Science of the Total Environment 659 (2019) 1526–1536

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Land use change in an agricultural landscape causing degradation of soil based ecosystem services

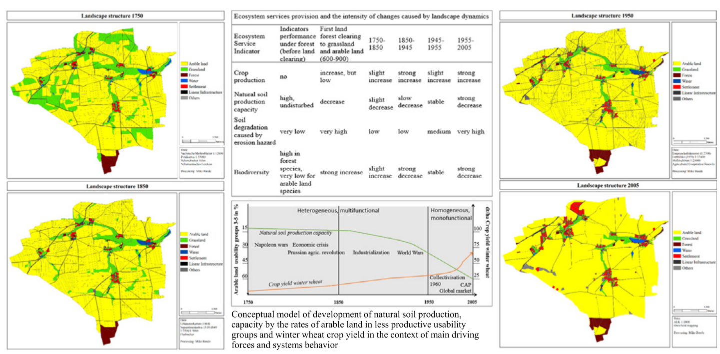
Mike Baude [a,*], Burghard C. Meyer [a], Marcus Schindewolf [b]

[a] Department of Geography, University of Leipzig, Johannisallee 19a, 04103 Leipzig, Germany
[b] Department of Plant Production, Thuringian State Institute of Agriculture, Naumburger Str. 98, 07743 Jena, Germany

HIGHLIGHTS

- Land use changes are highly dynamic in changes of landscape structure and influencing the ecosystem services provision
- Crop yield production increased from 1900 by around 100 % and has stagnated since 2000
- Species richness and distribution increased until 1850 and has decreased strongly until today
- Degradation of natural soil production capacity at around 60 % of agricultural land
- Erosion hazard risk is modeled for 25 % of arable lands as very high and amount about 30 t/ha per simulated rainfall event

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 13 May 2018
Received in revised form 28 December 2018
Accepted 29 December 2018
Available online 2 January 2019

Editor: Jay Gan

Keywords:
Long-term degradation of ecosystem services
Driving forces analysis
Cadastral map analysis
Historical soil assessment
Land use change

ABSTRACT

Landscape structure and ecosystem service (ES) provision in Central Europe have changed fundamentally and some ES have been irreversibly degraded over the last 250 years. The land use change analysis of a typical agricultural landscape near Leipzig (Germany) uses digitized historical GIS-data, serial cadastral maps and documents in time steps 1750, 1850, 1950 and 2005. Arable land area increased from 73.4% (1750) to 87.2% (2005) and grassland decreased from 22.1% to 4.2%. ES provision change analysis has resulted e.g. in a significant increase of winter wheat production comparing the decades 1990–1999 to 2000–2009.

However, natural soil production capacity has degraded based on the interpretation of historical soil assessment maps (1864, 1937) and the actual erosion risk hazard has increased strongly in the same period. Caused by the Prussian agricultural revolution between 1750 and 1850 a high biodiversity level is found, followed by a slight decrease during the industrialization in the second half of the 19th century. By industrialized production and collectivization since 1960 devastation of vegetation structures has brought habitat degradation and a dramatic biodiversity loss. Driving forces analysis shows that significant drivers of land use and ES changes since 1750 are socioeconomic, political and technical drivers. It clarifies the impact of landscape changes by Prussian agrarian reforms, industrialization, technical and land management innovations, Kolkhoz system and Common Agricultural Policy on ES degradation based on the indicators crop production, natural soil production capacity, soil degradation caused by erosion hazards and biodiversity.

* Corresponding author.
E-mail address: mike.baude@gmx.de (M. Baude).

https://doi.org/10.1016/j.scitotenv.2018.12.455

1. Introduction

The ecosystem service provision of landscapes is often modified by land use type, production system and the land use intensity. Ecosystem services are defined by Millennium Ecosystem Assessment as goods and services provided by nature to satisfy essential human needs (MEA, 2005). Ecosystem services are typified as provisioning, regulating and cultural services. In this study we analyze primarily soil dependent ecosystem services in intensively used agricultural landscapes by the crop production (a provisioning service), the natural soil production capacity (a proxy of a provisioning service), erosion hazard (a proxy of a regulating service), and biodiversity (a proxy for a cultural service). The study focuses in regard to the data availability on soil dependent ecosystem services in a time period longer than 250 years. In the last three centuries land use changes may have positively, none or negatively influenced the capability of landscape to provide ecosystem services and landscape functions by changing the geo-factors, the landscape structure, and the landscape elements and the interrelated processes.

Intensified since the 1960s and not known before in history, land use change by augmented application of substances and technologies has resulted in fast changes in landscape structure, landscape functions and in the provision in amount and quality of the ecosystem services (Antrop, 2005; Bastian and Bernhardt, 1993; Diáz et al., 2015; Foley et al., 2005; MEA, 2005). A land use change e.g. from pasture to arable land, leads as well to new landscape structures (e.g. hedgerows, paths) and in a modified (changed, degraded, decreased, neutral or increased) capability of a site/landscape to perform ecosystem services (Jongman, 2002). It causes changes in factors and processes including their interrelationships (Verburg et al., 2013). Agricultural landscapes in Central Europe and their systems behavior is well investigated due to their (cultural) landscape structure and their landscape functions. However, the landscapes are less investigated in respect to their performance of ecosystem services (Mücher et al., 2010). In the last 250 years in Central Europe main land use changes in intensively used agricultural landscapes show the significant increase of arable land by a simultaneous decrease of grassland, forest and abandoned land (Baude and Meyer, 2012). The same authors describe in detail the increase of arable land plot sizes and the decline in length of linear landscape elements like pathways and hedgerows.

Driving forces are the sum of influencing external factors of landscape development including the progress of landscape dynamics (Bürgi et al., 2004). The key driving forces of a changing landscape since 1800 in Central Europe are socioeconomic, political and technological caused by global agricultural activities (Ramankutty et al., 2008). A societal or technological change as well as a major natural disaster or impact may have been the causal driving force inducing new (intensified or reduced) processes. A change in landscape structure may modify the functionality and the ecosystem services performance – in other words: a land use change may lead to the risk of degradation of the nature use potentials (Haase and Richter, 1980).

The landscape structure (sizes, shapes, mix and distribution of land parcels and linear infrastructures) and the landscape functions as the proxies of the capacity or potential of landscapes to provide ecosystem services have been modified multiple times by agriculture for around 7500 years. Landscape dynamics are defined as the changes of landscape structures and functions and ecosystem services caused by "driving forces".

Since 1850 changes in habitat qualities have been a cause for biodiversity decrease (Baessler and Klotz, 2006). Furthermore, other ecosystem services and landscape functions e.g. regulation functions (groundwater formation and erosion regulation) have been degraded by landscape and climate changes of multifunctional origin (Degórska, 2002; Harvey et al., 2014; Ladányi et al., 2015; Lorencová et al., 2013; Meyer and Rannow, 2013; Mezősi et al., 2016).

Landscape degradation is an irreversible or non-resilient system change of a landscape, causing effects on the landscape systems components (their geo-factors, land use and interlinkages) when changing natural and cultural capacities in structure, processes, landscape functions (productive, ecological and social) and ecosystem services significantly negative (Mezösi et al., 2013; Meyer et al., 2017).

Caused by mono-functional production and resulting loss of natural and cultural diversity, one major effect has been the landscapes homogenization (Jongman, 2002). Furthermore, landscape resilience – the capacity of landscapes to retain similar structures and functioning after the changing of external factors or after natural hazards – is seen as an important goal in science, policy and planning to reach sustainability. A hold of the decline of theses capacities caused by degradation in the performance of ecosystem services and landscape functions as well as the goal to develop climate change resilient production systems is intensively discussed in diverse studies (Darradi et al., 2012; Folke, 2006; Heijman et al., 2007; Liu et al., 2007).

In this study we analyze long-term land use change and landscape structure change dynamics on crop production, natural soil production capacity, erosion hazard as a measure of erosion regulation and biodiversity in an agricultural landscape north of Leipzig (Germany). The analysis is based on the time period around the last 250 years and is supported through the use of modern soil maps, soil inventories, cadastral maps (that shows boundaries of land parcels, ownerships, the value of parcels and productivity details on ownership allotment level), historical maps and land registers, as well as by driving forces analytics about the important trends influencing the provision of ecosystem services. Land use changes have been discussed in regard to socioeconomic, political and cultural causing factors.

One major challenge of this study is the generation of historical map and document based digital data for quantitative model analysis. There are strong data gaps in availability and quality for several criteria/factors analyzed. The study is facing the fact that it is essential to describe general developments by historical time steps based on findings of comparative studies and literature. The documentation of historical landscape structures and ecosystem services capacities and the comparison with recent situations are important for the thresholds generation to clarify system level changes.

2. Materials and methods

Long-term land use change through the reconstruction of four time steps 1750, 1850, 1950 and 2005 have been analyzed on a local scale (Table 1). Driving forces have been discussed regarding their impact on land use and ecosystem service changes and degradation. Ecosystem services and degradation analysis are focused on changes of crop production, natural soil production capacity and biodiversity. Spatial explicit analysis of ecosystem services has been applied only for the natural soil production capacity and erosion hazard. In case of data not being available in one of the four time steps, general changes, interpreted data by use of comparative analyses and literature have been employed (Table 2).

2.1. Study area

The study landscape (area size of 2639 ha) is located in the municipality Jesewitz (N 51.422614/E 12.564669) to the north of the City of Leipzig in Saxony/Germany (Fig. 1) and is characterized by precipitations in a range of 550–600 mm/a and an average yearly temperature of 8,5 °C (Mannsfeld and Richter, 1995). Lessivé and brown soils of medium suitability for biomass production are heterogeneously dispersed in the area formed by the Saale glaciations (Meyer, 1997). The study area choice is based for this analysis as part of a larger and more detailed investigated research and modeling study area and its data availability (e.g. German Soil Inventory, aerial photographs). Furthermore, based on an earlier study, the availability of historical maps and documents (serial cadastral maps and registers) was successfully proven (Baude, 2006). The study area is a typical intensively used agricultural area of

Table 1
Data of the time steps 1750, 1850, 1950 and 2005 by data name, year of publication, scale, data description and sources.

Time step	Data name	Year	Scale	Description	Archive/Source
1750	Atlas Augusteus Saxonicus 1711–1742; Atlas Saxonicus novus 1752	1711–1742/1752		Historical topographic map with settlements, road network, administrative plots and statistical data	Hauptstaatsarchiv Dresden: Makro 00644 Bl. 21/Makro 00614 Bl. XXXI/Makro 00596 Bl. IX/Makro 00598 Bl. XI/Makro 00612 Bl. XXVIII/Makro 00614 Bl. XXXI
	Petri, I.: Karte vom Kurfürstentum Sachsen	1761	cca. 1:33,000	Land use types: arable land, grassland, forest, bodies of water, settlements, roads, pathways	Sächsische Landesbibliothek - Staats und Universitätsbibliothek Dresden: SLUB/KS A16827-A16838
	Saxonian mile map Dresden Edition, sheet 21 Gottscheina and 30 Püchau	1801	1:12,000	Land use types: arable land, grassland, forest, bodies of water, settlements, roads, pathways	Hauptstaatsarchiv Dresden: Makro 00021/00030
1850	Separation maps Gotha, Jesewitz, Bötzen, Weltewitz, Gordemitz, Pehritzsch (Wöllmen)	1822–40	1:2500/1:3000	Land use types: arable land, grassland, forest, bodies of water, settlements, roads, pathways, etc. on ownership allotment level	Landesarchiv Wernigerode/Rep. C 20 V Gotha K., Nr. 1; Nr. 2., Nr. 3; Jesewitz K., Nr. 1; Bötzen, K, Nr. 1; Weltewitz K., Nr. 1; Gordemitz, K., Nr. 1; Pehritzsch K., Nr. 1, Nr. 2 (Wöllmen)
	Urkatasterkarten (Basic cadastral maps)	1864	1:2500/1:3000	Land use types: arable land, grassland, forest, bodies of water, settlements, roads, pathways, etc. on ownership allotment level	Staatliches Vermessungsamt Torgau
	Land register	1864		Numbering, Ownership information, land use type, class of classification tariff, tax information etc.	Data Prussian Taxation
	Interpretation of historical soil degradation	1998		Meta data and amounts of soil degradation (erosion, humus concentration) on national level	Bork et al., 1998; Dotterweich, 2013
1950	Real estate cadastre	1950	1:2500/1:3000	Land use types: arable land, grassland, forest, bodies of water, settlements, roads, pathways, etc. on ownership allotment level	Staatliches Vermessungsamt Torgau
	Aerial photographs, 159/59/111-116	1959	1:12,400	Landscape structure and land use types	Militärarchiv Potsdam
	Map and Register of German Soil Inventory	1937		Soil types, soil granulometry, the geological origin, humus content, soil number etc.	Meyer, 1997
2005	Automated ownership map (Automatisiertes LiegenschaftsKataster; ALK)	2005	1:2500/1:3000	Land use types: arable land, grassland, forest, bodies of water, settlements, roads, pathways, etc. on ownership allotment level	Staatliches Vermessungsamt Torgau
	Own investigation	2005		Land use types: arable land, grassland, forest, bodies of water, settlements, roads, pathways, etc. on ownership allotment level	Field mapping and Stakeholder interviews
	Data of soil erosions hazard investigation	2006		Amounts and spatial distribution of soil loss and deposition in kg/m^2	Schindewolf et al., 2012

Central Europe determined in land use by the Russian style of land transformation with a continuous agricultural land use history over more than the last 250 years. From the beginning of the 19th century significant land use changes have taken place. Therefore, we have used the time step 1750 as a starting point for the spatial analysis.

2.2. Data

2.2.1. Land use

The analysis of land use changes uses data from multiple historical maps, historical documents as land registers, as well as serial cadastral maps drawn since the beginning of the 19th century (Table 1). The reconstruction of the time step 1750 is based on the topographic Petri maps (1761) and on the Saxonian mile maps in the scale of 1:12,000. Land use type information is taken from “Atlas Augusteus Saxonicus” and “Schenk'scher Atlas”. The study area was mapped first by serial cadastral maps by the “Separation Maps” drawn up between 1822 and 1840 in the scale of 1:2500 to 1:3000. The associated land register holds information about ownership, production capacities, land use types and field sizes. The basis for the time step 1850 is the cadastral maps (the “Urkataster” of 1864) also including information about landscape elements.

The time step 1950 is also based on the cadastral maps. Furthermore, aerial photographs from 1959 are interpreted and a local stakeholder was interviewed to reconstruct details of former landscape structure and land use change since 1950. The time step 2005 uses new digital cadastral maps and the land register included in the automated digital ownership map (ALK-data) and field verification works. In 2015 a field verification study by the author was carried out and has not shown significant changes.

With regard to their validity historical maps and documents must be critically checked. The spatial explicit mapping of landscape structural changes especially for historical times is accompanied with uncertainties concerning scales and contents of the information.

2.2.2. Crop production

Since the 19th century the major ecosystem service provided by the landscape analyzed is the crop production. Since 1990 the winter wheat crop yield in dt/ha has been used to show the change in crop production as well as in the last decades (Dietrich, 2016, farm data). Spatial explicit digital data have been available since 1990. Studies of Bork et al. (1998), Finck von Finckenstein (1960) and Körschens et al. (1994) have been used for the interpretation of general changes of the 18th and 19th century crop production systems.

2.2.3. Natural soil production capacity

The changing potential of natural soil production capacity is based on the analysis of soil data referring to the natural soil production

Table 2
Information and studies used for ecosystem services indicator derivation at the time steps 1750, 1850, 1950 and 2005.

Ecosystem Service Indicator /Year	1750	1850	1950	2005
Crop production	Implicit in the authors land use and landscape structure analysis; interpretation of comprehensive studies by Bork et al., 1998	Implicit in the authors land use and landscape structure analysis; interpretation of comprehensive studies by Fink von Finckenstein, 1960	Findings of Körschens et al., 1994; implicit in the authors land use and landscape structure analysis	Farm data; crop yield in dt/ha by Dietrich, 2016
Natural soil production capacity	Implicit in the authors land use and landscape structure analysis; interpretation of comprehensive studies by Bork et al., 1998	Classification tariff based on soil parameters (geology, soil granulometry, water availability, land use, crop production) (Prussian Taxation 1864)	Soil number based on soil parameters (geological basis, soil granulometry, development status, groundwater conditions, land use, crop production) (German Soil Inventory 1937)	Interpretation of comprehensive studies by Dotterweich, 2013
Soil degradation caused by erosion hazard	Implicit in the authors land use and landscape structure analysis; interpretation of comprehensive studies by Bork et al., 1998	Classification tariff based on soil parameters (geology, soil granulometry, water availability, land use, crop production (Prussian Taxation 1864)	Soil number based on soil parameters (geological basis, soil granulometry, development status, groundwater conditions, land use, crop production) (German Soil Inventory 1937; by Meyer, 1997)	Original work; soil parameters (geological basis, soil granulometry, development status, infiltration, runoff generation, land use, soil morphology) (Schindewolf et al., 2012); interpretation of comprehensive studies by Dotterweich, 2013
Biodiversity	Implicit in the authors land use and landscape structure analysis; interpretation of comprehensive studies Bignal & McCracken, 2000; Butchart et al., 2010; Knapp et al., 2016	Implicit in the authors land use and landscape structure analysis; interpretation of comprehensive studies by Bignal & McCracken, 2000; Butchart et al., 2010; Knapp et al., 2016	Findings from Baessler & Klotz (2006) to species distribution and total number of weed species; implicit in the authors land use and landscape structure analysis; interpretation of comprehensive studies by Bignal & McCracken, 2000; Butchart et al., 2010; Knapp et al., 2016	Findings by Baessler & Klotz (2006) to species distribution and total number of weed species; implicit in the authors land use and landscape structure analysis; interpretation of comprehensive studies by Bignal & McCracken, 2000; Butchart et al., 2010; Knapp et al., 2016

capacity mapped by the Prussian Taxation (1864) and the German Soil Inventory (1937). The Prussian Taxation gives for each land parcel a soil classification tariff and ecological characteristics of water, temperature and vegetation period. The classification provides eight classes of arable land (class 1 means the highest natural soil production capacity) to assess the natural soil production capacity. The German Soil Inventory data also gives an assessment of the natural soil production capacity. This is attained by including soil parameters information about the soil granulometry, the geological basic material and the soil development status and a soil quality assessment number used to compare the two soil assessments. For the interpretation of the recent changes results from the analysis of Dotterweich (2013) about the history of soil erosion were used.

2.2.4. Soil degradation caused by erosion hazard

Erosion risk interpretation has used the general overview on degradation and landscape dynamics since medieval times from the findings of Bork et al. (1998), Meyer (1997) and Dotterweich (2013). Landscape

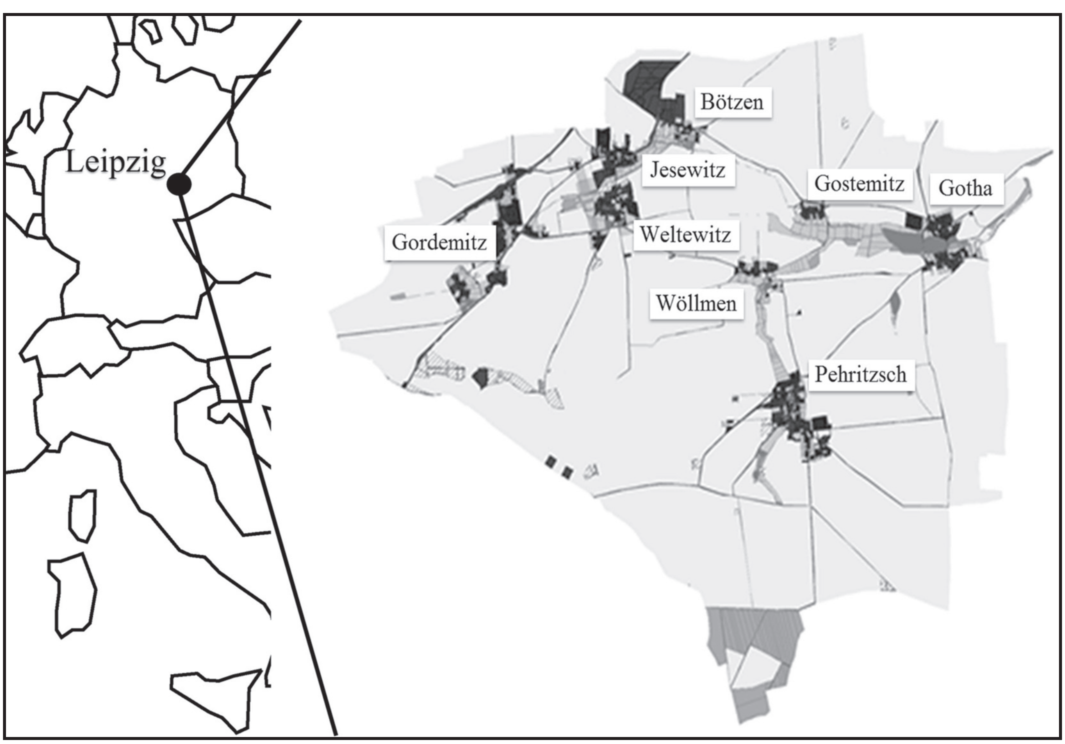


Fig. 1. Investigation and study area landscape near Leipzig, Germany.

erosion risk was analyzed by data of both named soil inventories 1864 and 1937 to interpret the erosion risk for time steps 1850 and 1950. At time step 2005 rates of soil loss and accumulation were calculated with the EROSION 3D model.

2.2.5. Biodiversity

We interpret the biodiversity change for time steps 1950 and 2005 using the findings of Baessler and Klotz (2006). Impact data of land use and landscape structures changes on Floristic inventories of arable fields weed species (species richness and diversity) were available for three surveys periods performed in 1957, 1979 and 2000. For earlier time steps general findings by scientific literature have been used (Bignal and McCracken, 2000; Butchart et al., 2010; Knapp et al., 2016).

3. Methods of analysis

Land use and soil change on ecosystem services in agricultural landscape is analyzed by changes or degradation in land use, driving forces and ecosystem services and is based on data in landscape structure, land use types, soil taxation and erosion hazard. The aim is the indication of changes in the performance of ecosystem services. Our study therefore focuses on crop production, natural soil production capacity, soil degradation caused by erosion hazard and biodiversity indicators. Both land use change analysis and ecosystem service analysis are based on digital GIS data.

3.1. Land use change analysis

With GIS we reconstruct the landscape structure and the distribution of the land use types arable land, grassland, forest, bodies of water, settlement, linear infrastructure and other land uses by land parcels in four time steps. Historical cadastral maps for the time step 1850 were scanned, geo-referenced and digitalized. The information of the land registers was adopted into attribute tables to generate a spatially explicit data set about the ownership allotments. The information for the time step 1750 from Petri maps, Saxonian mile maps, “Atlas Augusteus Saxonicus” and “Atlas Saxonicus novus” was transformed and georeferenced to vector data from 1850. For the 1950 and 2005 time steps the vector data of the digital governmental cadastral map of ownership plots of ALK data was used. The data set 2005 was revised by the author by making a field verification campaign. The data set of the time step 1950 was adapted to the content of cadastral registers. Information has been added by the interpretation of aerial photographs from the year 1959 and by interviewing a local land owner. The attribute tables contain data about the area digitalized land parcels by land use types of the four time steps. Descriptive statistic was employed to calculate the area in ha of the land use types and the percentages of the land use types in the study area. The cartographic data model includes the geographic distribution and the borders of aerial and linear landscape elements. Consequently, we interpreted land use changes in the time steps by spatial statistics available in GIS (see also the results and discussion of this article). Historical data sources have been critically checked regarding their validity. The scale of the data sets, the (historic) cadastral survey technology and the interpretation of content of historical maps concerning their limited quality or undocumented data bases are interpreted critically (Bender et al., 2005). The authors have reconstructed the land use information from the divers' maps with regard to the aim of using the historical data for a better understanding of the changes in landscape structure and ecosystem services.

3.2. Driving forces analysis

To understand land use change during the last 250 years the major driving forces and their impacts on landscape change and on the availability and quality of ecosystem services have been analyzed. The driving forces analysis uses a systematic procedure proposed by Bürgi et al. (2004). First a study area is defined as well as the study periods and the temporal data resolution envisaged. Then the subject of the study is specified by literature holding information about major landscape structure changes and about the specific time period categorized by the authors into five groups of the most important driving forces (socio-economic, political, technical, natural and cultural) to understand major landscape changes. Finally, the driving forces are interpreted regarding causal relationships and their impacts on changes of land use types, landscape structure and ecosystem services.

3.3. Ecosystem services analysis

Ecosystem services analysis is concretizing changes in the four services crop production, natural soil production capacity, soil degradation caused by erosion hazard and biodiversity. The analysis of crop production is based on literature research for the historical time steps. Actual farm data from Jesewitz farm are used to concretize here the actual crop production.

The degradation of the natural soil production capacity as impact indicator of the agricultural production analysis is based on the two historical soil assessment maps of German Soil Inventory (GSI) and the Prussian Taxation (PT) digitized by the authors. First, the data set from the GSI (1937) is summarized into five main groups of soil productivity (Matz, 1956). Second, the five main groups are compared with the soil assessment numbers from the GSI. The first main group contains soils of high soil assessment numbers and a high natural soil production capacity. The classification tariffs from the PT are compared to the five main groups according to the level of their taxation class and assigned to the main group's productivity as well. For more details see Baude and Meyer (2012).

The soil erosion hazard regulation provided by the landscape is modeled in our study by rates of soil erosion and accumulation. Soil loss and deposition data originates from a comprehensive erosion survey by the German federal state of Saxony (Schmidt, 1991) carried out using the process based EROSION 3D simulation model (Defersha and Melesse, 2012; Schmidt, 1992). EROSION 3D is a tool for the estimation of infiltration, runoff generation, soil loss, deposition and sediment transfer on different scales. The model was validity proofed in different environments and case studies (Jetten et al., 1999; Starkloff and Stolte, 2014; Stumpf et al., 2016).

To run the EROSION 3D model rainfall, soil, land use and morphology input data is required. Land use and soil maps model parameters are taken from data bases (Michael, 2000; Schindewolf and Schmidt, 2012; Siebert et al., 2011) in 20 m grid cell resolution. These mentioned data bases cover measured runoff and erosion from artificial rainfall simulations from the most typical soil and land use combinations in Germany. Further information on model parameterization is provided by Schindewolf et al. (2012).

To obtain potential losses for one single extreme event, worst case conditions were presumed. In this respect the entire arable land was assumed to be in seedbed conditions after ploughing, resulting in low soil erosion resistance without any soil surface protection due to the cover by crop residues. The simulation refers to a statistical 10-years rainfall event of 22 mm precipitation in 40 min (German Weather Service, 1994). Model input data are land use maps based on the digital basic land use model (ATKIS-DLM) in 1:25,000 scale, soil maps in a 1:200,000 scale and the digital terrain model (ATKIS-DGM) with a 20 m grid cell size. All this mentioned data is provided by Saxonian State owned data bases.

Model parameters are derived afterwards as functions of land use and soil characteristics by applying a data base deducted from a plot scaled rainfall experiment (Michael, 2000; Schindewolf and Schmidt, 2012; Siebert et al., 2011).

The biodiversity data analyses focus on the species richness and the diversity by interpretation of floristic inventories of weed species of arable land and the time steps 1959, 1979 and 2000 published by Baessler and Klotz (2006). The study refers to a comparable intensive arable land case study area located near our investigated area influenced in the past by same driving forces and arable field management practices. Arable weed species composition and distribution are good indicators of wider biodiversity in intensively used agricultural areas since weeds are typical plants adapted to arable land use.

Baessler and Klotz (2006) use a pairwise Wilcoxon-test to test differences of average species numbers per relevé among all periods. Relevé is a standard field method of sampling vegetation classification developed by Braun-Blanquet (1964). The total species number for each period was calculated by Baessler and Klotz (2006) by resampling and was furthermore linked to the average cover of each species over all relevés of each period. The testing of the differences of the average cover among periods was done by one-factorial variance analysis (ANOVA) and by subsequent multiple comparison (Scheffé-test).

4. Results and discussion

In the context of degradation land use change, driving forces and ecosystem services have been analyzed. The results are interpreted as human/cultural induced landscape changes and their impacts on ecosystem services. Multiple data sources and methods are combined in this study to reach the analysis.

4.1. Impacts of driving forces on landscape change

In 1750 arable land covered 1938 ha or 73.4% of the total area. Grassland was 582.8 ha or 22.1% of the area respectively (Table 3). The other land use types were of minor significance by the land use type forest 2.2%, bodies of water and settlements both being 1.1%. The road and path network was constructed after the medieval period of land colonization with a length of approximately 34.1 m/ha (Fig. 2).

After the end of the Napoleonic era and the Wiener Congress in 1815 the study area became a part of Prussia. Caused by the high costs of the Napoleonic wars and related economic crisis, Prussia focused on structural changes by reforming the agricultural management systems in the period between 1807 and 1850. This reformation resulted in new land ownership allocations and changed land use distribution ("Separation") causing also landscape structure changes in the study area. The comparison of the time steps 1750 and 1850 shows increasing arable land percentage from 73.4% to 86.0%. The grassland area decreased from 22.1% in 1750 to 9.4% in 1850. The land use types forest and settlement increased only slightly, the area of bodies of water decreased slightly and the land use type "others" remained unchanged. The road network lengthened from 34.1 m/ha to 35.8 m/ha (Baude and Meyer, 2012). Degórska (2002) found similar changing rates in Central Poland between 1770 and 1890. The arable land area percentages increased by 37.1% to 65.4% of the total area and the grassland area percentages decreased from 19.2% to 12.0%.

Between 1850 and 1950 arable land area increased slightly by 2.1% and the grassland area decreased still further by around 43%. No significant change in the percentage of forest and bodies of water was found, but the settlement area increased by 72%, nevertheless only slight changes in the road network length can be detected (Baude and Meyer, 2012). Skaloš (2007) published comparable results of a study area in Hungary (Honbice) clarifying a slight increase of arable land area (89.1 to 90.7% of total area) and a decrease of grassland area (4.7 to 1.9%) between 1839 and 1950.

In 1945 after World War II, Soviet authorities implemented a major land reform in Eastern Germany, organizing the landscape structure firstly in multiple small-sized fields managed by new farmers. The main driving force changing the landscape after 1950 organized by the German Democratic Republic (GDR) government by adopting the Russian Kolkhoz system, resulted in a general enlargement of the field plot size often larger than 100 ha per single field plot. This Kolkhoz system did not at all reflect the land use distribution of arable and grasslands as developed and cultivated during history. Nevertheless, the comparison of the 1950 and 2005 results shows a nearly unchanged percentage of arable land but a decrease in the grassland area by 22%. The road network was strongly shortened from 36.4 m/ha to 28.7 m/ha. Thus, the political (land management) program of 'collectivization' in the 1950s met the needs of the intensification of agriculture by changing the landscape structure into a homogeneous landscape structure based on very large-sized fields and accompanied by the destruction of former linear road infrastructure (Baude and Meyer, 2012). Later in the same time period multiple new hedgerows were planted to reduce catastrophic wind erosion calamities envisaged in the study area after the field size enlargements (Grabaum et al., 1999; Meyer, 1997).

The land use changes between 1750 and 2005 analyzed for the study area are interpreted as typical land development of intensively used agricultural areas in the former East European countries with regard to the Russian Kolkhoz system since 1950 (Jepsen et al., 2015).

Since 1990 the area used for agriculture has become smaller, primarily due to the urban sprawl of Leipzig. Thus, the settlement area has increased from 55.2 ha to 106.4 ha, and the percentage of forest and bodies of water has remained the same (Baude and Meyer, 2012).

Current main driving forces steering the landscape change are, for example, European Union norms and regulations by the Common Agricultural Policy (CAP), the Habitats Directive, the NATURA 2000 network, the EU Water framework Directive or the regulation of impact compensation all influencing the land use distribution and the crop systems management directly or indirectly. Furthermore, global economic markets are fostering changes in crop systems and animal husbandry (Beilin et al., 2014).

4.2. Impacts of land use change on ecosystem services and degradation

Between 1750 and 1850 the increase of crop production was steered by the enlargement of agricultural land and the implementation of new management practices e.g. including longer crop rotations for holding humus and fertility loss (Dabbert, 1994; Kopsidis and Pfister, 2013). During the time period 1850 until 1950 the production increase was based firstly on the application of mineral fertilizers, melioration and major technical achievements in land-engine technology. After 1960 the "collectivization" resulted in a new dimension of intensity of agricultural land use. The large field sizes and the dominantly technical field management practices including melioration, the mass application of fertilizers and pesticides result in a significant growth in crop production. During the period 1906 to 1992 the crop production of winter

Table 3
Areas and Percentages of main land use types in the time steps 1750, 1850, 1950 and 2005 (Baude and Meyer, 2012).

Time step	Land use type												
	Arable		Grassland		Forest		Water		Settlement		Road	Others	
	ha	%	ha	%	ha	%	ha	%	ha	%	m/ha	ha	%
1750	1938	73.4	582.8	22.1	60.9	2.2	24.7	1.1	29.5	1.1	34.1	3.7	0.1
1850	2270.1	86	249.2	9.4	60.3	2.3	24.1	0.9	32.1	1.3	35.8	3.7	0.1
1950	2316.5	88.7	141.4	5.1	70.6	2.7	20.1	0.8	55.2	2.1	36.4	14.6	0.6
2005	2297	87.2	110	4.2	70.5	2.7	20.1	0.8	106.4	4	28.7	30.4	1.1

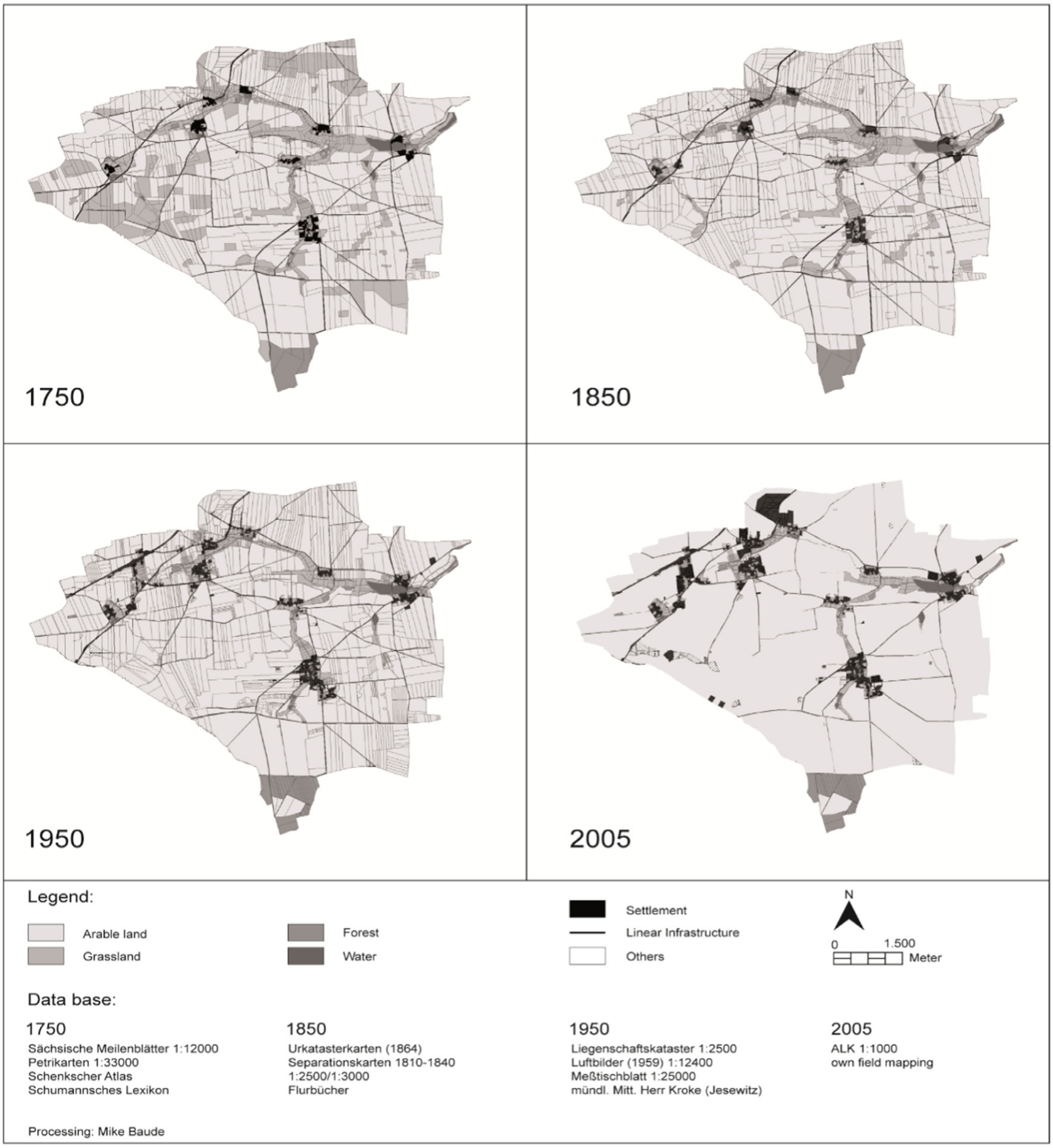


Fig. 2. Landscape structure changes showing the land use type distribution and the changing field margins based on parcel ownerships information and the decrease of grassland between 1750 and 2005 (Baude and Meyer, 2012).

wheat increased by 100% (Körschens et al., 1994). In the study area the crop yield of winter wheat increased further on from 55.7 dt/ha (1990–1999) to 69.6 dt/ha (2000–2009) in only two decades (Dietrich, 2016, Jesewitz farm data). Nevertheless, the increasing amount of agricultural inputs has resulted in a decrease of the natural soil production capacity as described in the following paragraph.

The comparison of the two historic soil quality assessments by the classification into five main usability groups (Matz, 1956) based on the 97.7% of the agricultural lands without a land use change since 1850. Table 4 shows the percentage area distribution of the two soil assessments in the main usability groups (arable land in group 1 with the best crop yields). It gives information about the soil quality and the land use types in the earlier second half of the 19th and 20th century not yet strongly influenced by the change from extensive use into intensive agricultural land management practices used in the Soviet era. The analysis of GSI and PT shows a significant higher area percentage in 1864 in the productive main group of usability compared to more areas in less productive main groups of usability 3–5 in 1937. The results suggest a decrease in the natural soil production capacity between 1850 and 1950 caused by various not yet known processes, shown by a larger area of soil in a lower group of usability. For more details see Baude and Meyer (2012).

Table 4
German Soil Inventory 1937 by soil number and Prussian Taxation 1864 by classification tariff on arable land in % and changes in classification to main usability groups in the investigation area (Baude and Meyer, 2012).

Main usability group	Classification tariffs (PT)	Soil number range (GSI)	1864 PT in %	1937 GSI in %
1	1–2	64–81	2.1	4.1
2	3–4	49–63	83.7	66.6
3	5	36–48	14.1	22.9
4	7	29–35	0.2	2.5
5	8	18–28	0	3.9

The intensified biomass production from 1750 till today is interpreted as a decline in the landscape capacity to provide other ecosystem functions, especially to provide the regulation functions of groundwater formation in quantity and quality and as well to a decline of the capacity of the landscape to protect the soil against soil erosion. Several studies have proven a strong negative impact on soil and groundwater systems by soil degradation and by soil erosion since medieval times (Dotterweich, 2013). Almost the entire loess belt in Central Europe has been negatively modified due to high soil losses caused by wind and water erosion as is typical in arable loess landscapes. It is obvious that the same problems will occur in the future since the loess belt is potentially prone to drought periods caused by climate change (Blanka et al., 2013; Dotterweich, 2008; Mezösi et al., 2015; Wolf and Faust, 2013). The soil organic matter is soil texture attached and a continuation of the soil erosion in the study area may lead to serious soil degradation under non-protective soil management. Soil losses on arable land were modeled in this study by using a typical 10-year rainfall event, 22 mm of precipitation in 40 min. On the other hand the study shows that on grassland sediment accumulation predominantly takes place (Table 5). The highest erosion rates of >60 t/ha, which correspond to a 4 mm soil loss per event are simulated in thalweg areas, where runoff is concentrated. Former land managers and farmers prevented these areas from degradation by using grassland. Further endangered areas have soils with mainly silty texture and steep slopes e.g. around the village of Gotha. Slopes covered with sandy soils in the western part of the area reveal soil losses up to 30 t/ha, corresponding to a 2 mm soil loss per event, which is high enough to result in soil degradation (Fig. 3).

The erosion simulations depict high risk for sediment translocation processes and accordingly soil degradation by water erosion. The area suffered from large field size enlargements in the 1960s and by the ongoing industrialization of agriculture application of heavy machinery. The current process of soil erosion is interpreted as the major driver of soil degradation in the study area. Our soil erosion and accumulation results are comparable with other results of erosion modeling e.g. of Baumgart et al. (2017) that show for the Saxon Loess Province, comparable high rates of erosion from 15 t/ha up to 121.5 t/ha for precipitation periods of heavy and intense rainfalls.

The capacity of erosion regulation provided by the soils and the landscape decreased with the increase of intensive agricultural land management practices. This degradation may be reduced by the implementation of mitigation measures as conservation tillage and grassed water discharge pathways (Rickson, 2014). Furthermore, current soil degradation in intensively used agricultural landscapes generally shows high rates and is related to socioeconomic and political challenges (Lorencová et al., 2013).

Technical literature about the development of cultural landscapes in the time period from 1750 to 1850 describes an increase in biodiversity followed by a dramatic loss in biodiversity since the beginning of agricultural industrialization (Bignal and McCracken, 2000; Butchart et al., 2010; Knapp et al., 2016). Extensive arable management practices using divers' crops, long crop rotations and a low level of mechanization, farm techniques and fertilizers resulted in a high biodiversity in a short period after the Second World War until 1960 (Baessler and Klotz, 2006). The biodiversity then strongly decreased caused by the “collectivization” and the high input intensity of energy, fertilizers and herbicides as well as the greatly enlarged field plots. Baessler and Klotz (2006) found a highly significant decrease of 30% of the average number of weed species per relevé between 1957 (20 species) and 1979 (14 species). Between time steps 1979 and 2000 (15 species), there was no significant change.

Table 5
Rates of erosion and accumulation modeled with EROSION 3D model and a typical 10-year rainfall of 22 mm precipitation in 40 min in the investigation area.

Erosion/accumulation in t/ha*event	Arable land		Grassland	
	ha	%	ha	%
Erosion				
>60	364.0	15.9	4.5	4.2
30–60	461.8	20.1	3.1	2.9
0–30	1043.9	45.5	13.1	12.1
0	166.2	7.2	63.9	59.1
Accumulation				
>60	54.0	2.4	3.6	3.3
30–60	28.8	1.3	2.1	2.0
0–30	174.9	7.6	17.7	16.4

Biodiversity decrease is still ongoing (Jackson et al., 2007) and problematic, because a high species richness may increase the resilience of a system and may also affect the performance of other ecosystem services in agricultural landscapes, the discussed soil fertility, the soils wind erosion risk and the crop pollination (Hirt et al., 2011; Meyer et al., 2012).

Table 6 summarizes the changes of the analyzed ecosystem services provisions caused by landscape dynamics. The second column interprets the density of forested areas as initial status before major changes in land use types occurred and indicates the provision of the indicators before arable land use.

4.3. Driving forces, ecosystem services and system behaviors

The Prussian agricultural revolution caused by the Napoleonic wars and economic crisis lead to new ownership allocation and new land use distribution (“Separation”) and to changed agricultural practices. Thus, undeveloped or abandoned land in common land ownership was converted into arable land - a major cause for an increasingly heterogeneous and multifunctional landscape during this period. Between 1750 and 1850 essentially one single land use objective was prioritized by the expansion of arable land area resulting in a slightly increasing crop production. At the same time the natural soil production capacity slightly decreased caused by the impacts of arable land expansion and new agricultural practices (Dotterweich, 2013). Furthermore, ecosystem services like natural erosion protection provided by hedgerows or divers and site adapted agricultural practices (e.g. the utilization in summer only) brought the cultural landscape into a balanced status by regulating negative or unwanted processes caused by natural hazards and increased land use intensity (Fig. 4).

Between 1850 and 1950 increasing land use intensity and the beginning of industrialization melioration, the beginning of the usage of fertilizers and pesticides lead to an increase of the crop yield of winter wheat up to around 100% (Finck von Finckenstein, 1960). The natural soil production capacity decreased as demonstrated by the changing percentage of soil in a lower group of usability (groups 3–5), changing from 14.3% in 1864 to 29.3% in 1937 (Table 4). The heterogeneous landscape was slightly changed till 1945 in the direction of a homogeneous monofunctional landscape. After 1960 a strong change towards monofunctional landscape is observed.

After World War II, a land reform in the Soviet zone of Germany was applied. For a short period between 1945 and 1952 (beginning of collectivization) a heterogeneous landscape holding biodiversity e.g. caused by a lack of fertilizers and organized by very small field plots overall, shows low erosion problems (Baessler and Klotz, 2006).

In the time period from 1952 to 1990 the Russian Kolkhoz system, through the implementation of collectivization, was applied. During this period the crop yield of winter wheat was very high and increased by around 100% compared with the decade of 1906 and 1915 (Körschens et al., 1994). Since the year 2000 the average winter wheat crop yield has stagnated by around 70 dt/ha (Dietrich, 2016, farm data). Any influences of EU agricultural policy have not yet been investigated in the context of the presented study. However, biodiversity loss and soil degradation increase are related to the decrease of the natural soil production capacity observed in our study and may result in a lower systems status of stability. In accordance with the decrease of arable land, a longtime linear process was found in natural soil production capacity by the increase in the main usability groups

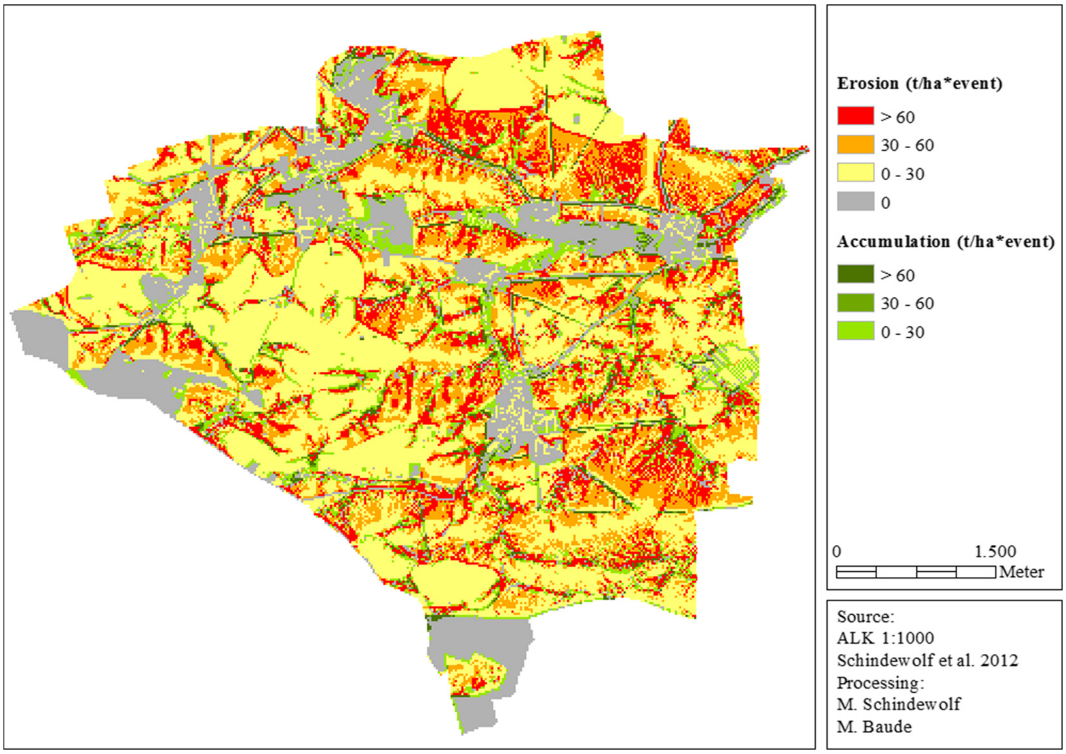


Fig. 3. Erosion and accumulation hazard rates (t/ha) per simulated 10-years rainfall event in the investigation area.

3–5 between 1864 and 1937. Thus, an increase from 29.3% in 1937 to around 60% of arable land in the lower groups of usability was observed and interpreted as a proxy of landscape degradation. Indicators of groundwater and surface water pollution due to agriculture have not been subject of the study. The current agricultural landscape is homogeneous and mono-functionally used by causing degradation of natural soil productivity, but also in biodiversity and landscape structure diversity. The actual landscape provides the production of a small number of arable crops by neglecting other important ecosystem services of the production system.

5. Conclusion

Landscape changes in the last 250 years steered by socioeconomic, political and technical driving forces are of high influence on landscape structure and at the same time on the provision and the degradation of ecosystem services. However, a change is sometimes very fast, often not linear and multi-causal. We found in three main periods of stability/activity: a first period of high activity of landscape change from 1750 to 1850, a relative stable period between the end of the 19th century up until 1955 and a period of very high activity of change since 1960 until 2005. Furthermore, crop production increased over the entire time period as a result of political and socioeconomic objectives. The biodiversity of farmland, wild species and weed herbs indicator clearly indicates a systems change leading to a negative provisioning of ecosystem services in biodiversity in general. The increasing potential for erosion hazard and at the same time the decrease of the natural erosion regulation of the landscape relates to the decreasing natural soil production capacity – a signal of soil degradation. Impacts of this land and landscape degradation on current and future land use options by planning and management may confront the society with the related social, economic and ecological problems.

Landscape and land use change and the change of landscape structure and ecosystem services provision will also depend in future on (not yet known) key driving forces (as changing climate). For the management of a sustainable future a better understanding about interlinkages of driving forces, landscape change and the provision of ecosystem services in spatial context are needed. The aim of the research should be more focussed on the landscape scale instead of the common practice of field plot based land use interpretations and modeling. A landscape planning of major challenges is essential to find a wise balance between productive uses, techniques and the ecological

Table 6
Ecosystem services provision and the intensity of changes caused by landscape dynamics interpreted since the initial land use change after the glaciations in Central Germany.

Ecosystem service indicator	Indicators performance under forest (before land clearing)	First land forest clearing to grassland and arable land (600–900)	1750–1850	1850–1945	1945–1955	1955–2005	Source
Crop production	No	Increase, but low	Slight increase	Strong increase	Slight increase	Strong increase	Bork et al., 1998 Körschens et al., 1994; Dietrich, 2016
Natural soil production capacity	High, undisturbed	Decrease	Slight decrease	Slow decrease	Stable	Strong decrease	results of this study, Bork et al., 1998; Dotterweich, 2013
Soil degradation caused by erosion hazard	Very low	Very high	Low	Low	Medium	Very high	Bork et al., 1998; Dotterweich, 2013; Meyer, 1997; Schindewolf et al., 2012
Biodiversity	High in forest species, very low for arable land species	Strong increase	Slight increase	Strong decrease	Stable	Strong decrease	Baessler and Klotz, 2006; Bignal and McCracken, 2000

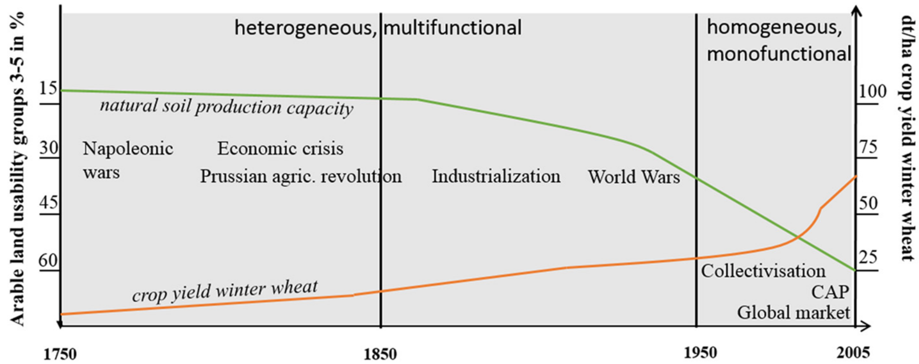


Fig. 4. Conceptual model of development of natural soil production capacity shown by the rates of arable land in less productive usability groups (Table 4; Bork et al., 1998; Dotterweich, 2013) and winter wheat crop yield (Finck von Finckenstein, 1960; Körschens et al., 1994; Dietrich, 2016) in the context of main driving forces and systems behavior.

systems basis to avoid unwanted systems changes. Investigation of the system resilience should be based on long term data series.

The historical information of a >250 years period analyzed in this study may help to understand landscape structure changes including the vulnerability and the availability and quality of ecosystem services provisioning. The historical analysis gives new insights to elaborate land use/landscape intensity and landscape dynamics analysis. It may also help to better understand a thresholds formulation on land and landscape degradation factors by indicators.

Acknowledgement

We would like to thank the financial authority of Eilenburg, and the Cadastral Office of Torgau, for kindly granting permission for the use of the cadastral maps and register data. We also would like to thank the agricultural cooperative Jesewitz for providing the statistical data of crop yield.

References

Antrop, M., 2005. Why landscapes of the past are important for the future. Landsc. Urban Plan. 70, 21–34. https://doi.org/10.1016/j.landurbplan.2003.10.002.

Baessler, C., Klotz, S., 2006. Effects of changes in agricultural land-use on landscape structure and arable weed vegetation over the last 50 years. Agric. Ecosyst. Environ. 115, 43–50. https://doi.org/10.1016/j.agee.2005.12.007.

Bastian, O., Bernhardt, A., 1993. Anthropogenic landscape chances in Central Europe and the role of bioindication. Landsc. Ecol. 8, 139–151.

Baude, M., 2006. Landschaftsdynamik und Produktionsfunktion in einer heutigen Intensivagrarlandschaft im Raum Taucha-Eilenburg. (Diplomarbeit). Uni Leipzig, Institut für Geographie, Leipzig (147 S. unveröffentlicht).

Baude, M., Meyer, B.C., 2012. Changes of landscape structure and soil production function since the 18th century in north-west Saxony. J. Environ. Geogr. III, 11–23.

Baumgart, P., Eltner, A., Domula, A.R., Barkleit, A., Faust, D., 2017. Scale dependent soil erosion dynamics in a fragile loess landscape. Z. Geomorphol. 61, 191–206. https://doi.org/10.1127/zfg/2017/0409.

Beilin, R., Lindborg, R., Stenseke, M., Pereira, H.M., Llausàs, A., Slätmo, E., Cerqueira, Y., Navarro, L., Rodrigues, P., Reichelt, N., Munro, N., Queiroz, C., 2014. Analysing how drivers of agricultural land abandonment affect biodiversity and cultural landscapes using case studies from Scandinavia, Iberia and Oceania. Land Use Policy 36, 60–72. https://doi.org/10.1016/j.landusepol.2013.07.003.

Bender, O., Boehmer, H.J., Jens, D., Schumacher, K.P., 2005. Using GIS to analyse long-term cultural landscape change in Southern Germany. Landsc. Urban Plan. 70, 111–125. https://doi.org/10.1016/j.landurbplan.2003.10.008.

Bignal, E.M., McCracken, D.I., 2000. The nature conservation value of European traditional farming systems. Environ. Rev. 8, 149–171. https://doi.org/10.1139/a00-009.

Blanka, V., Mezösi, G., Meyer, B.C., 2013. Projected changes in the drought hazard in Hungary due to climate change. Időjárás 117, 219–237.

Bork, H.-R., Bork, H., Dalchow, C., Piorr, H.-P., Schatz, T., Faust, B., 1998. Landschaftsentwicklung in Mitteleuropa: Wirkungen des Menschen auf Landschaften. Klett-Perthes, Gotha, Stuttgart.

Braun-Blanquet, J., 1964. Pflanzensoziologie. Grundzüge der Vegetationskunde. Springer Verlag, Wien, p. 3 (Aufl. 1. Aufl. 1928).

Bürgi, M., Hersperger, A.M., Schneeberger, N., 2004. Driving forces of landscape chance – current and new directions. Landsc. Ecol. 19, 857–868. https://doi.org/10.1007/s10980-005-0245-3.

Butchart, S.H.M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J.P.W., Almond, R.E.A., Baillie, J.E.M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K.E., Carr, G.M., Chanson, J., Chenery, A.M., Csirke, J., Davidson, N.C., Dentener, F., Foster, M., Galli, A., Galloway, J.N., Genovesi, P., Gregory, R.D., Hockings, M., Kapos, V., Lamarque, J.-F., Leverington, F., Loh, J., McGeoch, M.A., McRae, L., Minasyan, A., Morcillo, M.H., Oldfield, T.E.E., Pauly, D., Quader, S., Revenga, C., Sauer, J.R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S.N., Symes, A., Tierney, M., Tyrrell, T.D., Vié, J.-C., Watson, R., 2010. Global biodiversity: indicators of recent declines. Science 328, 1164–1168. https://doi.org/10.1126/science.1187512.

Dabbert, S., 1994. Ökonomik der Bodenfruchtbarkeit. Ulmer, Stuttgart.

Darradi, Y., Saur, E., Laplana, R., Lescot, J.-M., Kuentz, V., Meyer, B.C., 2012. Optimizing the environmental performance of agricultural activities: a case study in La Boulouze watershed. Ecol. Indic. 22, 27–37. https://doi.org/10.1016/j.ecolind.2011.10.011.

Defersha, M.B., Melesse, A.M., 2012. Field-scale investigation of the effect of land use on sediment yield and runoff using runoff plot data and models in the Mara River basin, Kenya. Catena 89, 54–64. https://doi.org/10.1016/j.catena.2011.07.010.

Degórska, B., 2002. Landscape change in Central Poland. Geogr. Cas. 54, 203–218.

Dıáz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., Larigauderie, A., Adhikari, J.R., Arico, S., Báldi, A., Bartuska, A., Baste, I.A., Bilgin, A., Brondizio, E., Chan, K.M.A., Figueroa, V.E., Duraiappah, A., Fischer, M., Hill, R., Koetz, T., Leadley, P., Lyver, P., Mace, G.M., Martin-Lopez, B., Okumura, M., Pacheco, D., Pascual, U., Pérez, E.S., Reyers, B., Roth, E., Saito, O., Scholes, R.J., Sharma, N., Tallis, H., Thaman, R., Watson, R., Yahara, T., Hamid, Z.A., Akosim, C., Al-Hafedh, Y., Allahverdiyev, R., Amankwah, E., Asah, S.T., Asfaw, Z., Bartus, G., Brooks, L.A., Caillaux, J., Dalle, G., Darnaedi, D., Driver, A., Erpul, G., Escobar-Eyzaguirre, P., Failler, P., Fouda, A.M.M., Fu, B., Gundimeda, H., Hashimoto, S., Homer, F., Lavorel, S., Lichtenstein, G., Mala, W.A., Mandivenyi, W., Matczak, P., Mbizvo, C., Mehrdadi, M., Metzger, J.P., Mikissa, J.B., Moller, H., Mooney, H., Mumby, P., Nagendra, H., Nesshover, C., Oteng-Yeboah, A.A., Pataki, G., Roué, M., Rubis, J., Schultz, M., Smith, P., Sumaila, R., Takeuchi, K., Thomas, S., Verma, M., Yeo-Chang, Y., Zlatanova, D., 2015. The IPBES Conceptual Framework - connecting nature and people. Curr. Opin. Environ. Sustain. 14, 1–16.

Dietrich, R., 2016. Statistical Data From Agricultural Cooperative Jesewitz (Personal notification from 16.02.2016, not published).

Dotterweich, M., 2008. The history of soil erosion and fluvial deposits in small catchments of Central Europe: deciphering the long-term interaction between humans and the environment - a review. Geomorphology 101, 192–208. https://doi.org/10.1016/j.geomorph.2008.05.023.

Dotterweich, M., 2013. The history of human induced soil erosion: geomorphic legacies, early descriptions and researches, and the development of soil conservation – a global synopsis. Geomorphology 201, 1–34. https://doi.org/10.1016/j.geomorph.2013.07.021.

Finck von Finckenstein, H.W., 1960. Die Entwicklung der Landwirtschaft in Preussen und Deutschland 1800–1930. Holzner, Würzburg.

Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N., Snyder, P.K., 2005. Global consequences of land use. Science 309, 570–574. https://doi.org/10.1126/science.1111772.

Folke, C., 2006. Resilience: the emergence of a perspective for social-ecological systems analyses. Glob. Environ. Chang. 16, 253–267. https://doi.org/10.1016/j.gloenvcha.2006.04.002.

German Weather Service, 1994. Zentralamt, Abt. Klimatologie. Zentralstelle für Hydrometeorologische Entwicklungen und Anwendungen (Reg.-Nr. 322-93).

Grabaum, R., Meyer, B.C., Mühle, H., 1999. Landschaftsbewertung und-optimierung: ein integratives. Konzept zur Landschaftsentwicklung. UFZ-Bericht 32, Leipzig (109 p).

Haase, G., Richter, H., 1980. Geographische Landschaftsforschung als Beitrag zur Lösung von Landeskunde und Umweltproblemen. Sitzungsberichte der Akadamie der Wissenschaften der DDR (5 N), pp. 23–51.

Harvey, F., Kaim, D., Gajda, A., 2014. Analysis of historical change using cadastral materials in the carpathian foothills. Eur. J. Geogr. 5, 6–21.

Heijman, W., Hagelaar, G., van der Heide, M., 2007. In: Tomic, D., Ševarlić, M.M. (Eds.), Rural Resilience as a New Development Concept. Development of Agriculture and Rural Areas in Central and Eastern Europe. European Association of Agricultural Economists (EAAE), Novi Sad.

Hirt, U., Mewes, M., Meyer, B.C., 2011. A new approach to comprehensive quantification of linear landscape elements using biotope types on a regional scale. Phys. Chem. Earth 36, 579–590. https://doi.org/10.1016/j.pce.2011.05.005.

Jackson, L.E., Pascual, U., Hodgkin, T., 2007. Utilizing and conserving agrobiodiversity in agricultural landscapes. Agric. Ecosyst. Environ. 121, 196–210. https://doi.org/10.16/j.agee.2006.12.017.

Jepsen, M.R., Kuemmerle, T., Müller, D., Erb, K., Verburg, P.H., Haberl, H., Vesterager, J.P., Andrič, M., Antrop, M., Austrheim, G., Björn, I., Bondeau, A., Bürgi, M., Bryson, J., Caspar, G., Cassar, L.F., Conrad, E., Chromý, P., Daugirdas, V., Van Eetvelde, V., Elena-Rosselló, R., Gimmi, U., Izakovicova, Z., Jančák, V., Jansson, U., Kladnik, D., Kozak, J., Konkoly-Gyuró, E., Krausmann, F., Mander, Ü., Mcdonagh, J., Pärn, J., Niedertscheider, M., Nikodemus, O., Ostapowicz, K., Pérez-Soba, M., Pinto-Correia, T., Ribokas, G., Rounsevell, M., Schistou, D., Schmit, C., Terkenli, T.S., Tretvik, A.M., Trzepacz, P., Vadineanu, A., Walz, A., Zhllima, E., Reenberg, A., 2015. Transitions in European land-management regimes between 1800 and 2010. Land Use Policy 49, 53–64. https://doi.org/10.1016/j.landusepol.2015.07.003.

Jetten, V.G., de Roo, A.P.J., Favis-Mortlock, D., 1999. Evaluation of field-scale and catchment-scale soil erosion models. Catena 37, 521–541. https://doi.org/10.1016/S0341-8162(99)00037-5.

Jongman, R.H.G., 2002. Homogenisation and fragmentation of the European landscape: ecological consequences and solutions. Landsc. Urban Plan. 58, 211–221. https://doi.org/10.16/j.agee.2006.12.017.

Knapp, S., Winter, M., Klotz, S., 2016. Increasing species richness, but decreasing phylogenetic richness and divergence over a 320 year period of urbanization. J. Appl. Ecol. 54, 1152–1160. https://doi.org/10.1111/1365-2664.12826.

Kopsidis, M., Pfister, U., 2013. Agricultural development during early industrialization in a low-wage economy: saxony, c. 1790–1830. EHES Working Papers in Economy History 39, pp. 1–69.

Körschens, M., Stegemann, K., Pfefferkorn, A., Weise, V., Müller, A., 1994. Der Statische Düngungsversuch Bad Lauchstädt nach 90 Jahren. B.G. Teubner Verlagsgesellschaft, Stuttgart, Leipzig.

Ladányi, Z.S., Blanka, V., Meyer, B.C., Mezősi, G., Rakonczai, J., 2015. Multi-indicator sensitivity analysis of climate change effects on landscapes in the Kiskunság National Park, Hungary. Ecol. Indic. 58, 8–20. https://doi.org/10.1016/j.ecolind.2015.05.024.

Liu, J., Dietz, T., Carpenter, S.R., Alberti, M., Folke, C., Moran, E., Pell, A.N., Deadman, P., Kratz, T., Lubchenco, J., Ostrom, E., Ouyang, Z., Provencher, W., Redman, C.L., Schneider, S.H., Taylor, W.W., 2007. Complexity of coupled human and natural systems. Science 317, 1513–1516. https://doi.org/10.1126/science.1144004.

Lorencová, E., Frélichová, J., Nelson, E., Vackár, D., 2013. Past and future impacts of land use and climate change on agricultural ecosystem services in the Czech Republic. Land Use Policy 33, 183–194. https://doi.org/10.1016/j.landusepol.2012.12.012.

Mannsfeld, K., Richter, H., 1995. Naturräume in Sachsen. Forschungen zur deutschen Landeskunde, p. 238 (Trier).

Matz, R., 1956. Agraratlas über das Gebiet der DDR. I. Bodenarten und bodenartliche Ertragsbedingungen nach den Ergebnissen der Bodenschätzung. Erläuterungen und Ortsverzeichnisse. Agraratlas über das Gebiet der DDR (Gotha).

Meyer, B.C., 1997. Landschaftsstrukturen und Regulationsfunktionen in Intensivagrarlandschaften im Raum Leipzig-Halle. Regionalisierte Umweltqualitätsziele - Funktionsbewertungen - Multikriterielle Landschaftsoptimierung unter Verwendung von GIS. Institut für Geographie, Universität zu Köln, Köln (UFZ-Bericht, Nr. 24/1997).

Meyer, B.C., Rannow, S., 2013. Landscape ecology and climate change adaptation: new perspectives in managing the change. Reg. Environ. Chang. 13, 739–741. https://doi.org/10.1007/s10113-013-0502-y.

Meyer, B.C., Wolf, T., Grabaum, R., 2012. A multifunctional assessment method for compromise optimisation of linear landscape elements. Ecol. Indic. 22, 53–63. https://doi.org/10.1016/j.ecolind.2011.07.020.

Meyer, B.C., Mezösi, G., Kovacs, F., 2017. Landscape degradation in different spatial scales caused by the aridification. Morav. Geogr. Rep. 25, 271–281. https://doi.org/10.1515/mgr-2017-0023.

Mezösi, G., Meyer, B.C., Loibl, W., Aubrecht, C., Csorba, P., Bata, T., 2013. Assessment of regional climate change impacts on Hungarian landscapes. Reg. Environ. Chang. 13, 797–811. https://doi.org/10.1007/s10113-012-0326-1.

Mezösi, G., Blanka, V., Bata, T., Kovácz, F., Meyer, B.C., 2015. Estimation of regional differences in wind erosion sensitivity in Hungary. Nat. Hazards Earth Syst. Sci. 15, 97–107. https://doi.org/10.5194/nhess-15-97-2015.

Mezősi, G., Blanka, V., Bata, T., Ladányi, Z.S., Kemény, G., Meyer, B.C., 2016. Assessment of future scenarios for wind erosion sensitivity changes based on ALADIN and REMO regional climate model simulation data. Open Geosci. 8, 465–477. https://doi.org/10.1515/geo-2016-0033.

Michael, A., 2000. Anwendung des physikalisch begründeten Erosionsprognosemodells EROSION 2D/3D - Empirische Ansätze zur Ableitung der Modellparameter. (Dissertation Technische). Universität Bergakademie Freiberg, Freiberg.

MILLENIUM ECOSYSTEM ASSESSMENT (MEA), 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

Mücher, C.A., Klijn, J.A., Wascher, D.M., Schaminée, J.H.J., 2010. A new European Landscape Classification (LANMAP): a transparent, flexible and user-oriented methodology to distinguish landscapes. Ecol. Indic. 10, 87–103. https://doi.org/10.1016/j.ecolind.2009.03.018.

Ramankutty, N., Evan, A.T., Monfreda, C., Foley, J.A., 2008. Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000. Glob. Biogeochem. Cycles 22, 1–19. https://doi.org/10.1029/2007GB002952.

Rickson, R.J., 2014. Can control of soil erosion mitigate water pollution by sediments? Sci. Total Environ. 468-469, 1187–1197. https://doi.org/10.1016/j.scitotenv.2013.05.057.

Schindewolf, M., Schmidt, J., 2012. Parameterization of the EROSION 2D/3D soil erosion model using a small-scale rainfall simulator and upstream runoff simulation. Catena 91, 47–55. https://doi.org/10.1016/j.catena.2011.01.007.

Schindewolf, M., Schmidt, J., von Werner, M., 2012. Modeling soil erosion and resulting sediment transport into surface water courses on regional scale. Z. Geomorphol. 57, 157–175. https://doi.org/10.1127/0372-8854/2012/S-00087.

Schmidt, J., 1991. A mathematical model to simulate rainfall erosion. In: Bork, H.-R., de Ploey, J., Schick, A. (Eds.), Erosion, Transport and Deposition Processes - Theories and Models. Catena-Verlag, Reiskirchen, pp. 101–109.

Schmidt, J., 1992. Modeling long term soil loss and landform change. In: Abrahams, A., Parson, A. (Eds.), Overland Flow - Hydraulics and Erosion Mechanics. University College London Press, London, pp. 409–433.

Siebert, S., Auerswald, K., Fiener, P., Disse, M., Martin, W., Haider, J., Michael, A., Gerlinger, K., 2011. Surface runoff from arable land - a homogenized data base of 726 rainfall simulation experiments. CRC/TR32 Database (TR32DB). TU München.

Skaloš, J., 2007. Czech and Swedish intensively utilised agricultural landscapes - parallels and divergences during the last 300 years. In: Dreslerová, J. (Ed.), Ekologie krajiny (Journal of Landscape Ecology). 0. číslo časopisu. CZ-IALE, Brno, pp. 135–162.

Starkloff, T., Stolte, J., 2014. Applied comparison of the erosion risk models EROSION 3D and LISEM for a small catchment in Norway. Catena 118, 154–167. https://doi.org/10.1016/j.catena.2014.02.004.

Stumpf, F., Goebes, P., Schmidt, K., Schindewolf, M., Schönbrodt-Stitt, S., Wadoux, A., Xiang, W., Scholten, T., 2016. Sediment reallocation due to erosive rainfall in the Three Gorges River, Central China. Land Degrad. Dev. 28, 1212–1227. https://doi.org/10.1002/ldr.2503.

Verburg, P.H., Erb, K.H., Mertz, O., Espindola, G., 2013. Land system science: between global challenges and local realities. Editorial overview. Curr. Opin. Environ. Sustain. 5, 433–437. https://doi.org/10.1016/j.cosust.2013.08.001.

Wolf, D., Faust, D., 2013. Holocene sediment fluxes in a fragile loess landscape (Saxony, Germany). Catena 103, 87–102. https://doi.org/10.1016/j.catena.2011.05.011.