Table 4.1: Review of research on monitoring methods

A: Paper/report	**B: Measurement/method**	**C: Methodology**	**D: Evaluation - as a monitoring method**
Species composition/abundance			
Goldsmith, B. (1991) Monitoring for Conservation and Ecology, Chapman & Hall.	Presence or absence of species (frequency)	Presence of all species is recorded in fixed sized quadrat	Easy to record. Low observer error. Changes can only be detected in a limited range of species due to single size of quadrat.
Goldsmith, B. (1991) Monitoring for Conservation and Ecology, Chapman & Hall.	Presence or absence of species combined with frequency symbol (DAFOR)	As above but an abundance level is assigned to each species present: Dominant Abundant Frequent Occasional Rare	Easy to record. Higher observer error than above method. Not sensitive enough to monitor change over time.
Goldsmith, B. (1991) Monitoring for Conservation and Ecology, Chapman & Hall.	Density	The number of individuals per unit area is counted.	Not useful for species which spread vegetatively as it is difficult to identify individuals. Useful for trees and annuals - but with annuals, timing is important.
Goldsmith, B. (1991) Monitoring for Conservation and Ecology, Chapman & Hall.	Cover: (proportion of ground covered by individual species) Methods: i. random pins ii. pins in a frame iii. cross-wires in a frame iv. estimate by eye v. estimate by eye in range of value (e.g. Domin)	Numerous pin hits/cross-wire sightings are recorded in a fixed unit. Pins can record the uppermost species or can record all species to the ground. Cover is estimated - or the cover value is assigned to a specified range of values - within a fixed unit.	Random sampling by pin is probably the most accurate method though is very time consuming especially if all vegetation layers are being recorded. Sampling within a frame is less time consuming but pins within a frame are not independent of one another. Cross wires are less time-consuming and useful in same situations (ADAS 1999). Whether changes of a specific species are detected over time will depend on the size of the quadrat in relation to the scale and pattern of the species' distribution. Estimation by eye is time-consuming and subject to enormous intra and inter user observation. (a complete waste of time) Using two observers increases accuracy (Nilsson 1992;Poulton & Critchley ;Poulton, Critchley & Myers) but even so, change over time can be hidden by observer error. It can be useful when large changes are expected e.g. to monitor re-vegetation of bare ground. Scales such as the Domin scale are not sensitive enough to

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			detect most changes over time.
Goldsmith, B. (1991) Monitoring for Conservation and Ecology, Chapman & Hall.	above-ground biomass or yield	A plot is harvested, sorted into species then dried and weighed.	This method is destructive therefore not suitable for most monitoring studies or on nature reserves. It is time-consuming.
Goldsmith, B. (1991) Monitoring for Conservation and Ecology, Chapman & Hall.	Basal area	Basal area of trees or tussocky species is measured.	Only suitable for a restricted range of species; rarely used for monitoring.
ADAS (1999) *Statistical assessment of techniques for monitoring species compostion in upland plant communities. Final Report to MAFF.*	4 methods of monitoring heathland vegetation used in MAFF-funded experiments are described and assessed: i. First hit using cross-wires ii. Domin iii. dominant species iv. key species.	The assessments all used a gridded quadrat with 10cm^2 subunits **First hits** and **Domin** are described above. The **dominant species** is subjectively recorded for each cell and effectively give a % cover for each species up to a maximum of 100% (as does the first hit measurement). The presence of **key species** e.g. *Calluna*, *Molinia*, *Nardus* were recorded in each 10cm^2 subunit, to give a frequency measurement as described above. Each technique was evaluated for a) accuracy in detecting occurrence of key moorland species (species abundance b) ability to detect change in cover of these species. c) ability to detect change in plant community composition.	**First hits** is the most consistent, less variable and sensitive technique, though it is not good at detecting species present at low (<10% cover) densities, or of understorey vegetation. The other techniques were variable, less sensitive and more subject to observer error.
Poulton, S.M.C. & Critchley, C.N.R. (unpublished) Observer consistency in estimating the plant species composition of grassland. I. Variation due to recording method and vegetation characteristics.	The following methods were tested for inter- and intra-observer variation Presence absence Cover Local rooted frequency Nested quadrats	A replicated block trial was set up using 17 observers at 14 sites. ANOVA was used to test inter- and intra-observer variation when using these methods. An index of consistency was used to assess variation for abundance measurements.	There was a significant bias between observers for presence/absence records. This was sometimes greater than the spatial variation in the vegetation. Fewer species were recorded from open than from gridded quadrats. For quantitative assessments there was a significant bias between observers, 16-46% of estimates were in agreement between observers and 19-62% for the same observer . Consistency was best for nested quadrats, then frequency, then cover.

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			Higher species richness resulted in lower observer consistency when measuring frequency. Nested quadrats appear to be the most consistent method for collecting botanical data.
Poulton, S.M.C., Critchley, C.N.R. & Myers, G.M. (unpublished) Observer consistency in estimating the plant species composition of grassland. II. The quantification of precision limits.	Presence absence Cover Local rooted frequency Nested quadrats	For each species record in a quadrat using one method, a statistic was calculated to measure variation between 3 estimates by different observers. Precision limits could then be measured.	Overall, precision was low; only 28.7% of observations were within precision limits of +/-0.1. Cover estimates had widest limits, then local frequency and nested quadrats. Species of low abundance were most likely to be found using nested quadrats. With frequency quadrats, precision was reduced with increasing species richness. Precision limits were narrower for dicots than monocots, for rosette species than non-rosette, and for species with a lot of lateral spread. Previous estimates for precision limits are likely to be over-optimistic. Precision probably varies with site characteristics. Precision is most likely to be improved by using nested quadrats than by limiting records to certain species.
Winward, A.H. & Martinez, G.C. (1983) Nested frequency - an approach to monitoring trend in rangeland and understory timber vegetation. *Renewable resource inventories for monitoring changes and trends*, (ed. Bell and Atterbury)	Nested frequency sampling	This paper suggests the use of 2-4 'plots' nested within a larger one. Species found in the smallest 'plot' are given a score of 1, additional species receive a score of 2, 3 or 4 depending on the plot in which they are first found. % frequency for each species at each 'plot' size can then be calculated e.g. in plot 1: no. of plots with 1's/total no. of 'frames' sampled.	**Frequency** measurements are less affected by seasonal environmental factors and lack personal bias associated with cover measurements. They also lack errors associated with density counts. Finding the 'plot' (quadrat) size that will ensure all species within the community are measured between 20-80% is difficult. **Nested frequency** methods are less likely to exclude species, or generate frequencies of 100%. They take a similar length of time to assess as a single-sized 'plot'. Data can be evaluated from selected plot sizes as the frequency changes.
Hodgson, J.G.*et al.* (1994) A simple method for monitoring grassland vegetation. *Grassland Management and Nature Conservation BGS Occasional Symposium No. 28*, (ed. R.J. Haggar and S. Peel), pp. 286-	Frequency at different scales using nested quadrats	The area to be monitored is divided into 5 strips. In each strip, 6, 1m x 1m quadrats are randomly located. Each quadrat contains a series of nested cells of increasing size, within which species are recorded cumulatively.	Observer consistency is high. Monitoring of quadrats is rapid, but many quadrats are required to represent an area so if the area is heterogeneous, the method is time consuming.

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Critchley, C.N.R. & Poulton, S.M.C. (1998) A method to optimize precision and scale in grassland monitoring. *Journal of Vegetation Science*, **9,** 837-846.	Frequency at different scales using a grid of nested quadrats (ADAS plot method)	The 'plot consists of a rectangular fixed unit containing an 8m x 4m grid of square subunits. Each subunit contains a series of nested cells (normally 10 cells) of increasing size, within which species are recorded cumulatively. The **optimum scale** for a species is the scale at which its frequency count is closest to the midpoint. **Sensitivity** is absolute change detected) **Blindness** is the failure to detect change in a species	More efficient for monitoring large geographical areas than described in Hodgson *et al*. Optimum scale had greater sensitivity and lower blindness than any single scale in the majority of plots. When combining sensitivity and blindness, optimum scale always superior. Type I or Type II errors are less likely to occur at the optimum scale. Observer consistency is high. There is a risk of damage by trampling in fragile habitats (but this is also the case with other methods) The method was developed for grassland but has been successfully used in other communities e.g. heaths. In taller vegetation, or where variables of interest occur at a larger scale, it is difficult to record variables at the smallest scales. This could be overcome by using larger plots with **larger** cells within each nest. Conversely, smaller plots Results can be influenced by starting position; e.g. if sparsely occurring species is in the smallest cells (this could be overcome by increasing no. of nests within the plot and no. of plots in sample). The method is not suitable for estimating sp.-richness of surrounding vegetation by extrapolation from species-area curves (due to high correlation between scales and spatial autocorrelation between nests within the plot) The method is time consuming.
Burke, M.J.W. & Critchley, C.N.R. (1999) *Improving the cost-effectiveness of the ADAS plot method for monitoring grassland*. ADAS,	Frequency at different scales using a grid of nested quadrats (ADAS plot method)	In order to reduce time and therefore costs of the ADAS plot method, the validity of using fewer nests within each plot and fewer cells within each nest was investigated.	Major changes could be detected in all the scenarios (including 4 nests & 2 cells). Smaller changes required at least 16 nests and 4 cells. 16 nests and 10 cells was the recommended size - and this would save 40% of the costs of fieldwork resources (not including travel etc.). Reducing no. of nests will reduce ability to detect changes for individual species.
Grazing assessments			

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Grant, S.A.*et al.* (1976) The utilisation of blanket bog vegetation by grazing sheep. *Journal of Ecology*, **13,** 857-869.	Grazing on dwarf shrub heath and graminoid species.	Leaves/shoots were allotted subjectively to one of four classes and an arbitrary weighting (in brackets) given to each level of grazing intensity. i. removal of leaf/shoot tip (0.25), ii. less than half leaf/shoot removed (0.5), iii. more than half leaf/shoot removed (0.75), iv. graminoids grazed to stubble, heaths grazed to previous season's wood (1.0)	This method gives an assessment not only of presence of grazing but also of level of grazing intensity- which is important as low levels can stimulate whilst high levels suppress growth. The level of grazing is assessed subjectively therefore observer variation can be high. The values assigned are arbitrary and not necessarily a true representation. The method is useful where grazing is low, but in where it is high, it is difficult to assess how much of the current seasons growth has been grazed.
Grant, S.A., Hamilton, W.J. & Souter, C. (1981) The responses of heather dominated vegetation in North East Scotland to grazing by red deer. *Journal of Ecology*, **69,** 189-204.	Grazing on heather	This method is based on above method except: i. it is described only for heather ii. the first two categories are combined iii. the arbitrary weighting values are 0.3, 0.8 and 1.2 respectively.	Presumably it was felt that the first two categories could be combined to save time with little subsequent loss of information
Grant, S.A.*et al.* (1996) Controlled grazing studies on *Nardus* grassland: effects of between-tussock sward height and species of grazer on *Nardus* utilisation and floristic composition in two fields in Scotland. *Journal of Applied Ecology*, **33,** 1053-1064.	Grazing on *Nardus*	On a random selection of *Nardus*, tillers and leaves, presence or absence of grazing was recorded, giving a proportion of grazed *Nardus*.	This method is less subjective and presumably quicker than described for graminoids above, though it gives no indication of severity of grazing on individual leaves/tillers.
ADAS (1998) *Monitoring the Maintenance and Enhancement of heather Moorland*. MAFF Publications, London, UK.	Grazing on heather (heather condition)	A heather stem is taken from each corner of a quadrat. In the lab, the top 4cm is cut from each stem and each resulting shoot/shoots is classified as grazed, ungrazed or indeterminate. Grazing Index (GI) is then calculated: (1-ungrazed shoots)/total shoots A sample of heather stems is collected. This is divided into 2 halves, one for assessment of GI and one for measurement	The removal of the top 4cm of shoots means that heavily grazed shoots are omitted from the sample therefore the sample is biased towards ungrazed shoots. Inconsistencies occur between observers. The method is subjective as it relies on observer's ability to collect a sample of full range of grazing levels, growth stages, etc. Detection of current year's growth is difficult in heavily grazed heather. Matching of ungrazed and grazed shoots is not easy.

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		of Biomass utilisation (BU) BU is measured by identifying grazed and ungrazed shoots, matching each grazed shoot with an ungrazed shoot then weighing each shoot within its matched pair. A Quantile-Quantile plot of GI against BU is constructed and a regression equation fitted to the data. GI is then calibrated in terms of BU	The Quantile-Quantile plot is not valid. (Kirkham & Wilson 2000) The method is useful for detection of grazing by inexperienced observers. It might be possible to develop the GI to reduce observer variation and so to be a useful method of monitoring grazing units within ESAs. Further research is required.
Sward height/structure			
ADAS (2001) *Development of sward-based guidelines for grassland management in ESAs and Countryside Stewardship*.	Comparison of methods Sward stick Drop disc (10cm diameter) Drop disc (30cm)	The three techniques were compared	**Conclusions** Drop discs gave lower readings for sward height compared with the sward stick. Drop discs give less information on sward heterogeneity. There is more information in the literature relating sward stick height to animal production. **Recommendations** Techniques for assessing sward heterogeneity need to be developed.
Stewart, K.E.J., Bourn, N.A.D. & Thomas, J.A. (2001) An evaluation of three quick methods commonly used to assess sward height in ecology. *Journal of Applied Ecology*, **38,** 1148-1154.	HFRO Sward stick (SS) Drop disc (DD) Direct method (DM)	All 3 methods were tested. Random stratified points were selected and a measurement of sward height was made at the same point using each method. The temperature of the top 1cm of soil was taken. This was correlated with the sward height measurements.	**Recorder variation** was least using DD, was still low using DM, and highest using SS. **Time:** DM was quickest, though all the methods were quick. **Cost** was highest using the SS and least using DM. **Heights**: SS gave consistently significantly higher values than the other methods and DD significantly lower values (SS 73% higher than DD). In short turf relationships were more complex. DD results did not correlate with other methods (due to recording variation in microtopography rather than vegetation height). SS consistently over-estimated the turf height compared with other methods, whilst DD over estimated height in swards less than 4cm and under estimated height in swards taller than 10cm. **Square root of sward height correlated with soil temp.** for

			all methods, especially DD **Conclusions:** SS is the best quick method for recording structural heterogeneity but it is unsuitable for recording variation in short vegetation asa large number of samples are needed. DD is the least suitable for measuring microheterogeneity in sward architecture and is completely unsuitable for measuring variation in short turf. It is however good in all other situations. It is objective, consistent, cheap, simple to use and doesn't need group training beforehand. Other independent tests revealed that there were much closer correlations between herbage dry weight and sward height using DD than using the SS It is the most suitable method for measuring productivity and vertebrate herbivory, and for large-scale monitoring of sward height on nature reserves and land in AE schemes.
Near infrared reflectance spectroscopy			
ADAS *Investigation of the feasibility of using near infrared reflectance spectroscopy as a means of monitoring botanical diversity in grassland*. MAFF Publications, London, UK Also: Atkinson, M.D., Jervis, A.P. & Trueman, I.C. (1996) The potential of near infrared spectroscopy for monitoring species diversity in grassland. *Aspects of Applied Biology*, **44,** 431-436.	Near infrared reflectance spectroscopy	Samples taken from 6 sites; 5 of them were hand sorted into species, dried and weighed; 1was not hand sorted but was calibrated with visually estimated cover-abundance data. For NIR analysis the dried samples were ground, packed into sample cells with a quartz window, then scanned with monochromatic radiation.; The average spectrum from 24 scans used for calibration. For calibration modified partial least-squares regression and stepwise regression were used on the 1st and 2nd derivatives of the raw spectral data. Cross-validation was used to test the equations.	It is possible to derive robust predictive equations for estimating the proportions of most of the tested species in grassland, though care should be taken that the samples have a wide range of evenly proportioned species. The equations can be applied over a large geographical range. Requires further development before the method can be applied to AE monitoring.

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Remote sensing			
Hooper, A.J. (1992) Measurement and perception of change: Field monitoring of environmental change in the Environmentally Sensitive Areas. *27th ITE (Institute of Terrestrial Ecology) Symposium.*	Aerial photography	In ESAs an attempt to monitor change in land cover was made using aerial photography. The aerial photographs were interpreted then the accuracy of the interpretation was determined by comparing the results with those of ground survey using a method based on (Berry & Baker 1968). A grid of suitable density is placed over the square to be assessed. A ground surveyor assigns the vegetation/landscape at each intersection to a class using the same class descriptions as aerial photo interpretation. The ground results are compared with the aerial photo map. Accuracy coefficients were calculated.	Aerial photography gives a quick and permanent complete record of large areas. It can, however, be difficult to identify and delineate feature of interest consistently. (It is suitable for monitoring large habitat changes or detecting areas of burnt heather. It is not sensitive to small changes.)
ADAS (1996) *Assessing vegetation characteristics of enclosed grassland using satellite imagery.*	Satellite imagery.	In order to investigate the feasibility of using satellite imagery to discriminate between grassland types, 4 ESAs with a range of grassland types were selected for study Within these, 711 fields on which ground botanical assessments had been carried out, resulting in NVC communities and suited species scores. For each field, mean field reflectance values by Landsat TM band were extracted from an image. The relationship between mean reflectance values (Normalised Difference Vegetation Index - NDVI) and NVC/suited-species scores was determined statistically. NDVI indicates the presence and condition	There are discernible relationships between grassland characteristics recorded from field quadrats and spectral characteristics . There are limitations however: 2 NVC types may differ in broad conservation value but be characterised by similar productivity levels, e.g. U4 and CG2c pasture (acidic and calcareous vegetation types) recorded similar NDVI values. Data accurate enough for use in large-scale strategic studies but detailed grassland discrimination not possible .

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		of green vegetation and helps compensate for changes in extraneous factors such as slope and illumination.	
Mino, N., Saito, G. & Ogawa, S. (1998) Satellite monitoring of changes in improved grassland management. ,. *International Journal of Remote Sensing*, **19,** 439-452.	Satellite remote sensing	Satellite images were acquired during the grass cutting season in a dairy farming region in Japan. This enabled changes in grassland use and mowing strategies to be analysed.	The images acquired showed distinctive reflectance characteristics therefore remote sensing is an effective tool for monitoring the status of grassland management.
Inoue, Y., Morinag, S. & Tomita, A. (2000) A blimp-based remote sensing system for low-altitude monitoring of plant variables: a preliminary experiment for agricultural and ecological applications. *International Journal of Remote Sensing*,, **21,** 379-385.	Blimp-based remote sensing system	A radio controlled blimp (a helium filled balloon, 23m long with a maximum diameter of 7m), which cruised at a maximum speed of $40kmh^{-1}$ at altitudes between 30 and 400m, collected data using 4 monochromatic CCD video cameras with interference filters.	The hovering ability of the blimp allowed collection of a continuous set of high-quality images. The system proved to be suitable for low-altitude remote sensing of plant variables such as above-ground biomass.