RESEARCH ARTICLE

Forest cover changes in the Prignitz region (NE Germany) between 1790 and 1960 in relation to soils and other driving forces

Monika Wulf · Michael Sommer · Rolf Schmidt

Abstract Decadal to centennial land-cover changes are important drivers of many environmental issues, including biodiversity, biogeochemical cycles and, especially, the global carbon balance. In general, changes are well documented over only a few decades. Studies of land-cover changes and its drivers over centuries are rare. Therefore, the main objectives of this study are (1) to trace the development of the actual pattern of forest-open land over 170 years, and (2) to associate land-cover classes with site conditions (soils) as well as with other driving forces during three periods (1790–1838, 1838–1870, and 1870–1960). For these purposes, we used a combined approach of GIS-techniques and historical reconstructions from archives. The shifts of percentages for established forests, afforestation, clearings and open land on different soils were checked using a chi square test. From the archives, we obtained information on demographic, political/institutional and economic/technological factors, which are assumed to be drivers for past land-cover changes. Percentages of most land-cover classes hardly differed between the periods. However, established forests remained mainly on sandy soils and, to a large extend, afforestation was realised on sandy soils. Clearings reached high percentages on fluvial sands and organic sediments in the early period. A complex of demographic, political/ institutional and economic/technological factors also had a considerable impact on land use/cover change in the Prignitz region. Thus, in addition to the strong association of land-cover classes with soils, our study demonstrated that other driving forces, i.e. political and economic factors, played an important role in the full understanding of land use from the past to the present.

M. Wulf (✉)
Institute of Land Use Systems, Leibniz
Centre for Agricultural Research (Leibniz-ZALF e.V.),
15374 Müncheberg, Germany
e-mail: mwulf@zalf.de

M. Sommer
Institute of Soil Landscape Research, Leibniz
Centre for Agricultural Research (Leibniz-ZALF e.V.),
15374 Müncheberg, Germany

M. Sommer
Institute of Geoecology, University Potsdam,
Karl-Liebknecht-Straße 24-25, 14476 Potsdam,
Germany

R. Schmidt
16225 Eberswalde, Germany

Introduction

Throughout time, the Central European landscape has been extensively influenced by humans. About 4,000 years ago, forests reached their maximum extent in Europe. Since then, the forest cover in, for example, Germany greatly decreased from nearly 100 to 28% (Becker 1995). This decline in forest cover was not a continuous trend. Comparisons of historical maps from the eighteenth century with recent maps illustrate that the distribution of forest and open land has changed repeatedly on a large scale. The distribution of forests and open land in Germany, as well as in other regions, is the result of a mutual relationship between various environmental and socioeconomic factors (Foster 1992; Cousins 2001; Glaser and Hauke 2004; Lambin and Geist 2006). The investigation of the complex interaction of both environmental and political/institutional factors as well as economic/technological factors is important to achieve an understanding of the driving forces for land-cover changes (Brandt et al. 1999; Wimberly and Ohmann 2004; Lambin and Geist 2006; Haase et al. 2007). The identification of driving forces in the past is helpful in understanding present land-use/cover patterns, and may be used to improve predictions of future changes (Marcucci 2000). Furthermore, knowledge of driving forces improves suggestions for the sustainable management of landscapes extensively influenced by humans.

For some time, geographical information systems (GIS) have been a useful tool for understanding relationships between land-cover changes and their driving forces (Kienast 1993; Cousins 2001; Lambin and Geist 2006). The handling and analysing of digital spatial data is relatively easy and efficient, and has already been applied to demonstrate land-cover changes over long periods (Andersen et al. 1996). However, studies using historical data more than 100–200 years old are rare, particularly those relating land-cover changes to environmental conditions (Iverson 1988; Foster 1992; Cousins 2001). The main reasons for this are the limitation of reliable historical maps and the very time consuming work to rectify and digitise them for intersection with actual maps (Cousins 2001).

Due to strong human impacts on landscapes, it is not surprising when relationships between land cover and environmental conditions are found to be weak (Iverson 1988). Despite this, several studies of changes in land cover have revealed close relationships with environmental conditions (Foster 1992; Pan et al. 1999).

The few studies from the United States using data reaching far back have demonstrated that preferable, productive soils and/or cost-effective areas have been converted from forests to arable fields (Foster 1992; Andersen et al. 1996; Hall et al. 2002), whereas forested areas remained largely on unproductive soils or those not suitable for agricultural land use (Foster 1992). This has been proposed as true in Germany also (Glaser and Hauke 2004), and some investigations have supported this (Wulf and Schmidt 1996; Haase et al. 2007). However, so far, this idea was not been verified via studies of the intersection of historical and actual land cover with soil maps.

There are two main purposes of this study. First, it is important to assess the value of intersected maps combining land-cover class distributions with a soil map and incorporating driving forces to interpret changes in land-cover classes. Second, it is also useful to trace the development of the pattern of land-cover classes over 170 years using historical and recent maps, and to associate land-cover classes with soils as well as other driving factors. More specifically, we address the following questions:

(1) Are there obvious changes in land-cover classes from 1790 to 1960 in the Prignitz region?
(2) Is the pattern of land-cover classes associated with soils?
(3) To what extent are driving forces associated with changes in the land-cover classes?

Following Lambin and Geist (2006) we denote biophysical, demographic, political/institutional, economic/technological and cultural factors as driving forces for land use/cover change (hereafter 'LUCC'). For the purpose of linguistic simplification we termed biophysical factors as 'natural driving forces' and all other factors as 'non-natural driving forces'.

Materials and methods

Study area

The Prignitz region (52°50′N–53°20′N, 11°30′E–12°30′E) is located in the western part of the Federal State of Brandenburg in north-eastern Germany (Fig. 1), and covers about 320,000 ha. Due to

Fig. 1 Location of the study area: Prignitz, Brandenburg, Germany

changes in administrative boundaries in the past, the size has changed repeatedly, ranging from ca. 320,000 to 355,000 ha (Wulf 2004a).

Climatically, the region is subject to sub-atlantic to sub-continental influences; the mean annual temperature is about 8.0°C, the range of mean annual variation in air-temperature is 17.5–18.5°C and the range of mean annual precipitation is 550–650 mm (Krumbiegel and Schwinge 1991).

The dominant parent materials for soil development are sandy to loamy ground moraines as well as glacio-fluvial sandy deposits. Nearly 10% of the land surface is composed of skeletal end moraines (Stackebrandt et al. 1997). The prevailing soil types are Eutric Cambisols (about 70%), while Haplic Stagnosols and Haplic Gleysols cover about 22% (nomenclature follow ISSS; ISRIC; FAO 1998; LGRB 2001).

Maps on distribution of land-cover classes

Two sets of hand-drawn map series, showing the distribution of land cover classes, exist for the Prignitz region for a time span of about 170 years (Table 1). The map series were produced in the context of site investigations of the State Forest Holding in the 1950s (IFS 1960, 1961). The former State Forest Holding of Perleberg (hereafter 'Perleberg') covers the western part and the former State Forest Holding of Kyritz (hereafter 'Kyritz') the eastern part. Since there were marginal variations in the period or time of the map series or maps between Perleberg and Kyritz, the investigated periods were

consolidated to 1790–1838 (early period), 1838–1870 (middle period), and 1870–1960 (late period). The scales of maps were unified to 1:100,000.

Both map series distinguished between forest in a narrow sense ('closed forest'), and heathland and fen as forest in a broad sense ('open forest'). The term 'heathland' was usually used for forests on sandy soils, even if they were devastated (Krausch 1956; Wulf and Groß 2004), and a fen was always stocked, at least with scattered shrubs (Wulf 2004a). Since those areas were definitely not used as arable field or grassland we designated them as forests.

While the maps of Perleberg contained four land-cover classes 'established forests', 'afforestations', 'clearings', and 'open land' for each of the three investigated periods, the maps of Kyritz distinguished only between forest and open land at the four points in time (Table 1). Thus, we must at first produce a map series with unified contents. We therefore intersect digitised map pairs of successive years. For the digitisation (with ArcView 3.3) reference points were set on the hand-made maps using the coordination system of Gauß-Krüger.

A comparison of the hand-drawn maps before digitisation revealed, that stable boundaries of forest areas from one to the next period matched mostly very good. Therefore, we found generally negligible deviations between the corresponding digitised polygon boundaries, and even the few deviations by 5 mm (50 m in the landscape) did not play a major role in the background of the scale and the size of the studied area. However, all deviations were corrected via rubber sheeting. Then the layers from Kyritz and Perleberg were fit together separately for each period, and small deviations at the boundary between the two sub-regions were also corrected.

Maps produced before the technique of surveying was introduced in Germany (triangulation according to Gauß since about 1820) were created by perambulation, i.e. counting steps. This approach leads to an imprecise reproduction of landscape elements, as contour accuracy is given only for small map segments (e.g. Cousins 2001). To overcome this problem, the historical maps were manually equalised. Unfortunately, this procedure was not described in the handbooks of the State Forest Holding (IFS 1960, 1961). For that reason, we compare the maps produced by the State Forest Holdings with maps produced by Wulf (2004a). She used maps from

Table 1 Maps used for investigation of land-cover class distributions between 1790 and 1960 produced by the former state forest holdings in the Prignitz (IFS 1960, 1961)

Perleberg (western part of the Prignitz)	Period/time	Kyritz (eastern part of the Prignitz)	Period/time
Map of Schmettau (1790) (ca. 1:50,000)	1790	Map of Schmettau (1790) (ca. 1:50,000)	1790
Map of von Witzleben (1838) (ca. 1:200,000)	1790–1838	Map of von Witzleben (1837) (ca. 1:200,000)	1837
Map of von Rappard (1870) (ca. 1:200,000)	1838–1870	Map of von Rappard (1870) (ca. 1:200,000)	1870
Ordnance survey maps, land register maps, aerial photographs (various dates) (all 1:100,000)	1870–1958	Map of the German Reich (1937) Ordnance Survey maps (1950s) (all 1:100,000)	1960

about 1780 (map of Schmettau), 1880 (first ordinance survey maps), and 1980 (recent topographical maps) at scales of 1:50,000 or 1:25,000. A comparison of her map with those of the State Forest Holding shows a similar pattern of forest-open land distribution. This was also true for comparisons of the other maps (1870 with 1880, and 1960 with 1980) as well as for the intersected layers, and deviations were mainly restricted to small patches that can be explained by the differences in scales.

We stopped our study in 1960 for two main reasons. First, our aim is the focus on LUCC in the past. Second, the period after 1960 was characterised by several short-termed changes in agriculture, e.g. foundation of agricultural production cooperatives since 1952 and reorganisation of them in the 1970s in the former GDR, so that LUCC studies and their interpretation with driving forces will go beyond the scope of our study.

Soil map

Only one soil map exists that covers the entire area; the meso-scaled (1:300,000) digital soil map of Brandenburg (LGRB 2001), which contains detailed information on parent material and soil types according to ISSS; ISRIC; FAO (1998). On this map, six generalised groups of soils were distinguished according to parent material: Aeolian, anthropogenic, fluvial, glacial, ground moraine and organic sediments, as well as fluvial loams and clays (Fig. 2). For the group of glacial sediments we assigned 'sand,
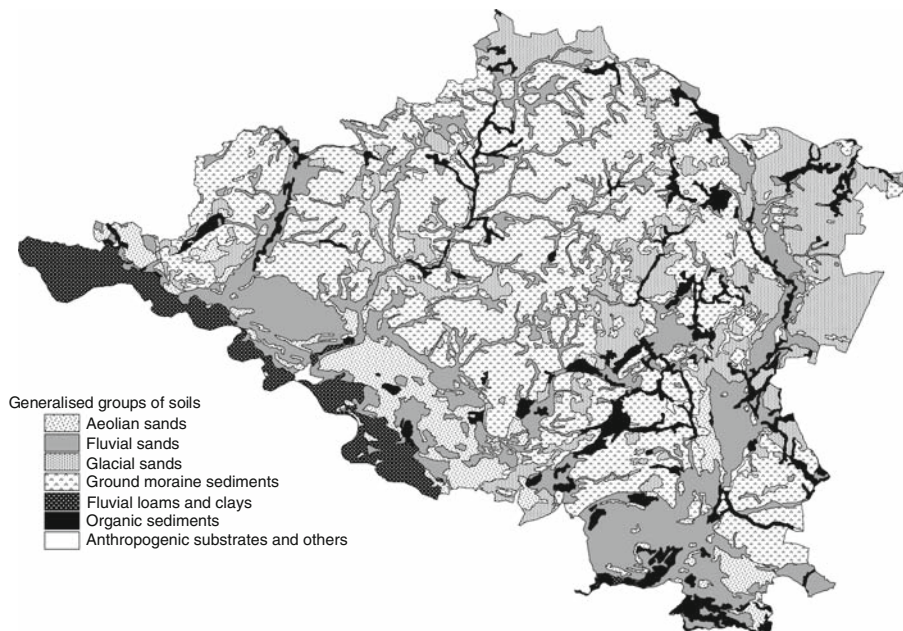

Fig. 2 Generalised soil map (original scale 1:300,000) of the study area

Table 2 Units of the meso-scaled soil map ('Bodenübersichtskarte' 1:300,000: Landesamt für Geowissenschaften und Rohstoffe 2001) and derivation of the potential suitability for use as agricultural land

Mapping units, summarised as typical sediments (no. of map units)	Total area (km^2)	Used as agri-cultural land (%)	Suitability for use as agricultural land[a]
Aeolian sands (1–12)	234	10	Very low (unprofitable)
Fluvial sands (13–29)[b]	782	62	Only to a limited extent
Glacial sands (38–48)	522	50	Low
Ground moraine sediments (loam, overlying sands) (30, 49–71)	1,421	79	Middle to good
Fluvial loams and clays (floodplains underlain by sands) (31–37)	165	84	Very good
Organic sediments (72–80)	221	72	After drainage (only to a limited extent)
Anthropogenic substrates (81–99)	Negligible		

[a] Estimation of suitability, see remarks in "Materials and methods"

[b] Includes <1% of sandy soils influenced by groundwater

influenced by groundwater' (only 0.8% of the total area) to fluvial sediments, and distinguished 'glacial sands' (pure sand) and 'ground moraine sediments' (loam, overlying sands) for ecological reasons.

The group of soils represented physical landscape attributes usually not (or extremely hardly) to be altered by different kinds of land use (human activities) or land-cover changes, and therefore be assumed stable throughout the investigated periods.

The estimation of the suitability (Table 2) based on the soil quality (e.g. parent material, nutrient and water supply), and ignored geo-morphological circumstances that usually excluded the use as agricultural land, e.g. flooding in the floodplains.

Intersection of land-cover classes maps with the soil map

For each period, layers with the four land-cover classes were separately intersected with the digital meso-scaled soil map to derive the percentages of each land-cover class on the specific soil substrates. The meso-scaled soil map was based on the so-called 'meso-scaled agricultural site mapping' (scale 1:100,000; Schmidt 1975). Therefore, relatively small patches of soil units are precisely enough represented (Fig. 2) to make the map serviceable for intersection with land-cover classes maps. Since the intersected maps served as a basis for deriving highly aggregated percentage values, shortcomings due to different

scales are assumed to be too small to have a relevant impact on the data for statistical analysis.

The association between a set of Y variables (here, land-cover classes) and a second set of X variables (here, groups of soil) can be tested by a canonical correlation analysis (Lesschen et al. 2005). This analysis required grid based data sets with normal distribution. Since our data did not fit the normal distribution, even after transformation (too many 0 values), we applied the non-parametric chi^2-test using the software Minitab (Anonymous 2000).

Enquiry on non-natural driving forces for LUCC

The Prignitz was colonised most intensively since the seventh/eighth century, and the development of the landscape was completed during the mid-thirteenth century (Krenzlin 1952). Mineral resources are negligible, but the soil quality and low relief energy of the landscape provided good preconditions for the use as agricultural land after clearing (Heuer 1927). At the end of the eighteenth and beginning of the nineteenth century, the majority of forest areas had been cleared and three-fourths of all settled people in the region lived in the country (Heimatkundliche AG 1925; Wulf 2004a). At least half of all inhabitants were active in agriculture, and more than 20% worked in the industry until 1960 (Staatliche Zentralverwaltung für Statistik 1966a, b). The industry mainly manufactured agricultural and forest products,

e.g. distilleries, factories for potato starch and flour mills (Heuer 1927). Together with grassland, at least 60% of the total area has been used for agriculture during the last 200 years (Wulf 2004a). Thus, agriculture played the prominent role between 1790 and 1960. We therefore focussed on those driving forces assumed to have a strong effect on the dynamic of land-cover class distributions at landscape scale, i.e. the development of agricultural land and its intensity of use. The relevance of driving forces for LUCC in the region was proven by as many varied sources as possible. Therefore, we studied several publications on the regional history of the Prignitz (Heuer 1927; Schultze 1956; Enders 2000). We also conducted intensive research on archival documents in the main archive of the Federal State of Brandenburg. Additionally, we evaluated several publications concerning the culture history in local areas, as well as chronicles of the towns of the Prignitz. Moreover, much detailed information on afforestation and clearings was given in the handbook of the State Forest Holdings (IFS 1960, 1961). The responsible persons of the site inventory working groups have made a comprehensive evaluation of archival documents from the main archive, and much of this material, together with additional information, had been published in Wulf (2004a). Therefore, we often referred to these publications.

Results

Changes in land-cover classes

Forest areas showed a maximum of about 32% in 1790 and decreased to 23% in 1960 (Table 3).

Shifts in land-cover classes within each of the three periods in the Prignitz region were highly dynamic (Fig. 3). Therefore, forest parcels that are mapped as forest since 1790 cover a relatively small portion of the landscape. Afforestation often occurred adjacent to already established forests, and was mainly conspicuous in the eastern part of the region in the middle period and in the western part in the last period. Clearings are conspicuous across the whole region in the first period, while they were concentrated in the eastern part during the middle period and in the northern part during the last period.

Table 3 Total area (ha) and percentages of forest and open land at four points in time in the Prignitz

Year	Forest (ha)	Forest (%)	Open land (ha)	Open land (%)
1790	113,459	31.7	244,945	68.3
1838	83,094	23.2	275,310	76.8
1870	86,004	24.0	272,401	76.0
1960	82,706	23.1	275,699	76.9

Despite clear shifts in the total area of most land-cover classes, the percentages did not vary much between periods. However, clearings reached a relatively high value in the early period, while the area of clearings in the last two periods was relatively low (Table 4).

Information on the usage of the open land is incomplete, but Table 5 shows that the study area was characterised by agriculture, especially arable fields, throughout the investigated period. In parallel, grasslands and cattle/ha increased until the 1960s.

Association of land-cover classes maps with soils

Table 6 shows significant results for all periods with regard to the percentage of land-cover classes on different soils. Among the land-cover classes, established forests were mainly to be found on aeolian and glacial sands in all three periods. In contrast, established forests were under-represented on soils with good nutrient and water supply. We found similar results for afforestation, particularly for the percentages on aeolian and glacial sands in the middle and last period, respectively. Afforestations are remarkably under-represented on fluvial loams and clays during the first and last period. Clearings were mainly realised on fluvial sands and organic sediments, and were under-represented on fluvial loams and clays in the middle period. In all three periods, the percent of open-land is under-represented on aeolian and glacial sands, but reached unexpected higher percents on fluvial loams and clays (Table 6).

Non-natural driving forces for LUCC

Investigation of various sources had revealed a complex of driving forces for LUCC in the Prignitz (Fig. 4). However, while several demographic, political/institutional and economic/technological factors

Fig. 3 Distribution of land-cover classes in the Prignitz (NE-Germany) within the three periods **A** 1790–1838, **B** 1838–1870, and **C** 1870–1960
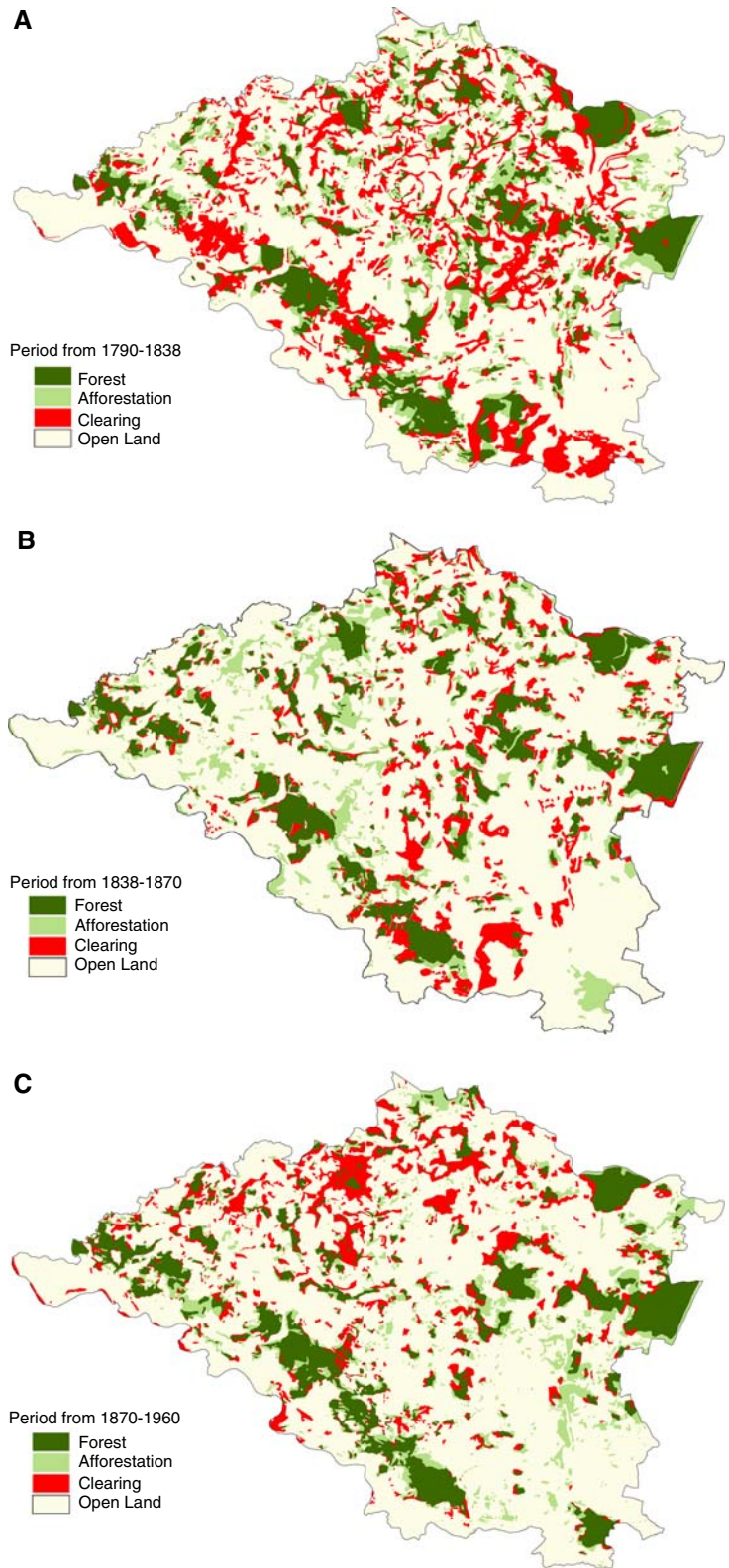
Table 4 Total area (ha) and percentages of land cover classes within the three time slices 1790 to 1838, 1838 to 1870, and 1870 to 1960 in the Prignitz

Land cover classes	1790–1838	1838–1870	1870–1960
Established forests (ha)	48,409	51,834	50,287
Established forests (%)	13.5	14.5	14.0
Afforestations (ha)	34,685	34,170	32,418
Afforestations (%)	9.7	9.5	9.0
Clearings (ha)	65,050	32,526	35,906
Clearings (%)	18.1	9.1	10.0
Open land (ha)	210,261	239,874	239,792
Open land (%)	58.7	66.9	66.9

Table 5 Percent of the land-cover class 'open-land' and number of cattle from about 1780 to 1966 in the Prignitz

Year Total area	1780 323,410 ha[a]	About 1800[c] 334,000 ha	1925[c] 334,000 ha	1966[d] 322,100 ha
Arable fields	45[b]	–	53.6	45.4
Grasslands	10[b]	–	17.1	20.3
Pastures	–	–	–	11.2
Meadows	–	–	–	9.1
No. of cattle	47,123[a]	About 49,720	–	149,341
Cattle/ha	0.15	About 0.15	–	0.46

–, no information

Sources: [a] Bratring (1804)

[b] Information obtained in two steps, first by manually transferring arable fields and grassland areas from original historical maps onto transparency paper, then determining the area of both land cover classes and the total area using underlying graph paper. Thus, only rough % values are given

[c] Heimatkundliche AG (1925)

[d] Staatliche Zentralverwaltung für Statistik (1966a, b)

are important, we found no indication that cultural factors played a role in the investigated region.

The early period is characterised by a doubling of inhabitants in the nearby residential town of Berlin, while the increase in the number of inhabitants in the Prignitz, despite the settlement of colonists, was relatively low. The first separations of mixed manor and farmer estates took place in this period. Another important political/institutional factor was the comprehensive afforestation with pine on sandy soils pushed by King Frederick II ('the Great') of Prussia.

Among the economic/technological factors, were increases in crop yields, prices for rye, number of cows and number of cattle/ha. Furthermore, clearings and subsequent drainage for the purpose of cultivation became conspicuous.

In the middle period, the inhabitants of Berlin doubled again. Further separations were realised and completed. Afforestation of relatively unproductive soils proceeded, especially triggered by the abolishment of forest easements in 1840. Important economic/technological factors included a further increase in crop yields and number of cattle per hectare. After a strong decrease, rye prices increased again. After about 1850, farmers used increasingly more (artificial) fertiliser in order to increase yields. In this period, the changeover from drainage by ditches to drainage by clay tubes resulted in the first manufacturing of clay tubes in Berlin. This new development allowed the drainage of sites that could not be sufficiently drained by ditches, thus allowing clearings to be pursued on these sites. Wooden ploughs were superseded by iron ploughs; allowing an intensification of cultivation and a rapid increase in the mechanisation of land use.

The last period is characterised by a doubling and tripling of inhabitants in Berlin, with only a small increase in the inhabitants of the Prignitz. Afforestation on boggy soils increased, while afforestation on sandy sites decreased. Especially at the beginning of the period, the development of country roads and the expansion of railways were important political/institutional factors that facilitated the trading of agricultural products with Berlin. Among the economic/technological factors, there were further increases in the use of (artificial) fertiliser, the mechanisation of land use and the number of cattle/ha. Again, prices for rye increased after a decrease, though not as strongly as in the two periods before.

Discussion

Overall land-cover changes in the Prignitz landscape

The traditional agricultural use of land for several 100 years before the end of the eighteenth century (Heuer 1927; Krenzlin 1952; Schultze 1956) led to a shifting mosaic of the forest-open land distribution

Table 6 Percent of established forests, afforestation, clearings and open land between 1790–1838, 1838–1870, and 1870–1960 on different soils

	Aeolian sands	Fluvial sands[a]	Glacial sands	Ground moraine sediments	Fluvial loams and clays	Organic sediments	Anthropogenic substrates	Sum
Total area in the Prignitz region [ha]	23,402	78,228	52,187	142,090	16,471	22,063	2,181	336,623
Portion of the total area	7.0	23.2	15.5	42.2	4.9	6.6	0.6	100
								Chi²-value
1790–1838								*P-value*
Established forests	**33.2*****	11.0	**27.0*****	6.7	*0.4****	9.2	0.2	
Afforestation	14.0	7.5	**21.4*****	9.1	*0.7***	6.0	5.3	
Clearings	22.0	**29.0****	10.0	15.6	11.1	**(24.8)**	11.4	*170.963*
Open land	*30.8*****	52.5	*41.6**	68.6	**87.8*****	60.0	83.1	*<0.001*
1838–1870								
Established forests	**37.2*****	*(7.7)*	**36.9*****	8.9	*0.1****	*4.7**	2.9	
Afforestation	**18.4****	10.5	10.1	8.2	9.6	6.1	1.9	
Clearings	10.5	11.0	12.1	7.1	*1.1**	10.5	2.7	*183.515*
Open land	*33.9*****	70.7	*41.4*****	75.8	**89.2**	78.7	92.5	*<0.001*
1870–1960								
Established forests	**50.7*****	*7.4**	**38.2*****	*5.0***	*0.3****	*4.2***	2.7	
Afforestation	**19.1****	9.7	**19.9****	*(5.0)*	*1.0***	5.7	10.6	
Clearings	5.1	10.9	8.8	12.1	9.5	6.6	2.1	*262.203*
Open land	*25.2*****	72.1	*33.0*****	77.9	**89.2*****	**83.5**	84.7	*<0.001*

Chi²-tests included all soils, but results of anthropogenic substrates were not demonstrated and not discussed due to the very small portion of the total area. Significantly higher values as expected are given in bold letters and significantly lower values as expected are given in italic letters; * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$. In parentheses: higher or lower values as expected at P-level <0.10

[a] Includes <1% glacial sands influenced by groundwater

around 1790 (Wulf 2004a). However, the decrease from 1790 to 1960 in forests is the most striking change in the land cover of the Prignitz region (from about 32 to 23%; Table 3); clearings were realised to a great extent, especially between 1790 and 1838 (Table 4).

Changes of land-cover classes in relation to soils

The Prignitz landscape has been intensively altered by human activities over the last several 100 years (Wulf 2004a). Therefore, it could be assumed that the present relationships between land cover and site conditions would be weak (Iverson 1988; Schneider and Pontius 2001). Instead, we find land-cover classes significantly associated with soils within all three periods (Table 6). Obviously, soils and site conditions are driving forces

behind the use of a specific site as a forest (established forest and afforestation) and as agricultural land (clearings and open land; Tables 2, 6). These findings are generally in parallel with observations in the United States (Foster 1992) and Canada (Pan et al. 1999). The strong association of land-cover classes with site conditions, especially soils, can be explained mainly by spatial scale. Patterns of land use/land cover at the landscape level reflected the influence of conditions in a biogeographic region, e.g. climate and geology, while, on the local level, land-use history and small-scaled demographic trends played a major role (Wiens 1989; Hall et al. 2002). Since climate varies slightly within the Prignitz landscape but parent material show a clear spatial patterning, it is not surprising that land-cover classes are associated with soils.

Year	1780	1800	1820	1840	1860	1880	1900	1920	1940	1960	Source(s)
Demographic Factors											
Population (Inhabitants)											
• Berlin: ~1680 <10,000		>100,000		>200,000	500,000	>1 Mio.	>2 Mio.				29,34,39
• Prignitz (Inhabitants/ha)	0.23	0.25	0.26	0.36	0.43	0.45	0.46	0.51	0.42	0.57	16,23,35,36, 38

Settlement of colonists — 1740-1770 [a]; 1750-1790 [b]. Colonists from Bohemia, France and the Netherlands. — Source(s): 29; 1,9,18,19,20, 22,24,25,37

Political/Institutional Factors

Separations — 1750 - 1820 - 1870. First separations of mixed manor and farmer estates. Further separations due to edicts from 1816 and 1821. — Source(s): 19,32

Afforestations — 1764 [c] — Source: 41

1765 until beginning 20th century: extensive afforestations with pine on sandy soils unprofitable for agricultural use — Source(s): 3,26,27,30,41

especially since the abolishment of forest easements in 1840 — Source: 30

20th century: relatively extensive on previously insufficiently drained boggy soils — Source: 41

Road network — Length of developed country roads for trade: Before 1800 ca. 460 km; in 1910: ca. 670 km — Source: 32

Railways — ♦ Expansion of railways; ♦ 1846 first railway between Hamburg and Berlin — Source(s): 22,32

Year	1780	1800	1820	1840	1860	1880	1900	1920	1940	1960	Source(s)

Fig. 4 Driving forces for land use/cover changes in the Prignitz region (and in Prussia or Germany, explicitly mentioned) between 1780 and 1960. Prussia was a north German state from the fifteenth to the nineteenth century, embracing an array of provinces centred on Brandenburg (Hagen 2002). *Vertical dotted lines* indicating the three investigated periods. Source(s): No. see reference list in Appendix A—Electronic Supplementary Material. [a] Frederick II ('the Great') supported the settlement of about 300,000 colonists in Prussia in order to build channels, and to cultivate fens/swamps. [b] 134 new 'small farms' ('Vorwerke') build, always combined with the cultivation of fens/swamps in the Prignitz. [c] Circular from Frederick II ('the Great'): Barren sandy soils have to be afforested with alder, birch, and pine. [d] First manufactory for clay tubes in Berlin. The clay tube press (creating clay tubes for drainage) was invented 1835 in England

Year	1780	1800	1820	1840	1860	1880	1900	1920	1940	1960	Source(s)

Economic/ Technological Factors

Field crops

Increase in wheat-sowing of ca. 60% — 16

Yield increase for crops between 30% and 50% — 33

Fertilisation

Increasing use of (artificial) fertiliser in Prussia/Germany : bone manure, chile salpeter, guano, potassium salt, superphosphate — 28

1910 in Germany: production of synthetic ammonia (N-fertiliser) — 28

Prices

Increase of prices for rye of ca. 140% — Increase of prices for rye of ca. 70% — Increase of prices for rye of ca. 35% — 33,38

Cattle

Increase in number of cows by ca. 35% — 16

Increase in number of cattle/ha: ca. 0.15   ca. 0.46 — 16,35,36

Drainage/meliorations

Drainage of lowlands by ditches: conversion of forests to grassland — Drainage by clay tubes: in Prussia about 450,000 ha meliorated — 19,33

1847 [d] — 33,38

Since 16th/18th century: clearings and drainage of lowlands of rivers - conversion to grassland — 2,19,40

1710   until   1820: clearings and drainage of lowlands of water courses - cultivation — 5,6,7,9,12,14, 15,23,31,40

1775   until   1900: clearings and drainage of lowlands of the flat plateaus: areas of few ha to several hundred ha — 4,8,10,11,13, 15,17,20,40

Mechanisation

Rapid increase in mechanisation of land use — 22,33

1850/1860: development of a new iron plough in Prussia – intensification of cultivation — 28

Year	1780	1800	1820	1840	1860	1880	1900	1920	1940	1960	Source(s)

Fig. 4 continued

Sandy soils of the highlands usually limited the growth of cultivated plants due to water shortage and nutrient deficiencies, as long as the soils were not fertilised. Sandy soils influenced by ground water, on the other hand, often impede the growth of plants by an oxygen deficit in subsoil horizons. Therefore, these soils are less attractive for use as agricultural land, and we predict that such soils would mainly be covered by forests. The results in Table 6 confirmed our assumption and are in accordance with the observations of Iverson (1988), who found prairie converted to forests preferentially on sandy soils with a low productivity index. Conversely, we assumed that soil substrates with a higher suitability for use as agricultural land should be cleared and used as such. Our data corroborate this assumption. Iverson (1988) again found similar results; fertile soils with a high productivity index are usually converted to arable fields. Since the land-cover class 'open land' on our maps is not differentiated into arable field and grassland, we cannot conclude that soils with higher suitability for use as agricultural land are mainly used as arable fields. However, the above assumption is the most likely, since arable fields reached a much higher portion on the total area than grasslands (Table 5); this is true over a long time scale, as shown by literature on landscape history (Schultze 1956; Enders 2000).

Non-natural driving forces as explaining variables for changes in land-cover classes

Our results demonstrated that the percent of land-cover classes on certain soils does not vary randomly among the three periods. Previous studies of landscape history, as well as many archival documents, suggest that the extent of afforestation, clearing and usage of open-land as arable fields or grasslands in each period were influenced by a complex of non-natural driving forces (Krzymowski 1961; Schulze 1995; Fig. 4). First, there was a strong increase of inhabitants in the cities throughout the investigated periods (Schultze 1956; Mauch 2004) and these people had to be nourished. This need was met with different measures in each period, depending on the economic and technical possibilities of the time. Additionally, farmers were encouraged to accelerate the clearing and intensification processes by the rapidly increasing prices for rye (Fig. 4), which made its cultivation highly attractive. Even some strong but short-term

decreases around 1820–1830 and 1890–1900 did not arrest this development until the middle of the twentieth century (Schulze 1995). Besides crops, the Prignitz was a major supplier of meat and milk to the rapid increasing town of Berlin (Heimatkundliche AG 1925).

During the early period (1790–1838), Johann Heinrich von Thünen (1783–1850, an important agrarian scientist) developed and published his rules of intensification of crop production and livestock breeding. The intensification was attained inter alia by deeper tilling, more intensive crop rotations and fertilisation, and careful breed selection (Krzymowski 1961). Due to economic and temporal limitations (farmers lacked money, and acquiring new knowledge and skills requires time), the implementation of the Thünen'sche rules did not take place until the second half of the nineteenth century (Fig. 4). Therefore, in the early period (1790–1838), an increase in crop yields and livestock could be obtained mainly by the enlargement of agricultural land, to the detriment of forested areas, and subsequent melioration of the gained agricultural area (Enders 2000). On the potentially most productive soils of lowlands along rivers (fluvial loams and clays), forests had been converted to grasslands by the middle of the eighteenth century (Enders 2000). Thus, there was increasing pressure on productive soils covered by forests on the highland. Since mechanisation in agriculture was not well developed at that time (Fig. 4), wet or moist sandy soils were preferred for conversion to agricultural land, compared to loamy soils (Krenzlin 1952). Wet or moist sandy soils could be easily drained by ditches, as had been the common practice for several centuries (Schulze 1995). However, all of these activities required labour, and the region was scarcely populated at the end of the eighteenth century as a long-lasting consequence of the huge number of victims in the 30-year war of the seventeenth century (Heuer 1927). Consequently, King Frederick 'the Great' massively supported the settlement of new colonists in order to cultivate as much area as possible for agricultural use (Mauch 2004).

The middle period (1838–1870) is characterised by a continued conversion of forests on moist/wet soils to arable fields or grasslands, and further extensive afforestation on sandy soils (Fig. 4). The invention of the clay tube press in 1835 triggered the use of clay tubes for drainage (Schulze 1995). Since

clay tubes allowed very effective drainage of wet soils, people converted much of the remaining forests on wet soils to agricultural land (cf. Cousins 2001). However, these soils covered a relatively small part of the region, and the strong increase in agricultural production during this time had not yet been extensively realised on the newly gained agricultural land. The greatest hindrance to achieving increased yields was the small-scale mix of manor and farmer estates. This problem was solved by separation due to governmental edicts from 1816 to 1821 (Schultze 1956), which resulted in the coalescence of arable field and grassland into larger patches that could be more efficiently used for agriculture (Hagen 2002). All of these factors, combined with increasing mechanisation in land use and intensification of cultivation, led to a strong increase in agricultural production (Schulze 1995), and allowed the abandonment of less productive soils for agricultural use, explaining the extensive afforestation on sandy soils in this period.

In the late period (1870–1960), afforestation on sandy soils was mainly complete until 1920–1930, while clearing continued on the flat plateaus and ground moraine sediments (loamy soils; Fig. 4). The clearing activity latter is reflected in unexpectedly low %-values for established forests and afforestations on ground moraine sediments (Table 6). Development was enabled by the rapid increase in mechanisation of land use (Schulze 1995). However, in this period, farmers benefited from the overall improvement of agricultural practices. Thus, agricultural production became more efficient. Additionally, marketing of surplus production to cities was facilitated by the rapid expansion of trade routes (Heimatkundliche AG 1925). In particular, an increase in agricultural production in this period was achieved mainly on the already existing acreage (Krzymowski 1961). Consequently, all soils unprofitable for agricultural use were given up and afforested. At the end of the investigated periods, human activities had led to a shift, with forests growing nearly exclusively on unproductive soils, and a maximum use of the productive soils as agricultural land.

Land-cover data and applied methods

The value of comparing historical and recent maps for analysis of landscape changes is established (Cousins 2001; Hall et al. 2002). However, the underlying reasons for LUCC cannot be derived from the maps themselves. Understanding the driving forces for changes in land use requires additional information on the socioeconomic circumstances in certain periods (Brandt et al. 1999; Hall et al. 2002; Haase et al. 2007), and the explanation of land-cover changes over long periods must especially consider the complexity and variability of driving forces across space and time (Lambin and Geist 2006). To meet these requirements, we chose the approach of associating a spatial-explicit presentation of LUCC (Fig. 3) with a natural driving force (Table 6), and connecting data in Fig. 3 with descriptions of LUCC and its potential non-natural driving forces from various sources (Fig. 4). For this investigation, only one natural driving force could be considered, although further potential forces may play a role, e.g. relief, hydrology and vegetation (Lambin et al. 2001). There was no possibility of a spatial-explicit presentation of the non-natural driving forces in our study, a problem that is well-known from other LUCC studies, e.g. spatial representation of sociological facts (Lambin and Geist 2006). However, we found reasonable interpretable results (Table 6) and spatial-explicit data in high coincidence with descriptions of LUCC for the Prignitz (Fig. 4). As such, our study contributes to answering important scientific questions in the frame of the LUCC-project as formulated in Lambin and Geist (2006).

Conclusions

The Prignitz landscape has undergone clear shifts in the total area of most land-cover classes between 1790 and 1960. A strong decrease in forests with a parallel increase of agricultural areas, mainly arable fields, is the most obvious change. Despite extensive influences by humans many centuries before the investigated periods, the actual pattern of land-cover classes is strongly associated with soils. Sandy soils, unprofitable for use as agricultural land, are mainly covered by forests. In contrast, nearly all soils potentially suitable as agricultural land are used as those today.

Our study shows the chronology of LUCC within a long period of 170 years. During this period, clear changes and trends occurred. It is an essential result that any change or trend is explicitly associated with both site conditions (soils) and non-natural driving

factors. Therefore, we recommend that discussions on effective landscape planning and sustainable management of natural resources should take place with comprehensive knowledge of the landscape history. Also patterns of biodiversity can be better understand if they are underlain by knowledge of former land use/land cover, as demonstrated for plant species richness by Wulf (2004b).

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