Impact of Landscape Change on Landscape Functions in the Saxon Switzerland

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Abstract

In this contribution the effects on environmental protection assets and landscape functions are examined on the basis of the analysis of the past landuse structure changes (see preceding contribution). Exemplary investigations into abiotic (e.g. soil erosion) and biotic (e.g. flora) landscape functions were made. The effects on the potential use of landscape for the human being (e.g. suitability for recreation) were modelled. Furthermore, the protection asset "unfragmented open space" was examined. For these purposes new methods and models were developed and existing GIS tools extended by self made adjustments. In the result, clear effects of the changed landuse structure on the examined landscape functions can be shown.

1 Motivation

Changes to landscapes, especially changes in the way in which land is used, result in alterations to the landscape structure – and hence also to the abiotic and biotic functions and potentials of a landscape. Central Europe is a region dominated by anthropogenic development for housing, trade, industry and intensive agriculture. Especially within the last 60 years the human exploitation of natural resources such as soil, water and flora, fauna and space itself due to urban expansion was on a far greater scale than ever before (BASTIAN and SCHREIBER, 1999). Although the increase in population, which was the major driving force for landuse and landscape change for centuries, lost its dynamics in Central Europe, it has to be stated that there is still an increasing demand on land for settlement and infrastructure. As a result, open space is subject to greater fragmentation by technical infrastructure owing to intensive road construction arising from an increased mobility of our society and related transport infrastructure construction (JAEGER, 2002; WALZ, 2005b).

Land consolidation and drainage projects resulted in an intensification of farming, increasing the average size of individual agricultural patches combined with the disappearance of structural elements of the landscape. Thus, the general trend of landscape development in Central Europe is heading towards more monotonous, less diverse landscapes combined with the impairment of landscape functions over large areas. Especially in the Eastern part of Europe the socialist planning regime led to extremely large management units.

The use and transformation of the landscape by humans influences landscape functions and thus leads to a change in the condition of ecological systems (cf. FORMAN and GODRON, 1986). A consequence can be for example a decrease of biodiversity, as it is in most cases today. However the human influence here has also created habitats, which did not exist in the Central European natural landscape before. Thus, an increase of biodiversity was the result. Such interactions between landuse structure and landscape functions can be pointed out and quantified partially. Investigations of the development of landuse structure pursue thereby not only the goal of explaining historical causes for today's structures, but also that of evaluating the current condition of landscapes and/or ecological systems.

Studying these processes and integrating the knowledge obtained into relevant instruments of control, e.g. in landscape monitoring and information systems (WALZ, 2002) will become one of the main themes of landscape ecology in coming decades. Investigating the historical development of landscapes serves as an important basis to reduce uncertainty of landscape development.

The study is exemplified by the National Park region Saxon Switzerland, delineated by the border of the National Park and its surrounding landscape protected area. The area covers 398 km², whereof 93 km² are protected as National Park and 275 km² are declared as landscape protected area. The unique landscape in Central Europe represents the German part of the Elbe Sandstone Mountains which extends to Bohemia, with a corresponding National Park and landscape protected area.

2 Analysing Landscape Functions

Based on the digitized and analysed landuse changes in the Saxon Switzerland (see contribution NEUBERT et al., pg. 81ff), in different case studies selected landscape functions and their changes over the time have been evaluated:

- Nature-oriented recreation value (WALZ & BERGER, 2004);
- Soil erosion (WOLF, 2006);
- Correlations between landuse change and species richness (BAMBERG, 2006);
- Landscape fragmentation (WOLF & WALZ, 2005).

The following text will focus on a brief description of the methods used and the results. For the detailed methodical descriptions of the landscape functions analyses we refer to the original publications.

2.1 Effects on the Landscape Function "Nature-oriented Recreation Potential"

In this investigation the "nature-oriented recreation potential" was selected, because the test area is a national park region. In this kind of region the recreation is mostly oriented towards activities to experience landscape and nature. The assessment is based on natural or semi-natural landscape elements and thus considers the acceptability of a landscape for recreation activities like promenades and hikes (MARKS et al., 1992). In the foreground is the experience of nature mainly by variegated, natural and characteristic landscape scenery and lines of sight (HOISL et al., 2000).

A method was developed to evaluate the effects of structural changes on the potential of a landscape for nature-oriented recreation. For the choice of the several assessment parameters to naturalness and diversity of landscape as the main criteria for the nature-oriented recreation, the reliability and validity of the parameters is very important. With the number of the parameters the probability of correlations between these parameters increases. This can lead to the neutralisation of several parameters or to a unidirectional offset of the results of the assessment (WIEMANN, 1985). To avoid this, a correlation analysis of the several parameters was made. The following six parameters were chosen:

The degree of naturalness of landuse or rather land cover determines as a main precondition the nature-oriented recreation. For the evaluation of the degree of naturalness the concept of hemeroby, an expression of the human influence, was used.

For the consideration of urban or rather densified rural areas the parameter proportion of open space was used. This parameter indicates the proportion of unsettled area. A low proportion of open space indicates a low potential for nature-oriented recreation, while a high proportion of open space means an increase of perceived naturalness (AUGENSTEIN, 2002).

The parameter edge effect is well suited to judge on the one hand the naturalness and on the other hand in addition the alternation wealth (diversity) of a landscape unit (HOISL et al., 2000).

The shape of landuse elements is computed with the help of the landscape structure measure shape index and refers to the complexity of the landuse elements and/or the irregular run of the edges. For this reason it concerns likewise a parameter, which characterizes both naturalness and alternation wealth of a landscape.

The relief contributes greatly to the variety of the landscape and the resulting alternation of landscape elements. The determination of the relief diversity took place by relief classes, which are formed by the relief characteristics: slope inclination, exposition and curvature.

The parameter overview was determined as a function of the relief and the landuse; it shows the potential of a landscape to grant prospects. Prospects and/or possible overviews are positive characteristics for nature-oriented recreation. On the one hand they enable exploration and interpretation of the landscape and on the other hand they give orientation and thus supply a feeling of security (AUGENSTEIN, 2002).

As super-ordinate spatial reference system a regular grid network with a raster width of 250 m was specified. Thus the contents density and the detailedness of the data are considered, so that also small landscape structures (e.g. tree rows, groups of trees) are included appropriately in the determination of the landscape potential. If one considers the strongly structured relief in the investigated area, in particular the narrow ravines of the rock districts, then this value corresponds also to the demand for an adjustment of the raster width to the human perception scale.

The aggregation of the parameters took place via a simple addition of the standardised parameter values. Reasons for this were firstly a simple conversion and comprehensibleness and secondly to exclude subjectivity as far as possible. In contrast the weighting of individual parameters or the interpretation in terms of content of the determined classes would have led to subjectivity.

For the better and easier application of the method to all landuse data from the different time series and for the application in other regions, a GIS tool was programmed using Arc Macro Language (AML). With this tool all working steps of the developed assessment method can be processed automatically as far as possible (WALZ & BERGER, 2004).

The results of the appraisal procedure for suitability for recreation are differentiated spatial maps to the different time levels. The nature-oriented recreation value decreased from 1780 till today, especially since 1940 (fig. 1). This is due to the fact of increasing landscape fragmentation (road construction, growing settlements) as well as due to landuse changes, especially by landuse rededications from small grassland patches to extensive fields, or arable land to pomiculture and as a consequence the changed naturalness (WALZ & BERGER, 2004). Thus, the majority of agricultural areas of the point in time 1992 are classified as less suitable for the nature-oriented recreation compared with preceding considered time points. This is to be seen as a consequence of the structural changes and the transformation of small-structured grassland into large fields.

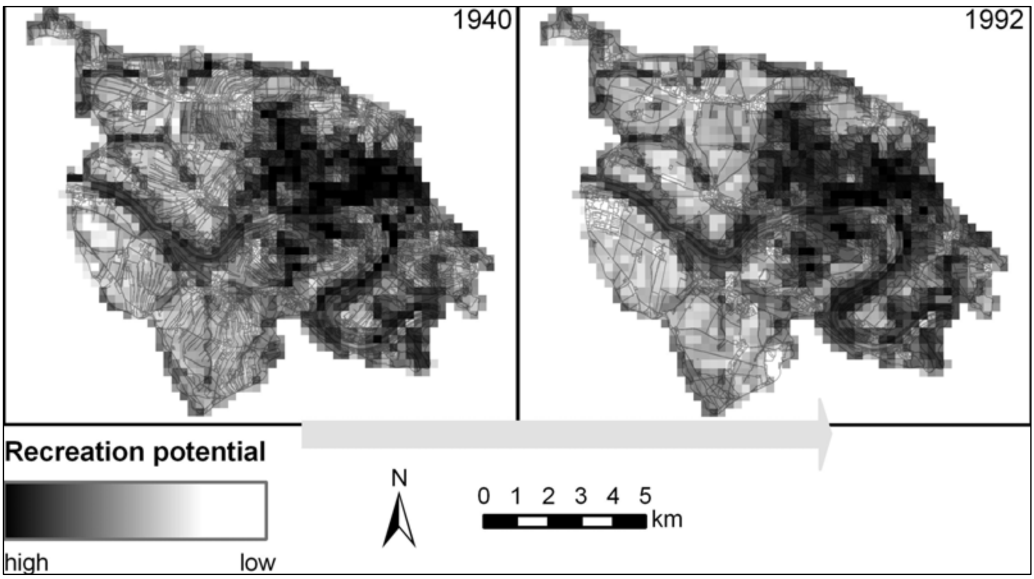

Fig. 1: Potential natural recreation value (detail in the western part of the Saxon Switzerland). (Processing: A. Berger & U. Walz)

The application of the appraisal procedure offers the possibility of analyzing the effects of the landscape change on the suitability of the landscape for nature-oriented recreation. This can be an important contribution to an overall concept for the future development of landscape. With the selection of evaluation parameters, which have already been used successfully in landscape evaluation procedures (KIEMSTEDT, 1967; MARKS et al., 1992; AUGENSTEIN, 2002), the list of clear input instructions and the execution of a transparent and comprehensible parameter aggregation can proceed with a high validity of the procedure.

2.2 Effects on Grassland and Species Distribution

Between 1940 and 1992 in the Saxon Switzerland a clear change in the structure of the grassland landuse class can be detected. These concerns the distribution of the several grassland plots as well as the size of the plots. On the one hand the area of grassland increased during this time by the factor 1.4 and on the other hand the average size of the plots increased in the mean by 280 %. In 1940 a lot of small plots were distributed in the agricultural landscape relatively equally. By the process of collectivisation in the former GDR, these plots were consolidated to larger units.

In this investigation we tried to answer two questions:

- Does the structure of the grassland distribution match to the natural suppositions like e.g. slope or soil wetness?
- Has the change of grassland structure affected the abundance of species (plants)?

In a first step we calculated with GIS tools and models several abiotic parameters for the whole Saxon Switzerland: height above sea level, slope, curvature, topographic wetness index and the solar radiation. Furthermore, we included the geology as an indicator for the soil substrate (acidic or alkaline sites).

Based on these parameters we identified “extreme” localities with high inclination, strong curvature very high / very low soil wetness and very high / very low solar radiation.

Altogether the steep surfaces with scarcely 35 % constituted the largest portion of these locations, followed by the areas with high soil wetness (about 19 %) and steep situations with high solar entry (approx. 15 % surface portion). The grassland surface on these extreme locations in the year 1940 amounted to about 620 hectares, in comparison to 517 hectares in the year 1992. Thus in total, meadows and pastures on extreme locations decreased by around more than 100 hectares. The loss is particularly great in the locations of the wet grassland surfaces (fig. 2.).

Apart from the analysis of the changes of situation, size and local conditions of the grassland in the Saxon Switzerland, floristic data should also be included into the investigations, in order to determine possible effects of this change on the plant spreading. For this purpose a botanical mapping of FÖRSTER from the period between 1935 and 1965 could be used. The original, analogue mapping on the basis of 1 km² raster quadrants was digitized and compared with current botanical mapping of the national park authority.

By the comparison of the historical (~1950) and of today’s distribution of wet and dry grassland plant species correlations between landuse change and species richness could be detected.

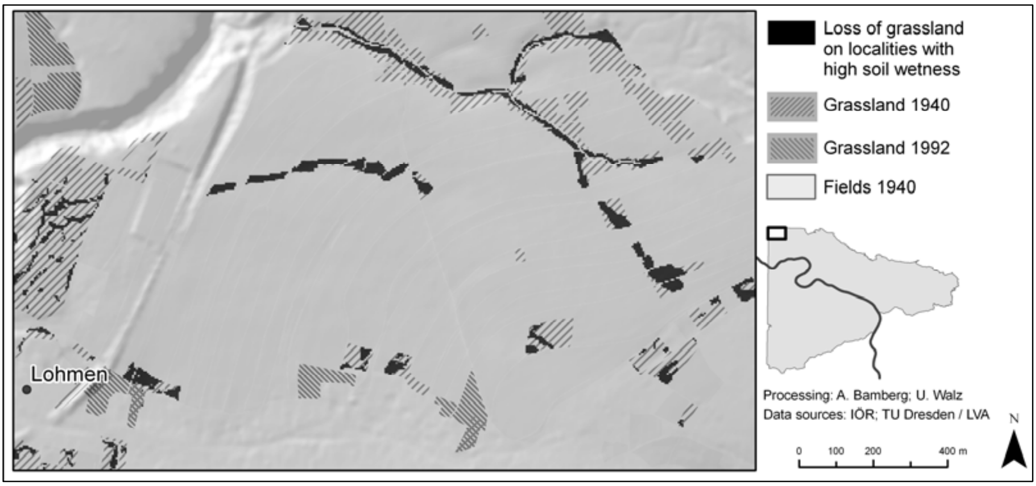

Fig. 2: Grassland loss on surfaces with high potential soil wetness east of Lohmen. (Processing: A. Bamberg, 2006)

Both groups of species decreased in number over time due to the increased intensity of landuse and melioration processes in the frame of farming collectivisation. On the other hand the proportion of grassland has increased by 3 % in the same time. The more extensive use of dry areas helped to preserve about two-thirds of the plant habitats, but wet grassland habitats were nearly eliminated due to drainage measures mostly followed by a landuse change to arable land (BAMBERG, 2006, Fig. 3). In addition, the development of single plant species was monitored. As an example, the total loss of Arnica *(Arnica montana)* from 1940 till today was detected.

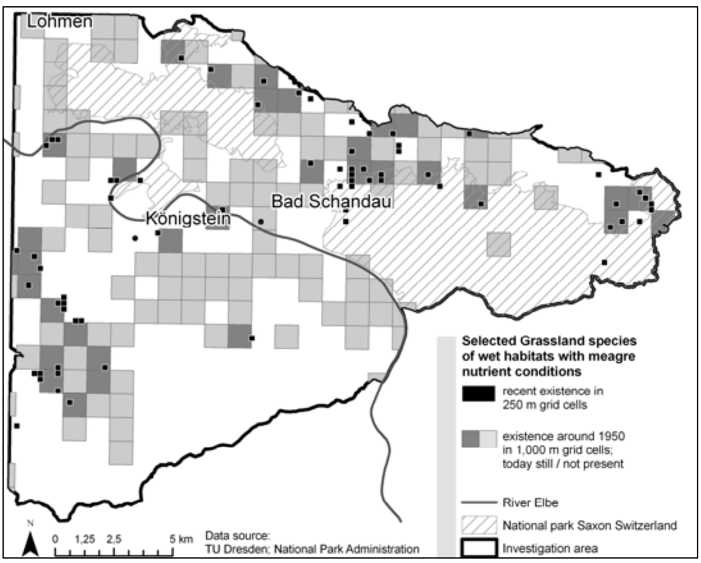

Fig. 3: Existence of Selected Grassland species of wet habitats with meagre nutrient conditions between 1950 and today (Processing: A. Bamberg, 2006).

2.3 Effects on Soil Erosion

Structural changes of landuse in Saxon Switzerland led to a consolidation of small fields as well as to the conversion into other types of use. For this reason, in this study the development of soil erosion was examined due to changed slope lengths. The Revised Unified Soil Loss Equation (RUSLE) was used as an erosion model, which belongs to the most frequently assigned models. For the determination of its partial factors a multiplicity of computation methods exists. It could be shown, that e.g. the use of corrected and orographic adapted precipitation is as basis for an exact erosion prognosis. A high-resolution model from airborne laser-scanning was used as the digital elevation model (see contribution KIRÁLY et al., pg. 41ff).

The computation of the L-factor on the basis of the erosive effective slope lengths formed the methodical emphasis of the work. It could be shown that the consideration of irregular slopes and in particular the discharge modelling with “Multiple Flow Algorithms” forms an important basis for the exact and surface covering computation of the erosive effective slope length. With the vertical exaggeration of the flow barriers a new approach was introduced to more realistically model the process of the surface discharge and thus to determine the erosive slope length more exactly.

The field plot-referred modelling of the average soil erosion took place for the period from 1900 to 1992. The results show that the spatial focuses of high soil erosion hardly changed during this time. In contrast with this, clear changes are to be recognized within the plots of arable land, in particular between 1940 and 1992. In the test area Weissig (fig. 4) a retreat of the agriculture from unfavourable relief positions took place. On the other hand increased soil erosion on 45 % of the arable land is clearly recognizable, especially by the consolidation of field plots.

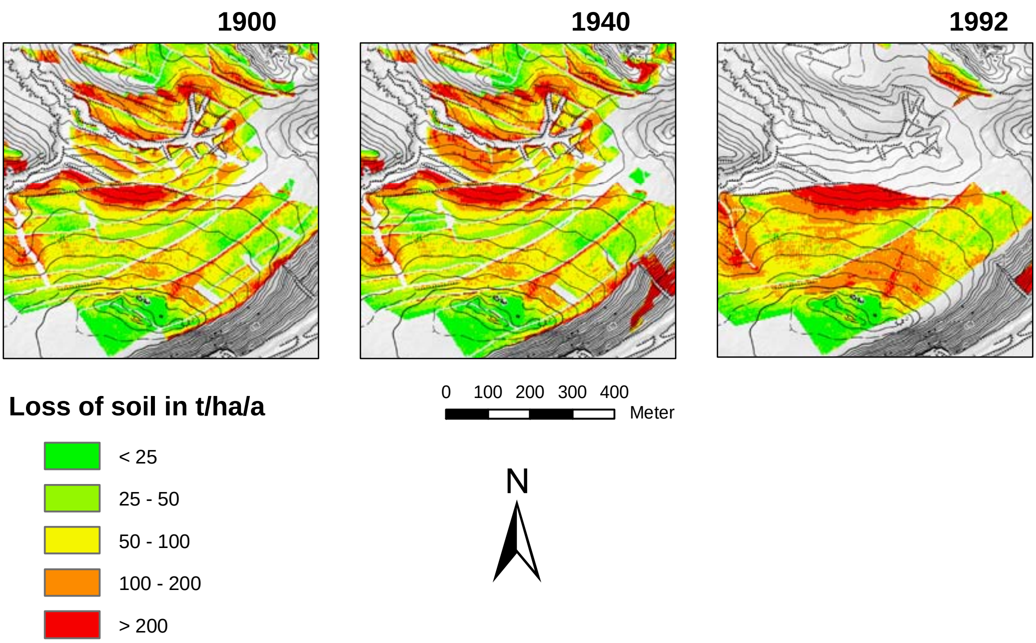

Fig. 4: Soil loss changes between 1900 and 1992 in the test area “Weissig” (Grid size: 5m). (Processing: S. Wolf, 2006)

The results of the performed modelling by the example of the national park region Saxon Switzerland show that changes of landuse structure strongly affect soil erosion. Measures of reallocation and consolidation of agricultural land led to an increase of the erosive effective slope lengths and thus an increase of the soil erosion. In the investigation time frame 1900 to 1992 soil erosion has decreased in total, mainly caused by the reduced area of arable land. However, the amount of eroded soil mass increased highly in some areas. Only due to changes of landuse structure, soil erosion increased within Saxon Switzerland in the last 100 years, in particular after 1940, on approximately 40 % of the areas of arable land. This is the effect of changed field structures, mainly the increase of erosion effective slope length by the elimination of erosion barriers, like hedges, tree rows or field paths and waysides (WOLF, 2006).

With the methodology presented here it is possible to simulate apart from historical views also the effects of future changes of the landuse structure on the soil erosion. Such spatial statements are important for the agrarian and landscape planning. The realisation of erosion protection measures could reduce the danger of irreversible soil losses and declining yields. Examples of such measures are the partitioning of areas of arable land, the creation of barriers reducing erosion and partly the conversion of fields to grassland. Thus, a contribution for the sustainable use and development of the agrarian use in a sensitive landscape can be made.

2.4 Analysis of Landscape Fragmentation

The issue of large unfragmented open space, becomes more and more important because of the connections between the landscape fragmentation and the increasing noise pollution, the suitability for recreation and the habitats for certain animal species. The landscape fragmentation due to traffic lines and settlement areas represents the cumulation of different anthropogenic impacts on the landscape in a spatial and temporal sense (e.g. settlement expansion, motorway and road system densification, development of rail routes and channels). Thereby it is an important indicator of the condition of the landscape with close references to the suitability for recreation, like hiking (LASSEN, 1990), to the noisiness and to the quality of habitats for certain animal species (EUROPEAN COMMISSION, 2000; FORMAN et al., 2003). In the meantime large unfragmented open space is recognized by the planning authorities in Germany as a limited available conservation resource. This shows for example the designation of large unfragmented space as “priority areas for nature and landscape” in newer planning instruments like the Regional Development Plan of Saxony (SMI, 2003).

In numerous studies, the administrative borders were regarded as the boundary of the area studied. Because large unfragmented open space particularly exists in the border region between the German Free State of Saxony and the Czech Republic, in the present work of the IOER special attention is dedicated to a border transcending view (WALZ, 2005b). In a cross-border case study of the Saxon-Bohemian Switzerland the historical development of this space and the effects of fragmentation on individual environmental subjects of protection are particularly examined (fig. 5). Geo-statistic tools are necessary for the quantification and evaluation of unfragmented open space by indicators.

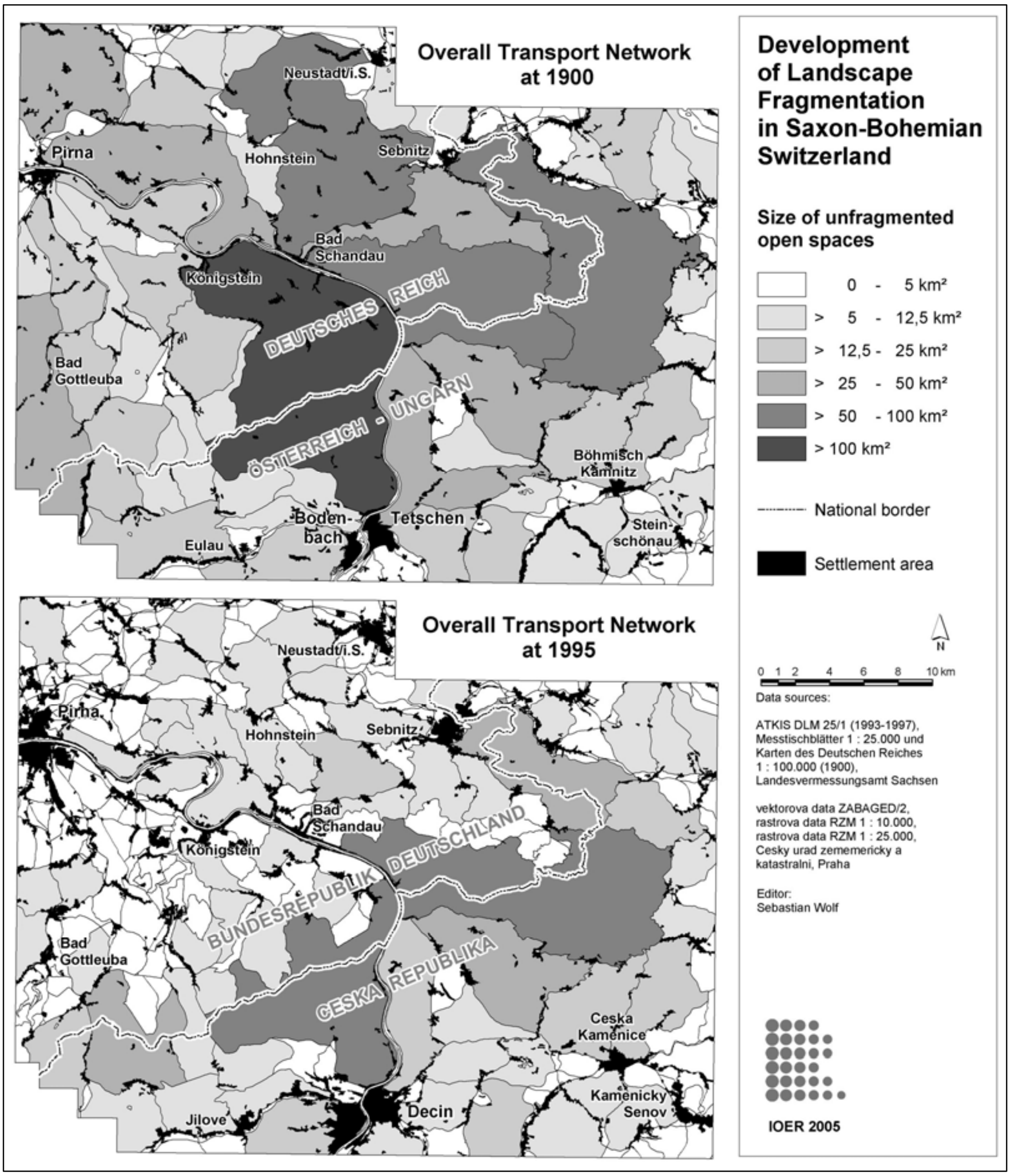

Fig. 5: Cross-border development of unfragmented open space in the national park region of Saxon-Bohemian Switzerland during the 20th century. (Processing: S. Wolf, 2000)

The integration of heterogeneous data from Germany and the Czech Republic and different times (with different geodetic reference parameters, accuracies as well as classifications of traffic lines) into a consistent geographical information system represented a time consuming and challenging step. For the retrospective view historical maps were scanned, geo-referenced and evaluated concerning the traffic infrastructure.

For the quantification of landscape fragmentation the number and the area of unfragmented open space as well as the effective mesh size (m_{eff}) (JAEGER, 2000; 2002) are commonly used as indicators to describe the state and to compare the changes over time. The parameter "area of unfragmented open space" has been in use for 25 years (GAWLAK, 2001); the parameter "effective mesh size" is proposed for use in all federal states of Germany (SCHUPP, 2005) while it is also used by the European Environment Agency (EEA).

In Saxon-Bohemian Switzerland, the landscape fragmentation increased since the end of the 19th century, especially in the time after World War II as a result of the increasing mobility and the growth of settlements. In many places driveways were paved and the road network enlarged. Because of this, the value of the parameter "effective mesh size" was more than halved (from 174,9 km² in 1900 to 71.3 km² in 1995, fig. 6). If one compares the Saxon and the Czech areas, there are noticeable differences: due to economic regression and depopulation the remaining unfragmented space in the Czech Republic is significantly larger than these spaces in the German part. A cross-border management and the cohesive assessment of impacts in consideration of this fact is a very important issue.

If the analysis of large unfragmented open space is restricted to the individual national territories, there is a high risk of not recognising all cohesive unfragmented space. Therefore, they can not be considered in case of future planning and possible impacts. Especially in case of long-term planning of road corridors it seems necessary to pay attention to the environmental subject of protection of unfragmented open space. They should be included in the regional plans, like it is the case in Saxony.

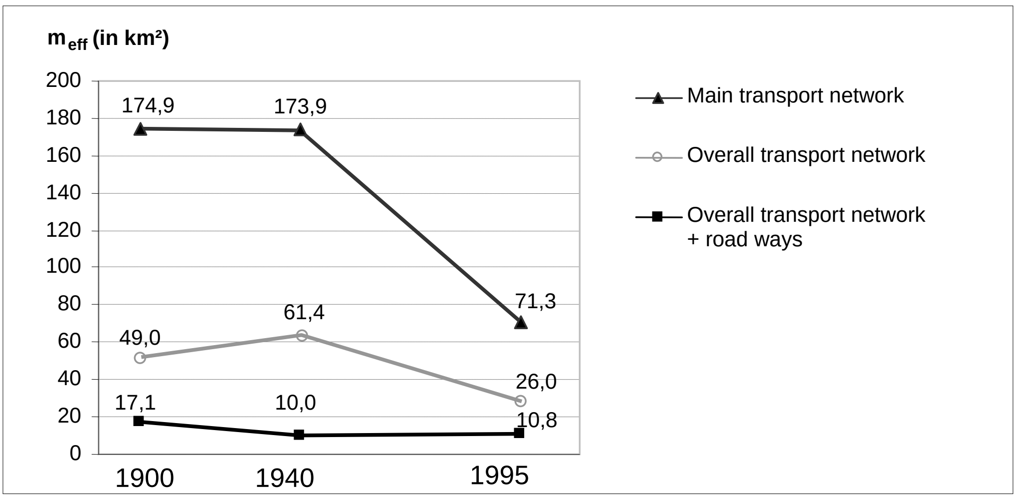

Fig. 6: Development of effective mesh size [km²] between 1900 and 1995. (Processing: S. Wolf, 2000)

3 Conclusions and Discussion

The case studies presented here analyse how landuse changes affect selected structures, functions and potentials of landscapes. Regarding the methodology used in historical landscape analysis, it can be concluded that historical maps can be integrated into a GIS with sufficient accuracy for medium-scale investigations.

The analysis of historic landscapes is the basis to show for recent landscapes which habitats, biotopes, landuses and use proportions were present at the beginning and which changes were typical in this biogeographical province. Thus, the development of landuse can be shown quantitatively over a period of more than 200 years. Furthermore, the influence of the parameter “landuse” on the degree of performance of landscape functions can be shown (qualitative analysis of historical landscape state). This knowledge can be used as a contribution to the regeneration of lost landscape functions and for the development of a future overall concept for landscapes. In the assessment of landscape change it is important to consider the ‘loss’ not only of land in the meaning of total area but also resources and landscape functionality (WALZ, 2005a).

Currently the most serious processes of landscape change in such a sensitive region like the national park region Saxon Switzerland is not the development caused by processes of urbanisation, especially urban sprawl, but e.g. the fragmentation of landscapes by infrastructure development which finally leads to a decline of large continuous habitat patches and changes to the structure of farmland. Furthermore the often “invisible” small changes in rural landscape have also considerable effects to the environment in cumulation.

In the context of environmental monitoring the regular balance and analysis of the landscape development possesses therefore a substantial meaning. Such structural changes run "creeping" and can only hardly be noticed in their extent from the view of individuals. Only the monitoring of larger areas and periods makes the extent and the consequences of the change recognizable.

Attention must be paid to ensure that the functionality of landscapes is sustainably maintained and landscape planning has to meet the specific requirements of a multifunctional landuse in our cultural landscape. The historical knowledge and the material from such investigations are important for landscape planners and regional planning authorities for current and future shaping of the landscape.

Results should also be used for public awareness and decision making, for instance by presentations in visitor centres or in the internet as interactive maps. In this sense environmental information systems and visualization methods will become more important for public awareness of environmental problems and the support of decision makers in planning and development. Furthermore, managing authorities of nature protected regions will integrate the findings into their landscape planning instruments to optimise the further conservation as well as the development of the region.

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