods are objective and quite precise in suitable conditions. Accuracy depends upon the precision of the vertical projection of tall canopies. A number of periscope sighting devices have been developed for this purpose, as described more fully by Bonham (1989). Small canopy gaps below a defined threshold diameter (e.g. 15 cm) are usually ignored for trees and shrubs, and counted as part of the canopy.

Plotless methods

Plotless methods have the advantage that no laying out of quadrats is required, and they can be efficient for easily seen plants in a limited number of categories or where few species are present. They are therefore useful for monitor-

The length of tape intercepted by the plant to be sampled is recorded to give an estimate of cover. In this example the sections A–B and C–D are recorded as intercepted by the crown of the shrub, but B–C is not, because it counts as a gap which exceeds a preset threshold value (a smaller gap between A and B is ignored as it is below the threshold).

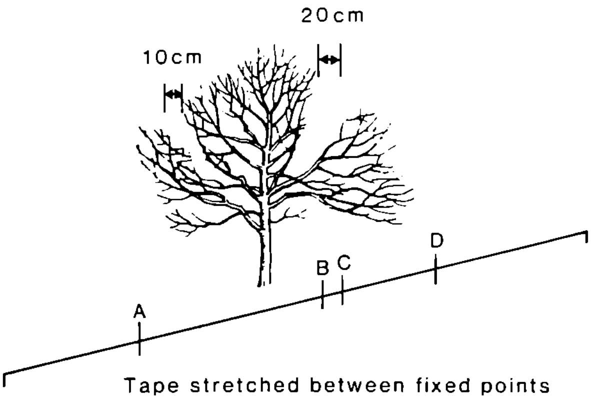

Figure 4.3 Use of line intercept sampling to estimate cover.

ing shrubs and trees in fairly open conditions. For example, Bonham (1989) describes various plotless methods, including the *point-centred quarter method (PCQ)*. In this particular example, density, basal area or canopy cover of trees and shrubs may be estimated. Four quarters are established at each sampling point (Figure 4.4). A cross of two lines, one in the direction of the compass and the other perpendicular to the compass line, passing through the sample point, is established. Distance to the midpoint of the nearest tree from the sample point and its diameter at breast height (dbh) is measured in each quarter. The mean area occupied by a plant is determined by averaging the four distances of a number of observation points. A density estimate can be obtained from the equation:

$$\text{Density} = \frac{1}{d^2}$$

where density is determined by squaring the reciprocal of the average mean distance, d, per point. The density estimate is multiplied by the average basal area to give the basal area per unit area. A minimum of 20 points is recommended for an adequate sample (Bonham, 1989).

The method does have some limitations in its application to the measurement of cover for trees and shrubs. If small shrubs and trees are obscured by larger plants, counting may be difficult. It is generally not recommended in situations where field layer vegetation cover exceeds

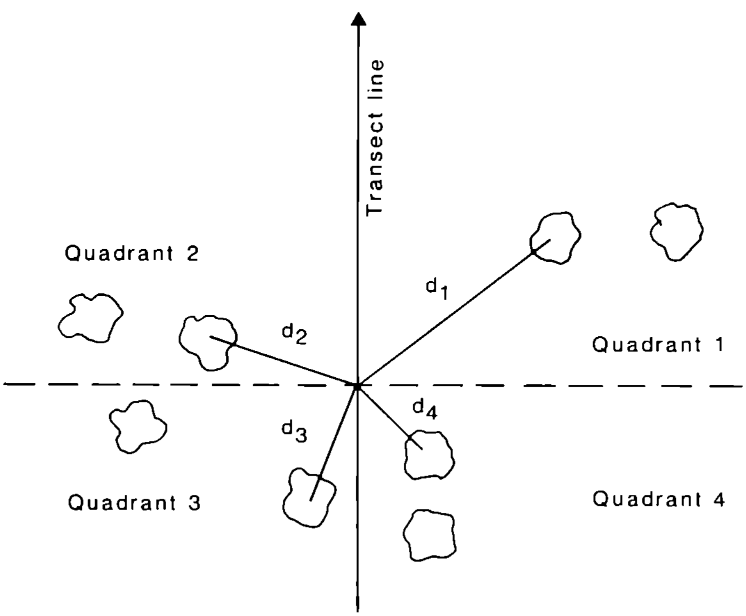

Figure 4.4 The point-centred quarter method for measuring the distance *d* of plants in four quadrants from a point, from which cover can be calculated (after Bonham, 1989). (See text for explanation.)

about 35% (Bonham, 1989). Some errors also result from plants with irregular outlines or canopies. Locations of PCQ random points in steep terrain with a mosaic of communities is difficult, and density is usually underestimated because distances are overestimated. This happens when the measurement tape is not perfectly aligned and extended.

However, the PCQ method is generally favoured over other plotless methods, and has been used extensively in a number of vegetation types. The method can be used to measure cover of shrubs as well as trees. In the case of shrubs, instead of measuring dbh, two measurements of crown diameter are recorded at right angles from each other. Average foliar cover multiplied by density of shrubs gives total cover.

Photographic methods

Photographic monitoring is a relatively rapid method, but frequently requires more time than is realised. For photographs to be of real use in monitoring vegetation change, they need to be taken from fixed points, and these need to be permanently marked. Time is also required for the analysis of the photographs, so that changes in community boundaries or the distribution of a dominant species can be described in some sort of quantifiable way (MacDonald and Armstrong, 1989).

Photographic monitoring is able to show only gross changes in cover of particular, distinctive, dominant species (e.g. heather, *Calluna vulgaris*, or bracken, *Pteridium aquilinum*), and it can only reveal these some time after they have occurred. One of its limitations lies in the resolution of complex, layered vegetation.

All photographs should include some form of labelling, with a unique code for site and sample. A record should be made of the date and time at which the photograph is taken, and databack devices are particularly useful in this respect. A scale is extremely useful for height comparisons on fixed-point photographs, e.g. a ranging pole (Rowell, 1988). A rigid ruler or steel tape may be used to provide a horizontal scale if required.

There are a number of advantages to photographic monitoring, in addition to it being relatively fast. The basic data set requires no selectivity or subjective assessments in the field (MacDonald and Armstrong, 1989). Where monitoring is long term and a change of recorder is likely, this has the advantage of reducing variability in results. Although it is possible for variability to arise at the analysis stage, it is always possible to return to the previous photographs and check for consistent interpretation. The analysis of photographs can be made easier by the use of grid overlays, from which cover can be assessed. The possibility of digitizing the image allows for even more accurate assessment. Furthermore, if the photographs provide detailed coverage, then they may prove useful in recording changes whose importance was not foreseen at the start of the monitoring.

The methods described all have their limitations and no single method of measuring cover can be recommended for all situations. In general, there is a trade-off between speed and cost of sampling and the objectivity and precision of the likely results (Table 4.2).

Methods of measuring vegetation structure

Vertical structure can best be measured by field assessments of cover. In dense woodland, taller vegetation can be difficult to assess. It is best done using vertical point quadrats and a sighting device (see Figure 4.2). Another method of assessing vertical structure of the shrub layer is to estimate cover visually, against a vertically placed 'quadrat' made of white board. Similar considerations apply to those outlined for cover assessments in a horizontal plane. In more open woodland or scrub, line transects are an efficient method (see p. 15 and Figure 4.3).

Structure may also be assessed horizontally over a compartment or forest block, by measuring the distribution and abundance of patches of defined structure classes (as described in Chapter 2).

Horizontal patchiness of this sort can often be assessed from aerial photographs, even at a scale of 1:10 000 if the resolution is good. A scale of 1:5000 is preferable. Stock maps and limited ground survey may be helpful to check the vegetation classes used on photographs.

Table 4.2 Summary of advantages and disadvantages of various methods of estimating abundance.

Method	*Advantages*	*Disadvantages*	*Applications*
Frequency	Precise. Quick. Objective (low observer error). Simple to use.	Does not measure quantity directly (cover or density). Can be slow at detecting changes for perennial spp.	Most situations, except where cover or density is important. Best method for tall field layer vegetation.
Cover/density			
Visual estimates of cover	Widely used for survey; familiar to ecologists. Simpler and faster than pins for field layer vegetation.	Subjective (high observer error). Imprecise. Scales not suited to statistical analysis.	Community composition monitoring e.g. NVC. Where low precision is accepted.
Point quadrat sampling	Precise. Objective.	Slow. Impractical for tall field layer or dense multiple canopy.	Short swards/field layer. Single layer tree canopies. Where precise estimates of cover are required.
Line-intercept	Objective and precise in suitable conditions.	Not suitable for dense multilayer woodland or dense tall field layers.	Open scrub and woodland. Tussock grasses, dwarf shrubs and other compact dominants.
Plotless point-centred quarter method	Fairly precise. Objective. Quick (no plots to lay out).	Not suitable for dense tall field layers, cryptic spp. or dense multilayered woodland canopies.	Tree dbh. Sparse field layers and shrubs and trees. Density and cover for compact individual plants.
Photographic methods	Fairly fast. Precise and objective (for distinct species). Permanent record: can be reassessed.	Not suitable for multilayer vegetation or spp. which are hard to recognise.	Density or cover of trees/shrubs and easily recognised dominants, e.g. heather or bracken. Good for detecting successional changes over large areas (aerial or vantage-point photographs).

The detection of structural changes in woodland vegetation, whether vertical structure or horizontal patchiness, is enhanced by the use of pairs of stereo photographs. These are simple to take: for short vegetation, photographs should be taken from vertically above the sample area. Problems of height and depth of field will be encountered with tall vegetation, and side views will often be more informative (Rowell, 1988). Stereo-pair prints can be studied under stereo viewing equipment, available in a simple desktop form, as used for aerial photographs.

Methods of monitoring plant communities

Species composition data are a combination of presence/absence frequency information and abundance information, which are combined as described earlier. Where the monitoring exercise is designed to detect change in species composition relative to a defined community type (obtained from a number of samples taken locally or from some form of classification system, such as the NVC), change can be assessed by listing the changes in individual species and interpreting their ecological significance. For example, groups of plants with similar ecological needs may increase or decrease together, thereby indicating trends.

The 'closeness of fit' to NVC communities may be monitored through time for any number of quadrats, using frequency and cover data. MATCH, a computer programme developed in conjunction with the NVC, compares sample data collected in the field with the community (and subcommunity) diagnoses of the NVC. It lists the best fits of the data to the diagnostics, thus providing a short list of the likely vegetation communities within which the sample data may fit (Malloch, 1990).

How long and how often to monitor vegetation

It is important to consider the period and frequency of monitoring from the outset, and to set criteria which will determine when monitoring will cease (Usher, 1991). Several factors are important:

1. The types of plants which are of principal interest. Annual species will fluctuate more rapidly in abundance than perennials such as trees and shrubs, and so a shorter interval between sampling occasions is appropriate.
2. The rate of change expected, e.g. in response to management. Where the object is to monitor the response to management for wildlife conservation, then a shorter interval is required than for unmanaged sites, where little change is anticipated.
3. The importance of the attribute being monitored. Monitoring intervals on important conservation sites should normally be shorter than for less valued sites, other things being equal, because the likelihood of early detection of any deleterious change is important and will be improved.

Table 4.3 Suggested monitoring intervals and frequencies for varous plant groups.

Plant type of interest	*Interval (years)*	*Minimum (preferred) number of sampling occasions*
Perennials: trees and shrubs in the canopy	5–10	3(5)
Perennials: saplings and seedlings	1–5	3 (5)
Perennials: others	2–5	4 (6)
Biennials	1–2	6 (9)
Annuals	1	8 (12)
Mixtures of all types	2–3	5 (8)

4. 'Background' changes. Several sampling occasions are required for any trends to show themselves distinctly from year-to-year fluctuations.

Given these factors, the timetable outlined in Table 4.3 may be appropriate. This table indicates that most monitoring schemes ideally need to last 8 years or more to yield meaningful results. This period should be extended where the monitoring objective is to evaluate the effects of management, because a pretreatment monitoring period of at least one assessment is required for comparison.

Summary of Chapter 4

1. Abundance can be assessed by means of non-absolute (frequency) and absolute (cover, density, basal area, biomass) measures.
2. There is no ideal method which fits all situations. The parameter to be used and method of assessment should be selected according to the monitoring objective and the desired level of precision, plus practical factors related to the vegetation type being monitored.
3. Frequency is probably the single most useful parameter to use for monitoring abundance, although it is essentially a measure of distribution and not quantity. Care must be taken in selecting quadrat size. It has the advantages of objectivity, speed and ease of use.
4. Visual assessments of cover, which are widely used for vegetation survey, are often not suited

to monitoring because of statistical problems, low precision and observer error. The use of more precise measures, where practical, is usually preferable, e.g. point sampling using pins, line intercept, plotless, and photographic methods.

5. Vegetation structure can be measured: (a) vertically by using vertical point quadrats and sighting devices, or visually; (b) horizontally by assessing distribution and abundance of patches of defined structure classes.
6. Changes in species composition can be assessed by listing individual species changes. Plant groups with similar ecological needs increase or decrease, indicating trends.
7. It is important to plan the period and frequency of monitoring, taking into account the principal types of plant, the expected rate of change, the importance of the attribute being monitored and background changes.

Chapter 5

Interpretation of Monitoring Data

It is not good use of resources to collect a lot of information without thinking about what can be done with it. At the planning stage, careful thought should have been given to the form of the data to be collected and whether analysis is both possible and likely to provide ecologically useful information.

The interpretation process will be greatly assisted by the precise definition of objectives, of relevant attributes to measure and of target or threshold values, as described in earlier chapters.

Two types of questions can be asked of monitoring data:

1. Are the differences between values for successive monitoring occasions *statistically* significant?
2. Are the changes *ecologically* meaningful?

If a difference in mean values from successive samplings is not statistically significant, it is not possible to say that a real change in values has occurred in the population being sampled. It is important to know this before attempting to decide the management significance of the changes observed from the samples.

Calculating statistical significance

As an example, the cover of a herbaceous species is being monitored using data derived from lowering a pin-frame in a series of 20 quadrats, whose positions have been determined randomly. The mean cover has increased from 20 to 30% between the first and second sampling occasion. Confidence limits can be calculated for the value of the means of the two sampling occasions, using calculations of standard error of the mean and the appropriate value of t (Appendix 2).

If the sample variances on occasions A and B are 720 and 1620, respectively, and it is assumed that the population variance has not changed between the two occasions, the *pooled estimate of the common variance* is:

$$\frac{(19 \times 720) + (19 \times 1620)}{38} = 1170, \text{ with 38 d.f.}$$

The variance of the *difference* between the means is:

$$\frac{2 \times 1170}{20} = 117.0$$

and the standard error of the difference is the square root of this, or 10.81.

An approximate 95% confidence interval for the true value of the difference is:

$$\text{difference} \pm 2 \text{ x s.e. (difference), or}$$

$$10 \pm 21.6$$

The difference is significant at the 5% level only if this interval does not include zero. The observed difference of 10 is obviously not significant.

The above calculations assume two independent samples. This is the case if there are different random placements of the 20 quadrats on occasions A and B. If the same quadrat positions are used on both occasions, a difference in cover should be calculated for each quadrat position, and the mean and standard error calculated from the single sample of differences.

Similar calculations can be applied to frequencies. A transformation (e.g. arcsine) will sometimes improve the distributional properties of cover or frequency data.

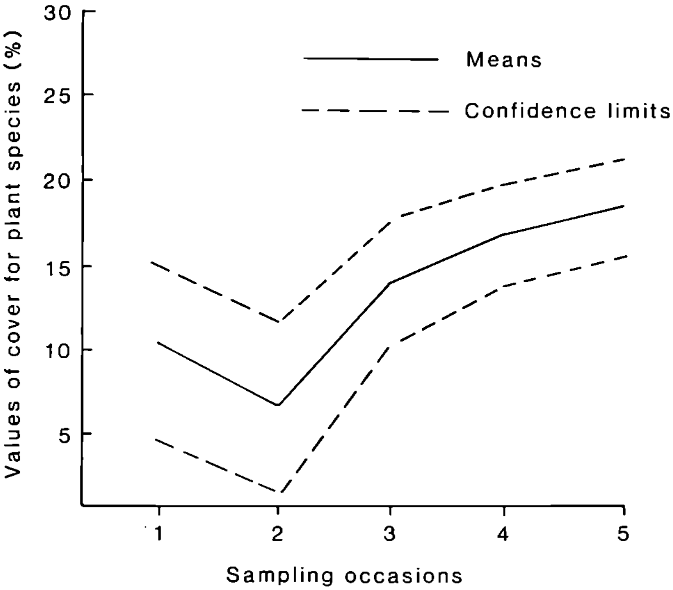

Figure 5.1 Interpretation of monitoring data by plotting confidence limits.

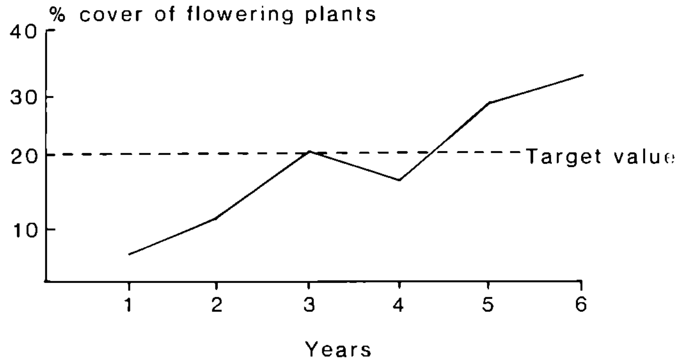

Figure 5.2 An example of monitoring the cover of flowering plants on a rideside, after management is applied.

The changes between sampling occasions can be plotted along with confidence limits (Figure 5.1), to show whether and when statistically significant differences have been obtained. In the example shown, the only significant differences are between the second and the fourth and fifth sampling occasions.

Vegetation changes: significance to the manager

If appropriate attributes and targets/thresholds have been selected, interpretation becomes a simple matter of comparing the observed values with these objectives. If the target is achieved, then change is 'significant' and management may be judged successful. Alternatively, the threshold could be a minimum value below which the conservation value of a site is judged to be harmed.

Attention should be given to how many sampling occasions the results are judged over, as shown in Figure 5.2. The figure indicates that the target is achieved in 3 years out of 5, following management being implemented after year 1. If the monitoring programme had been stopped at year 4, the conclusion drawn would have been different.

The plotting of confidence limits in relation to target values will also assist in judging whether objectives have really been achieved.

Interpreting long-term changes

Where the purpose of monitoring is to detect whether changes in ecological status are taking place, rather than to observe the results of a management action over a few years, interpretation may need to distinguish fluctuations due to cyclical change and year-to-year variation from trends, which are what the manager wishes to detect. Data-smoothing techniques, such as moving averages, are useful for damping noise and helping to show cycles and trends. Regression equations can be used to detect trends. A fuller description of methods is given by Rowell (1988) and Usher (1991).

Comparison with control areas

As outlined in Chapter 2, control areas where no treatment is undertaken are often useful in interpreting the changes in treated areas after a management treatment has been carried out. Control areas should be as similar as possible to the treated area prior to the treatment. Mean values from treated and control areas can be compared, with confidence limits calculated for each in order to determine the significance of the differences. However, without replication, differences cannot be taken as proof of a management effect, because of the possibility of initial differences related to the site.

Summary of Chapter 5

1. Good use of resources involves careful planning of the form of data to be collected in order for it to provide ecologically useful information. It is important to establish that the monitoring data show (a) whether and when statistically significant differences have been obtained, and (b) whether the changes are ecologically meaningful.
2. The significance of vegetation changes can be readily interpreted if appropriate attributes and targets/thresholds have been selected.
3. Interpretation of long-term ecological changes may require data-smoothing techniques and the use of regression equations.
4. Control areas are valuable for comparison purposes. Mean values and their calculated confidence limits can be used to determine the significance of the differences.

Chapter 6

Suggested Approaches to Monitoring in Different Habitat Types

Brief outlines, intended only as a rough guide, are given for monitoring in three broad situations: linear habitats, woodland and open areas within forests.

Linear habitats

Monitoring of vegetation changes on forest edges, or any linear habitats (e.g. riparian zones, compartment boundaries), usually tries to take account of the different bands of vegetation across the edge, as well as changes in species abundance. There are two main methods. *Method One* is for fixed vegetation bands, which may be defined by deliberate management. *Method Two* is for mobile boundaries.

In the first situation, sample areas may be divided into a number of quadrats, each replicated and matched with an adjacent untreated control sample area. In the second, where boundaries are unclear, or their movement with time is to be monitored, the layout consists of quadrats arranged end-to-end in parallel replicated 'ladder transects', perpendicular to the edge. Systematic sampling along such transects is useful in order to record the abundance of a species in relation to any environmental gradient or marked topographical feature (Figure 6.1). In certain situations with limited numbers of species of plant groups, line transects may be used (see p. 15 and Figure 4.3).

Woodland

For small areas of woodland (<1 ha), random sampling may be considered, provided that the layout and relocation of plots is easy to achieve. Stratification should be undertaken if necessary, and if strata are evident. For larger areas of woodland, two broad approaches may be identified, using either stratified sampling (random or systematic) or systematic sampling. The latter may be considered in situations where strata are not easily discernible, e.g. homogeneous vegetation (in terms of structure and composition). In such cases, care should be taken to avoid sampling positions coinciding with any regular pattern in the sample area. Randomising the distance between positions on the grid is one way of overcoming this problem. Where there is evidence of a strong environmental gradient, such as a slope, transects or one grid axis should traverse the gradient, i.e. up and down the slope (Figure 6.2).

Open areas within forests

These may be very varied, including features such as deer glades, old pasture or moorland. An appropriate strategy needs to be selected for each particular situation, based on the area of the site and the presence of regular features. Stratification is likely to be more practical than in wooded areas, and should be based upon relatively permanent topographical features or changes in soil type. Alternatively, clear vegetation boundaries or existing vegetation maps may be used to define strata.

For small areas, random quadrat arrangements should be used, especially if the site is easily accessible and the plot markers are likely to be clearly visible. Random quadrats may also be suitable if the monitoring interval is short, or if the site contains regular features.

Systematic arrangements are suitable for large areas, or those in which access and visibil-

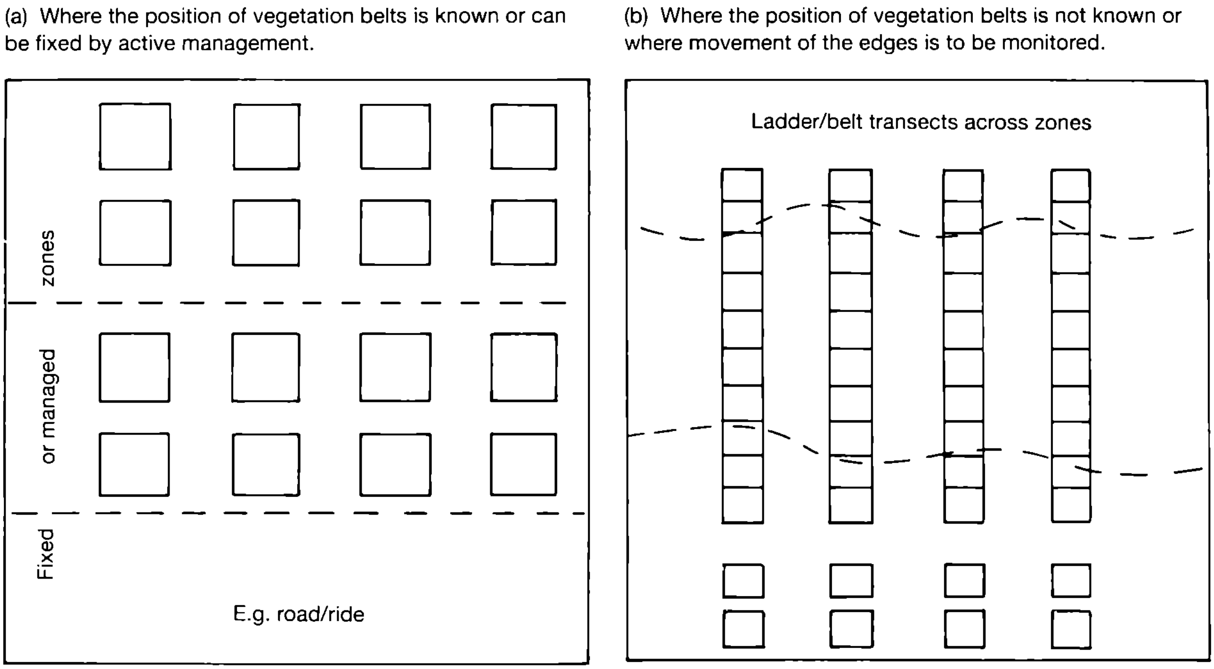

Figure 6.1 Quadrat layout for monitoring vegetation changes along forest edges and linear features: (a) method one, (b) method two.

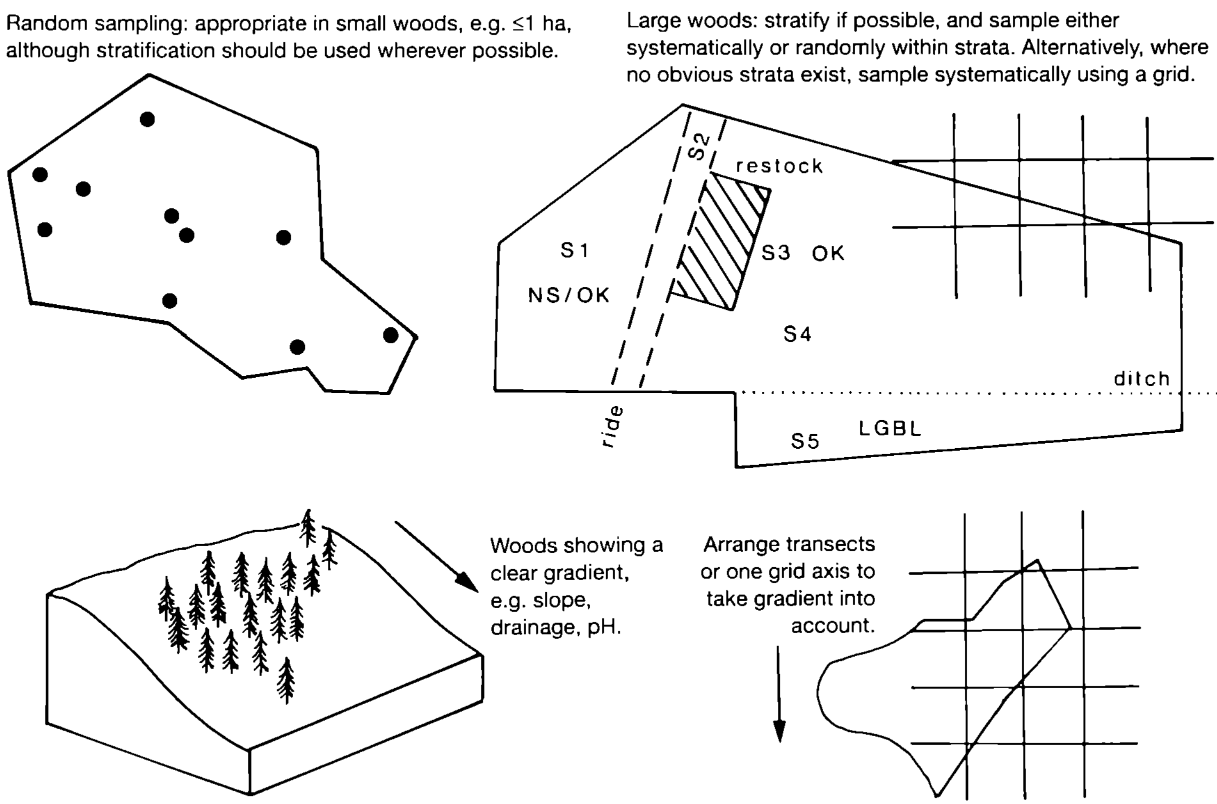

Figure 6.2 Possible sampling strategies for use in woodlands.

ity are difficult, e.g. scrub or tall grass vegetation. They are also best if the monitoring interval is longer (i.e. >5 years), if no regular features appear to exist, or if mapping is an objective of the monitoring programme.

Plotless methods, such as line transects, are efficient in open areas, particularly if used to detect changes at the level of distinct groups of plants.

Summary of Chapter 6

1. Linear habitats may be monitored using two main methods: for fixed vegetation bands and for mobile boundaries. Quadrats, replicated and with controls, are used for fixed vegetation; replicated ladder transects for mobile vegetation.
2. For woodland, random sampling (with or without stratification) is used for small areas, stratified or systematic sampling for larger areas.
3. Open areas within forests require specific approaches, for example stratification, random quadrat arrangements, systematic arrangements and plotless methods.

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APPENDIX 1

Calculation of required sample size

A monitoring programme to examine vegetation structure within a tall shrub community has been proposed. One of the parameters to be measured is shrub height. From a pilot study, it has been found that the mean height (m) is 200 cm, with a standard deviation (s) of 25 cm.

It is desirable to obtain an estimate of the population mean (μ) which is accurate to within ± 5% (i.e. 95% confidence limit). In this example, this requires that the acceptable variation about the mean is 200 cm ± 10 cm. The formula $n = 1600 \left(\frac{s}{m}\right)^2$ applies as follows:

$$n = 1600 \left(\frac{25}{200}\right)^2$$

$$n = 1600 \times \frac{1}{64}$$

$$= 25 \text{ samples}$$

APPENDIX 2

The Student's t *distribution*

Values given are those for which a particular percentage, *P*, of the Student's *t* distribution lies outside the range – *t* to + *t*. Values given for 10, 5 and 1%.

Degrees of freedom	*P* 0.1	0.05	0.01
1	6.314	12.706	63.657
2	2.920	4.303	9.925
3	2.353	3.182	5.841
4	2.132	2.776	4.604
5	2.015	2.571	4.032
6	1.943	2.447	3.707
7	1.895	2.365	3.499
8	1.860	2.306	3.355
9	1.833	2.262	3.250
10	1.812	2.228	3.169
11	1.796	2.201	3.106
12	1.782	2.179	3.055
13	1.771	2.160	3.012
14	1.761	2.145	2.977
15	1.753	2.131	2.947
16	1.746	2.120	2.921
17	1.740	2.110	2.898
18	1.734	2.101	2.878
19	1.729	2.093	2.861
20	1.725	2.086	2.845
25	1.708	2.060	2.787
30	1.697	2.042	2.750
40	1.684	2.021	2.704
60	1.671	2.000	2.660
∞	1.645	1.960	2.576

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