Approaches to Swiss Mire Monitoring

A. GRÜNIG, G. M. STEINER, CH. GINZLER,
U. GRAF & M. KÜCHLER

Abstract: Following a referendum in 1987, the Swiss Federal Government introduced regulations that set strict terms and targets for the protection and rehabilitation of mires. Three national inventories have been established, each designating sites of national importance embracing 550 bogs, 1.200 fens and 90 mire landscapes. It is now the duty of the 26 Swiss cantons to implement compulsory mire conservation measures in order to obey the federal law, which states that mires of outstanding beauty and national importance are to be preserved in their entirety. Where feasible, regeneration operations should be implemented on mires already suffering disturbance. According to this legislation mire protection in Switzerland comprises both quantitative and a qualitative aspects and, consequently, the size of mire sites of national importance must not be reduced and their diversity with respect to structure, types, vegetation, and species richnesshas to be maintained or improved. There are different ways to achieve the protection required by legislation and there is an on-going discussion about the best way to reach both the legislation targets and a general acceptance by landowners and users. Considering the high cost of public and private efforts involved in the national mire conservation scheme it is important to detect advantages and disadvantages of the different implementation procedures as early as possible. A stepwise procedure has been recommended to achieve this, starting with evaluation of the implementation of the regulations and measures by the cantons and ending up with monitoring of their effects on mire habitats. Therefore, in 1993, the Advisory Service for Mire Conservation was commissioned by the Federal Office of Environment, Forests and Landscape to develop a sensitive nationwide long-term mire monitoring strategy in order to reveal discrepancies between targets and reality. It was also directed to provide scientific results that would enable the authorities to evaluate and revise their protection policies. The basic problem of any nature conservation monitoring scheme is to answer the following questions: "How is it possible to get precise information from vague estimates?" and "Which is the most efficient method to detect changes in space and time?" Thus, to develop a successful monitoring approach it is absolutely vital to set clear objectives, have an appropriate sampling design and conduct a professional baseline assessment of the target sites. The Advisory Service for Mire Conservation has developed and tested several methods to assess both the quantitative and qualitative aspects of mire change. The pilot survey of „Gross Moos" in Schwändital (canton of Glaris) is presented in this paper as an example.

Key words: habitat evaluation, indicator values, mire conservation, mire monitoring, remote sensing, sampling design, vegetation change

Introduction

There are on-going debates about the difference between monitoring and research. We think there is no clear distinction, although some would have us believe otherwise. Much basic research depends on repeated survey and observation. This is especially the case with mires, where only sound monitoring programmes can produce evidence of long-term effects, e.g. of a given management regime or climatic change.

To emphasise this, we present some results of an international co-operative project to develop a national monitoring programme for the mires of Switzerland.

Since the 1987 Referendum, when the Swiss voted in favour of the Rothenthurm amendment to the Federal Constitution, strict terms and targets for the protection and rehabilitation of mire sites have been laid down by legislation and the responsible Federal Authorities. According to this

Tab. 1: Synopsis of the different mire inventories of Switzerland

Mire inventories	Number of sites	Total mire site area [ha]	Average size [ha]	% of the country's surface
Raised bogs	549	1.524	2.8	0.037
Fenlands	1.163	19.186	16.5	0.465
Total mire habitats	1.314	20.710	15.8	0.502
Mire landscapes	89	87.334	981.3	2.115

Tab. 2: Development of federal mire protection in Switzerland since 1978

Year	Raised Bogs	Fens	Mire landscapes	Events / Monitoring
1978	Start of survey			
1979	↓			
1980	↓			
1981	↓			
1982	↓			
1983	↓			Submission Mire Conservation Referendum
1984	End of survey			
1985				
1986		Start of survey		
1987		↓		Referendum accepted by the Swiss people
1988		↓	Start of survey	
1989	Consultation phase	↓	↓	
1990	Negotiations	End of survey	↓	
1991	Enactment of Bog Decree	Consultation phase	End of survey	
1992		Negotiations	Consultation phase	
1993		Negotiations	Negotiations	Studies for nationwide mire monitoring
1994		Partial enactment of Fen Decree, 1st series	Negotiations	↓
1995		Negotiations	Negotiations	↓
1996	Start of 2nd survey	Partial enactment of Fen Decree, 2nd series	Enactment of Mire Landscape Decree	Implementation of a national mire monitoring scheme
1997	↓	Negotiations		Start monitoring bogs and fens, 1st cycle
1998	↓	Partial enactment of Fen Decree, 3rd series		↓
1999	End of 2nd survey			↓
2000	Consultation phase			Start monitoring mire landscapes
2001	Negotiations			↓
2002	Negotiations			Monitoring bogs and fens, 1st cycle completed
2003	Enactment of revised Bog Decree			Start monitoring bogs and fens, 2nd cycle

„Mires and mire landscapes of outstanding beauty and national importance are protected areas. The construction of any kind of building or installation whatsoever, and any operations changing soil structure are strictly prohibited."

A set of three national inventories has been established to comply with the demands for interpretation and definitions in the field of mire conservation: a bog, a fen, and a mire landscape inventory (Tab. 1). Based on these surveys, about 550 bogs, 1.150 fens and 90 mire landscapes have been designated as being of national importance (and some are still waiting to be classified).

The whole ratification system appears to be a rather tedious and time-consuming exercise (GRÜNIG et al. 1986), considering that systematic mire conservation started as early as 1978 with the raised bog survey (Tab. 2) and that 15 years ago it was hoped that the whole procedure could be concluded - at least on the federal level - in 1997 for the bogs and 2004 for the fens, respectively. In reality, however, the implementation of the whole mire conservation project was (and still remains) several years behind schedule (GRÜNIG 1994, OFEFP 2002).

It is the responsibility of the 26 cantons to devise and implement compulsory mire conservation measures, for which they have several options.

In view of the high level of public spending and private efforts involved, the obvious question inevitably arises as to which cantonal measures best meet the objectives of mire conservation and legislation. A national scheme to monitor the designated mire habitats is required to answer this question. Consequently, the Advisory Service for Mire Conservation was commissioned by the Federal Office of Environment, Forests and Landscape in 1993 to develop a sensitive long-term and nationwide mire monitoring strategy. This should reveal as early as possible any discrepancies between conservation targets and actual developments. It should also become a practical instrument providing the people responsible for conservation with feedback about their measures and scientific results and enable them to evaluate their policies and adapt them to the actual situation.

General Approaches to Monitoring of Habitats

The basic problem of any nature conservation monitoring concept can be summed up with the following questions:

- What are the objectives of the monitoring scheme?
- What target surfaces and key factors are to be monitored?
- Which is the most appropriate procedure (sampling design) to monitor the effectiveness of conservation measures and to detect as early as possible significant changes in space and time?
- What will it cost?

The answers to these questions as applied to the monitoring programme of Swiss mires can be summarised in the the main objectives of Swiss mire conservation stated in the Federal Decree on the Protection of Mire Habitats: "The mires of outstanding beauty and national importance are to be preserved in their entirety. In mire areas already suffering disturbance, regeneration operations should be implemented where feasible."

Preservation of mires "in their entirety" does not only mean that reduction of the size of the protected area cannot be accepted; it also means that deterioration of the quality cannot be tolerated. Hence, to assess the effectiveness of conservation, monitoring should examine both the quantitative and the qualitative aspects of mire conservation.

We propose identifying an appropriate and representative set of reference sites that will be investigated with the necessary precision to arrive at conclusions applicable to all protected mire habitats.

A step-wise procedure is employed to comply with the targets set by the federal decrees (i.e. preservation of both quantity and quality of mires). This should both monitor the implementation of the regulations and measures by the cantons and determine their effects on the conservation of mire habitats (Fig. 1).

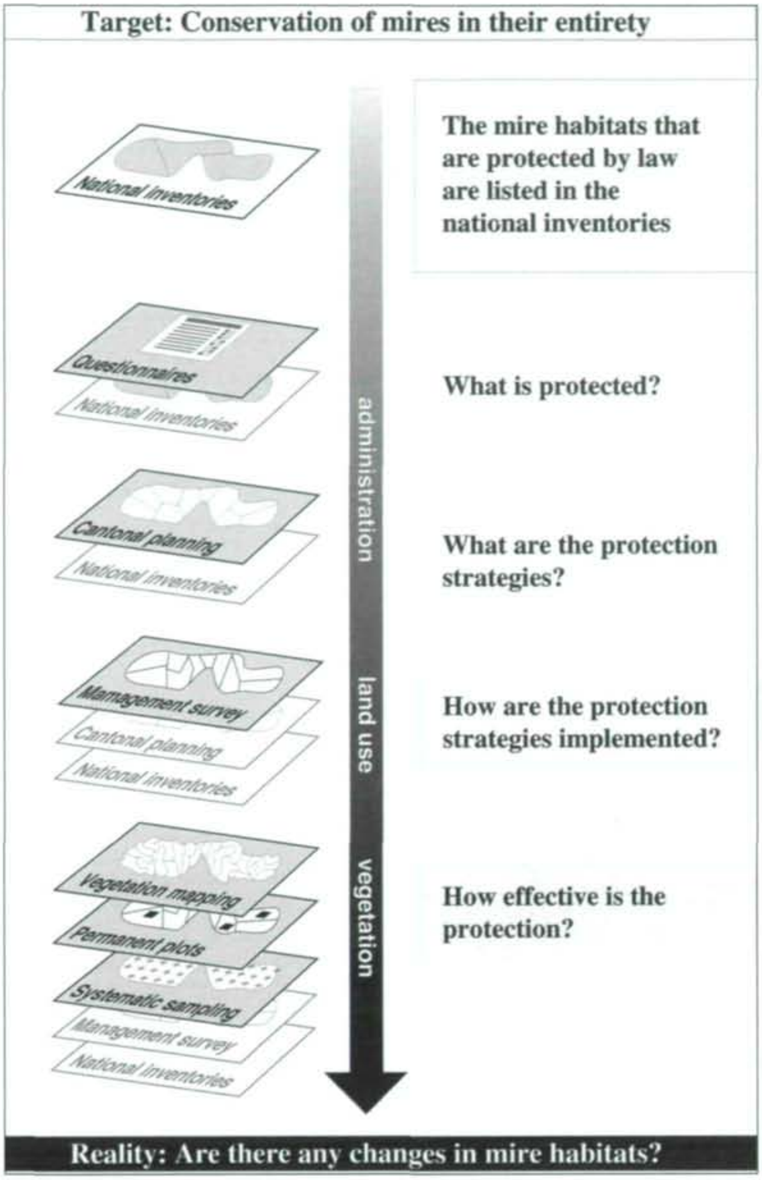

Fig. 1: Conservation of mires in their entirety (modified from LONGATTI 1994)

In Switzerland, there are 1.500 bogs and fens scattered all over the country, covering about 20.000 ha in total (Tab. 1; Fig. 2; GRÜNIG et al. 1986, BROGGI 1990, HINTERMANN 1992, GRÜNIG 1994, http://www.wsl.ch/land/inventory/mireprot/besmos/projekte/versuchsanordnung-en.ehtml). The aim of a national mire monitoring scheme is to obtain unbiased information on the site conditions on the whole surface of the peatlands under investigation. Therefore, a procedure providing meaningful (representative) and statistically verified information on any changes in area or quality is needed. But, the optimal monitoring design can only be selected when cost-efficiency is involved (KÖHL et al. 2000). Consequently, choosing a representative sample of sites is both a first and absolutely vital step for

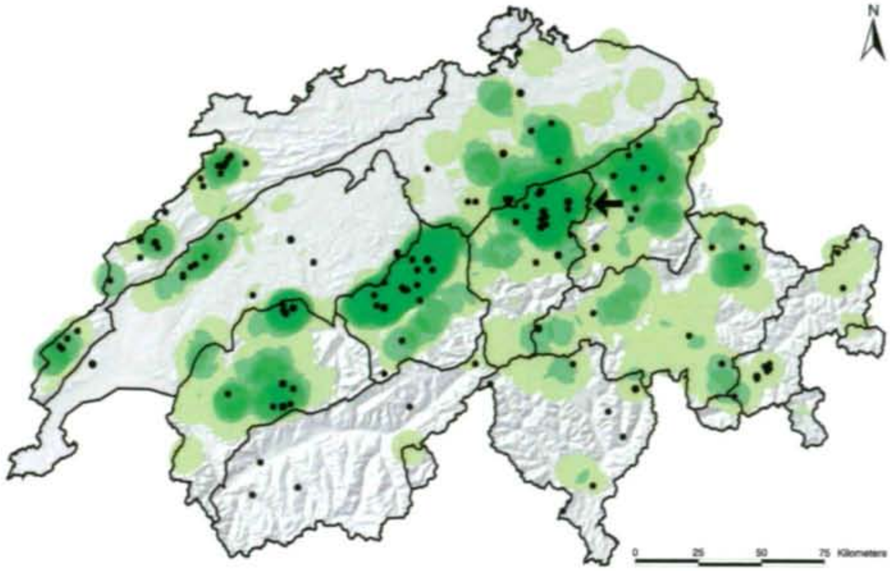

Fig. 2: Distribution of bogs and fens showing (by green colour) the densities of occurrence of mire habitats of national importance summarised by 1 km squares of the Swiss National Grid. 124 black dots mark the monitoring sites selected according to a stratified random sampling procedure. (The 1st 5 year cycle comprises 103 sites. To enable sampling with partial replacement in the 2nd 5 year cycle, an additional sample comprising 21 mire sites is set aside). Also shown are the individual biogeographical mire regions of Switzerland. The Case Study Area of Gross Moos in canton of Glaris is located by an arrow and is not an element of the Swiss mire monitoring sample.

long-term monitoring. However, the selection of the mires must not be completely random. To ensure representativeness, the database of both the bog and fen survey had to be stratified according to various criteria:

- to give more weight to landscape types (i.e. bio-geographic regions) with few mires;
- to give preference to mires at low and high altitudes over those at medium altitudes;
- to give raised bogs more weight than fenlands, which are twelve times as frequent (Tab. 1);
- to give preference to the few large mire areas over the small ones which are much more frequent.

The resulting sample of 124 representative mire sites, as shown in Figure 2, will be surveyed at regular intervals to monitor possible changes in the mire habitats themselves. In addition to developing an optimal sampling design on the national level, there was a need to identify appropriate indicators and methods to assess the quality of site conditions in the field.

How to Detect Changes in Mire Habitats?

To find an answer to the question "Which method or which combination of methods is the most appropriate for describing mires and their changes in space and time?", it is necessary to focus on the reality of observing and measuring.

Both a survey of the literature and a study report suggest that a national monitoring scheme to detect even small changes in mire systems as early as possible is a very ambitious project that must be particularly sophisticated in the following objectives (GRÜNIG 1998):

- definition of clear aims and targets;
- selection of representative sites (biotopes, habitats) to allow inter-regional comparisons;
- selection of sensitive variables (i.e. indicators) and appropriate criteria of significance;
- choice of the methods which should be cheap and robust for both data gathering and data analysis;
- recording of raw data and to avoid the collection of derived or interpreteded data
- flexibility, so as to allow modification.

In 1993, when the Advisory Service for Mire Conservation was commissioned to develop a nationwide mire monitoring strategy (GRÜNIG et al. 1996), an international co-operative project was started between the Universities of Vienna and Berne and the Swiss Federal Institute for Forest, Snow and Landscape Research. This project focussed on rehabilition of the Canton of Glaris's largest, most damaged and highly diverse bog complex, Gross Moos, covering almost 20 ha at an altitude of about 1.250 m. Gross Moos is a sloping percolation mire, which was drained about 100 years ago and subsequently grazed heavily by cattle.

The data gathered during the baseline assessment for the Gross Moos rehabilitation study (GRÜNIG & STEINER 1994) proved to be very valuable for the evaluation of both the quantitative and qualitative aspect of the Swiss mire monitoring programme. Several indicators and methods - e.g. vegetation cover and its floristic composition, hydrology, the trophic status, remote sensing techniques, etc. - have been tested to assess both the qualitative and qualitative change of mire habitats which should remain untouched or be returned to a state as natural as possible. As vegetation cover and especially its indicator values derived from floristic composition provide much useful information on the ecological conditions pertainig at a site (HILL et al. 1999) - hence on habitat quality, too - it serves the purpose of monitoring environmental changes as well. In addition, vegetation can be investigated rather easily at relatively low cost. Therefore, selecting vegetation as a key indicator is not only a sound scientific solution but also an economical solution, and this approach to mire monitoring fits very well into a long-term and nationwide monitoring concept.

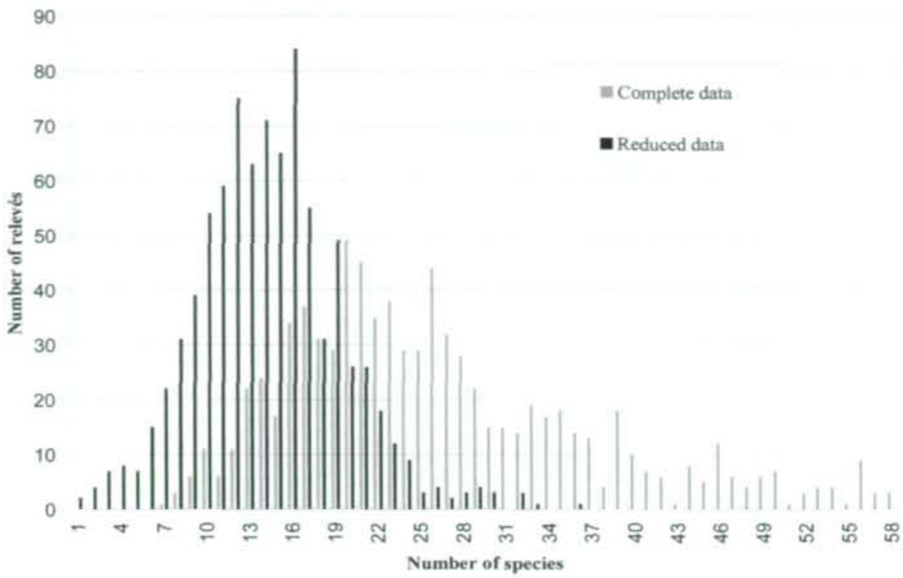

Fig. 3: Distribution histogram of 856 relevés of about 15 m² from Gross Moos with all species (grey) and a reduced species list (black).

Alternatives of Recording and Analysing Changes in Vegetation

Vegetation recording methods

Complete versus reduced plant species list

It is often argued that for monitoring, a reduced plant species list is optimal, as this can make it easier to recognize the species in the field and therefore reduces the observer bias between different surveyors recording vegetation relevés. Reduced field-work time is said to be another benefit of this method (MARTI & TSCHANDER 1995) However, a test of a complete versus a reduced species (specifically without mosses) list carried out in Gross Moos in 1995 showed that the reduction of species is linked with a big shift of the distribution curve (see Fig. 3). The use of a reduced species list results not only in a change of both the mean and the shape of the distribution curve, but also in a considerable loss of information. In fact, this is not consistent with the general monitoring objectives claiming to collect whenever raw data.

Relevé size

It is well known that an increasing vegetation relevé size is correlated to some extent with increasing plant species numbers. The reason for this is that usually the site homogeneity of the vegetation plots decreases with increasing size, hence the diversity of microsites within the habitat may permit more species to occupy specialised microenvironments within the community (HARPER 1977) This hypothesis is also supported by the findings from a representative sample of 53 nested vegetation plots recorded in the open mire area of Gross Moos (Fig. 4; to locate the plots see the triangels in Fig. 12).

On the one hand the findings from the nested plot data of Gross Moos do support DIERSSEN (1982) who recommended 1 m² being the most appropriate size to describe hummock-hollow complexes of raised bogs, but on the other hand, there is a discrepancy between the Gross Moos data and textbooks

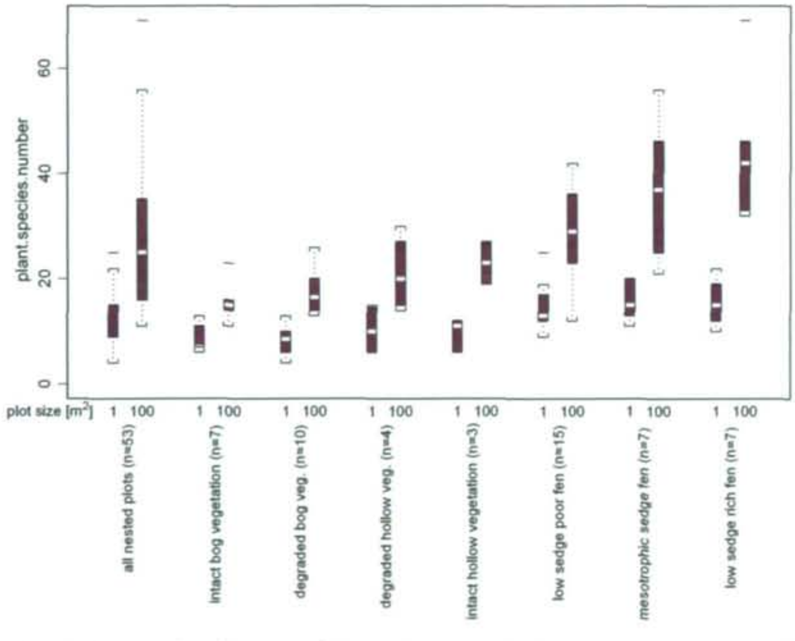

Fig. 4: Plant species diversity of Gross Moos recorded in a representative stratified random sample of 53 nested vegetation plots of 1 m² size and 100 m² size, respectively, in relation to the plant species diversity of seven mire vegetation units. The vegetation units are arranged according to a trophic gradient ranging from very poor to quite rich site conditions. The solid horizontal line in the box plots is located at the median of the species number data, and the upper and lower ends of the boxes are located at the upper quartile and lower quartile of the data, respectively. Hence, the box, i.e. the interquartile range (IQR) comprises 50 % of the data and provides a useful criterion for identifying outliers. Any observation which is beyond the whiskers, i. e. more than 1.5 x IQR above the third quartile or below the first quartile is a suspected outlier marked by a horizontal line.

(e.g. DIERSCHKE 1994) suggesting an ideal plot size of 25 m^2 for recording fens and other wetland vegetation types. To overcome these problems, the use of patches of variable size (of about 200 to 500 m^2) and the greatest site homogeneity possible seems to be the appropriate method for both a reliable record of raw data sets in the field and a sensitive description of (mire) habitats and their plant species diversity. For the identification of such spatial units or homogenous habitat patches, high resolution aerial photographs can be a very useful tool (see Fig. 8).

Ecological indicator values

"The basis of indicator values is the realised ecological niche. Plants have a certain range of tolerance of temperature, light, soil pH, and so on. If we whish to make inferences about the ecological conditions pertaining at a site, much useful information can be obtained from the flora. Indeed, the flora may indicate quite a narrow range of conditions" (HILL et al. 1999). Ecological indicator values represent the habitat conditions in which species occur under normal (natural or near natural) competition. In most cases, the values are estimates, prepared by well-trained vegetation ecologists in Germany (ELLENBERG et al. 1992), Switzerland (LANDOLT 1977), and Great Britain (HILL et al. 1999). The following values are available for Switzerland and Central Europe: nutrient, soil reaction, humidity, light, temperature and continentality; and only for Switzerland, humus and dispersity values (soil porosity). The Ellenberg-values for Central Europe are ranked into 9 classes (humidity into 12), the Landolt-values for Switzerland into 5 classes. The mean values together with their deviations are normally used for the characterization of a vegetation sample (plot, patch, unit) or a habitat (see Fig. 11). For monitoring purposes, mean indicator values for vegetation samples are calculated at intervals over time, and changes are interpreted by reference to the indicator in question. For example, increasing nutrient values are likely to indicate eutrophication.

Using indicator values is a quite effective means to reduce the problems stemming from the subjective observer bias inherent in each vegetation relevé. An other advantage of indicator values is that they may be more sensitive to the requirements of the plants than is a selected physical variable such as depth to the water table.

For special vegetation types (e.g. mire vegetation), it is possible to calibrate the indicator values using reference data. Before the Swiss mire monitoring programme was launched in 1996, a reference data set of Austrian mires was available containing more than 4.500 relevés (STEINER 1992). The reference data enabled indicator values to be based on particular combinations of species and tuned to specific project requirements.

Remote Sensing Methods

Aerial Photographs

It is possible to document changes over longer periods by means of repeated aerial photographs since each one documents a part of the terrain at a given time and is the medium providing the densest package of information available. The use of stereoscopic CIR (false-Colour InfraRed) aerial photographs is especially recommended for monitoring wetland vegetation (DEVILLEZ & DE SLOOVER 1978, BIERHALS 1988). The scale of the photographs has to be chosen with respect to the resolution demanded for the project.

To provide basic data on vegetation pattern and the spatial distribution of plant communities in Gross Moos pilot study area (and in the Swiss mire monitoring sample at a later period), high resolution CIR aerial photographs at a scale of 1:5.000 were taken in 1994 (see Fig. 8). It is noteworty, that in terms of image resolution even recent satellite images did not cope with the requirements of the Swiss mire monitoring programme.

A priori segmentation of aerial photographs

All land cover features have their signature on aerial photography. These signatures are defined by pattern, colour, structure, texture, and tone. By observing the context and extent of the photo signatures, e.g. peatland boundaries and other mire features, for example, vegetation types, forest edges, drainage ditches, etc., can be delineated by hand by a photo interpreter using a stereoscope to view the CIR stereo-paired diapositives. A possible outcome of such an a priori segementation is shown in Fig. 8 (see the black outlines). Usually, when the work is done by an experienced and trained photo interpreter, most of the delineated spatial units reach certain homogeneity standards with respect to colour composition, structure, and texture(see SCHERRER et al. 1996, for details).

Analytical photogrammetry

Aerial photographs have a central perspective which means that they are more or less distorted towards the margin. Thus, analytical photogrammetry is needed for the geometrical reconstitution of both the terrain surface (e.g. by means of contour lines) and other features in the terrain and to provide basic data for further analysis with geographical information systems (GIS). A more recent method to get a geometrically correct model of the area under investigation is the production of orthophotographs using digital terrain models (DTM) and image processing methods.

Digital photogrammetry and image processing methods

At the beginning of the Swiss mire monitoring programme, several procedures for automated image segmentation (WOODCOCK & HAWARD 1992) were tested, but, too often the calculated patches did not comply with the vegetation pattern and the delineation quality needed for field work was not met. Swiss mire monitoring still relies, therefore, partly on traditional a priori delineation of aerial photographs although, automated image processing can be very useful for the analysis of a priori delineated orthophotographs. In order to assign patches to strata, similarities of colour, structure and texture are used to form a series of two or three dozen strata, which can be regarded to reflect distinct vegetation units. Thus the establishment of the strata is not founded on the occurrence of vegetation types or plant communities observed on the ground, but exclusively on attributes (e.g. colour composition, structure,texture) interpreted and/or assessed in aerial photographs.

The Gross Moos aerial photographs were scanned and digitized for the production of orthophotographs and these were analyzed by means of digital photogrammetry using a HELAVA DPW 770 station (see KÜCHLER et al. 2004, for details).

Sampling Design

One-phase Sampling Designs

A traditional approach in vegetation monitoring is to rely on one-phase sampling designs and assess a set of systematically or non-systematically distributed sampling units and remeasure it at successive occasions. However, in long-term monitoring applications it has often been shown that cost-efficency can be improved by combining information gathered, for example, from remote sensing and field assessment. In the Gross Moos pilot study three one-phase sampling designs have been tested.

1. Systematic sampling of regular vegetation plots

In principle, vegetation surveys relying on systematic sampling (i.e. on systematically distributed sample plots) are strictly field-based assessments. In the office, the data recorded for a single plot are extrapolated to the area represented by the plot (i.e. the surrounding area and/or the surrounding plots) and used to produce e.g. pixel maps.

In the case of Gross Moos, two people and a theodolite (or a DGPS = differential Global Positioning System) were needed to establish about 300 sample points at given co-ordinates and at regular intervals of twenty metres. After two weeks of field work the result looked like Fig. 5.

Afterwards, a trained vegetation scientist had to assess vegetation relevés (of 15 m^2 size each) in the field at the 300 grid points to obtain the relevant information about the state of the vegetation. Together with the data processing, it took another 6 weeks to get a picture of the mire vegetation in Gross Moos. Using the data from this systematic sampling combined with the mean indicator values calculated from the species recorded at the grid points, a variety of information can be garnered, e.g. the trophic status of the site can be derived using nutrient indicator values (Fig. 6).

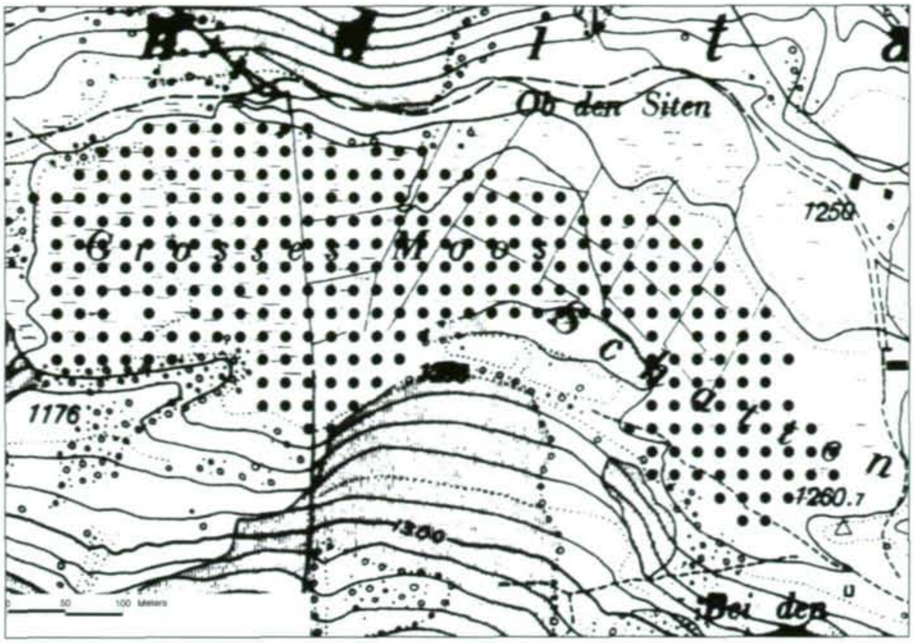

Fig. 5: Location of the 300 vegetation plots of the systematic survey on the Swiss Ordnance Survey map of the Gross Moos Case Study Area. Each plot has a size of 15 m²; the equidistance of the contour lines is 10 m. The missing grid points inside the mire boundary in Fig. 5 and Fig. 6, respectively, result from dense tree stands. The establishment of the grid points in these areas would have been difficult and too expensive for both a test and a regular survey.

Although, systematic surveys are said to be objective, they are in fact only authentic. This means that it is possible to reconstruct the geometric features of the grid and the plots later on, but many subjective decisions still have to be made. For example, the origin of the grid has to be chosen as well as the shape of its perimeter, its orientation and mesh-width. Comparable decisions on size, shape and orientation are needed to establish the plots. In addition, several studies have shown that vegetation recording on sample plots using area cover by species is prone to observer bias which cannot really be reduced by sample size (see GERTNER & KÖHL 1992, for details).

Also, the grid density of systematic sampling designs has to be fairly large to give a realistic situation of the spatial distribution and frequency of vegetation types, species, and indicator values in the area under concern. Especially, the necessary sample size to detect sensitive and meanigful changes of spatial patterns should not be underestimated (KÖHL et al. 2000).

2. Complete vegetation record by means of mapping vegetation over normal CIR aerial photography enlargements

In order to draw a vegetation map by means of traditional field verification, an experienced phytosociologist (being also a peatland specialist) had to spend one week of field work in the Gross Moos Case Study Area. The vegetation patches were originally drawn by hand in the field over normal, i.e. unrectified, CIR aerial photography enlargements at a scale of 1:2.000. In order to reduce ambiguities of identifying individual vegetation units, a map key – especially developed for mapping mire vegetation – was used.

However, the lack of information on the third dimension, inherent in every normal (i.e. non-stereoscopic) aerial photograph, made often very difficult to identify and delineate vegetation patches and to attribute them clearly to a vegetation unit directly in the field. This was especially true in cases where the vegetation cover did not seem to be homogeneous and clear boundaries between different vegetation types did not exist.

Fig. 6: Kriged distribution of soil fertility at the Gross Moos mire site in 1994. Soil fertility has been derived from 300 mean indicator values for nutrients (or nitrogen) which have been calculated from the vegetation data set presented in Fig. 5.

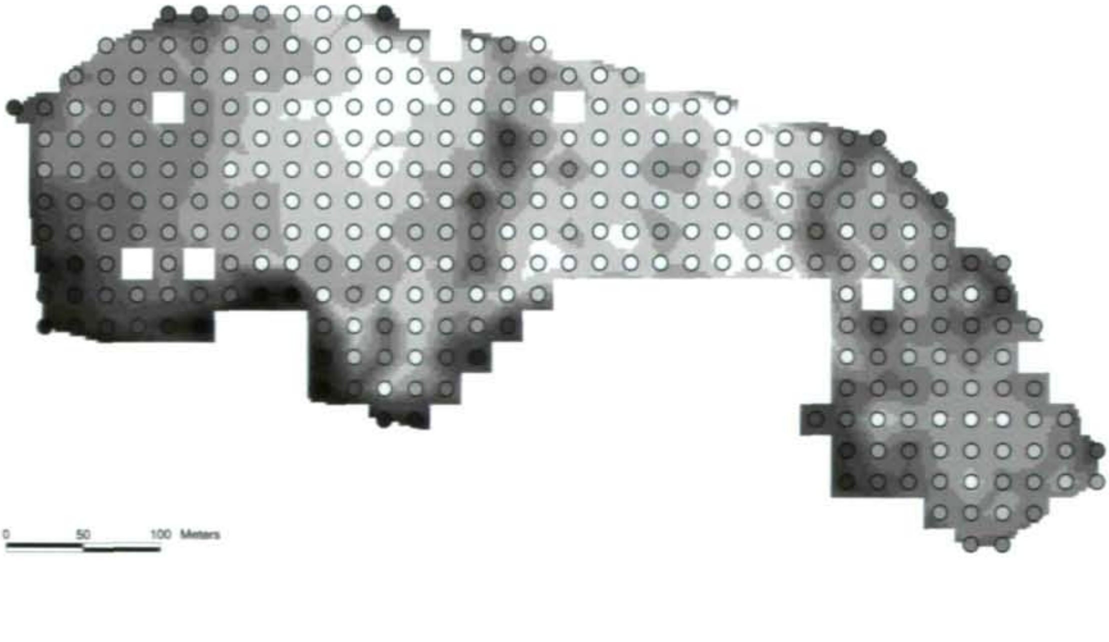

Fig. 7: Overlay of stratified random sampling plots (localised by black dots) from 1994 and the vegetation pattern of Gross Moos mapped in 1993 by a trained phytosociologist using unrectified CIR aerial photography enlargements at a scale of about 1:2.000.

As a result of the inherent distortion, vegetation maps drawn on unrectified aerial photographs are geometrically inaccurate. Therefore, orthorectification was needed to transform the central projection of the aerial photograph into an orthogonal view and to produce the map shown in Fig. 7 which can be used to make measurements and comparisons with other maps or (ortho-) photographs that have the geometric properties of a map.

Another problem arises from the fact that a traditional vegetation map based on a phytosociological map key contains no real raw data about the species composition of the described units but only interpreted data with an unknown inherent bias. Therefore, the detection of both floristic and vegetation changes will be very difficult, even when they seem to be significant. To overcome this problem it is better to use the (preliminary) units of this vegetation map e.g. as the basis for both an improved stratified random sampling and the preparation of a map key enforcing the mapper into establishing a consistent definition of what he has to portray. This procedure was applied in 1994 using vegetation relevés made at the locations marked by black dots in Fig. 7. Some of the resulting vegetation units are shown in Tab. 3.

3. Complete vegetation record based on stereoscopically pre-delineated CIR aerial photographs

In the case of Gross Moos with its complex mire vegetation pattern covering an

Fig. 8: Rectified CIR aerial photograph of Gross Moos taken in 1994 at a scale 1:5.000. The black outlines confine about 1.000 spatial units reflecting homogenous patches which have been delineated a priori in the aerial photograph by a photo-interpreter using a stereoscope. In each of the 1.000 patches a vegetation relevé was recorded in 1995 and 1996, respectively. The yellow outlines confine a sample consisting of 163 spatial units which have been selected representatively for prediction. A soil fertility map of the entire Gross Moos area resulting from such a prediction is shown in Fig. 13.

Tab. 3: Vegetation units of Gross Moos derived from 59 plots of 1 m² in 1994. 1) Caricetum rostratae; 2) Caricetum limosae; 3) Sphagnetum magellanici; 3a) Typical subassoziation; 3b) Subassoziation of *Pleurozium schreberi*; 3c) Subassoziation of *Sphagnum tenellum*; 4) Eriophoro-Trichophoretum, Subassociation of *Sphagnum tenellum*; 5) Forest fragments (Vaccinio-Piceetea); 6) Caricetum nigrae; 7) Campylio-Caricetum dioicae; 8) Drepanoclado-Trichophoretum; 9) Tall-herb and riverside vegetation.

vegetation units	1	2		3		4	5	6	7	8	9
			a	b	c						
	2136	11.2	22.	21.4	.454	413155124323	53442	55.45	153532	43	.46...41..
relevé numbers (n = 59)	3870	6091	221	0268	3491	177558129359	69650	03286	742161	91	.412.2931.
	1195	0108	609	9269	3055	658492246410	07733	84941	413235	81	7330971448
Char. spec. ass. 1											
Carex rostrata	1334	2.11	2+.	1...	1111	..12.+11.1.1	.....	1....	1.....	1.	1..11.....
Char. spec. ass. 2											
Carex limosa	....	3322	...	....	....	1	.....	.....	......	..	....
Scheuchzeria palustris	....	.2.1	...	....	....	....	.....	.....	......	..	....
Diff. spec. ass. 3 & 4											
Sphagnum magellanicum	....	....	.44	231.	.133	5.3.1.32.33.	.....	1.3..	......	..	....
Sphagnum capillifolium	....	....	...	3313	.11.	24..1...1.1.	.+...	...1.	..1..3	..	....
Sphagnum angustifolium	....	....	11.	3...	...1	1	.....	1	......	..	....
Diff. spec. ass. 4 & 8											
Trichophorum cespitosum	..2.	..11	...	....	....	322324315441	.....	.....	......	43	....
Diff. spec. subass. of ass. 3 & 4											
Sphagnum compactum	....	.1.1	...	....	132.	232132+211..	.....	2+1.1	1..1..	..	....
Sphagnum tenellum	....	....	...	....	.1.1	131132	.....	..1..	..+...	+.	....
Gymnocolea inflata	....	....	...	....	.1..	....11.....1	.....	.....	......	..	....
Diff. spec. ass. 6 & 7											
Carex nigra	..2.	.1..	..1	2...	1232	211.21.21.1.	2..+.	12223	211122	..	.11...3...
Carex echinata	..22	...1	212	..31	2..1	..11211211.1	..1.+	.12.2	2.....	2.	.1.1......
Juncus filiformis	....	....	1+.	....	..11	..1.........	.....	..1.1	2.....	..	.1.4......
Diff. spec. ass. 7 & 8											
Carex flacca	....	....	...	....	....	....	.....	.....	...13.	.2	....
Carex flava	..2.	....	...	....	.1..	.1..........	.....	.....	.322.1	12	1
Oxycocco-Sphagnetea											
Eriophorum vaginatum	....	...1	122	.2..	12.3	2212..331.1.	.....	.....	1....1	..	....
Carex pauciflora	....	...1	1.1	2...	1...	..11..111111	.....	.....	......	..	....
Andromeda polifolia	....	...+	..1	2...	....	111...12...2	.....	.....	......	..	....
Polytrichum strictum	....	....	..2	2...	1..2	2.1...13..2.	.....	1+...	......	..	....
Vaccinium uliginosum	....	...+	...	.1..	....	1...........	.....	...1.	......	..	....
Drosera rotundifolia	....	...1	...	....	....	..1.+1..1.1.	.....	.....	......	..	....
Vaccinio-Piceetea											
Picea abies	....	....	...	..5+	....	1.1.+++.++..	....+	5+...	.+.+..	..	.....4....
Hylocomium splendens	....	....	...	1..1	....	....	.....	.....	1	..	....
Pleurozium schreberi	....	....	...	2+11	2...	11..........	131..	1....	.2++.2	..	...53.....
Dicranum scoparium	....	....	...	.+11	1...	....	+1...	1....	......	..	....
Homogyne alpina	....	....	...	2...	....	.1..........	..14.	.....	..2..2	..	...1......
Vaccinium myrtillus	....	...1	...	.235	1..1	11..........	33..1	1....	..+..1	..	....
Vaccinium vitis-idaea	....	....	...	.121	1..1	.1..........	.....	1....	......	..	....
Rhytidiadelphus squarrosus	....	....	...	..1.	....	....	..44.	+.11.	21+...	..	.+.1.13..3
Polytrichum formosum	....	....	...	..1.	....	....	+4...	1....	......	..	....
Sphagnum girgensohnii	....	....	...	..1.	1...	....	2	.....	......	..	....
Scheuchzerietalia & Caricetalia nigrae											
Eriophorum angustifolium	+121	22.1	.1.	2...	..11	.1..21..1213	.....	.....	...1..	1.	....
Polytrichum commune	3...	....	322	2..1	1.22	...11.......	..2.2	1.2.1	..1...	..	...13.1...
Sphagnum recurvum	5...	....	112	....	....	....	.....	..1.2	...+..	..	....
Calliergon stramineum	....	....	..1	1...	..11	..1..+..+...	.....	..211	4...1.	1.	....
Aulacomium palustre	....	....	..1	1...	..21	....1..11...	.....	..11.	1.+..1	1.	....
Viola palustris	....	....	...	....	..1.	....+.......	.....	+.111	11.+..	..	.1..1.....
Agrostis canina	..1.	....	...	....	..+.	....	.....	..2..	2...2.	..	.2........
Sphagnum russowii	....	....	54.	2...	..21	....	..4..	.....	......	..	....
Sphagnum subsecundum	....	...+	...	....	....	.......1+.11	.....	..1.1	...1..	1.	....
Equisetum palustre	....	....	...	....	....	....	.....	.....	.1++..	..	..111+....
Caricetalia davallianae											
Drepanocladus revolvens	....	.511	...	....	....	..1....1.1.	.....	1	21.1..	12	....
Tofieldia calyculata	....	....	...	....	....	.1..........	.....	.....	.1.+.1	+1	....
Juncus articulatus	....	....	...	....	....	.....+......	.....	.....	.1.1..	..	....
Juncus alpino-articulatus	....	....	...	....	....	....	.....	.....	..1..1	22	....
Trichophorum alpinum	....	....	...	....	....	...........+	.....	..1..	......	11	....
Campylium stellatum	....	....	...	....	....	....	.....	.....	.1..11	1.	....
Companions											
Juncus effusus	....	....	...	..+.	1.1.	....	.....	.....	.12...	..	....1.....
Calluna vulgaris	....	...1	...	.2..	...2	34..1.1.1...	1....	.....	..11.3	..	....
Molinia caerulea	4...	...1	321	2.1.	1.22	232.21121222	1....	.12+2	2132.2	12	.+........
Potentilla erecta	....	...+	212	2.1.	.221	121.1+..121.	1.23.	.1122	122.22	13	.1.21.....
Nardus stricta	....	....	...	....	.51.	.2..1...1..	5.+4.	.2231	333332	.3	.3.1......
Agrostis stolonifera	....	....	...	....	....	....	..11.	+...1	......	..	21212+1.1.
Polygonum bistorta	....	....	...	....	....	....	...1.	1....	......	..	1..21....1
Descampsia cespitosa	....	....	...	....	....	....	1	.....	......	..	..1.2.222.
Taraxacum officinale	....	....	...	....	....	....	.....	.....	......	..	.+.11..1.1
Climacium dendroides	....	....	...	....	....	....	.....	..121	.1....	..	..2..++...
Calliergonella cuspidata	....	....	...	....	....	....	.....	.....	......	..	331.......
Caltha palustris	....	....	...	....	....	....	.....	.....	......	..	1.11112.1.
Scirpus sylvaticus	....	....	...	....	....	....	.....	.....	......	..	3.321.....
Trifolium repens	....	....	...	....	....	....	.....	.....	.1.1..	..	.31....1.4
Trifolium pratense	....	....	...	....	....	....	.....	.....	1...1.	..	111
Lotus corniculatus	....	....	...	....	....	....	.....	.....	...11.	.1	........1.
Prunella vulgaris	....	....	...	....	....	....	.....	.....	.+.+1.	.1	1.1.1...11
Alchemilla vulgaris	....	....	...	....	....	....	.....	.....	......	..	1.1.....11
Senecio alpinus	....	....	...	....	....	....	.....	.....	......	..	2.1.13.121
Chaerophyllum hirsutum	....	....	...	....	....	....	.....	.....	......	..	1.2..2111.
Cardamine amara	....	....	...	....	....	....	.....	.....	......	..	1...1+1.1.
Glyceria fluitans	....	....	...	....	....	....	.....	.....	......	..	1...1...22
Filipendula ulmaria	....	....	...	....	....	....	.....	.....	......	..	2...1....2
Poa annua	....	....	...	....	....	....	.....	.....	......	..	121
number of species/relevé	....	...2	111	111.	1111	121.11111111	1.11.	1.111	122222	11	1111211.11
	5283	3640	124	9059	6379	507784438354	05106	89967	701500	88	5368150875

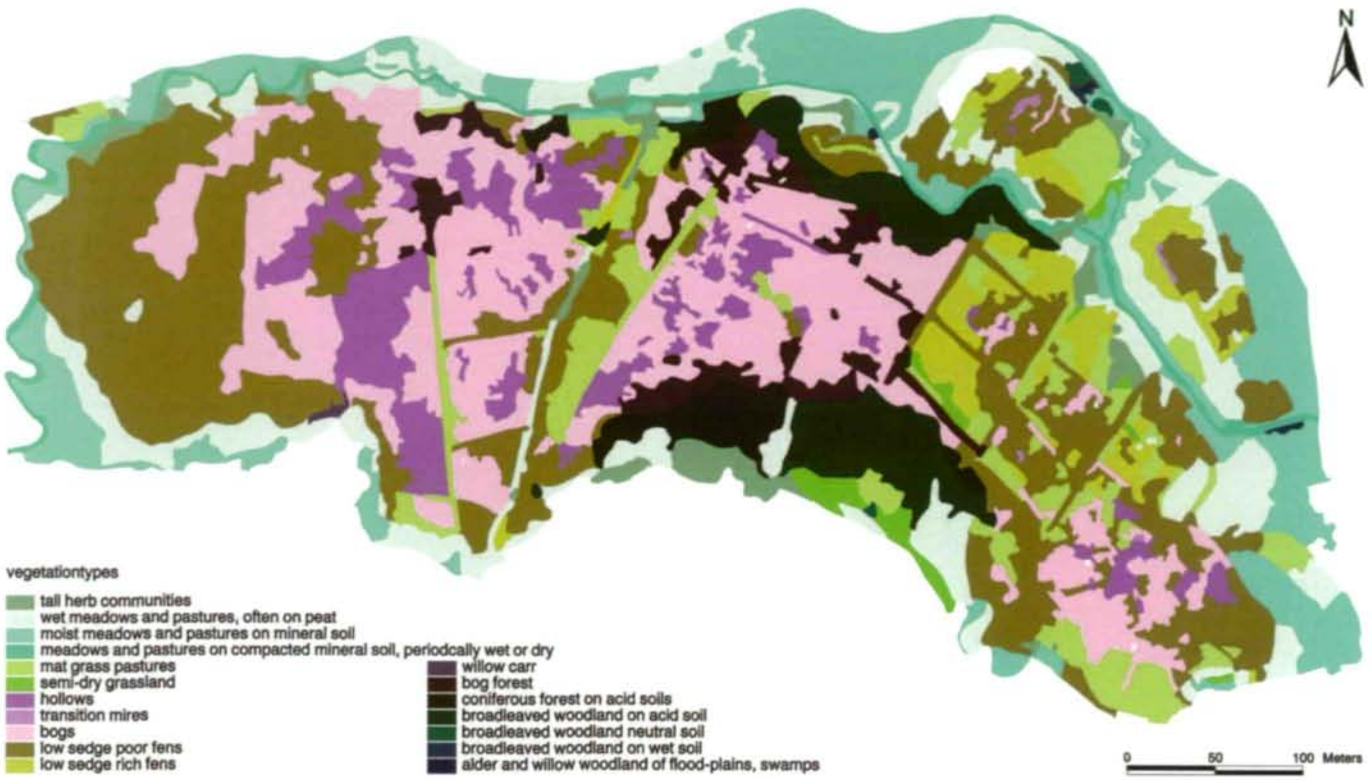

Fig. 9: Vegetation units of Gross Moos derived from both 1.000 delineated spatial units and the relevant complete vegetation data set recorded in 1995 and 1996, respectively.

Fig. 10: Distribution of *Primula farinosa* in Gross Moos showing both the recorded occurrence of the species (black dots) and their predicted distribution (gray shading) as derived from the complete vegetation data base. Comparison with Fig. 9 and Fig. 11, respectively, reveals that *Primula farinosa* and its predicted distribution pattern are fairly good indicators of low sedge rich fens.

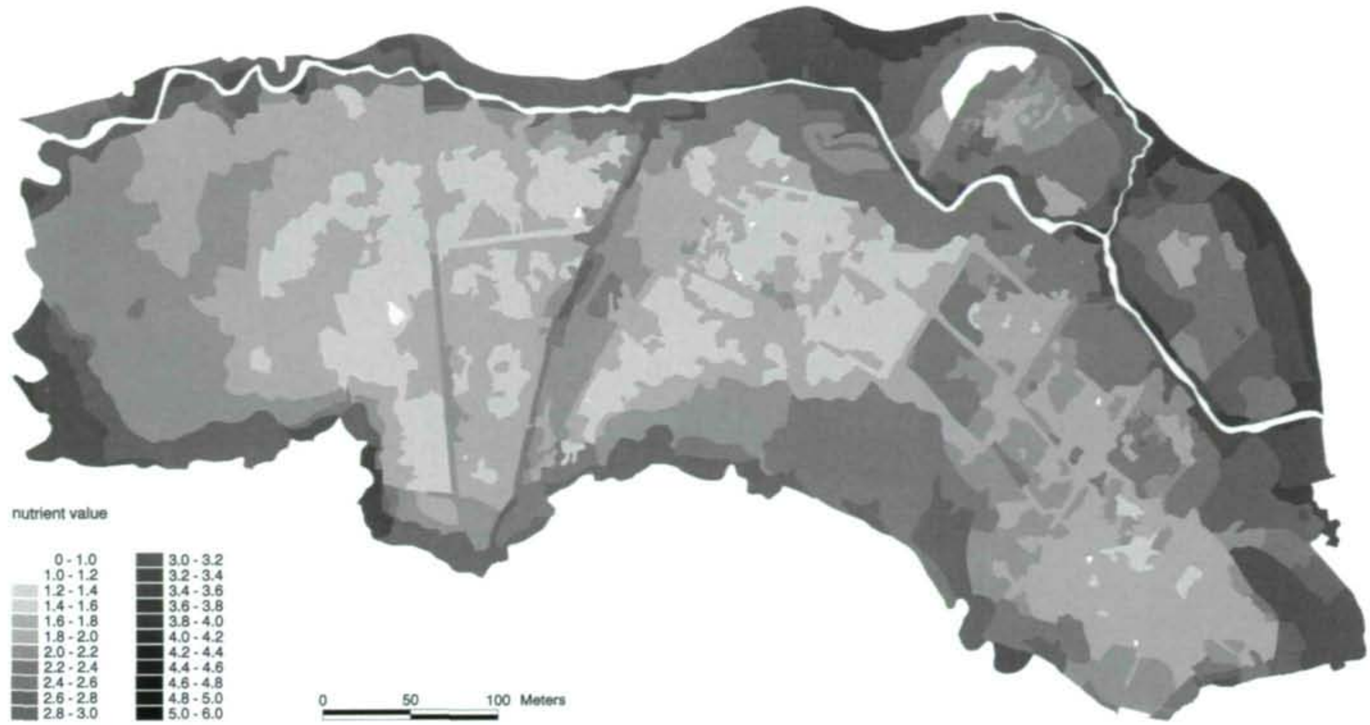

Fig. 11: Soil fertility or trophic status of the Gross Moos area derived from a combination of 1.000 delineated spatial units and the mean nitrogen indicator value calculated from the respective vegetation relevé.

area of 20 ha, the analysis of the aerial photographs was done in two and a half days by an experienced photo-interpreter using a stereoscope to view the CIR stereo-paired diapositives. The delineations of the vegetation boundaries represent about 1.000 vegetation patches which are homogenous in terms of photo signature, i.e. colour, structure and texture on the photograph (see the black outlines in Fig. 8 and Fig. 10, respectively).

With this interpreted orthophotograph in hand, a skilled vegetation-scientist assessed in 1994 traditional Braun-Blanquet vegetation relevés within each delineated surface or patch. The aim was to get as complete a list of the species as possible, including the mosses. The abundance was estimated by a logarithmic scale. The data were processed by means of multivariate statistics. An outcome received after 12 weeks of work is shown in Figure 9.

Based on this exhaustive dataset, it is possible to produce a distribution maps of individual species or to calculate the potential for a certain species to occur in a given patch. The results of the two processes can be combined (see Fig. 10 and KÜCHLER 2004, for details).

It is also possible to calculate an average indicator value for each vegetation relevé or patch from these data and, thus, a rather detailed map of the trophic status of the Gross Moos can be derived (Fig. 11).

Compared, for example, with a vegetation survey based on systematic sampling (see Fig. 6), the complete vegetation record method using delineated aerial photographs provides, for roughly the double of the costs, a much more realistic picture of the spatial distribution of, for example, soil fertiliy in the whole Gross Moos Case Study Area. However, in a mire like Gross Moos, a site that contains at least 1.000 different vegetation patches, the effort to assess the vegetation of the whole area in detail is very great (and expensive). Therefore, there is an evident and urgent need to overcome this temporal and financial bottleneck by more resilient sampling design.

Two-phase Sampling Designs (Stratified Random Sampling)

As a financially more realistic alternative, there are two-phase sampling designs using image-processing methods based on orthophotographs combined with ground truthing on a reduced number of ecologically homogenous vegetation patches. Principally, two-phase sampling designs rely on both

Fig. 12: Topographical strata derived from the Digital Terrain Model (DTM) of Gross Moos area overlaid with stratified random vegetation sampling plots from 1993 (marked with triangels) and 1994 (marked with circels), respectively.

the stratified (hence representative) and reliable selection of the sample units providing the statistically sound raw data of the survey, and

the combination of data of different resolution and quality gathered from different resource, e.g. digital terrain models, remote sensing technique, field assessment, interpreted or derived data, etc.

This is in contrast to one-phase sampling designs which do not rely on stratified sampling approaches.

The principle of stratification is that before the sampling points are selected, the population or the area under study is divided up into groups or strata on the basis of major and usually obvious features and traits including their variations. Thus, the resulting strata are more or less homogeneous in relation to the criteria in question. In each stratum the sampling points are distributed randomly.

In the case of Gross Moos, two different stratification criteria have been used to test two-phase sampling approaches:

1. Selection of a representative set of sampling locations by means of stratification according to topography and geomorphology

To define strata based on topography and geomorphology, patches with similar altitude, inclination and exposition derived from the DTM were overlayed onto a sketch map showing the peatland boundaries and drainage ditches of the Gross Moos area (see Fig. 12). Based on these geomorphological and topographical strata, sampling points have been derived from stratified random sampling. For a preliminary survey, the vegetation of Gross Moos was recorded in 1993 and 1994 at the given sampling points in nested plots (cf. WILDI & KRÜSI 1992) of 1 m^2 and 100 m^2, respectively, and classified using TWINSPAN (HILL 1979) and MULVA-5 (WILDI 1993). Results are shown in Tab. 3, Fig. 4 and Fig. 12, respectively. Preliminary maps derived from this approach could be used as additional collateral information for the next approach.

2. Selection of a representative set of sampling locations by means of stratification in combination with traditional aerial photograph interpretation, remotely sensed data, and digital surface models

The idea underlying to modelling on spectral data is simple: "What looks similar on an aerial photograph is assumed to be similar in nature, too." (KÜCHLER et al. 2004). By relying on both different homogenous patches showing similar colour composition on the aerial photograph, and field inspection, therefore proving that these patches have more or less the same vegetation cover, it is very possible to make predictions about the distribution of different vegetation types within the site under consideration. It is also feasible to gain additional ecological information about the

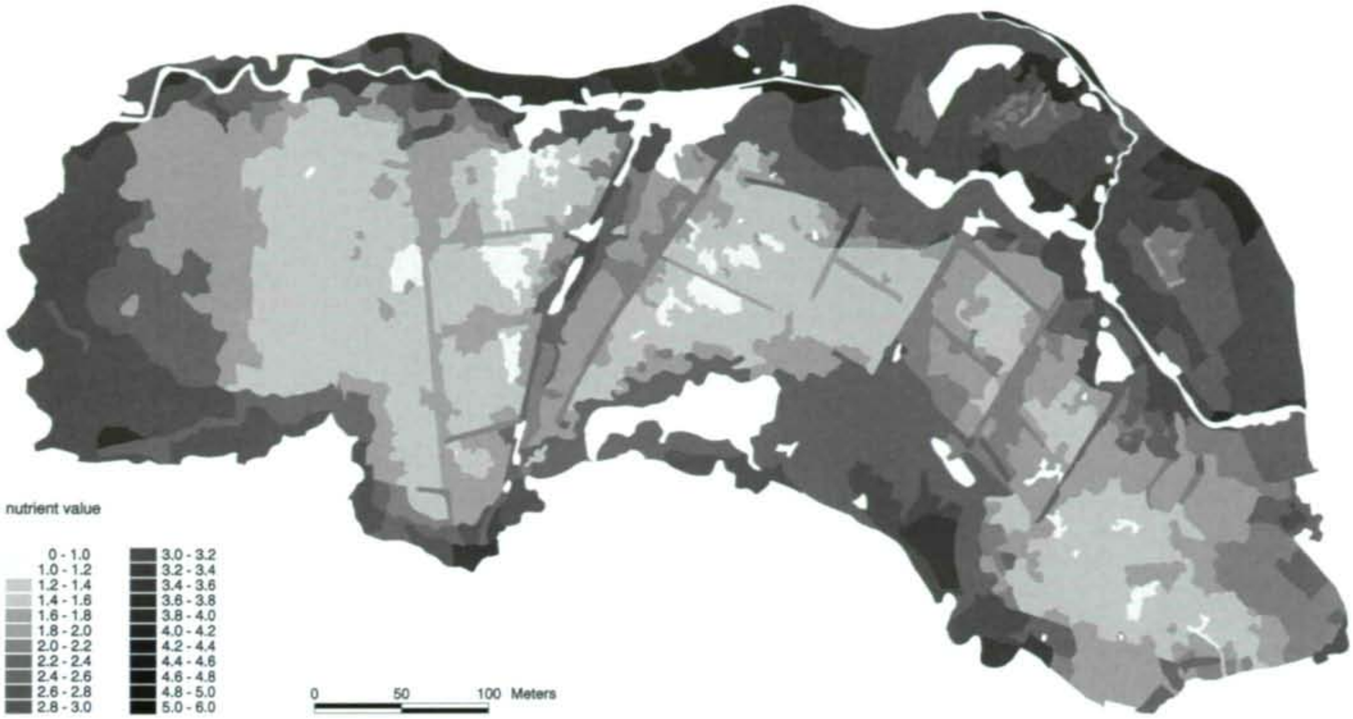

Fig. 13: Predicting soil fertility of Gross Moos area based on mean nitrogen indicator values derived from a sample comprising 167 vegetation relevés and spatial units, respectively (see the yellow outlines in Fig. 8, for localisation). The sample has been selected both representatively and randomly in combination with traditional aeria photo interpretation, remotely sensed data, and digital surface models. Prediction is mainly due to both spectral and topographical similarities among the sample set and the 1.000 delineated spatial units. Blank polygons stand for spatial units "where the corresponding predicted nutrient values have been filtered out because they are extreme with respect to the range of calibration data. The polygons affected mostly represent forest where the ground is completely hidden " (KÜCHLER et al. 2004).

whole site by extrapolation from the vegetation data recorded from selected patches in the field.

To reduce costs, a stratification supported by both traditional interpretation of aerial photographs and image processing methods is applied to sample randomly a limited but representative number of patches for vegetation recording. The performance of several selection procedures and prediction methods as well as combinations of them was tested using the vegetation and terrain (DTM) data of the Gross Moos pilot study. In many cases, the variation of most site factors could be explained satisfactorily by 100 to 200 vegetation relevés (see KÜCHLER et al. 2004, for details.)

In order to give an idea of the method's performance, Fig. 13 shows the pattern of soil fertility in the Gross Moos pilot study area, predicted as mean nitrogen values on the basis od a sample of 167 vegetation relevés, which stand for 167 spatial units selected both representatively and randomly of a population exceeding 1.000 individual vegetation patches (see Fig. 8 and 10, respectively, black and yellow outlines). A comparison withn Figure 11 reveals that the two maps have a quite similar pattern reflecting quite well the main features of Gross Moos. For example, on either map there are more or less infertile bog centres, usually surrounded by vegetation types indicating sites ranging from intermediate fertility to richly fertile. The huge drainage ditches are displayed, too, as well as a small stream winding from South to Northeast amd separating hydrologically the Western part of the Gross Moos mire complex from its Central and Eastern parts. However, a closer inspection of details reveals differences between predicted and observed fertility. According to the limited data set, for instance all ditches are predicted to be nutrient-rich (Fig. 13), whereas, according to all observed data, some of them in reality are not (Fig. 11).

Concernig cost-efficiency of different methods and alternatives, the total cost of obtaining aerial photographs, aerial photo interpretation, and amortization of the technical equipment as well as the field assessment has to be considered. The present method relying on stratified two-phase sampling, remote sensing, and recording 167 vegetation relevés in the field, provides, for roughly both half the cost of systematic sampling (see Fig. 6) and a quarter the cost of a complete vegetation record (see Fig. 9 and 11, respectively), a reasonably realistic picture of the site qualities and their spatial distribution in the whole Gross Moos Case Study Area. Similar tests in other mire sites led also to a considerable increase in efficiency, especially for extensive mire sites. This is evidence that the costs of a monitoring programme can be reduced substantially using stratified random sampling in combination with sophisticated remote sensing technique and reliable ground verification focused on recording unbiased raw data (i.e. complete vegetation relevés).

Conclusions for Application to the 1st Cycle of Swiss Mire Monitoring

Experience from both Gross Moos pilot study and other studies has shown that two-phase stratified random sampling designs combining remotely sensed data, digital surface models, and traditional interpretation of aerial photographs with selected ground truthing, i.e. recording a limited number of vegetation relevés, are most likely to be superior in terms of cost-efficency (KÖHL et al. 2000). Taking into account other side-effects of aerial photographs such as the documentation of a historical situation, providing a piece of evidence for later investigations, and allowing retrospective analysis at a later date, the superiority of two-phase approaches is even more evident.

Although further verification in the field was very satisfactory, we realised that the methodology has not yet been fully elaborated and further research was necessary (see KÜCHLER et al. 2004, for details).

However, based on all this evidence, the initial questions "How is it possible to get precise information from vague estimates?" and "Which is the most efficient method to detect changes in space and time?" could be answered quite satisfactorily, and in 1996, the Swiss mire monitoring programme was initiated at WSL in partnership with the Swiss Agency for the Environment, Forest and Landscape.

To provide valid data for the whole country, a stratified random sample has been drawn from the mires listed in both federal bog and fen inventories. The resulting sample comprises 103 mire sites (see Fig. 2.) These 103 mire sites have been assessed during the first 5 year cycle of the Swiss mire monitoring scheme which was launched in 1998 and finished in 2002. The field work essentially consisted of listing as fully as possible all the vascular plants and mosses occuring within each of the 20.000 homogeneous patches selected in the 103 mire sites. The cover of each species was estimated on a rough logarithmic scale. Together with the aerial ortho-photographs, the terrestrial data form a sound baseline databank which will allow, after an ongoing second 5 year cycle of monitoring and recording, to detect quantitative and qualitative changes of the mire resource in Switzerland.

There is a homepage on the internet that provides further outcomes in detail from every mire site which has been investigated:

http://www.wsl.ch/land/inventory/mireprot/besmos/projekte/ersterhebung-de.ehtml

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Zusammenfassung

Vorschläge für das Moor-Monitoring in der Schweiz – Im Jahr 1987 stimmte das Schweizer Stimmvolk über einen Verfassungszusatz ab, welcher einen verbesserten Schutz der Moore zum Gegenstand hatte. Wider erwarten ging das Referendum positiv für den Moorschutz aus, und die Schweizer Regierung musste eine Reihe von Gesetzen und Verordnungen erlassen, welche für die Moore und Moorlandschaften von nationaler Bedeutung einen strengen Schutz gewährleisteten.

Zur Bezeichnung und flächenhaften Ausweisung der Gebiete von nationaler Bedeutung wurden drei landesweite Inventare erstellt, die 550 Hoch- und Übergangsmoore, 1.200 Niedermoore und 90 Moorlandschaften umfassen. Die Bundesgesetzgebung verpflichtet nun die 26 Schweizer Kantone, diese Moore und Moorlandschaften von besonderer Schönheit und nationaler Bedeutung ungeschmälert zu erhalten. Dies bedeutet, dass die Kantone dafür zu sorgen haben, dass die Moore nicht nur flächenmässig, sondern auch in qualitativer Hinsicht geschützt werden. Insbesondere sind ihre Eigenschaften wie Vielfalt an speziellen Arten, Strukturen, Vegetations- und Moortypen sowie ihre Torfkörper integral zu erhalten oder zu fördern und gestörte Moorflächen sind, soweit sinnvoll, bei jeder sich bietenden Gelegenheit zu regenerieren.

Es gibt mehrere Wege, die Ziele von Naturschutzgesetzen und -verordnungen zu erreichen, und es ist immer zu erwägen, wie gesetzliche Vorgaben mit hinreichender Akzeptanz der Nutzer und Grundeigentümer umzusetzen sind. In Anbetracht der hohen Kosten für Öffentlichkeit und Private, welche derartige Vorhaben auslösen, ist es dringend angebracht, die Vor- und Nachteile der verschiedenen Ansätze so früh wie möglich zu erkennen und gegeneinander abzuwägen. Beim integralen Schutz der Moore und Moorlandschaften, dem bisher grössten Naturschutzprojekt in der Schweiz, war ein schrittweises Vorgehen angezeigt. Die Kantone haben die notwendigen Massnahmen zu ergreifen während der Bund die Aktivitäten mit Umsetzungs- bzw. Erfolgskontrollen begleitet.

1993 erteilte das zuständige Bundesamt für Umwelt, Wald und Landschaft (BUWAL) der Beratungsstelle für Moorschutz an der Eidgenössischen Forschungsanstalt für Wald, Schnee und Landschaft (WSL) den Auftrag, eine hinreichend empfindliche, landesweite Langzeit-Erfolgskontrolle zu entwickeln, die geeignet ist, Unterschiede zwischen den vorgegebenen Zielen und den tatsächlichen Zuständen möglichst objektiv und nachvollziehbar aufzuzeigen. Zudem hat die Erfolgskontrolle wissenschaftlich fundierte Grundlagendaten zu liefern, welche es den Behörden ermöglichen, den Erfolg bzw. Misserfolg von verschiedenen Massnahmen abzuschätzen und unerwünschte Entwicklungen rechtzeitig zu erkennen.

Bei jeder Erfolgskontrolle von Naturschutzmassnahmen stellen sich folgende Fragen: „Wie kann man mit unpräzisen Schätzungen klare Aussagen machen?" und „Was ist die geeignetste Methode, um Veränderungen in Raum und Zeit festzustellen?". Unabdingbare Voraussetzungen für jede Erfolgskontrolle ist die Definition der Grundgesamtheit, die Formulierung klarer Ziele, die Erarbeitung eines angepassten und flexiblen Stichprobenplans (sampling design) und die hinreichend genaue Erhebung des Ausgangszustandes (baseline assessment) der zu beobachtenden Gebiete und Flächen. In den letzten Jahren hat die Beratungsstelle für Moorschutz an der WSL zahlreiche Methoden zur Beobachtung und Überwachung von qualitativen und quantitativen Veränderungen von Moorgebieten entwickelt und geprüft, als Beispiel dafür wird hier die Pilotstudie „Gross Moos im Schwändital, Kanton Glarus" vorgestellt.

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Address of the Authors:

Andreas GRÜNIG
Agroscope, FAL Reckenholz
Swiss Federal Institute for Agri-Ecology
and Land Use Research,
Reckenholzer Str. 191,
CH-8046 Zürich, Switzerland
E-Mail: andreas_gruenig@fal.admin.ch

Gert Michael STEINER
Dept. of Conservation Biology, Vegetation
and Landscape Ecology
Faculty of Life Sciences
of the University of Vienna
Althanstr. 14, A-1090 Vienna, Austria

Christian GINZLER, Ullrich GRAF &
Meinrad KÜCHLER
Advisory Service for Mire Conservation
WSL, Swiss Federal Institute for Forest,
Snow and Landscape Research
Züricherstr. 111, CH-8903 Birmensdorf,
Switzerland