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A framework for monitoring landscape functions: The Saxon Academy Landscape Monitoring Approach (SALMA), exemplified by soil investigations in the Kleine Spree floodplain (Saxony, Germany)

Ralf-Uwe Syrbe[a,*], Olaf Bastian[a], Matthias Röder[a], Philip James[b]

[a] Saxon Academy of Sciences (SAW), Working Group 'Natural Balance and Regional Characteristics', Neustädter Markt 19, D-01097 Dresden, Germany
[b] BuHu and the School of Environment and Life Sciences, University of Salford, Peel Building, The Crescent, Salford, Greater Manchester M5 4WT, UK

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Abstract

A framework for landscape monitoring based on a functional approach is presented. Landscape monitoring is defined as regular, long-term surveillance of landscapes. Suitable monitoring resulting in the early recognition of crucial changes in the environment is a prerequisite if timely counteractions are to be carried out. Such monitoring provides spatially and temporally homogeneous data sets, and allows for adjustment to and validation of ecological models. The peculiarities of the framework presented are as follows. Landscape functions, and ecological conditions and processes are scrutinized from a strong human perspective. The procedure employs various methods based on models, balances, calculations and estimations. Thus, far-reaching data integration is possible, which allows for the drawing of conclusions which are important for human society. The landscape monitoring proposed also follows a differentiated scale-dependent approach (at local, sub-regional and regional levels) with a stepwise integration of data. Data sampling and analysis are organized according to a scale-dependent set of assumptions allowing a problem-oriented approach. The framework is exemplified by changes in soils in a small (16.1 km^2) floodplain in Saxony (Germany). The assessment proposed also takes into account historical data. Essential changes in soils have been established, e.g. losses in humus, deposition of soils by excavation matter and peat degradation. It was found that the percentage of arable land increased, and the groundwater level decreased in several areas. This finds expression in several physical and chemical parameters, e.g. in reduced field and sorption capacities. Therefore, the performances of soil protection functions and of production functions became worse.

Keywords: Landscape monitoring; Landscape change; Landscape functions; Landscape assessment; Landscape indicators; Soil functions; Floodplain

1. Introduction

The term 'landscape monitoring' is regarded as the regular, long-term surveillance of a landscape, aiming at the early recognition, assessment and prediction of landscape change, and focusing on the effects of human impacts.

Landscape changes are considered as qualitative landscape alterations concerning the balance of matter and energy, use of natural resources and landscape aesthetics (Bastian and Steinhardt, 2002). Landscape functions describe the performance of a landscape in the broadest sense. Landscape functions reflect the capacity of natural processes and components to provide goods and services that directly and/or indirectly satisfy human needs (de Groot, 1992). According to Haase (1978), the assessment of the social functions of a landscape is a precondition for relating actual landscape state to economic categories and processes. By investigating changes in landscape functions, fundamental landscape changes relevant to human society can be identified. Such an integrated approach has advantages over methods based on single indicators, such as land cover changes, loss of landscape elements and biotopes, and decrease in biodiversity. For the landscape functions under investigation (see Section 2.3) a large number of assessment methods at different scale levels have been published (e.g. Marks et al., 1992; Knospe, 1998; Bastian and Schreiber, 1999; Bastian and Steinhardt, 2002).

Landscape changes also affect the functions of landscapes. Identifying emerging changes and trends becomes more important in order to counteract unfavourable future developments.

* Corresponding author. Tel.: +49 351 81 41 68 05; fax: +49 351 81 41 68 20.
E-mail addresses: syrbe@ag-naturhaushalt.de (R.-U. Syrbe), Olaf.Bastian@mailbox.tu-dresden.de (O. Bastian), roeder-m@rcs.urz.tu-dresden.de (M. Röder), p.james@salford.ac.uk (P. James).

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Such monitoring can be seen as a prerequisite in working towards sustainable development.

The development of holistic conceptual frameworks and the design of efficient monitoring programmes and their co-ordination are in their infancy, and much more effort is necessary on these matters. Therefore, fundamental research into the scientific basics of landscape monitoring is seen as a priority (Petit and Lambin, 2002).

To date, many specific monitoring programmes have been developed by various institutions. Examples of important long-term international programmes are: the Blue Plan (Antipolis, 1995), ROSELT/OSS (2005), AMAP (2005) and UNEP-WCMC (2005). Though these programmes are rather comprehensive, they are always focused on specific questions, such as biodiversity and water protection. However, few initiatives are multifunctional – one exception is the British Countryside Survey (Howard et al., 2000). Others initiatives are focused on specific land use systems (Dramstad et al., 2002), nature reserves (Luthardt et al., 1999) or on special landscape types, e.g. the Wadden Sea (TMAP, 1997). A frame for worldwide co-operation between national partners is provided by the International Long-Term Ecological Research (ILTER) network; details of which can be found at http://www.ilternet.edu.

The Saxon Academy Landscape Monitoring Approach (SALMA) is a contribution to the German Long-Term Ecological Research (LTER-D) programme, which started in 2005 (http://www.lter-d.de). The monitoring approach is focused on the 'normal' landscape, i.e. it is not limited to protected areas or special landscape types. This approach is also a response to the European Landscape Convention (CMCE, 2000), which requires standardization of landscape-related investigations; therefore, the development of suitable and comparable monitoring methods is necessary. At present, the authors are not aware of another comparable holistic monitoring programme.

The authors describe the main characteristics of the SALMA (Section 2). Following an explanation of the general methodology, the implementation steps are presented (Section 3), and the further development of the methodology is outlined (Section 4). The steps are exemplified by data from soil inventories in the Kleine Spree floodplain. Section 4 surveys whether the presented methodical innovations are satisfying the specific demands.

The Kleine Spree floodplain is a 16.1 km^2 wide part of the Upper Lusatian Heath and Pond Landscape biosphere reserve. It is a Pleistocene lowland in the northeast of the German Federal State of Saxony. Ponds, wet meadows, dunes and pine forests are typical of this landscape. The rivulet Kleine Spree is a branch of the River Spree flowing into the River Havel in Berlin.

2. The Saxon Academy Landscape Monitoring Approach

The landscape monitoring approach described here (SALMA) differs from other monitoring programmes in some key points. One of the most outstanding characteristics is the understanding and treatment of landscape as an entity of natural components, e.g. ecological structure, relief, soil, water, climate, bios (flora, fauna) and land use (see Bastian and Steinhardt, 2002). With regard to soil, however, the whole monitoring procedure can be demonstrated, and the existence of historical soil data allows for temporal comparisons. Therefore, apart from common problems of data sampling, a major challenge facing a monitoring procedure is the integration of data related to different space and time scales into complex statements. For a versatile interpretation of monitoring results clear documentation is necessary, as well as appropriate aggregation and analysis in relation to social and political questions that enable the formulation of hypotheses. As a key concept for the solution of the integration problem, the authors propose the assessment of landscape functions described in Section 2.3 and in Bastian and Schreiber (1999) and Bastian and Röder (2002).

The problem-oriented approach is another characteristic of the proposed monitoring procedure. The selection of indicators (see Section 2.3) relates to a set of hypotheses about current and anticipated landscape changes. By identifying modifications in landscape functions with regard to time, threats which are critical to human society can be revealed.

Finally, the selection of test areas takes landscape classification into consideration (see Section 3.1). The character of reference units influences the detection of landscape changes. This fact is important when implementing a monitoring programme aiming to quantify landscape changes. Otherwise, essential landscape changes could fall into the limits of data accuracy and remain undetected (see Section 3.3).

The SALMA has three main goals: early recognition and quantification of emerging landscape changes, assessment of their consequences and predictions of future alterations. Additional benefits of the SALMA are:

- Differentiation between (for human society) critical and unproblematic landscape changes.
- Tailored data supply for models and for the assessment of landscape functions.
- Problem-oriented research of effects.
- Continuous adjustment of recommendations for effective landscape management.

The SALMA framework (Fig. 1) starts from environmental problems (Section 2.1) that are formulated as hypotheses or assumptions (Section 2.2). To verify these hypotheses and assumptions, relatively simple indicators or the more complex landscape functions (Section 2.3) are selected. The data set to be analyzed depends on the assessment methods applied (Section 2.4). After designing such a problem-oriented framework (Section 3.1), data sampling follows (Section 3.2), indicators are calculated (Section 3.3) and landscape functions are analyzed and assessed (Section 3.4). The results are used to test hypotheses (Section 3.5), to construct meta-data (Section 3.6), and to propose measures to support sustainable landscape development.

2.1. Environmental problems approach

From the beginning, appropriate landscape monitoring should be focused on the problems of landscape change and sus-

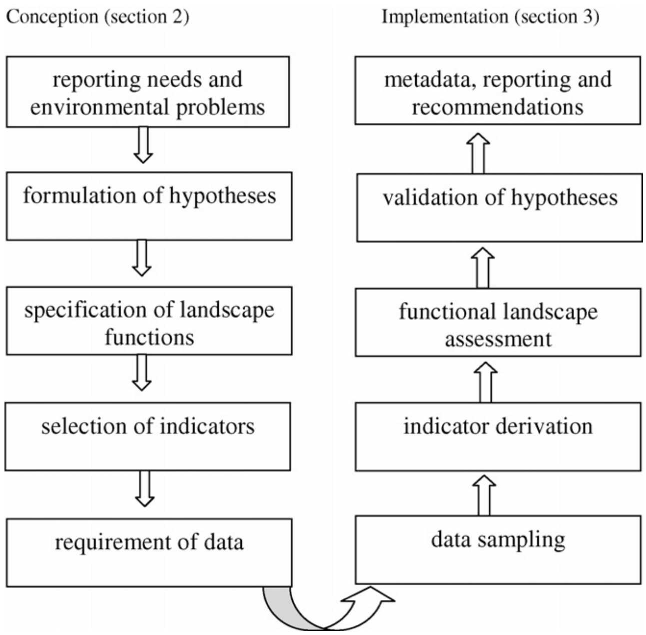

Fig. 1. Landscape monitoring – composition.

tainable use. To guarantee such a problem-oriented approach, a set of hypotheses containing questions and assumptions about possible landscape change and related environmental problems at different scales is established. The general methodology of this monitoring approach is presented in Fig. 2. The themes to be investigated come from different thematic fields (line 1 in Fig. 2). The hypotheses must be formulated exactly with respect to spatial scale and content. The choice of test areas and all measurements should be driven by this set of questions and assumptions (left side in Fig. 2).

The assumptions about anticipated landscape changes give reasons for the selection of landscape functions to be examined within an area. The choice of indicators (see Section 2.3) depends on the functions under consideration and takes account of the specific scale or dimension of each test area (see Section 2.4). The parameters to be measured must be chosen in such a way that the selected assessment procedures can be realized in practice (right side in Fig. 2).

2.2. *Specification of relevant hypotheses and assumptions*

First of all, questions and assumptions about current trends in landscape development are identified. Following this, monitoring tasks arise from practical decisions relevant to landscape ecological problems. These take into account undesired effects, ambiguous and critical development trends, and uncertainties regarding future problems. The success of landscape management, the impacts of human interventions and the effects of environmental changes can be examined in this way. Assumptions allow an evaluation of the goals fixed in landscape plans. They describe possible future landscape changes, which can either support or counter these goals. Knowledge of the spatial differentiation in landscape changes is especially important. Thus, a spatially specified handling of problems arising from landscape changes is needed.

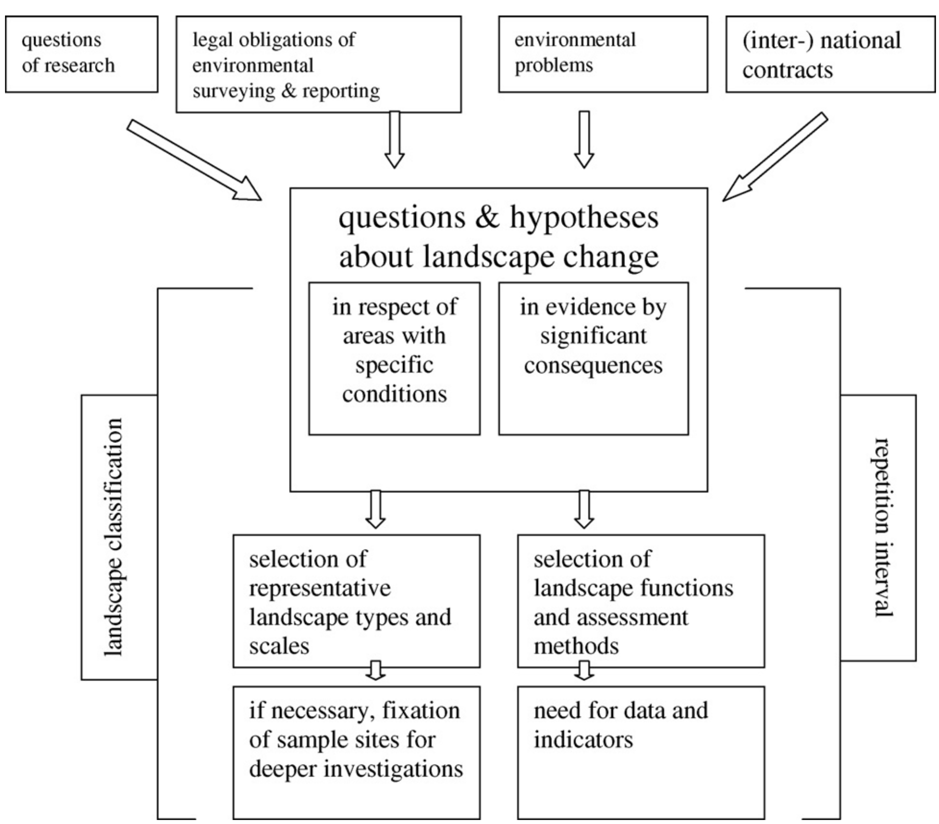

Fig. 2. Landscape monitoring – the concept.

The assumptions relate to landscape indicators and landscape functions. Identification of test areas requires consideration of spatial and scale factors to ensure that they are representative of the whole site. The choice of methods for landscape analysis and landscape assessments depends on scale (Syrbe et al., 2001). Consequently, the scale and size of test areas must be reconciled to financial resources.

As an example, the authors formulated a differentiated set of hypotheses (A1–A6) on the possible future development for the Kleine Spree test area with regard to the problems of soil dynamics. The hypotheses describe chains of effects, which are partly dependent on one another:

A1 Draining floodplain bogs will cause both a lowering of the soil surface and substantial soil degradation. Consequently, the soil substrata will alter and the relief will show several new depressions at the surface.

A2 For economic reasons, the drainage systems will no longer be maintained, and parts of them will decay more and more. The deepest locations in the floodplain could become wet, or they will be flooded again.

A3 Wet and depressed areas will be regarded as favourable places to infill by excavation matter, which is amply available in floodplains, in order to dispose of it and to improve the accessibility of fields and meadows.

A4 Despite cultivation measures, both ecosystems and land use will be more sensitive to extreme weather conditions, pests and other influences.

A5 Areas covered by deposits of excavation material (e.g. from fish-ponds) show homogenized and levelled soil and site conditions. In addition, a more intensive cultivation procedure and the resultant soil compaction will influence habitat and soil functions.

A6 Good accessibility will result in an earlier commencement of land management in spring. Therefore, farmers will tend to remove intensively cultivable and profitable fields from agri-environmental programmes. That will lead to increased loads on floodplain ecosystems.

2.3. Connecting landscape functions and indicators to the hypotheses

In order to verify the hypotheses (in Section 2.2), the following functions have been assessed in the test area: habitat functions (naturalness and landscape habitat value); soil protection functions (nitrate reduction, physico-chemical filtering capacity and groundwater protection); yield potential; water balance and water quality. At the local scale, indicator- and model-based assessment procedures commonly used in landscape planning and Environmental Impact Assessment (Bastian and Röder, 2002; Bastian and Steinhardt, 2002) were applied. At larger (coarser) scales, other procedures are necessary. The authors have developed some methods for such cases. Regional assessment procedures adopt methods appropriate to local scales, but using fuzzy logic, landscape metrics, area-related indicators and higher integrated data (Syrbe, 1995; Bastian et al., 1999; Syrbe et al., 2001).

Table 1
Indicator selection for the Kleine Spree test area

Indicator	Unit
Degree of surface sealing	%
Median annual total runoff	mm/a
Land use proportions	% in 9 classes
Soil humus content	Proportion of land area (7 classes)
Potential cation exchange capacity	Proportion of land area (5 classes)
Usable field-moisture capacity	mm/dm
Groundwater level	Proportion of land area (5 classes)
Cultivated fields in environmental programmes	%
Soil protecting land use	%
Effective mesh size of biotopes	Hectare

Monitoring indicators represent the medium stage of data integration. They abstract from raw data, they integrate different data, and they are related to geographical units. Also, indicators can be a result of balancing, or they are the output of an ecological model. They indicate a change in a landscape quantitatively and are value-free. Indicators can make clear development trends and time balances. If new monitoring frameworks are designed, consideration should be given to incorporating indicators already used in national and international observation programmes, e.g. Environmental Aspects of Sustainable Development (DPCSD, 1999), EEA Environmental Indicators (EEA, 1999), OECD Environmental Indicators (OECD, 2001) or European Biodiversity and Indicator Framework (ECNC, 2002).

Because of the different hypotheses and procedures, it is necessary to specify the indicator design for each scale and test area separately. Table 1 shows the set of selected indicators for the Kleine Spree test area.

2.4. Data concept

The identification of ongoing landscape changes requires data from at least two different time periods; therefore, in order to test the general applicability of the framework proposed, historical data were also included. The example used in this paper refers to the test area 'Kleine Spree' where data from the German Soil Inventory (scale: 1:1500 to 1:2500) from 1937 (southern part) to 1951 (northern part) were used.

Generally, the data set depends on the scale and the specifics of the test area. For that reason, according to scale, data from the following sources were used:

- National: official data (from environmental authorities, data banks and scientific publications).
- Regional: remote sensing and interpolated data.
- Local: field measurements and questionnaires.

Table 2 shows the data programme for the local level.

Because of the high cost, many parameters can be analyzed in small test plots or at single points only. Thus, for soil samples, points which are mostly representative of the whole area under investigation should be selected. A strategy was developed

Table 2
Local monitoring data programme

Component	Methods	Data
Soil	Digging/drilling, in-site measuring, soil samples	Relief situation, soil texture, soil type, humus content, pH-value, cation exchange capacity, C/N-ratio and contents, soil compaction
Water and climate	In-site measuring, water samples	Temperatures, oxygen content, pH-value, inorganic nitrogen, phosphorus, precipitation
Vegetation	Mapping	Biotopes, vegetation units, rare and indicator species, habitat elements
Land use and historical landscape elements	Mapping, remote sensing	Land use type, sealing, landscape elements and state
Land use practices and soil cultivation (management)	Questionnaries	Crops and intercrops, fertilization, agri-environmental programmes

which ensured an objective choice of sample points based on the landscape character (Syrbe et al., 2003). This choice starts from a landscape classification based on different characteristics (soil, relief and land use). The choice considers the spatial statistics. For example, if the percentage of a certain ecotope type with a specific combination of parameters (e.g. a soil type under a specific land use or vegetation cover) is 50% in the whole test area, 50% of all sample points should be assigned to this type. The sample points should be located using a GPS. Sometimes, these points are accessible only with difficulty. In such cases, substitute points can be selected.

According to the variability and importance of the data, three sampling programmes are distinguished. The so-called ‘basic data’ must be determined only during the first monitoring run, because these parameters are stable and no change must be expected. This data set represents a foundation for the efficient continuation of the whole monitoring project. In contrast to the basic data, the ‘monitoring data’ have to be sampled repeatedly. Among the monitoring data a ‘core set’ is defined that should be sampled under all circumstances, because these parameters are especially significant for (further) interpretation. An ‘extended set’ addressing more expensive parameters should be examined as far as possible (by co-operation and depending on the financial resources being made available).

3. Implementation and results

3.1. Monitoring procedure

Having drafted the framework for the investigation (Sections 2.1–2.4), the monitoring procedure can be regularly carried out in all test areas (Fig. 3).

The first step is the data collection (only once) to provide ‘baseline data’ that can be used again and again. The real monitoring procedure, which is repeated regularly, consists of the following steps:

I. Collection of comparable monitoring data on landscape characteristics (Section 3.2).
II. Interpolation and partial integration of raw data through the derivation of quantitative indicators with fixed time and space references (Section 3.3).

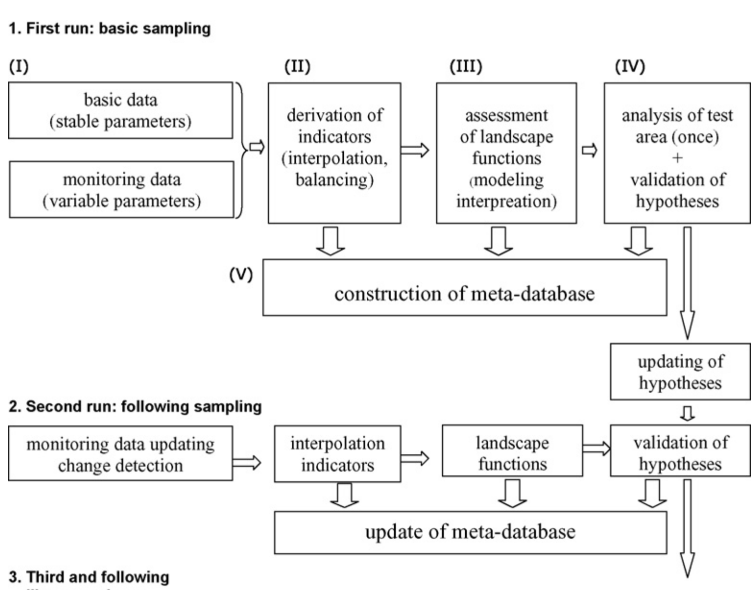

Fig. 3. Landscape monitoring – implementation.

Table 3
Data sampling using soil as an example

Basic data (collection uniquely)	Monitoring data (collection regularly)	
	Core programme	Additional programme
Relief situation	Humus content and humus form	Soil compaction
Soil texture	Upper soil pH-value	Heavy metal contents
Soil horizons and soil type	Upper soil cation exchange capacity	Upper soil nutrient supply
	Upper soil C/N-ratio	

III. Integration through the assessment of landscape functions, modelling and interpretation (Section 3.4).
IV. Validation of hypotheses on anticipated landscape changes (Section 3.5).
V. Construction and updating of a meta-database (Section 3.6) to ensure full information about existing data, progress in work and results.

By comparing with historical data or by structural analyses, even the first snapshot of landscape data can provide valuable results. Two or more snapshots allow multi-temporal analyses and interpretations: comparison of indicators, functions and assessments, and conclusions on trends, maximum loads and actions required when encountering unfavourable trends.

The working steps represent different levels of consideration: (I) data level (baseline data and monitoring data), (II) indicator level (derived and area-referred measures), (III) functional level (modelled or interpreted values), (IV) temporal level (landscape change) and (V) meta level. Each step needs its own methodical approach.

3.2. Data collection

Since 2000, a number of landscape change and landscape monitoring studies have been carried out in several test areas in Saxony (Syrbe et al., 1998; Röder et al., 1999; Bastian et al., 2002; Syrbe and Palitzsch, 2002). As a part of the whole data programme (Table 2), soil data was obtained from field surveys by drilling to establish the soil profile and determine the soil type, collecting samples from the top 1 m and analyzing these samples in the laboratory (Table 3). Temporal comparisons can be made by comparing these data with those from historic records.

The use of historical data is a special approach (distinguishing from the general data concept described in Section 2.4) to achieve two time cuts (one historical + one present) necessary for comparisons.

The German Soil Inventory for Taxation was established in 1934. All agricultural and horticultural land was analyzed and documented by ‘soil inventors’ engaged by the authorities. The comprehensive data is stored by, managed by and available from the financial authorities (AG Bodenkunde, 1994). The German Soil Inventory database contains various soil parameters for all sample points, specified for the different soil layers down to 1 m depth. In addition to measures for natural soil fertility, there is also data on the geological origin, soil texture, humus content, water supply, soil colour and other parameters.

Table 4
Frequency of selected changes in soil characteristics since the German Soil Inventory (1937–1951) in the Kleine Spree test area (*n*: total number of samples)

Change	Proportion (%) (relevant points in soil inventory)
Peat degradation (with profile change)	80.0 ($n = 5$)
Covering by silty sand or gravel	29.1 ($n = 296$)
Essential groundwater level lowering	12.5 ($n = 128$)
Essential humus decomposition by at least one class	9.3 ($n = 345$)

In the Kleine Spree test area of about 16.1 km^2, samples from 345 points are documented in the German Soil Inventory and were re-sampled in this study in 1998–2000. Therefore, all comparisons refer to the sample points included in the German Soil Inventory (1937–1951). The current research was more detailed than the historic inventory. A multiplicity of unexpected changes was observed, including data for parameters that are usually regarded as relatively stable such as soil substratum. Notwithstanding the uncertainty regarding the comparability of the data, various observation were made (Table 4), e.g. groundwater lowering, peat degradation and changes to the surface covering. The German Soil Inventory contains only a few soil profiles for this test area. The Inventory contains text describing each drill site. However, more importantly, the Inventory also documents its results by using maps which detail each drill site. Around each drill site are drawn buffer zones within which it is assumed that the site conditions are valid. Using the Soil Inventory maps it was possible to identify these historic sample points and assess the area again for this study.

Landscape change studies based on historical data often suffer from uncertainties concerning the methods used, and frequently the location of the old sample points (or plots) is not clear. Therefore, the comparability of the data is limited. If monitoring data are used, which are acquired especially for change detection, more reliable statements are possible. In particular, accurate area-related comparisons of landscape characteristics can be made only with those indicators, which are referring to an area (not to a point only).

3.3. Indicator derivation

Only for some indicators was it possible to make a direct comparison with the data from the old German Soil Inventory. The ‘usable field capacity’, the amount of water available for plants held in the soil against the pull of gravity (AG Bodenkunde,

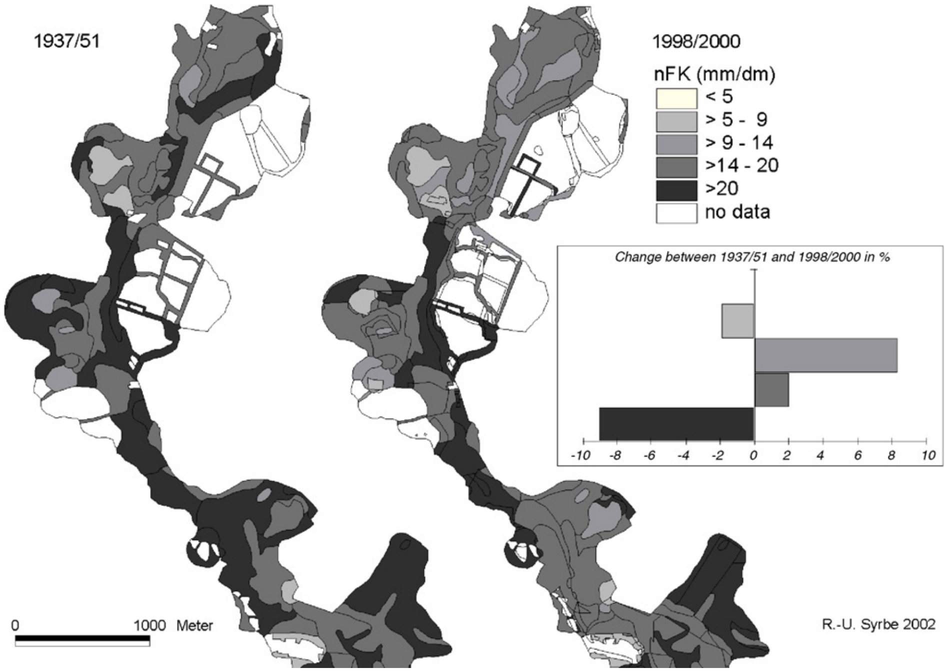

Fig. 4. Changes in the usable field-moisture capacity (nFK) in the Kleine Spree test area (northern part) since the German Soil Inventory (1937–1951).

1994), is one of these indicators. It was calculated after the method of BMFRBS (1986) using the parameters of soil texture and humus content (Fig. 4).

The data in Fig. 4 shows that between 1937/51 and 1998/2000 the proportion of the highest class of the usable field capacity (>20 mm/dm) clearly decreased in favour of medium classes (>9–20 mm/dm). This tendency is essentially caused by covering soils with sand or gravel, by peat degradation, and by humus decomposition, as mentioned in Table 2. These changes have different effects on the yield potential, and they impair the filtering and buffering function (Röder et al., 1999). Minor improvements from class '>5–9 mm/dm' to class '>9–14 mm/dm' are connected with the fact that some pure sandy soils have been covered by silt (excavation and mud from ponds and riverbeds). Altogether, the indicator values have changed by approximately 11% of the test area by at least one class.

3.4. Assessment and landscape functions

Based on the data and the indicators sampled during the preceding steps, landscape functions were assessed. One of these landscape functions is the filtering and buffering capacity. Physico-chemical filtering capacity is an important part of the filtering and buffering function of soil. It indicates to what extent penetrating water pollutants can be fixed or decomposed by (physical) adsorption and by (chemical) fixation to soil particles, before they reach the groundwater. Accordingly, groundwater level and cation exchange capacity (both are monitoring indicators) affect soil function, whereas humus content, soil type and soil substrate are the basic data (Marks et al., 1992).

The assessment results in Fig. 5 show degradation in the ecological state of the landscape over the last five decades. At the expense of medium and low values, the proportion of very low values for the soil's physico-chemical filtering capacity has increased. This development, on a total of 7% (115 ha) of the floodplain, is due to the destruction of peat horizons and other soil changes (already mentioned above). This effect has emerged, although in due course an artificial lowering of groundwater level, resulting from intensive agriculture and lignite mining, should have induced an opposite tendency. However, soil degradation outweighs the shelter effects of a deeper groundwater level for groundwater quality.

3.5. Treatment of the hypotheses

Finally, the hypotheses are verified by the results of the monitoring. The results of landscape change studies substantiate the hypotheses listed in Section 2.2 as follows:

- A1 Humus loss and soil degradation are clearly proven by the data.
- A2 Soil data demonstrate newly emerged local soil wetness as a consequence of the decay of drainage facilities.
- A3 During the last decades wet areas in the floodplain have been covered by excavation matter to a large extent (29%, see Table 3).
- A4 The usable field capacity (see Section 3.3) was reduced. That can cause problems with drought in summer (leading to lower yields), but also damage to habitats.
- A5 There is a clear homogenization of soil parameters and a significant loss in soil functions (see the example in Section 3.4).
- A6 Reports from local farmers give grounds for a high degree of probability that this hypothesis is correct.

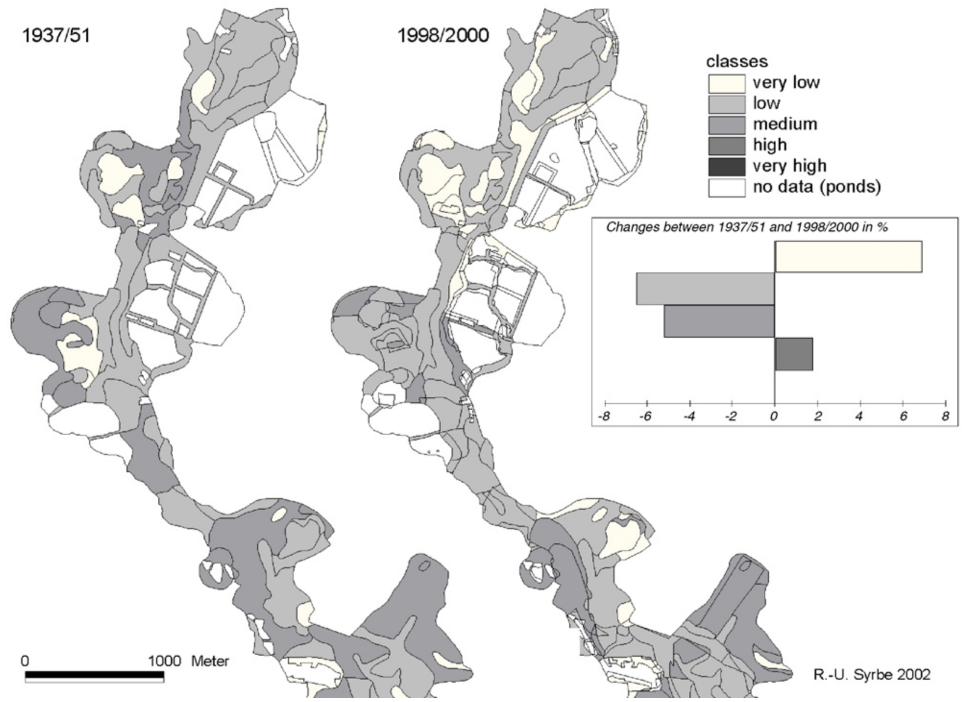

Fig. 5. Changes in the classes of physico-chemical filtering capacity in the Kleine Spree test area (northern part) since the German Soil Inventory (1937–1951).

3.6. Meta-data

A suitable meta-data concept is the core of a successful landscape monitoring scheme. To address this problem, it is necessary to balance two requirements: on the one hand, the system should be easy to build up, but on the other it should provide full information about the data available. The details of this meta-data concept are not described here. However, the key principle of this approach consists of two main points of view:

1. The thematic arrangement of data according to the individual working steps outlined in Sections 3.2–3.5 – that means, for every test area a working programme is elaborated, which gives an overview about hypotheses, functions, indicators and data to be analyzed. By the insertion of hyperlinks, this working programme becomes a meta-data bank. The hyperlinks show to what extent the working steps have been realized, and it opens the way to the (digital) results.
2. Documentation and putting together the ‘technical information’ in a tabular form according the Dublin-Core-Set (http://www.dublincore.org/documents/dces/) – the table contains only technical data, not thematic information. This limited extent of information is sufficient for the documentation and the understanding of data. This form is also usual worldwide. Thus, comparability is guaranteed.

3.7. Recommendations for landscape management

By using appropriate indicators, not only temporal changes can be identified, but also threats and management needs can be addressed. Such evaluations must consider all facets of a landscape, and they may not refer only to a single component (like soil or water). By comparing Environmental Minimum Requirements (Bastian et al., 2005) with the actual situation of the stated indicators, deficits become obvious.

Among the set of possible measures to overcome these deficits as formulated in hypotheses A1–A6, some points that show a relationship with monitoring results should be highlighted. The results of investigations outlined in Sections 3.2–3.4, including the hypotheses confirmed in Section 3.5, lead to the following consequences:

1. The relocation of soil in the course of water management must be reduced to a minimum.
2. In particular, engineered modifications to the river channel should be removed and the river re-naturalized.
3. Excavated material from future pond management measures should be deposited on poor sandy soils (if nature conservation is not adversely affected), in order to increase their yield potential and their resistance to soil erosion.
4. Covering peat and wet grasslands with excavated material should be avoided.
5. An increase in grassland proportion and a more extensive use of meadows is desirable. In particular, driving with heavy machines on wet areas should be avoided, especially during spring. Moist and wet grassland, as well as grassland situated close to waters, should be mowed, but not grazed by cattle.
6. Good humus and nitrogen balances on the arable land outside peat and wet areas must be maintained in general. Fields without vegetation coverage during wintertime should be covered by intercrops, or cultivated with alternative soil protecting methods.

4. Discussion

The framework presented enables holistic and goal-oriented observations of landscape changes. The monitoring is not restricted to detecting changes in land use and landscape structure. In fact, the ecological interpretation of miscellaneous landscape changes is the focus of this investigation.

Comparable monitoring results will be of crucial importance for future monitoring snapshots. Although time series based on historical data give much qualitative information on past landscape changes, they never reach the precision of quantitative statements that are possible if the data sampling follows a well-defined monitoring programme. In addition, a suitable set of monitoring data is a pre-condition for further tests to predict complex future landscape development. The monitoring programme also provides various data for landscape modelling. Accordingly, attention is paid to the usability of monitoring indicators in models.

Researchers and authorities can use the framework of the SALMA to design their own monitoring plans. The approach has proved to be feasible in a total of six local and four regional test areas in Saxony. Several issues could be examined at the scale of Saxony. Because of the methodical emphasis, a detailed presentation of all results achieved on several scales and in different areas would be beyond the scope of this article. Finding appropriate solutions for data management, meta-data construction and data exchange between different monitoring projects is a major challenge for the future.

5. Conclusion

The results from this investigation were obtained by following a newly designed SALMA framework which was tested in several areas in Saxony. It has been demonstrated here that essential landscape changes, even in ‘normal’ landscapes, are not always strongly influenced by human impacts only, but also by long-term, moderate, stepwise influences. Landscape components known to be relatively stable (e.g. soil) may also display changes. Nevertheless, changes which may at first not appear to be great can have considerable consequences for landscape and human society.

These facts indicate the importance of landscape monitoring programmes as a pre-condition of scientifically sound landscape management and landscape planning.

Relevant governmental authorities should recognize the necessity for monitoring programmes, and they should guarantee their long-term financing. Monitoring needs specific methods and procedures of data collection and computer-based processing. More fundamental research into the methodical basis is required, as well as international co-operation and co-ordination among individual programmes.

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