



Using GIS to analyse long-term cultural landscape change in Southern Germany

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Abstract

Two case studies of cultural landscapes in Southern Germany were conducted to develop appropriate techniques for quantifying and analysing the landscape change since 1850. Methods were derived from geographical landscape change analysis, based on cadastral maps and land registers, and were rendered at a land plot level by the use of GIS. The database for the diachronic GIS, especially cadastral maps and land plot records, are discussed in detail. This study emphasizes that an approach based on a land plot level and using a land record-based GIS provides valuable results relevant for planning processes and nature conservation in changing cultural landscapes.

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1. Introduction

Changes in land use and land cover are some of the far-reaching effects of human activities on modern landscapes. Among others, many of Europe's cultural landscapes have experienced a remarkable change since the early 19th century, particularly during the 20th century (Cousins et al., 2002; Petit and Lambin, 2002; Vuorela et al., 2002; Olsson et al., 2000; Pärtel et al., 1999; Verheyen et al., 1999; Houghton, 1994; Lamarche and Romane, 1982). As a result of the intensification of agricultural production on the one hand, and the retreat of agriculture from unfavourable

sites on the other hand, many of the extensively managed traditional land use systems have started to disappear. Today, both afforestation and the natural process of secondary succession of fallow fields, meadows and pastures have created new and unusual sights in many places, sometimes negatively affecting the attraction of certain landscapes for tourists (Hunziker and Kienast, 1999).

Landscape change has been a scientific object of study for a long time. In Germany, for instance, the concept of landscape change analysis has been developed through different geographical research approaches. These include the "Historic Geographical Land Survey" (Denecke, 1972) with its development of cultural landscape cadastres (Fehn and Schenk, 1993), the "Genetic Cultural Landscape Research" with studies related to the development of individual landscapes (Bund, 1998; Bender, 1994), and the

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“Applied Historical Geography” with contributions to landscape protection and landscape planning (Schenk et al., 1997; Gunzelmann, 1987).

Today, cultural landscape changes are particularly prominent in suburban areas (Breuste, 1996) as well as in those agricultural areas where intensification and expansion of agriculture is taking place. These changes are especially problematic in marginal agricultural areas where farming activity is withdrawn (Dosch and Beckmann, 1999). Here, in contrast to the other two area types, the future manifestations of the landscape are not easily predictable. However, exact knowledge of historical landscape conditions and of landscape change over time could facilitate and improve predictions about the current and future state of the landscape as well as enable scenarios for future conditions (Marcucci, 2000). This is particularly valuable for more effective landscape planning at the local level, where landscape changes are important relative to conservation planning. Appropriate linking of social and ecological data and scales for an effective natural resource management is still a challenge (Vogt et al., 2002; von Haaren, 2002; Oldfield et al., 2000).

The purpose of this study is the establishment of a large-scale¹ “diachronic cultural landscape information system”. It is more detailed than traditional approaches with topographical maps and, among other things, integrates land plot based data such as subsidies, land owner profiles, and soil quality information. This would serve the goals of:

- (a) compilation of data and characterisation of landscape change over the long-term in order to view the various eras of landscape use as a whole and to examine the causes of major shifts in landscape development;
- (b) explanation of landscape change resulting from natural and anthropogenic influences with the help of a quantitative approach;
- (c) modelling, with the assistance of the attribute database, a view of the future based on past landscape development patterns; and
- (d) support for decision-making in landscape planning and nature conservation management in Germany.

¹ This means a small extent project (2000–3000 ha) based on large scale maps (ca. 1:5000).

2. Research methods

2.1. Study areas

The study areas are located in montane regions with a traditionally high diversity of mixed agriculture, resulting in a complex cultural landscape. In both regions, policy makers have been called to action due to the fact that recent landscape changes have led to a loss of landscape diversity and scenic beauty, resulting in negative repercussions on tourism. From the perspective of landscape planning, it was difficult to evaluate the problems of change without detailed local analysis.

Owing to the fact that villages and their districts have historically formed the basic economical units of the cultivated landscape, we chose the village district as the basic land unit in the study areas. Each study area is approximately 2000–3000 ha in size, and includes 10 village districts.

In the Brotjacklriegel area of the Bavarian Forest (eastern Bavaria, Figs. 1 and 2) research has taken place since 1991 (Bender, 1994). The Bavarian Forest is a cultural landscape on gneiss formations with an elevation between 400 and 1400 m, and has been populated since the late Middle Ages. It is here that the concept of using land registers and cadastral maps for a diachronic landscape change analysis was first applied.

The northern Franconian Alb (northern Bavaria, Wüstenstein, Figs. 3 and 4), a karstic landscape of Jurassic limestone, has been the main study area where the use of GIS was added to the ongoing research in 1996. The Franconian Alb is a mountain range with elevations from 350 to 650 m, settled during the early Middle Ages.

The selected village districts represent all settlement types with regard to development and socio-economical conditions. These types are classified as green villages (“Angerdörfer”), dispersed settlements (in the Bavarian Forest), farmer’s villages and manorial villages (in the Franconian Alb). In manorial villages, a large proportion of the inhabitants were formerly landless people who were enticed by landlords to live there in the late 18th century. These people were then often forced to look for non-agricultural sources of income—just as the inhabitants of dispersed settlements of the Bavarian Forest that were founded in the early 18th century.



(1)



(2)

Figs. 1 and 2. Langfurth, ca. 1940 and 1990 (Bavarian Forest), showing notable increase in forest coverage. Photos by W. Roeßler and O. Bender.



Figs. 3 and 4. Ailsbachtal, ca. 1930 and 1990 (Franconian Alb), showing notable increase in forest coverage. Photos by H. Scherzer and H.J. Boehmer.

2.2. Data acquisition

Analyses were carried out by the use of GIS. The fundamental question for such a cultural landscape information system is how “landscape“ can be operationalised in order to assign a value to the diachronic approach for direct applications within the planning process. Landscapes can be seen as topological variations of vegetation cover, and it is possible to determine these landscape units based on the various forms of anthropogenic use (Palang et al., 1998). When assessing such units, for example, as a contribution to nature conservation management and landscape planning, one should not focus on individual objects but when possible consider a four-dimensional perspective that is oriented in both spatial and temporal interrelationships (Bender, 1994).

The analysis of cultural landscape change is generally based on a variety of sources, including topographic and historical maps, aerial and satellite photographs, land registers with geodetic survey maps and land plot records, original surveys of relict species (where available), as well as various statistical and archival data. A state of the landscape, which represents the traditional land use system, should be the starting point for the diachronic analysis of landscapes. Due to the fact that European landscapes achieved their highest diversity in pre-industrial times, it is important to obtain data that originate from the 19th century (Antrop, 1997; Leibundgut, 1986).

Likewise, the continuity of the sources is of great importance. This means, several time periods and corresponding landscape conditions must be

represented by common attributes that were collected and recorded using a standard procedure. However, these data sources must be reviewed on an individual basis in order to assure that the data are consistent. Many studies have up to now accessed and attempted to compare various data sources (e.g. McLure and Griffiths, 2002; Vuorela et al., 2002; Cousins, 2001) or have abstained from going back to temporal data from the 19th century (e.g. Olsson et al., 2000). This study has established a complete, integrative database from the Bavarian “cadastral archives”. Four time slices were chosen with cadastral maps and land registers and complementary data from agricultural administration (Table 1). These data include particular information regarding the soil quality and the owner of the land parcel. It details the names and ages of farm owners as well as the type of agricultural activities and information on successors. Such socio-economic data were supplemented with spatial data that were derived from a digital terrain model (DTM), i.e. altitude, slope gradient and exposure.

2.3. Diachronic GIS modelling

We assume that analyses of cultural landscapes ultimately require operationalisation with the help of a GIS in order to successfully manage the abundant information about land units, attribute data, and temporal layers (Fig. 5). The GIS serves here predominantly to analyse the changes and to calculate the proportion of each land use type.

The conceptual model for the GIS is, therefore, determined by land-register data. As a consequence, the

Table 1
Temporal layer descriptions and sources

Layer	Research area Bavarian Forest	Research area Franconian Alb
1	1827–1830 cadastral maps 1:5000 1843–1844 land register	1844–1847 cadastral maps 1:5000 1851–1854 land register
2	1872–1873 cadastral maps 1:5000 1858 ff. land register	1877–1902 cadastral maps 1:5000 1896–1908 land register
3	1937–1943 cadastral maps 1:5000 1938 aerial photo map 1:25000	1954–1961 cadastral maps 1:5000 1956–1962 land register 1963 aerial photos 1:23000
4	1984–1986 cadastral maps 1:5000 1992 land register 1989 aerial photos 1:5000	1997–2000 cadastral maps 1:5000 2000–2001 land register 1996 aerial photos 1:5000

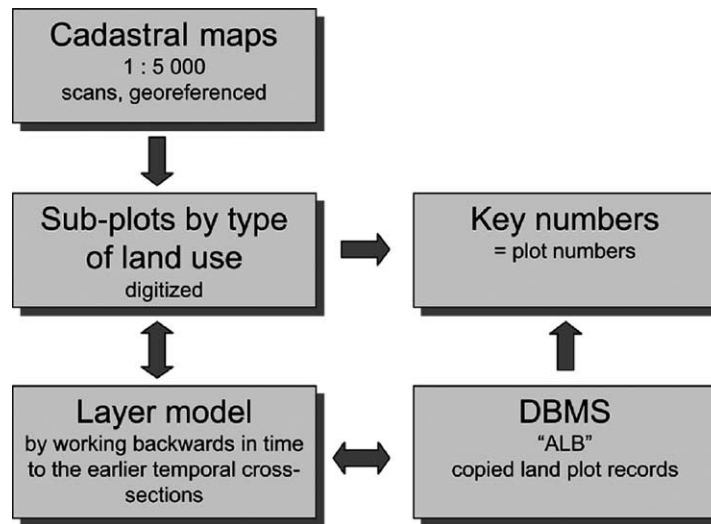


Fig. 5. Physical Modelling in a land-register based diachronic GIS.

cadastral landscape model consists of types of land use, ownership status and other attributes (mainly for tax purposes), while the geodetic survey maps document the boundaries of land plots. Thus, a database of land plot attributes can be compiled from data in older land plot records contained in the archives of the land register, and by entering the current data of the automated land tax register, which includes land cover, soil quality and property data. Nevertheless, in a diachronic comparison and in specifications of the land-register data, the terminology for the basic category “type of use” needs to be adapted, because it may vary and sometimes change over time (Ziegler, 1987; BayLVA, 1808). Key numbers were used to link the attribute database to a digitised parcel inventory of the cadastral maps.

The creation of these geodata was based on the current and historical Bavarian cadastral maps (1:5000). The corresponding map sheet division remained unchanged, so that all analogous map editions could be referenced in an identical manner to the sheet corner values (since 1961 in Gauss–Krüger coordinates) provided by the Bavarian Land Survey Department (Bayrisches Landesvermessungsamt).

Contents of the newest maps also trace back to the base map. Only newly measured parcels were incorporated with somewhat better accuracy (due to the

new triangulation network). The geometrical accuracy was, therefore, widely dependent on the very first entry into the survey records of the 19th century, where the average coordinate discrepancies ranged between 0.4 and 1.0 m (Heider, 1954). In addition, it was difficult to quantify point misalignments (the difference in the location of the same map point on different temporal layers) resulting from paper distortions in the originals. Errors arose also from smaller inaccuracies during scanning operations or georeferencing.

The implementation of GIS through the use of a vector model (in the present case, simple and complex polygons for sub-plots by type of land use) was consistent with the “. . . viewpoint of historical geography, to describe objects in the real world as discrete point, line or area elements of the cultivated landscape” (Plöger, 1999, p. 106). Then, the vector database was created on the basis of current and historic cadastral maps by digitising the land plots. The different time slices of our study were handled in a layer GIS model. A layer was created for each time period, beginning with the latest, and presumably most accurate cadastral map (if already available, by use of digital data), and working backwards in time to the earlier temporal layers (Privat, 1996). The older maps only served to identify the changes. Possible distortions and projection errors in the historical maps needed to be visually corrected.

2.4. Analysis

Analogous temporal layer maps offer the possibility of a visual analysis of landscape conditions over time. In order to determine the extent of landscape changes, land use categories must be laboriously planimeted (Krettinger et al., 2001).

The conversion of data into a GIS, which was done using the data set from the Franconian Alb, offered more than simply a visual interpretation of thematic maps or statistical evaluation (plot use balance), because this geo-relational approach also permitted an assessment of development trends. It thus became possible to determine various changes in land use according to categories of change (i.e. 'former use' versus 'subsequent use') and to calculate a plot balance of the cultural landscape.

The GIS also enabled the development of maps of landscape change, which were constructed by successively overlaying the various temporal layers according to categories of change, beginning with the oldest layer. With such maps it becomes possible to visualise changes between any two temporal layers, and thus to display the category of change for every land plot.

In order to go beyond the well-known models for structural change of agricultural landscapes, the use of a land record-based GIS can help to find explanations for cultural landscape change on a large-scale (1:5000) basis. Standardised approaches to changes in land use, including cultural and environmental factors, have been developed in order to understand which plots are involved, and why changes occur on these plots.

The GIS-based simulation model assumes that the future parcel utilisation is determined by the characteristics of the various attributes in the three categories of ownership structure, parcel structure and habitat quality. Based on the respective land uses, the variation of the predetermined influencing variables can be calculated. Through determination of the thresholds for these influencing variables with the described quantitative method, only "benchmarks" can be created, and a correction based on qualitative information is necessary.

The attribute queries result primarily from a combination of attributes (e.g. quality of soil <5 and hill slope >8, or quality of soil <6 or hill slope >12 leads to the cessation of farming activities). Here one must

be aware that these Boolean operations can simulate a causal chain of events but no definite outcome can be predicted. Ultimately, the simulation determines for each individual parcel whether a continued or subsequent use is anticipated by the owner or whether, under certain circumstances, the plot will become part of the leasing market, lay fallow or be completely abandoned.

3. Results

Layers 1 and 2 (representing the time slices 1830 and 1870) showed that the study area of the Bavarian Forest consisted of 40% woodland, 33% meadows and 20% arable land in the 19th century (Fig. 6). The proportion of arable land was twice as high in lower relief areas of the Bavarian Forest (Pietrusky, 1988). The remaining land uses consisted of rough pastures and moist meadows. Thereby the quantitative classification of land uses of the farmer villages (here in type of green villages) established in the 11th and 12th centuries was fundamentally identical to the dispersed settlements founded in the early 18th century.

Layers 1 and 2 (1850 and 1900) of the Franconian Alb demonstrated that the area was extensively used for crop production (66%), while forested land represented only 18–19% of the total region (Fig. 7). Forests were largely limited to North and East facing steep slopes, as well as to the knolls rising above the plains. A rather large fraction of 9% constituted rough pastures and wastelands situated on rocky sites on karstic terrain. Meadows were present only in the valleys and covered only 3% of the total area.

A less intensive use of agricultural land began in the Bavarian Forest at the end of the 19th century with the afforestation of marginal croplands. However, the arable land to meadow ratio was largely unchanged until 1940. Visual analysis of temporal layer maps illustrated a high degree of landscape change in the youngest period under investigation, which covered the period since World War II (Fig. 6). Within this period, arable fields in particular have transformed to grassland, while areas with marginal yield soils have been transformed into woodland. The biggest loss in agricultural land was in the districts of the dispersed settlements, where in the meantime almost all farming activities have ceased.

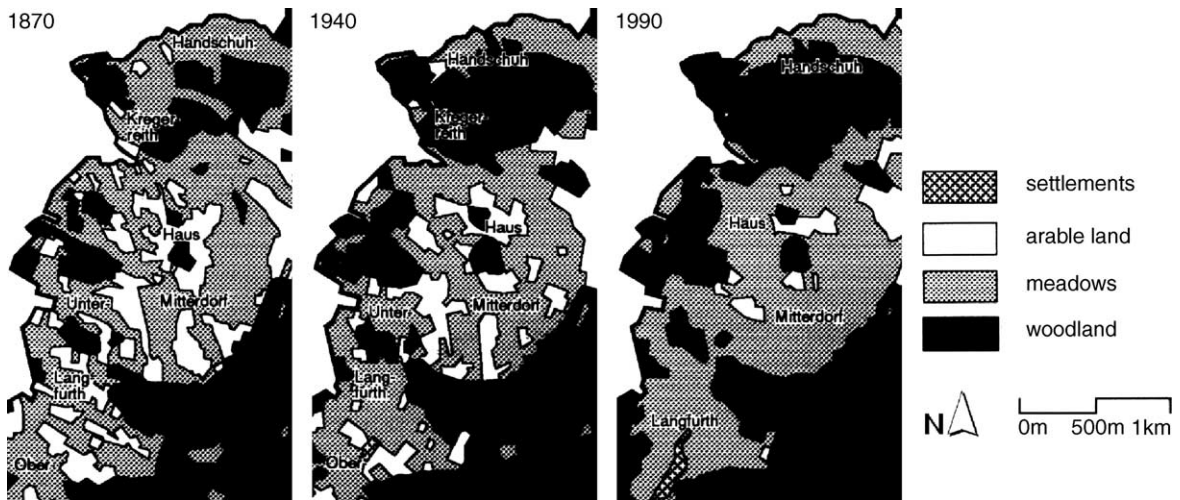


Fig. 6. Temporal layer maps of the distribution of land use categories in a section of the Brotjackriegel area (Bavarian Forest): 1870, 1940 and 1990.

The analysis of former and subsequent land use indicated that the increase in forested area in the Franconian Alb largely took place on former rough pastures (Weisel, 1971), doubling the proportion of the wooded surface in the districts to about 40%. Former rough pastures and wastelands in particular were either planted or abandoned. Thus, these categories have virtually disappeared except for a small remnant of 1% of the surface area of the districts (Table 2).

Comparison of maps (Fig. 7) and statistics showed that the most intense change in land use patterns in the Franconian Alb occurred during the period after 1900. Despite ongoing structural changes and mechanisation during the post-war period—in contrast to the Bavarian Forest—landscape changes after World War II were less intensive than in the previous period (Weisel, 1971).

In the study area of the Franconian Alb, we also investigated the relationship of slope (after DTM) and soil quality classes (after land plot record 1851–1854) and correlated them with subsequent changes in use (Table 3). The general trend towards a less intensive agricultural use of plots with low fertility was only partly confirmed, due to the fact that a large proportion of plots with average soil qualities were maintained for arable use, while some plots on both high and low soil qualities were converted to other use categories.

One interesting result, however, was that the clearing of wooded areas was rarely related to soil fertility, but rather a measure to increase efficiency during the process of land reallocation.

Analysis of the plot gradients showed the expected correlation with changes in land use. These were minor in cultivated plots with only slight inclination, whereas plots with steep slopes were frequently converted to woodland. Additionally, possible connections between changes in land use and the age and profession of the landowner, or a change of land use after a change of ownership, were investigated. No significant correlations were found for the time periods of 1850–1900 and 1900–1960. These factors are apparent only recently, as their impacts on land use change are growing.

4. Discussion

4.1. Database and landscape change

Use of the serial database of cadastral maps and land registers offers several advantages concerning availability, accuracy, and information contents (Table 4). The most important one is increased accuracy regarding content and geometry, which facilitates the detection and capture of data relevant to natural



Fig. 7. Temporal layer maps of the distribution of land use categories in the district of Wüstenstein (Franconian Alb) 1900, 1960, 2000 and 2020 (scenario).

Table 2

Categories of change in the balance of plot use for the Franconian Alb study area (1850–2000)—for a description of data accuracy see Table 4

Land use category (cadastre)	Period of research	Area, beginning of period (ha)	Change to area (ha)								
			Arable land	Orchards	Water bodies	Rough pastures	Waste land	Settlements	Traffic routes	Woodland	Meadows
Arable land	1850–1900	1378.31	1366.98	0.25	0.03	–	2.19	0.16	–	7.22	1.48
	1900–1960	1379.58	1013.57	4.26	0.00	7.57	3.30	0.55	6.80	327.61	15.93
	1960–2000	1035.80	977.80	0.66	–	0.08	0.52	14.85	17.80	21.69	2.41
	2000–	1029.93									
Orchards	1850–1900	25.68	1.25	23.57	–	–	–	0.86	–	–	0.00
	1900–1960	24.18	0.61	12.63	0.03	–	0.30	5.31	0.22	0.20	4.89
	1960–2000	17.78	0.95	1.78	–	0.01	0.03	8.66	0.24	0.04	6.08
	2000–	3.13									
Water bodies	1850–1900	6.47	–	–	6.47	–	–	–	–	–	–
	1900–1960	6.57	0.02	0.00	6.36	–	–	–	0.11	–	0.09
	1960–2000	6.84	0.01	–	6.66	–	–	0.04	0.07	–	0.07
	2000–	6.91									
Rough pastures	1850–1900	70.02	–	–	–	68.89	0.14	0.01	–	0.98	–
	1900–1960	70.86	5.98	0.15	0.03	15.86	1.00	0.44	0.50	45.95	0.95
	1960–2000	28.94	1.84	–	–	13.19	–	0.32	0.53	13.01	0.06
	2000–	13.95									
Wasteland	1850–1900	116.53	5.18	–	–	–	105.11	–	–	6.23	–
	1900–1960	107.70	5.89	0.24	–	4.66	4.21	0.17	0.21	90.80	1.52
	1960–2000	9.00	3.17	–	–	0.04	4.42	0.11	0.37	0.89	–
	2000–	6.13									
Settlements	1850–1900	7.08	–	0.25	0.00	–	0.00	6.82	0.02	–	0.00
	1900–1960	8.22	0.25	0.35	0.00	–	–	7.44	0.08	–	0.10
	1960–2000	14.35	0.03	0.30	–	–	–	13.51	0.18	0.02	0.32
	2000–	44.39									
Traffic routes	1850–1900	41.63	–	–	–	–	–	0.02	41.61	–	–
	1900–1960	41.61	0.78	0.02	0.00	0.10	0.02	0.04	40.49	0.06	0.10
	1960–2000	50.38	3.08	0.01	0.00	0.02	0.10	0.34	46.57	0.20	0.07
	2000–	71.74									
Woodland	1850–1900	379.42	4.78	0.02	–	0.20	0.26	0.24	–	373.84	0.07
	1900–1960	387.91	10.96	0.04	–	0.07	0.10	0.46	0.27	374.30	1.70
	1960–2000	840.06	37.77	–	–	0.62	0.79	1.47	4.27	793.21	1.92
	2000–	832.27									
Meadows	1850–1900	59.84	0.47	0.13	0.04	1.77	–	0.11	–	–	57.33
	1900–1960	58.89	2.44	0.09	0.19	0.33	0.08	0.33	1.18	2.04	52.21
	1960–2000	77.16	0.92	0.21	0.14	–	0.28	5.09	1.25	2.78	66.49
	2000–	77.52									

resource management. Furthermore, land plot based analysis of historical landscape structure and landscape development data can be directly integrated into landscape planning, which in Germany is standardised to a 1:5000 scale. Yet another advantage is that the cadastre also provides information concerning

economic, social and cultural factors, which can be used to develop explanations of changes in landscape patterns—exceeding the more physical data (DTM) of topographic maps. On this basis it is possible to develop prognoses and scenarios (Hawkins and Selman, 2002; Krettinger et al., 2001).

Table 3

Average soil qualities and slope gradients in land plots of the Franconian Alb study area by categories of change (1850–2000, unweighted by size of plot)

Categories of change; 1850–2000	Surface area (%)	Soil qualities	Slope gradient	Categories of change; 1850–2000	Surface area (%)	Soil qualities	Slope gradient
Arable land—meadows	0.89	8.37	6.20	Woodland—meadows	0.09	4.15	10.51
Arable land—arable land	46.91	5.86	4.04	Woodland—arable land	0.98	3.90	4.40
Arable land—pastures	0.10	5.65	7.02	Woodland—pastures	0.01	2.00	4.14
Arable land—wasteland	0.13	4.70	6.17	Woodland—wasteland	0.01	3.50	9.89
Arable land—woodland	16.00	4.10	7.45	Woodland—woodland	16.96	3.57	10.45

4.2. Factors influencing land use changes

On the basis of land use analysis it was determined that in the Franconian Alb study area the parcels used continuously as arable land had an average soil quality of 5.8 (minimum 0.5 to maximum 16; as classified from 1851–1854) and an average hill slope of 4.0°. Analysis of the agricultural land use structures following information from the agricultural administration and interviews with the farmers revealed that during the course of the upcoming generation, half to two-thirds of the farming activities would be given up (predominantly spare-time farmers in the manorial villages), while only one third of the agricultural enterprises would preferably lease additional fields. The overall extent of the lands to be leased is, however, strongly dependent upon the augmentation of productivity, because farms between 20 and 30 ha in size are not able to afford additional labour force. As a result, demand will probably decrease relative to supply in the future, whereby the further deterioration of these lands is then imminent. Given the ongoing transformation from the grazing of livestock to the use of feed

crops, valley meadows will no longer be needed in the future. These meadows and also mesoxerophytic grasslands that were traditionally used for grazing of sheep and goats can only be preserved by the farmers through “ecologically motivated” subsidies (Broggi et al., 1997). Further afforestations or secondary succession will arise from less productive fields.

The 2020 scenario shown in Fig. 7, which is based on a simulation model, is calculated for the unfavourable assumption that all parcels owned by farmers elder than 70 will be available for leasing. Arable land parcels with a soil quality measure not higher than 7.0 and a slope gradient higher than 8.0, and also meadow parcels located more than 100 m away from settlement areas, are rarely leased and, therefore, afforested. In addition, the scenario assumes that—as a result of the EU-expansion—the “ecologically motivating” subsidies will not be able to be maintained at its present scale. Therefore, in the future all rough pastures and wastelands will transform into forest. As a result, it is expected that, by 2020, forested lands will have increased by 35% and thereby cover 54% of the total area.

Table 4

Topographical and cadastral maps as a basis of landscape change analysis in Bavaria (after AdV, 1995; Veit, 1968; Heider, 1954)

	Topographical maps	Cadastral maps
Projection	Gauss–Krüger	Soldner
Scale	1:25000	1:5000
Concrete representation (m)	±3–15	±0.5–1.5
Beginning of observation	(1801–1841) 1920–1960	1808–1853
Temporal resolution (years)	~5, longer in former times	~10–40
Number of land use categories	~5+	~10+
Representation criteria	Area >1 ha (“ATKIS”)	“wahrer Zustand der Kultur” (~true condition of the land use)
Additional information	DTM/DEM	DTM/DEM, Soil quality (tax), “ALB”, data of agricultural administrations
Digital revision of maps	“ATKIS-DLM”	“DFK”

4.3. Change modelling and forecasting

In the Franconian Alb study area, two substantial processes were documented: an older process whereby rough pasture areas were transformed into pine forests, and the more recent decline in land use intensity and subsequent afforestation of former meadows in valleys. With the transformation of open meadows into less productive pine forests, another typical characteristic of the Franconian Alb's landscape would vanish.

In the Bavarian Forest's higher elevations, gradual return of near-natural woodlands as well as commercial afforestation with fir trees makes it difficult to maintain the attractive, mixed landscape. As a result of decreasing agriculture and tourism, many villages may decline or be abandoned. This process has already occurred in the dispersed settlements and hamlets formerly typical of the Bavarian Forest, and also

in the larger settlements that house commuters working in other areas. The deserted settlements described by Fehn as early as 1963 give proof of these trends (Fehn, 1963).

4.4. Categories of change

From an ecological point of view, the classes of vegetation cover surveyed in our analysis of landscape change can be regarded as biotopes or biotope complexes (Table 5). The classifications of "settlements", "orchards", "arable land", "meadow", "rough pasture", "wasteland" and "woodland" in the Cadastral Register of Bavaria can thus be assigned to plant communities determined in field surveys (cf. Gauckler, 1938).

The concept of categories of landscape change incorporated into the GIS helps to evaluate these

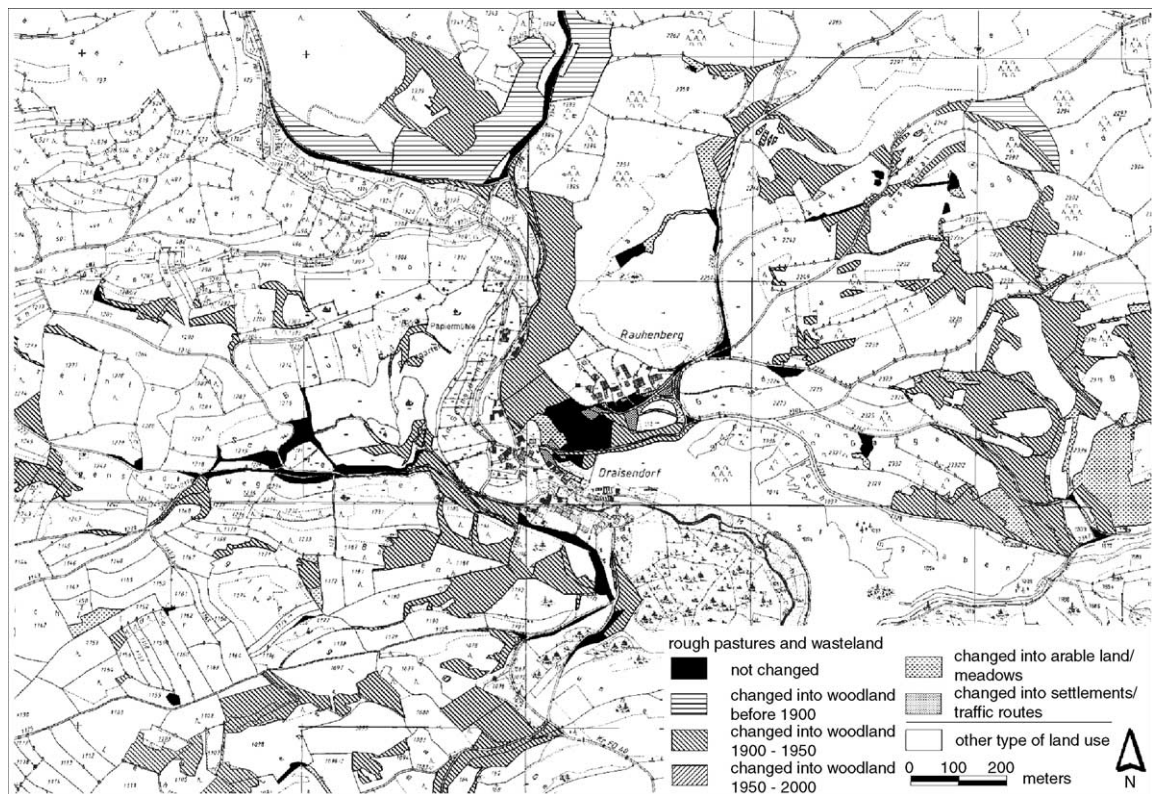


Fig. 8. Categories of change in rough pastures and wastelands in a section of the district of Wüstenstein (Franconian Alb). Map based on: Flurkarte 1:5 000, Nos. NW 82-10, NW 82-11, NW 83-10, NW 83-11; printed with permission by Bayerisches Landesvermessungsamt Munich, No. 865/03.

Table 5
Plant communities and biotope complexes (Franconian Alb)

Land use category (cadastre)	Biotope complexes
Settlements	Ruderal vegetation
Orchards	Dehiscent fruit stands, root crops, ruderal vegetation
Arable land	Cereals, root crops, wild herb vegetation
Meadows	Fertilised meadows
Rough pastures and wasteland	Mesoxerophytic meadows, rock vegetation, bushes
Woodland	Deciduous mixed forest, coniferous forest

biotope types more precisely. The change of ‘rough pasture/wasteland’ into ‘woodland’, which corresponds to periods of afforestation between 1850 and 1900 and between 1900 and 1950, denotes the sparse pinewoods characteristic of the Franconian Alb region (“Steppenheide-Kiefernwald”, after Gauckler, 1938). In contrast, the old woods of the category ‘woodland at all times’ represent mixed beech forests of the *Fagus sylvatica*. Therefore, “land use classes” and their categories of change designated sectors of the study area in which the presence of certain plant communities was highly probable (Fig. 8).

4.5. Nature conservation

Analysis should focus on anthropogenic habitat loss affecting threatened plant communities. Rough pastures and wasteland, for instance, can be defined as potential sites of the endangered gentian-hairgrass turf (*Gentiano-Koelerietum*). The reduction of rough pastures and wastelands equally represents a loss in potential habitats for plants and animals characteristic of limestone and gneiss formation grasslands, and can be used as a measure of habitat fragmentation. Furthermore, with the assistance of diachronic GIS, it is possible to clarify the historical perspectives of nature conservation: was the “pristine landscape” of former times, which today often serves as an ideal, merely a result or an intermediate stage of anthropogenic processes? Hedgerows, which are frequently regarded as a former, characteristic feature of the landscape of the Franconian Alb, appear to have been planted in the 20th century, as the cadastral maps recorded these hedges as grass verges up until 1900. Conversely, the mesoxerophytic meadows of South Germany’s

montane regions are still regarded as a characteristic landscape feature, despite the fact that they became atypical a long time ago (Boehmer, 1994).

5. Conclusions

A GIS-based model for research on cultural landscape change should provide a standardised procedure for the description and analysis of change which is applicable to any location. Our approach can be applied to all parts of Central Europe, e.g. Bavaria, Württemberg and Austria (Messner, 1967; Heider, 1954; Wagner, 1950) where successive, continual land-register data were compiled since the 19th century. A bottom-up approach that initially entails the detailed study of a small region, which can be later generalised to larger area units, is suitable. It should be a basis for a historical spatial model of South Germany (Ott and Swiaczny, 2001).

The integration of a variety of data types into GIS (“Multi Input”) often fails due to the incompatibility of data. Nevertheless, the approach can be useful when using cadastral data along with remote sensing data. The evaluation of land-register maps along with aerial photographs, for example, achieves a higher degree of resolution. This permits a discrimination of wooded areas into deciduous, coniferous and mixed woodlands; while other areas of relevance to nature conservation, such as orchards and small structures including field verges and hedges, can also be identified (Blaschke, 2001).

The land-register based diachronic GIS has proven to be advantageous especially for the quantification and description of landscape change at the local level. The standardised acquisition during the span of 150 years cannot always attain the optimal level of detail, however, “cadastral system has an important role to play in sustainable development” (Williamson, 2001). The quantitative approach used to explain historical landscape change is an essential component for the prediction of future landscape changes. Integrating data from both the natural sciences and the social sciences is a basic requisite for constructing a realistic simulation of the future local-level landscape development (Vogt et al., 2002).

Land-register based diachronic GIS seem to offer many opportunities for landscape planning. For

example, it can be employed to quantify the surface areas of habitat types, and to assess how, when and why the sizes of different habitats have changed. Diachronic GIS facilitates estimations of the feasibility of development concepts in the planning of habitat aggregates. One example is the ability to reconstitute a desirable habitat such as a mesoxerophytic meadow. It is possible to determine whether the envisioned aggregate (which may now be wooded, tilled or overgrown with shrubbery) was formerly a rough pasture, and when the change in use occurred. This makes it possible to evaluate the probability of success in re-establishing a mesoxerophytic meadow at the site in question. The categories of change thus represent a tool for decision-making, and can help to determine the effort involved in achieving a desired result in a given area (“decision support”; Czeranka, 1996). In general, it is possible to forecast the time required for certain vegetation elements to arise, including the potential natural vegetation (Lindacher, 1996).

For diachronic GIS, it should be remembered that data for the local district level are obtained at the scale of 1:5000. In ancient cultivated landscapes, a location may be of value to nature conservation (e.g. with respect to its species inventory) and at the same time have a historical value (often documented by the legal structure of the plots).

References

- Antrop, M., 1997. The concept of traditional landscapes as a base for landscape evaluation and planning. The example of Flanders region. *Lands. Urban Plan.* 38, 105–117.
- Arbeitsgemeinschaft der Vermessungsverwaltungen der Länder der Bundesrepublik Deutschland (AdV) (Ed.), 1995. Amtliches Topographisch-Kartographisches Informationssystem (ATKIS)—Gesamtdokumentation, Bonn.
- Bayer Landesvermessungsamt (BayLVA) (Ed.), 1808. Instruktion für die bey der Steuer-Messung im Königreiche Baiern arbeitenden Geometer und Geodäten. München, reprint 1993.
- Bender, O., 1994. Die Kulturlandschaft am Brotjackriegel (Vorderer Bayerischer Wald), eine angewandte historisch-geographische Landschaftsanalyse als vorbereitende Untersuchung für die Landschaftsplanung und -pflege. *Deggendorfer Geschichtsblätter* 15, Deggendorf.
- Blaschke, T., 2001. Multiskalare Bildanalyse zur Umsetzung des Patch-Matrix-Konzeptes in der Landschaftsplanung. “Realistische” Landschaftsobjekte aus Fernerkundungsdaten. *Naturschutz und Landschaftsplanung* 33, 84–89.
- Boehmer, H.J., 1994. Die Halbtrockenrasen der Fränkischen Alb—Strukturen, Prozesse, Erhaltung. *Mitteilungen der Fränkischen Geographischen Gesellschaft* 41, 323–343.
- Breuste, J., 1996. Landschaftsschutz—ein Leitbild in urbanen Landschaften. In: Bork, H.-R., Heinritz, G., Wiessner, R. (Ed.), *Deutscher Geographentag Potsdam 1995*, vol. 1. Stuttgart, pp. 133–143.
- Broggi, M.F., Kusstatscher, K., Sutter, R., 1997. Ökologisch motivierte Direktzahlungen in der Berglandwirtschaft des Alpenbogens. Beurteilung aus der Sicht eines standörtlichen, biotischen und landschaftlichen Ressourcenschutzes. Blackwell Scientific Publishers, Berlin, Wien.
- Bund, B., 1998. Der Wandel der Kulturlandschaft Nordschwarzwald seit der 2. Hälfte des 19. Jahrhunderts. Eine historische Raum-Zeit-Analyse mit Hilfe eines geographischen Informationssystems (GIS). *Mitteilungen der Forstlichen Versuchs- und Forschungsanstalt Baden-Württemberg*, 204, Freiburg im Breisgau.
- Cousins, S.A.O., 2001. Analysis of land-cover transitions based on 17th and 18th century cadastral maps and aerial photographs. *Lands. Ecol.* 16, 41–54.
- Cousins, S.A.O., Eriksson, A., Franzén, D., 2002. Reconstructing past land use and vegetation patterns using palaeogeographical and archaeological data: A focus on grasslands in Nynäs by the Baltic Sea in south-eastern Sweden. *Lands. Urban Plan.* 61, 1–18.
- Czeranka, M., 1996. Spatial Decision Support Systems in Naturschutz und Landschaftspflege? Umsetzungsaspekte für die raumbezogene Planung. *Laufener Seminarbeiträge* 96 (4), 21–28.
- Denecke, D., 1972. Die historisch-geographische Landesaufnahme. Aufgaben, Methoden und Ergebnisse, dargestellt am Beispiel des mittleren und südlichen Leineberglandes. *Göttinger Geographische Abhandlungen* 60, Göttingen, pp. 401–436.
- Dosch, F., Beckmann, G., 1999. Trends der Landschaftsentwicklung in der Bundesrepublik Deutschland. Vom Landschaftsverbrauch zur Produktion von Landschaften. *Informationen zur Raumentwicklung* 5–6, 291–310.
- Fehn, H., 1963. Siedlungsrückgang in den Hochlagen des Oberpfälzer und Bayerischen Waldes. *Mitteilungen der Fränkischen Geographischen Gesellschaft* 10, 155–167.
- Fehn, K., Schenk, W., 1993. Das historisch-geographische Kulturlandschaftskataster—eine Aufgabe der geographischen Landeskunde. *Berichte zur deutschen Landeskunde* 67, 479–488.
- Gaukler, K., 1938. Steppenheide und Steppenheidewald der Fränkischen Alb in pflanzensoziologischer und geographischer Betrachtung. *Berichte der Bayerischen Botanischen Gesellschaft* 23, 5–134.
- Gunzelmann, T., 1987. Die Erhaltung der historischen Kulturlandschaft. *Bamberger Wirtschaftsgeographische Schriften*, 4, Bamberg.
- Hawkins, V., Selman, P., 2002. Landscape scale planning: exploring alternative land use scenarios. *Lands. Urban Plan.* 60, 211–224.
- Heider, J., 1954. Das bayerische Kataster. Geschichte, Inhalt und Auswertung der rentamtlichen Kataster, Lager- und Grundbücher in Bayern sowie der zugehörigen Flurkarten. *Bayerische Heimatforschung*, 8, München-Pasing.

- Houghton, R.A., 1994. A worldwide extent of land-use change. *Bioscience* 44, 305–313.
- Hunziker, M., Kienast, F., 1999. Potential impact of changing agricultural activities on scenic beauty – a prototypical technique for automated rapid assessment. *Lands. Ecol.* 14, 161–176.
- Krettinger, B., Ludwig, F., Speer, D., Aufmkolk, G., Ziesel, S., 2001. Zukunft der Mittelgebirgslandschaften. Szenarien zur Entwicklung des ländlichen Raums am Beispiel der Fränkischen Alb. Bundesamt für Naturschutz, Bonn-Bad Godesberg.
- Lamarche, H., Romane, F., 1982. Analyse landschaftlicher Veränderungen aufgrund sozio-ökonomischer und ökologischer Kriterien am Beispiel einer südfranzösischen Gemeinde. *Natur und Landschaft* 57, 458–464.
- Leibundgut, C., 1986. Zur Methodik der Uferschutzbewertung. *Jahrbuch der Geographischen Gesellschaft Bern* 55, 151–171.
- Lindacher, R., 1996. Verifikation der potentiellen natürlichen Vegetation mittels Vegetationssimulation am Beispiel der TK 6434 “Hersbruck”. *Hoppea* 57, 5–143.
- Marcucci, D.J., 2000. Landscape history as a planning tool. *Lands. Urban Plan.* 49, 67–81.
- McLure, J.T., Griffiths, G.H., 2002. Historic Landscape Reconstruction and Visualisation, West Oxfordshire, England. *Transactions in GIS* 6, 69–78.
- Messner, R. (Ed.), 1967. 150 Jahre österreichischer Grundkataster 1817–1967. Ausstellungskatalog. Bundesamt für Eich- und Vermessungswesen, Wien.
- Oldfield, F., Dearing, J.A., Gaillard, M.-J., Bugmann, H., 2000. Ecosystem processes and human dimensions—the scope and future of HITE (human impacts on terrestrial ecosystems). *PAGES Newsletter* 8, 21–23.
- Olsson, E.G.A., Austrheim, G., Grenne, S.N., 2000. Landscape change patterns in mountains, land use and environmental diversity, Mid-Norway 1960–1993. *Lands. Ecol.* 15, 155–170.
- Ott, T., Swiaczny, F., 2001. Time-integrative Geographic Information Systems. Management and Analysis of Spatio-Temporal Data. Springer, Berlin.
- Palang, H., Mander, Ü., Luud, A., 1998. Landscape diversity changes in Estonia. *Lands. Urban Plan.* 41, 163–169.
- Pärtel, M., Mändla, R., Zobel, M., 1999. Landscape history of a calcareous (alvar) grassland in Hanila, western Estonia, during the last three hundred years. *Lands. Ecol.* 14, 187–196.
- Petit, C.C., Lambin, E.F., 2002. Impact of data integration techniques on historical land-use/land-cover change: comparing historical maps with remote sensing data in the Belgian Ardennes. *Lands. Ecol.* 17, 117–132.
- Pietrusky, U., 1988. Niederbayern im 19. Jahrhundert. Eine geographische Analyse zur Sozialstruktur. Morsak, Grafenau.
- Plöger, R., 1999. Anwendung geographischer Informationssysteme in der Angewandten Historischen Geographie. *Aachener Informatik-Berichte* 99 (6), 103–111.
- Privat, C., 1996. Einsatz von Geo-Informationssystemen bei Kulturlandschaftlichen Fragestellungen. *Beiträge zur Landesentwicklung* 51, 54–60.
- Schenk, W., Fehn, K., Denecke, D. (Eds.), 1997. Kulturlandschaftspflege. Beiträge der Geographie zur räumlichen Planung. Borntraeger, Berlin Stuttgart.
- Veit, H., 1968. Die Kartenwerke der bayerischen Landesvermessung. In: Bayerisches Landesvermessungsamt (Ed.), *Topographischer Atlas von Bayern*. München, pp. 292–310.
- Verheyen, K., Bossuyt, B., Hermy, M., Tack, G., 1999. The land use history of a mixed hardwood forest in western Belgium and its relationship with chemical soil characteristics. *J. Biogeogr.* 26, 1115–1128.
- Vogt, K.A., Grove, M., Asbjornsen, H., Maxwell, K.B., Vogt, D.J., Sigurdadottir, R., Larson, B.C., Schibli, L., Dove, M., 2002. Linking ecological and social scales for natural resource management. In: Liu, J., Taylor, W.W. (Eds.), *Integrating Landscape Ecology into Natural Resource Management*. Cambridge University Press, Cambridge, pp. 143–175.
- von Haaren, C., 2002. Landscape planning facing the challenge of the development of cultural landscapes. *Lands. Urban Plan.* 60, 73–80.
- Vuorela, N., Petteri, A., Kalliola, R., 2002. Systematic assessment of maps as source information in landscape-change research. *Lands. Res.* 27, 141–166.
- Wagner, H., 1950. Die Entwicklung des Katasters in Württemberg. Innenministerium Württemberg-Baden Stuttgart.
- Weisel, H., 1971. Die Bewaldung der nördlichen Frankenalb. Ihre Veränderungen seit der Mitte des 19. Jahrhunderts. *Erlanger Geographische Arbeiten*, 28, Erlangen.
- Williamson, I., 2001. Cadastres in the 21st century (3). The evolution of the modern cadastre. *GIM Int.* 15, 44–47.
- Ziegler, T., 1987. Einführung in das Automatisierte Liegenschaftsbuch (ALB). Ausbildungsvortrag des Bayerischen Landesvermessungsamtes 19, München.
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