# MONITORING OF PEAT BOG SYSTEMS

Richard Lindsay & Sarah Ross

**Abstract**

Monitoring can be carried out at a range of levels depending on the resources available. Although large-scale, detailed programmes may be appropriate for certain cases, the objectives of many monitoring exercises may be achieved using relatively rapid, uncomplicated and inexpensive techniques. The relative simplicity of structure and vegetation found in ombrotrophic bog habitats makes them particularly suited to such unsophisticated techniques. On the other hand, the sensitivity of bog habitats to disturbance is very great. Establishing the infrastructure for a monitoring programme which does not then cause more change than the effect being studied is, therefore not easy.

Lindsay, R. & S. Ross: **Monitoring von Mooren**

Monitoring kann in Abhängigkeit von den vorhandenen Ressourcen auf verschiedenen Genauigkeitsstufen durchgeführt werden. Obwohl detaillierte Untersuchungen in großen Maßstäben für bestimmte Fälle angebracht sein mögen, genügen für die meisten Fragestellungen verhältnismäßig einfache, schnelle und daher auch billigere Methoden. Die Einfachheit der Vegetationsstruktur insbesondere ombrotropher Moore erlaubt es, gerade hier diese einfacheren Methoden anzuwenden. Dabei darf allerdings nicht vergessen werden, daß Moore besonders empfindlich auf Störungen reagieren. Wird also ein Monitoringprogramm für ein Moor eingerichtet, ist es dabei häufig nicht einfach, untersuchungsbedingte Störungen so gering zu halten, daß sie nicht die zu untersuchenden Phänomene überlagern.

Lindsay, R. & S. Ross: **Monitorování rašelinišť**

Monitorování může být provedeno na několika úrovních v závislosti na dostupných prostředcích. Ačkoliv rozsáhlé, detailní programy jsou v jistých případech nezbytné, cíle mnoha monitorovacích programů mohou být dosaženy za použití relativně rychlých, jednoduchých a levných metod. Tyto nenáročné metody se dobře hodí k monitorování ombotrofních rašelinišť, které mají relativně jednoduchou strukturu a vegetaci. Na druhé straně, tyto lokality jsou velmi citlivé k rušivým vlivům. Z tohoto důvodu je poměrně složité vybudovat takovou infrastrukturu monitorovacího programu, která by nezpůsobila větší změny než je vliv studovaného jevu.

## INTRODUCTION

In military terms, "monitoring" is an essential intelligence operation, the objective of which is to detect the enemy's intentions in sufficient time to pre-empt these intentions and thereby to retain the military initiative. Such monitoring tends to consist of four stages:

1. The "sentry" observer
   A sentry posted in a forward position is expected to note and report any apparent change in enemy activity. The "sentry" may in fact be an air reconaissance plane, a satellite or even an espionage agent, but one of the characteristic features of this first stage is that change, any sort of change from the norm, is the trigger for further action. The sentry in a forward dug-out may not understand the significance of the observed change, but is nonetheless able to report that "something is up".

2. Sorting and sifting
   In a military operation a considerable volume of intelligence information may flow in to the central intelligence headquarters. To avoid drowning under a flood of such information it is necessary to evaluate and sift the mundane and unimportant from the unusual and vital signs of significant change. Such work requires specialist expertise but not necessarily a full understanding of the whole military and political picture.

3. Evaluation
   Having identified the key elements from the larger information flow, it is then important to piece these elements together and attempt to build up an overall picture of the enemy's likely intentions, as well as possible military responses to these - in other words, to construct a model of the future course of the war. This requires a complete understanding of the military position throughout the theatre of the war, as well as a sound knowledge of the art and science of war.

4. Action
   Finally, an appropriate response is agreed and implemented. The response may consist of many parts, some of which may be drawn up and carried out at local level while other, more large-scale strategic actions may be set in train by the high command.

Much environmental monitoring reflects this pattern of events and could thus be described as the "military model". However, military action usually has only a single very clear objective, which is the final defeat of the enemy. Environmental monitoring, on the other hand, embodies a wider range of objectives and may thus involve other approaches.

## THE OBJECTIVES OF MONITORING

The "military model" is appropriate for those occasions where a site, population or biotope may or may not be undergoing change and there is a need to establish whether any such change is indeed taking place, and if so, what the nature of that change might be. Essentially, it is most appropriate for **impact studies**. Such a use may appear to limit such monitoring to specific events on particular sites where impacts have already occurred, or are expected in the future. In fact, particularly in the case of Europe's peatlands other than perhaps Fennoscandia, the extent of human impact has been so widespread that it is difficult to identify any peatland site which has not already been significantly altered by human activity. Consequently it is fair to say that any monitoring of a peatland site is also likely to be in part a process of recording changes which result from a history of impacts.

A rather different philosophy is called for, however, where the objective of monitoring is the establishment of a **data archive** and **historical context**. The archive may then itself be used as a base-line for impact studies using the "military model", but the accumulation of the archive is a rather different exrecise. From a purely practical point of view, for example, none of us lives for ever, or even stays in the same job forever. It is therefore vital that a new warden for a nature reserve has access to monitoring records which provide a clear, unequivocal view of the past history and character of the site. For example, a new warden at Glasson Moss National Nature Reserve, in Cumbria, northern England, should know that, despite its present *Sphagnum*-rich vegetation, in 1976 the site was little more than an expanse of charcoal because of a fire which burned repeatedly across the site from July to November of that year.

Yet another philosophy relates to environmental monitoring as a means of **justifying** nature conservation action. The warden of a nature reserve may have spent very large sums of money in the course of carrying out positive conservation management programmes. At some point someone is going to ask for proof that this was money well-spent. Without data which show the "before" and "after" conditions, it is impossible to prove the success or otherwise of these conservation measures.

In practice these different objectives may be bound up in a single monitoring exercise, but it is important to recognise these differing elements because, firstly, monitoring is often a resource-hungry exercise and identification of the minimum necessary to provide the required evidence is therefore an important step. Secondly, the methods employed determine the nature and emphasis of the results obtained and it is thus important to select methods which give the type of results most appropriate to the issues being monitored.

These last points can best be appreciated by examining a number of different techniques employed in the pursuit of that elusive thing, the monitoring "result" (of which more later).

## MECHANISMS FOR MONITORING

The purpose for which monitoring is being carried out determines the scope of the programme and scale of detail envisaged. Questions about the efficacy of a single section of boardwalk on a site require a different approach from those which seek assurances about the condition of the entire peatland resource contained within a region. The mechanisms and objectives are thus often inseparable and together dictate the type of exercise required.

### 1. Resource monitoring

At its simplest this consists merely of recording the **presence or absence of the habitat** in relation to the extent at a previous date. For many habitats this is far from simple because loss of the original habitat leaves no trace of its former presence. However, in the case of peatlands, being both a biotope and a soil type, it is often possible to determine from soil maps the original extent of the peatland resource prior to human disturbance. In many cases, though, even the soil deposit has been completely lost through drainage and oxidative wastage. Under such drained conditions the peat soil boundary can retreat at rates of up to 10cm per year (BURTON & HODGSON, 1987). Small sites, in particular, can thus be lost altogether.

Nevertheless, in many instances even the remaining area of peat soils is sufficient to demonstrate the very dramatic change in the distribution of surviving peatland biotope between former times and the present day. For example, in Britain the National Peatland Resource Inventory (NPRI:

LINDSAY, ANDREWS, GORDON & IMMIRZI in press) is a Geographic Information System (GIS) dataset which has recorded the extent of deep peat soils (greater than 1 metre) for the whole of Britain. The distribution and extent of these soil deposits can then be compared with the present extent of the peatland habitat. The results from the NPRI for lowland raised bogs demonstrate the very great contrast between extensive peat *soil* deposits but the extremely small area of surviving bog vegetation. Agriculture, afforestation and commercial peat extraction now dominate the majority of these peat soils, leaving only 6% of near-natural vegetation remaining (see Figures 1 and 2).

## 2. Time-series resource monitoring

If specific dates can be put on a series of "snapshots" of the resource it is possible to produce time-series data which show the rate of change at different times. Using soil maps as described above, it is difficult to give the study a "start-date". The soils have existed in many cases for several thousands of years, but all that can be recorded is that the former area of peatland habitat has been replaced by agriculture with no sense of when, or at what rate. If, on the other hand, it is possible to use old maps and, at least since the 1940s, aerial photographs, specific dates or time-intervals can be identified for particular changes and thus an idea of the rate of change can be obtained.

A series of such data for a sample of lowland raised bogs in Britain (Nature Conservancy Council unpublished data) reveals that the rate of loss has been almost constant since at least the middle of the 19th Century, but also that the causes of change have differed from one time-period to another (see Figures 3 and 4).

The NPRI is currently engaged in an extensive survey programme designed to provide a base-line for the current condition of blanket bog in Britain, using LANDSAT TM satellite imagery. The intention, once the base-line has been established, is to carry out a regular programme of environmental audit using the most recent satellite images available. In this way a set of time-series data can be used to monitor, in a relatively continuous way and using limited resources, the condition of and changes to a particularly extensive semi-natural resource covering some 1,500,000 hectares in Britain (REID et al. in press).

## 3. "Condition" monitoring

Monitoring is most frequently associated with the concept of regular and repeated studies which determine whether the "condition" of a site, of species, biotope or suite of species, is changing in some way. This is usually in response to some perceived impact which may already exist or has been proposed.

In fact the previous example, involving satellite monitoring, goes beyond the mere concept of presence/absence data for the resource because the satellite image is a rich source of information. Beyond indicating whether an area presently has peatland vegetation or is an agricultural field, it can also identify the character and quality of any peatland vegetation found on a site. The NPRI audit programme of the future will thus be capable of measuring change in character of the blanket bog resource in addition to the the more basic questions of what has been lost.

A practical application of this work concerns the provisions of the EC Habitats and Species Directive (92/43/EEC). This Directive requires member states to ensure that sites identified as Special Areas for Conservation (SAC) should have "favourable status", which is defined as the condition under which "all structures and functions necessary for the long term maintenance of the site are in place".

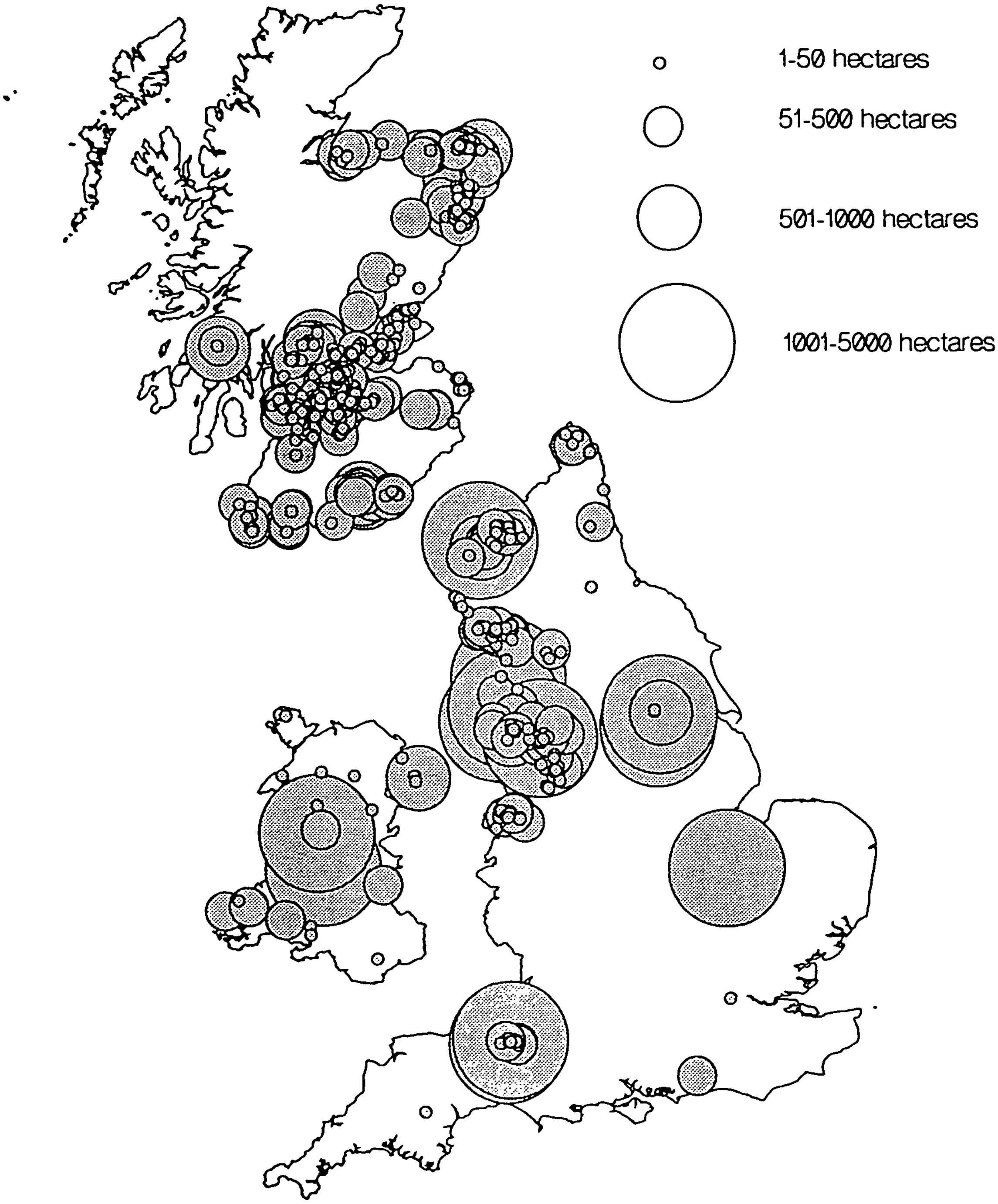


Figure 1: The distribution in Great Briitain of soils derived originally from raised bog habitat. Individual bogs are displayed as area ciircles allocated to four size classes (see key). The map indicates only the present distribution of the soil type, not the extent of the natural raised bog habitat today. (Taken from LINDSAY et al., in press).

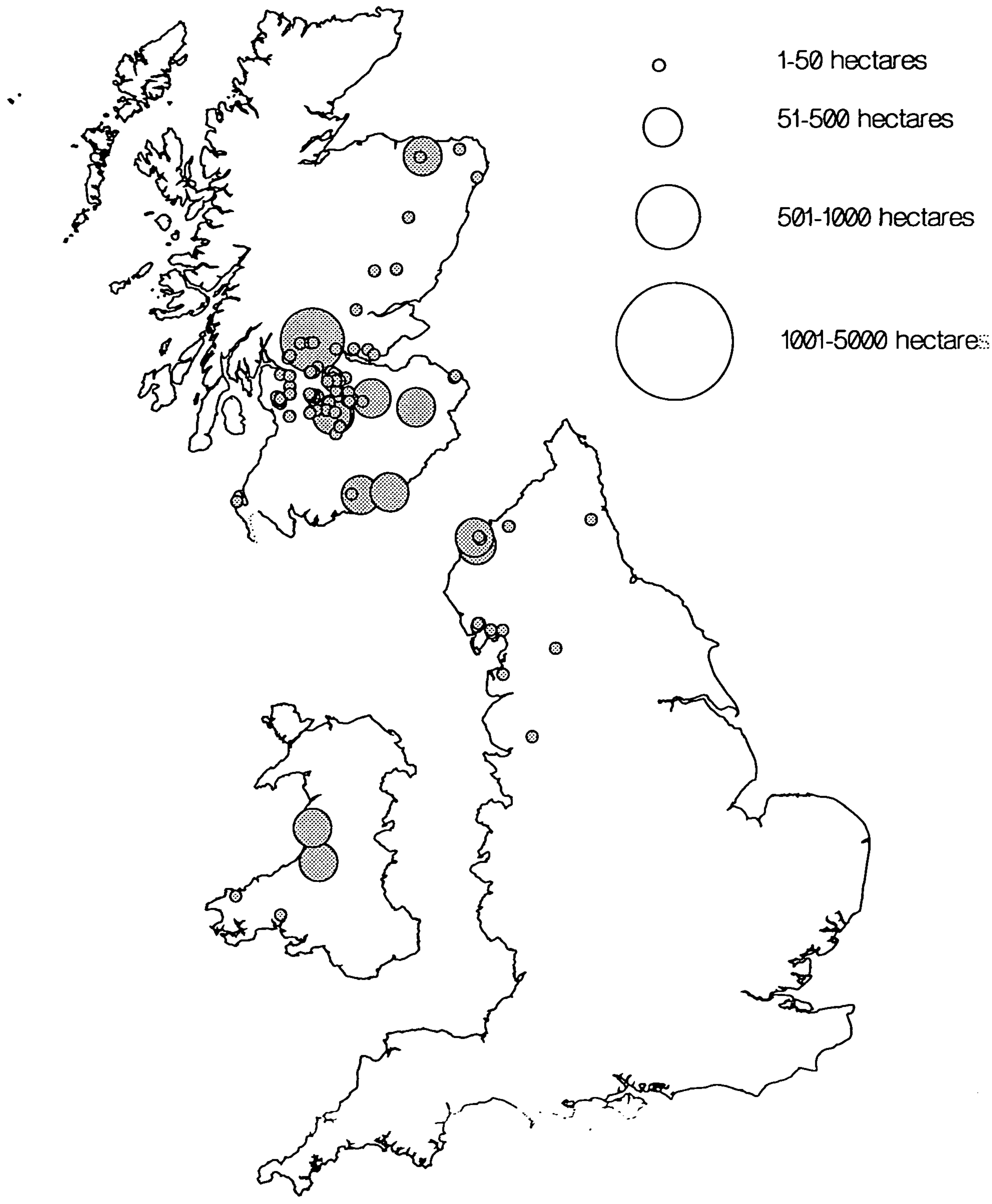


Figure 2: The distribution and estimated extent in Great Britain of near-natural raised bog habitat. Individual bogs are displayed as area circles allocated to four size classes (see key). (Taken from LINDSAY et al., in press).

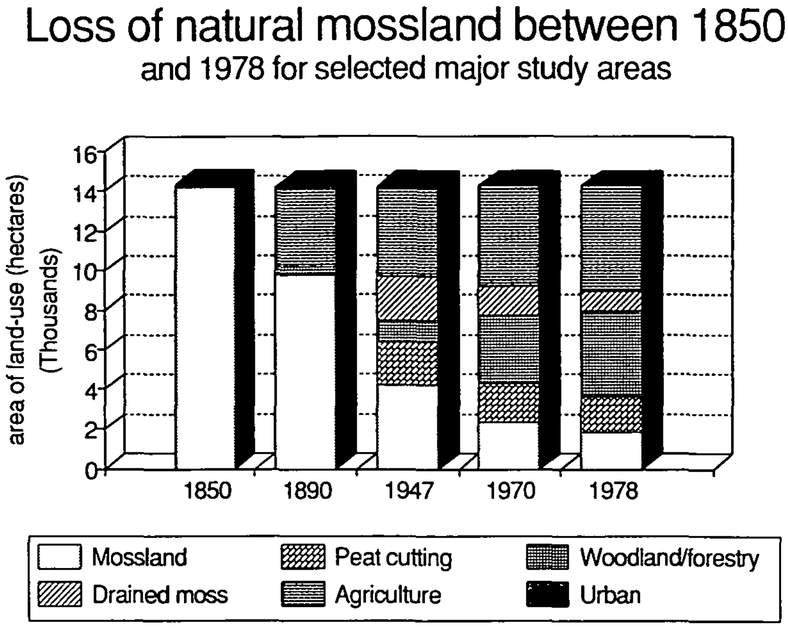


Figure 3: The change in land-use recorded for a large sample of lowland raised bog sites in Great Britain over a period of some 125 years. Sites were mapped from early national cartographic surveys (Ordnance Survey 1st Edition, 1:10560 scale), then followed through subsequent mapping editions, then using aerial photography and finally field survey. (Nature Conservancy Council, unpublished data).

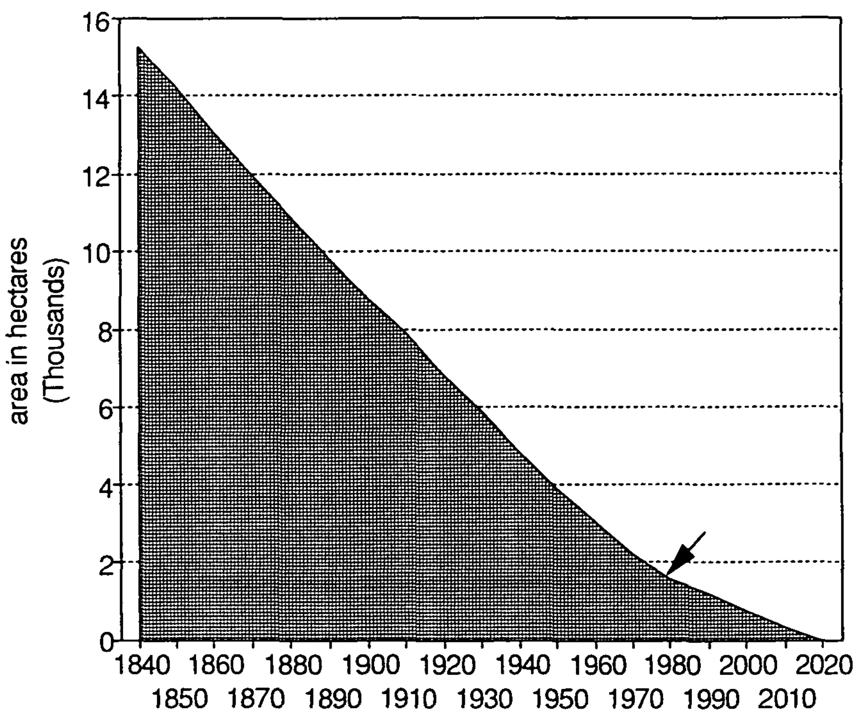


Figure 4: The decline in the area of near-natural raised bog habitat recorded for a large sample of lowland raised bog sites in Great Britain over a period of some 125 years, from 1840 to 1978. The data are the same as those used for Figure 3, but only the area of "open mossland without drains" is indicated here. The arrow points to the date at which the study ended. The curve beyond that point indicates an estimated extrapolation to extinction, assuming losses continue as before (Nature Conservancy Council, unpublished data).

This definition of SACs places on the member states an obligation to monitor such sites to ensure and demonstrate that the defined interest is being maintained. Blanket bog is defined as one of the priority habitats for action under the Directive, but most blanket bog sites are large. The resource implications for monitoring such extensive tracts of land are potentially enormous, but in Britian it is intended that the NPRI, using time-series satellite data, will provide a relatively resource-efficient means of fulfilling this obligation.

Whereas satellite data provide information at a scale appropriate to the monitoring of an entire resource, or even to some very large sites, the resolution of information is not generally sufficient for detailed site monitoring. Individual pixels, the smallest unit of resolution in a satellite image, cover an area of 30x30 metres. The monitoring resolution of such a system for many site-types characteristic of the lowlands, for example a typical raised bog, is such that only a very crude picture of the site can be obtained. It is necessary to employ different, more detailed techniques when monitoring these smaller sites or when looking for more subtle changes in the biotope.

## 4. "Indicator" species

"More detailed" does not necessarily mean "more complex". The use of individual species or species-groups as indicators of environmental health is a long-established practice, but is not widely recorded for peatland sites. There is no shortage of suitable species because the majority of bryophytes found on undisturbed peatland systems have quite narrow ecological tolerances. IVANOV (1981, p.199) emphasises the very small changes in average water table required for the moss layer of bog systems to undergo significant changes.

CHAPMAN & ROSE (1986) offer an example of a site where changes over a 30-year period are characterised by the difference in abundance of individual species. In 1958 Coom Rigg Moss was surveyed and a regular grid established across the site. The abundance of each species was recorded at each grid intersection. The site was revisited in 1986 and the same recording technique employed using the original grid. In the intervening period the site had become completely surrounded by commercial afforestation, with some of the site itself ploughed and afforested.

The results obtained from this study show very clearly that significant changes in the original bog vegetation have taken place since the original survey. Species such as *Sphagnum cuspidatum* are confined to bog hollows (Schlenken; carpets : SJÖRS 1948; T1 hollows : LINDSAY et al. 1988). The almost complete loss of this species by 1986 indicates not only a biological change but also significant structural alterations to the mire surface. Many other speces, both plant and animal, can be used in a similar way because they are intimately linked to the structures and processes of the bog. Monitoring programmes based on indicator species should usually therefore aim to maximise the information obtainable in this way by selecting species which display particularlity of behaviour, rather than species which are generalists whose presence or absence only says something about that species, and very little about the site as a whole.

## 5. Fixed points and permanent plots

The study at Coom Rigg Moss introduces the idea of a fixed, repeatable grid for monitoring. Fixed points have advantages in this context because it is possible to say with certainty that changes have occurred at particular localities, whereas, if random sample techniques are employed, it is only possible to offer a statistical probability that changes have occurred.

5.1. **Fixed-point photography**
If the site is accessible and can be visited, fixed-point photographs arguably represent the simplest and most effective method of monitoring, for a variety of reasons. The technique, to be really effective, should involve taking stereo-pairs of photographs, rather than mono-photographs at each point - **this cannot be over-emphasised. The value of stereo-photos compared to a mono-photo is roughly equivalent to the difference between a high-quality colour aerial photograph and a blurred, opportunist photo taken through the scratched window of a commercial airliner.**

Stereo photographs for this purpose involve no complex technology. It is sufficient to take two photographs of the same scene, moving the camera between photographs sideways by some 5-7cm (which can be achieved simply by shifting one's weight from left foot to right foot between photos).

The technique can be used for views across a site, for general foreground views of the vegetation, or vertically over fixed quadrats. The location of the photograph must be noted, as must the direction of view, film type and focal length of camera lens. The location of the photographer should be marked with a permanent post. If the photo is to be a vertical shot of a quadrat the post must be carefully constructed or should be off-set from the quadrat because marker posts themselves can cause problems (see below).

The photos can be viewed using a stereo-viewer for aerial photographs, placed on a light-box if the photos are transparencies. Small plastic stereo-viewers are also available which use natural light, and these can be used in the field with past photo-sets to check immediately whether there have been changes, or that the photographer is in the correct location.

Quantitative analysis is only possible at a relatively crude level using this technique because the equipment used is not planimetrically correct. Nonetheless the results can generate some of the most powerful evidence of change, particularly for the non-specialist decision-maker. Such non-specialists often find themselves in the position of having to decide whether funding of management work by specialists should continue, and although many will have at least a modicum of scientific training, it is often difficult to unravel the highly specialised and technical evidence from reports describing monitoring results. In contrast, a photograph is something which can be immediately grasped, especially one which virtually transports (perhaps in the future, virtual reality will make this more literally true than intended) him or her to the site, and in which evident vegetation changes can be seen between two sets of dates.

A further advantage of such monitoring is that, if used in conjunction with other techniques, it can provide a permanent and objective source of information which can be referred back to any stage in the future. The difficulty of maintaining standard recording between different surveyors, or the influence of different perceptions between those who successively describe the condition of the site, are notorious. Successive monitoring or wardening staff can maintain consistency from generation to generation simply by referring back to the archive of previous photographs.

**If resources are limited, such stereo-photos can be an extremely quick and effective means of providing a simple monitoring system.**

Arguably, this technique should form part of any monitoring programme, whatever other methods are involved, because it provides objective, visual support for any other data gathered.

5.2. **Fixed-point quadrats or transects**

One of the commoner approaches to fixed-point monitoring involves the establishment of a monitoring plot which is of the order of 2 metres x 2 metres or larger. Vegetation groups are noted within this plot and compared in subsequent years. The relatively large size of the plot means that edge-effects caused by marker-posts are minimised, and also relocation of the entire plot does not need to be a precision exercise accurate to a few centimetres.

Unfortunately this approach cannot be used for many peatland systems because it is impossible to sample such a large block of ground without trampling the vegetation. SLATER & AGNEW (1977) highlight the sensitivity of peat bog systems to such trampling, and our own experience in the former Nature Conservancy Council clearly demonstrated that annual visits to a fixed plot are enough destroy much of the bog vegetation being monitored.

Consequently a modification of the large fixed plot has been employed by the Nature Conservancy Council and its successors for a number of years on several sites. In practice it is possible to lean over a quadrat width of 0.5 metres without leaning on the vegetation while sampling. In order to permit a large area of vegetation to be monitored without exceeding this width, fixed transects were established (the isonome method OF KERSHAW & LOONEY 1985), having dimensions of 0.5 metres wide and 2 metres long. This gives a reasonable total area for each monitoring sample, bearing in mind the scale of patterning normally found on peat bogs (e.g. SJÖRS 1948, DIERSSEN 1982, EUROLA et al. 1984, LINDSAY et al. 1988).

The scale of data-gathering was increased in each case by dividing up the transect into 200 squares of 10x10cm. The presence of each species is recorded within each small square, and is then assigned an abundance value on a three-point scale:

1 = present
2 = semi-dominant/common
3 = dominant

The presence of differing growth layers, namely ground layer, herb layer and shrub layer, means that it is possible to have three species all of which score 3 because they form the dominants in their respective layers.

The small-scale surface pattern of a bog is an important component in describing the character and "health" of a peat bog. The microtopographic profile of the transect is therefore measured by noting the mid-point height of the sides forming each small square relative to an arbitrary datum. In this way a 3-dimensional model of the surface can be created using any one of the many computer surface-plotting routines available.

The final step is probably the most important of all. Stereo-pairs of photographs are taken along the transect, as described in the preceeding sections. Normally a 35mm lens on a 35mm camera will enable a 2-metre transect to be covered by two pairs of such photos. A tape measure should be placed along the nearer edge of the transect to provide a permanent record of the start and finish point of the transect, and a label should preferably be placed in at least the starting pair of each transect. These photos have proved invaluable in later years. They have:

a) enabled new monitoring staff to agree consistent usage of the abundance values;

b) provided an independent check of any unexpected (and possibly suspicious) results, particularly where species misidentification is suspected;

c) assisted the monitoring team, by use of a small stereo-viewer in the field, to ensure that they record in the same direction as previous years;

d) finally, and possibly most importantly, they provide clear images of change which a non-specialist can see, if not necessarily interpret.

Practical aspects of the monitoring technique involve the selection of transect locations, the marking of these transects, and the construction of boardwalks to prevent trampling alongside the transects.

**Transect location**
Two types of locality have been used, each providing rather different information:

a) **"Edge" changes**
These are located across distinct boundaries in the vegetation, and are designed to determine whether there is any spatial shifting of these boundaries.

b) **"Background" changes**
Located in homogeneous stands of vegetation, these transects should detect general changes in species composition even if there are no dramatic shifts in vegetation boundaries.

**Marking of transects**
Transect markers should meet three criteria. They should:

- be readily capable of detection from some distance;
- be resistant to fire, at least in part;
- not be the cause of additional nutrient input to the site. This last point is perhaps not quite as straightforward as might first seem, as we have discovered during the course of our monitoring programmes. The point is explored further below.

**Boardwalk**
The most important feature of any boardwalk is that, like marker posts, it should not cause additional nutrient loadings in the vicinity of the transect.

## 6. Glasson Moss NNR : a practical example

### 6.1. Introduction

One of the longest monitoring programmes established on a raised bog site by the statutory conservation agencies in Britain involves a National Nature Reserve (NNR) called Glasson Moss, in north-west England. The site caught fire during the great drought of 1976 and burned from July to November, the fire criss-crossing the site several times, finally leaving unburned just one very narrow strip in the centre.

In 1977 the former Nature Conservancy Council (NCC) carried out a preliminary survey of the site to establish whether there was any prospect for recovery (LINDSAY 1977). The survey concluded that recovery might be possible, and the following year the first steps in establishing a long-term monitoring programme were taken, and by 1981 all the aspects of the programme had been put in place.

Since that time the site has been monitored fairly regularly to the present day using the isonome transect grid system described above.

### 6.2. Methods

Two transects were placed in the unburnt strip of vegetation in the centre of the site and a further six were distributed across the site in a mixture of boundary and homogeneous locations. Vegetation and surface topography were measured, and stereo-photos were taken. An example of a completed transect form can be seen in Figure 5.

Transects were marked on a map in relation to numbered posts which form a complete 100 metre-interval grid across the site. The corners of the transect were marked by untreated wooden posts. The nearside left-hand corner, which represents the consistent starting point for recording, was marked by a taller post than the rest.

The boardwalk consisted of timber 7.5 x 7.5cm in cross section laid along the nearside edge of the transect, supported by deep-sunk uprights on which they rested. Unfortunately it later emerged that this timber had been treated with preservative.

6.3. **Results**

The detailed results of this work will be published elsewhere but it is worth examining a few of the key points here, to give an idea of the kind of data which can be obtained from such fixed point transects.

The use of contiguous small squares in the form of a belt transect, or isonome, offers the investigator a number of ways in which the data can be analysed. Two methods are simple and quick to carry out, and provide a surprisingly informative picture of events.

For a formal quantitative approach it is possible to sum the values for each species across all the individual 10cm squares in all the transects, thus obtaining a form of cover-abundance value for each species for each year of monitoring. Changes in cover-abundance values from year to year indicate overall shifts in species, though they provide little information about the spatial character of these changes. Thus all the change may be due to the species behaviour of a single transect, or it may be a more widespread phenomenon, but the drawing out of such information requires more sophisticated analysis.

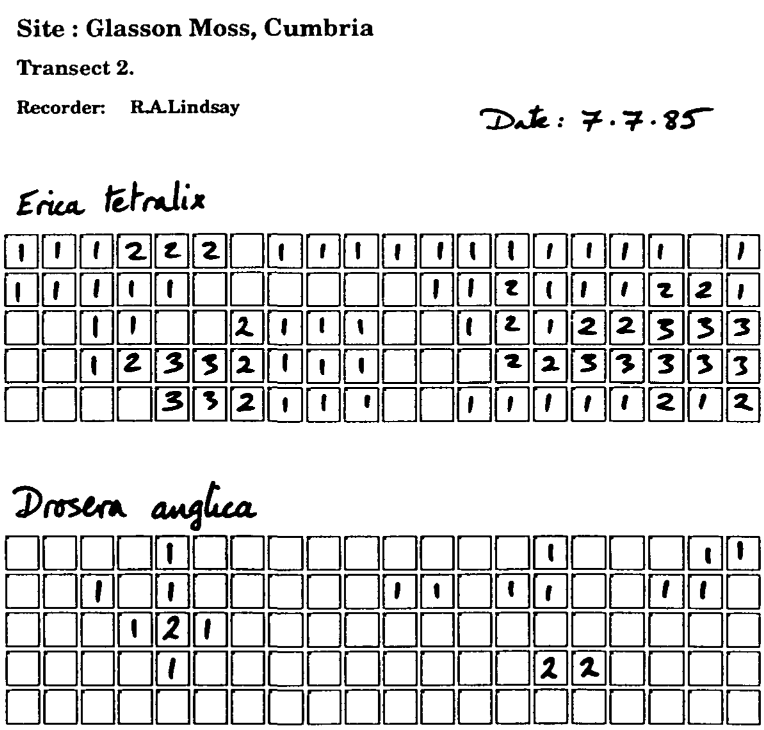


Figure: 5 An example of a recording sheet, or part of one, complete for two species, as used by the SHN monitoring programme when recording transect isonomes. Each species is recorded in turn, and assigned a score of 0 (absent), 1 (present), 2 (common/semi-dominant), 3 (abundant/dominant)

A second approach which is less quantitative, but which provides a clearer picture of the individual species recovery pattern, involves the simple mapping out of each year's data for a species. By comparing the successive "species transect maps" from consecutive years and, particularly, comparing those for the base-line year with the most recent data, it is possible to obtain a good visual impression of spatial changes over time.

These two methods of data-processing are considered below in terms of particular features the recovery reponse shown by the vegetation on Glasson Moss.

### *Sphagnum* recovery

The description provided by LINDSAY (1978) of Glasson Moss immediately after the fire makes it clear that, other than the narrow unburnt strip of vegetation, no evidently living *Sphagnum* remained on the site although in many areas it was possible to find hummocks or lawns which had been severely singed by the fire rather than utterly destroyed. It was impossible to say at that time whether such damaged *Sphagnum* was alive or dead.

By the start of formal recording in 1979, a few small pockets of evidently living *Sphagnum* had appeared within the transects and much of the singed material still remained, though looking increasingly moribund. The base-line data therefore contained very low levels of all *Sphagnum* species except *S.magellanicum* and *S.capillifolium*, both of which were recorded as large but singed hummocks.

There is no need to look at the response of every species in the intervening years, but the data for two species in particular reveal the way in which the process of summing the cover-abundance values is able to highlight different recovery responses in different *Sphagnum* species.

***a) S. capillifolium***

Initially the data for this species indicated a moderate cover-abundance value, but it can be seen from Figure 6 that in the following year this value drops dramatically, in fact by more than 65%. This represents the decay of hummocks which in 1979 were still being recorded as possibly alive. By 1980 the decay of such material was so advanced it was clear that the majority of these would not recover from the stem apex.

A steady recovery from the low of 1980 eventually results in a return to 1979 levels, although the majority of the total is derived from scores which are "present" only. This represents the appearance of small axillary shoots emerging through the decaying layer of upper stems and branches.

There is then another set-back between 1983 and 1985, this time because two of the transects were affected by leached preservative from the boardwalk, which was removed in 1985.

From this time on recovery is steady, with the data for 1992 showing a 100% increase on the values recorded for 1979. Almost one third of the 1992 score consists of semi-dominant or dominant *Sphagnum*, demonstrating, in other words, the re-emergence of hummocks and lawns.

**b) *S. tenellum***

This species shows a very different type of response, as can be seen in Figure 7. From a condition of almost complete absence at the start of the study in 1979, it undergoes a rapid expansion to reach a maximum cover-abundance within five years. This abundance far exceeds any values achieved by any other *Sphagnum* species and reflects the fact that *S.tenellum* is a coloniser species, particularly of wet bare peat.

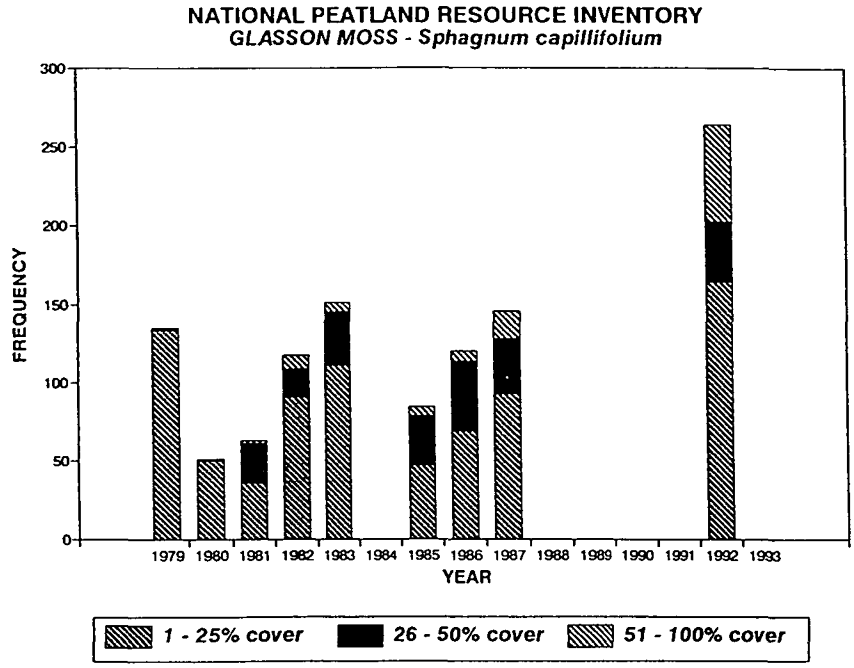


Figure 6: The frequency of cover values for the combined data from six transect isonomes on Glasson Moss, north-west England, for the period 1979-1992. The data for each year are summed for each of the cover classes, and presented as a stacked bar for each year. Thus it can be seen that almost all records for 1979 consisted of cover value 1 (1-25%), whereas by 1992 more than one third of the records consist of cover values 2 (26-50%) or even 3 (51-100%).

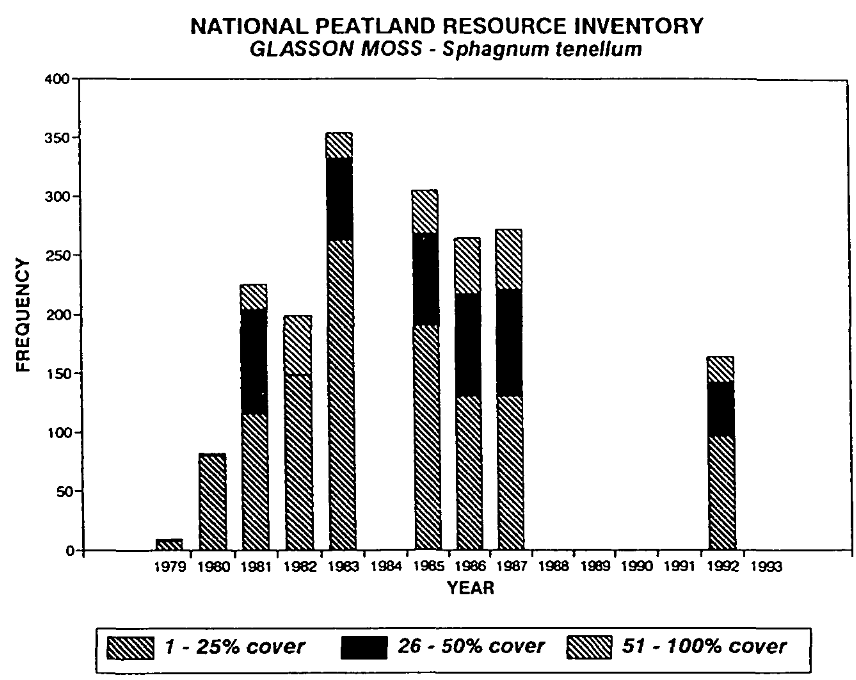


Figure 7: The frequency of cover values for the combined data from six transect isonomes on Glasson Moss, north-west England, for the period 1979-1992. The data for each year are summed up for each of the cover classes, and presented as a stacked bar for each year. In contrast to the response of *Sphagnum capillifolium* in Fig. 6, *S. tenellum* can be seen to have been almost completely lost after the fire of 1976. Its recovery is, however more dramatic, followed by a steady decline as this pioneer species is replaced by other *Sphagna*.

The decline in abundance after 1983 indicates the steady swamping of *S. tenellum* mats by more robust *Sphagnum* species as they re-establish their former patterns of distribution and abundance. On a natural bog, *S.tenellum* has only a limited niche within the surface pattern, and the decline observed here simply reflects the gradual transition from *S.tenellum* as coloniser to *S.tenellum* as minor component of the natural vegetation cover.

**The spatial pattern of species responses**
What is not evident from the cover-abundance totals is whether species are recovering by expansion from small foci of remnant living vegetation, or whether the steady rise in abundance values are caused by a more widespread but thinly-scattered recovery.

Examination of "transect maps" for particular transects reveals that both forms of recovery can be found. For example, Figure 8 shows a transect map for *S.capillifolium* and *Calluna vulgaris* from 1980 and 1992. It is immediately evident that recovery of *S.capillifolium* in this case is entirely due to lateral expansion of small pre-existing foci. In other words, the remnant hummocks have begun to grow and expand.

This contrasts with the response shown by *Calluna vulgaris*. The virtual dominance of the transect by this species in 1980 is very evident, as is the subsequent shift in abundance, though not distribution, in 1992. In this case the species is not altering the boundaries of its distribution, merely its relative dominance within the overall vegetation.

**Detection of technical problems**
Reference has already been made above to the decline in *S.capillifolium* as a result of leachate from treated boardwalk. This proved to be a significant problem on two transects and the quantitative and spatial analyses for these two bear this out. However, a more unexpected impact was also revealed through a combination of these two analytical techniques, backed up by evidence from stereo photographs taken of the transect.

One of the transects in the unburnt strip of vegetation was recorded originally as supporting quite considerable quantities of *Sphagnum*, particularly *S.magellanicum*, and possessed a relatively common assemblage of typical bog species. By 1993 the transect had changed very considerably. The cover-abundance values for *Sphagnum* had declined sharply whereas those for *Eriophorum angustifolium, Calluna vulgaris* and a variety of alien weed species had increased, quite dramatically in the case of the first two species.

Examination of the species transect maps revealed a significant pattern. As can be seen from Figure 9, *E.angustifolium* changed from being relatively constant but at low abundance throughout the transect, to almost complete dominance at either end of the transect. In contrast, *Sphagnum* cover is reduced to almost nothing during the same period.

On examining the stereo photographs, and also from observations in the field, it is evident that this vigorous growth is associated with the tall marker posts placed at either end of the transect. Birds have been perching on the posts, depositing faeces and seeds onto the vegetation at this point. The observed changes are thus, unfortunately, almost entirely due to the process of monitoring. These posts have since been modified to render them unsuitable for perching birds.

## 7. Hydrological Monitoring

7.1. Although probably the most fundamental aspect of a peatland system, particu larly a bog ecosystem, hydrology is all too

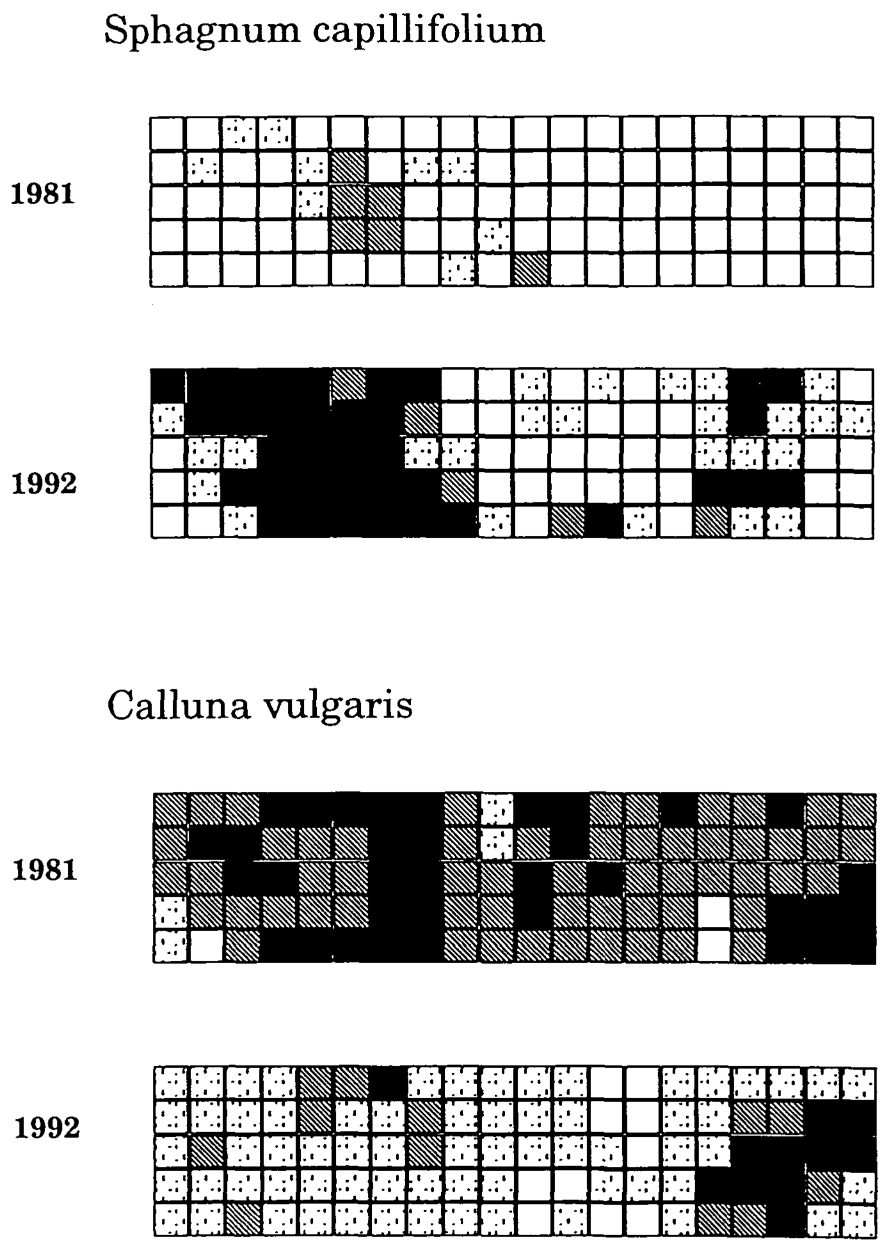


Figure 8: The pattern of recovery from a severe fire in 1976 on Glasson Moss raised bog shown by two characteristic bog species. The data represent a single transect isonome recorded on two dates (1981 and 1992). Data are represented for two species recorded within the transect. The shading represents the different cover-abundance values used, as described in the text: white=absent, small dots=present, hatching=common/semi-dominant, black=dominant.

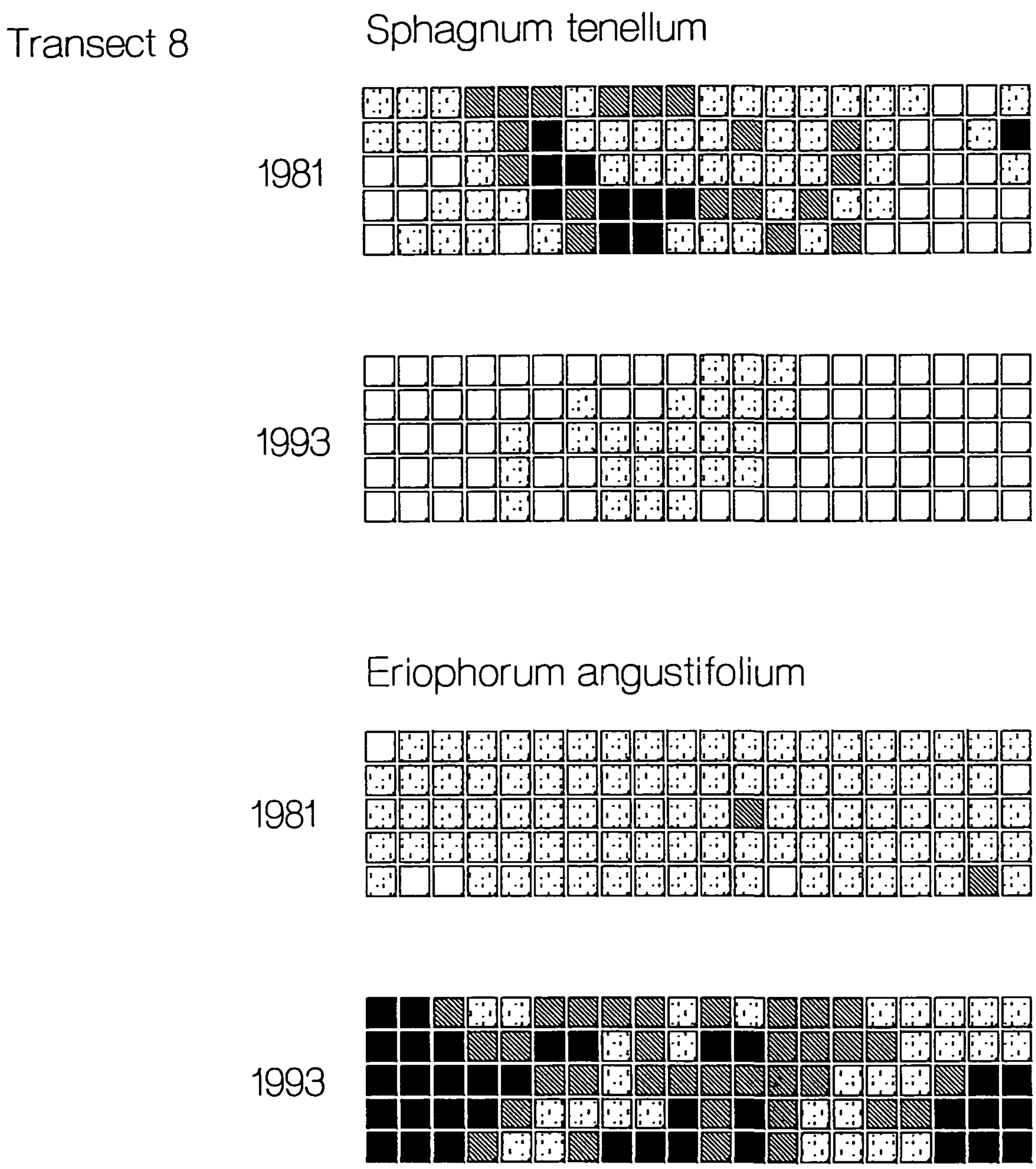


Figure 9: The pattern of change shown by two characteristic bog species within an unburned area of Glasson Moss. The data represent a single transect isonome recorded on two dates (1981 und 1992). Data are presented for two species recorded within this transect. The shading represents the different cover-abundance values used, as described in the text: white=absent, small dots=present, hatching=common/semi-dominant, black=dominant. The marked decline in *Sphagnum* cover and the even more dramatic increase in the cover of *Eriophorum angustifolium* indicate a transect heavily influenced by bird faeces. The birds perch on transect marker posts located in the bottom left and bottom right of the transect.

often either ignored in monitoring programmes, or is added merely as an afterthought. Various reasons are given for this, the most frequent being that hydrological monitoring is expensive, that it is complex to interpret, or that it requires too long a time-period to obtain a base-line.

To some extent all these are, or can be, true but it is also possible to set up a relatively simple system which, though incapable of providing detailed and comprehensive data, can nevertheless give an extremely useful picture of the water regime and any changes which it may be undergoing.

The hydrological package is based on the principle of a bog as a two-layered system, with its thin surface *acrotelm* and its underlying mass of *catotelm* peat. These two have differing hydrological properties and it is thus not appropriate to try to use a single approach for them both.

**Monitoring of acrotelm hydrology**

The water table in a natural peat bog should remain within a few centimetres of the bog surface for almost 95% of the time, only falling to 20-30 cms during extended dry spells. The water table in drained peat, however, spends a much greater proportion of the time at lower depths, and penetrates deeper into the peat than an undisturbed water table. Low water levels are thus lower, and occur more frequently, on a damaged bog. This altered pattern can be picked up using a relatively simple system of measurement.

A pipe, sunk into the peat, and within which are a float and a specially modified tape measure with little foam pads set in a channel. When the float sinks with the water table it draws down the lower of the foam pads, which is then left in place on the tape when the float rises once more. Similarly at the height of the water table rise, the float pushes the upper pad to a different, high position on the tape. In this way a reading is obtained for the maximum and minimum positions of the water table during the interval between readings. These **max-min water level recorders** are cheap to construct and easy to read, therefore it is possible to have an extensive network of such instruments across a site (BRAGG et al., in press).

Readings taken, say, once a month give three times the volume of data compared to the normal dipwell system because each visit obtains a maximum, a minimum, and the current water table reading. More significantly, however, these instruments provide a clear picture of the depth to which the water table sinks whereas if it happens to rain on every one of the twelve days for which dipwell readings are taken over the year (a not impossible circumstance in Britain), the data will simply indicate high water levels at all times.

Another means of detecting water table change in the acrotelm involves the use of the vegetation and its associated microtopography as a form of biological indicator. WOIKE & SCHMATZLER (1980) illustrate a generalised sequence of change which may be observed in the vegetation and surface pattern where a bog undergoes progressive de-watering. Steady loss of the *Sphagnum* component of the vegetation and its replacement by dwarf shrub communities, then eventually woodland, is matched by loss of *Sphagnum*-dominated hollows which are overgrown by lawn or ridge communities. With continued de-watering the surface pattern vanishes altogether, leaving a flat, bare peat surface.

Actual examples of this have been observed on blanket mire in Scotland and northern England (Scottish Natural Heritage, unpublished data) where surface patterns which adjoin areas of coniferous afforestation have progressively lost all trace of their original *Sphagnum* hollows. The reverse process has also been observed, whereby a formerly de-watered site surrunded by mature forestry plantation has regained its *Sphagnum* hollows within only a year or two of damming the surrounding forestry drains (Scottish Natural Heritage, unpublished data). A similar recovery from a fire-damaged surface, changing from a relatively flat condition lacking any evident pattern to a markedly hummock-hollow topography, can also be seen in the transects from Glasson Moss.

**Monitoring of the catotelm hydrology**

The hydraulic conductivity of catotelm peat is very low even in drained bogs. An instrument to measure water table behaviour in the catotelm therefore needs to be very sophisticated. It must be concerned with very slow rates of flow rather than with water table fluctuations because the water table never falls so low that it penetrates the catotelm, at least in undisturbed bogs. The rates of flow are so slow that detecting and measuring them involves highly complex and expensive instrumentation. If resources are limited it is therefore necessary to measure the water regime of the catotelm using less expensive, indirect means.

The prime response of the catotelm to de-watering is one of consolidation and oxidation - in other words the whole mass of peat begins to shrink. Detection of this shrinkage is possible by anchoring a solid rod into the underlying mineral base, and measuring the movement of the peat surface in relation to this rod. Seasonal changes can be expected in even a natural bog, whereby the catotelm swells in winter and shrinks in summer (*Mooratmung* of PRYTZ 1932), but longer-term trends can also be detected in this way.

The shrinkage of peat in the East Anglian Fens has been documented in this way with the famous Holme Fen Post, an iron pillar from the great Crystal Palace Exhibition. This pillar was sunk into the ground until its top was level with the bog surface at Holme Fen, just prior to drainage of Whittlesea Mere, the last of the great Fenland meres, in 1855. The top of the Holme Fen Post now stands more than four metres above the present ground surface, purely as a result of shrinkage and oxidation of the peat soils (DARBY 1983).

Perhaps more poignantly, there is a road which crosses Clara Bog, in Eire, called the "Famine Road". It was dug at a time when the staple food of the local communities, the potato, had failed catastrophically due to a fungal blight. Many thousands died of starvation during this period, but some were fortunate to find themselves part of work-aid programmes. In exchange for food, local people were given the task of constructing a road across what was, at that time, a huge, impassable bog. The work must have been desperately hard, but still it was better than starving. Today, on a telegraph pole beside this road, is a red-painted line which is some 3 metres above the present road surface. The line represents the original level of the bog surface when the road was dug, and Clara Bog now consists of two quite distinct domes which are still undergoing changes, separated by the "Famine Road". Those who worked on the construction of this road can hardly have guessed that they had set in train a process of change which would still be taking place more than a century later.

We in conservation, particularly wetland conservation, should constantly be aware of the need to construct our conservation and monitoring programmes in terms of such long timescales, rather than those more commonly applied to short-term economics, because the concepts of "sustainablity" and "wise use" seek evidence of long-term survival and enhancement of our natural resources. A steady decline in these resources, no matter how gradual, represents ultimate failure not only for us as conservationists but also for subsequent generations, who will otherwise inherit a world in which the supposedly infinite variety and bounty of Nature is increasingly found to be all too evidently finite. We must hope that such future generations will look on our present efforts with gratitude instead of despair.

## REFERENCES


BRAGG, O.M., P.D. HULME, H.A.P. INGRAM, J.P. JOHNSTON & A.I.A. WILSON (in press): A maximum-minimum recorder for shallow water tables, developed for ecohydrological studies on mires. Journal of Applied Ecology, Technical Report.

BURTON, R.G.O. & J.M. HODGSON (Ed.) (1987): Lowland Peat in England and Wales. Soil Survey Spec. Surv. No. **15**.

CHAPMAN, S.B. & R.J. ROSE (1986): An assessment of changes in the vegetation at Coom Rigg Moss National Nature Reserve within the period 1958-86. Wareham, Institute of Terrestrial Ecology, Furzebrook Experimental Station (contract report to NCC; ITE Project 1092).

DARBY, H.C. (1983): The changing Fenland. Cambridge, Cambridge University Press.

EUROLA, S., S. HICKS & E. KAAKINEN (1984): Key to Finnish mire types. In: European Mires, ed. by P.D. MOORE, 11-118. London, Academic Press.

IVANOV, K.E. (1981): Water Movement in Mirelands. London, Academic Press.

KERSHAW, K.A. & J.H.H. LOONEY (1985): Quantitative and Dynamic Plant Ecology. 3rd ed., London, Arnold.

LINDSAY, R.A. (1977): Glasson Moss and the 1976 fire. Nature Conservancy Council (unpublished report).

LINDSAY, R.A., J. ANDREWS, J. GORDON & P. IMMIRZI (In Press): Lowland Raised Bogs in Great Britain - a preliminary assessment: The National Peatland Resource Inventory (NPRI). Edinburgh, Scottish Natural Heritage.

PRYTZ, K. (1932): Der Kreislauf des Wassers. Samfund, Copenhagen, Danmark Naturvidenskabelige.

REID, E., G.N. MORTIMER, R.A. LINDSAY & D.B.A. THOMPSON (in press): Blanket bogs in Great Britain: an assessment of large-scale pattern and distribution using remote sensing and GIS. In: EDWARDS et al. (eds.) Large-Scale Ecology and Conservation Biology. Oxford, Blackwell Scientific.

SLATER, F.M. & A.D.Q. AGNEW (1977): Observations on a peat bog's ability to withstand increasing public pressure. Biological Conservation **11:** 21-27.

WOIKE, M., & E. SCHMATZLER (1980): Moore. Bedeutung - Schutz - Regeneration. Bonn, Deutscher Naturschutzring.



### Address of the authors:

**Richard Lindsay & Sarah Ross**

Scottish Natural Heritage
2-5 Anderson Place
Edinburgh EH6 5NP
UK