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RESEARCH ARTICLE

Changes in landscape naturalness derived from a historical land register—a case study from NE Germany

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Introduction

The naturalness of landscapes and its assessment is a major issue in landscape management and nature conservation (Ridder 2007a; Verhoog et al. 2007). Additionally, natural sites serve as a reference for ecosystem restoration and landscape planning (Siipi 2004; SER 2004; van Andel and Aronson 2006; Zerbe et al. 2009). However, it is often not clearly specified what naturalness is or could be (Ridder 2007b) with regard to time scale and human impact. Definitions and methods of assessment have been introduced and discussed by various authors (see for example Peterken 1996; Machado 2004; Kowarik 2006; Timmermann et al. 2006a; Ridder 2007b; Walentowski and Winter 2007; Reif and Walentowski 2008). The definition of a starting point ("natural state") with which ecosystems or landscapes in a given condition are to be compared turns out to be a crucial point. In most of these studies vegetation is identified as a measure for naturalness, as vegetation reflects anthropogenically changed abiotic and biotic site conditions and can be used as an indicator for landscape properties (Ellenberg 1996). It also offers important criteria for nature conservation assessments (Mueller-Dombois and Ellenberg 1974; Maarel 2005).

In the past decades, numerous methods have been applied to describe and reconstruct historical landscapes (see e.g. surveys by Egan and Howell 2001). One of the most important sources for historical landscape ecology are historical maps with which ancient landscapes can be reconstructed. In Central Europe, detailed mapping reaches back for about several hundred years (Küchler and Zonneveld 1988). Although there exist a great number of investigations and elaborate methodology with regard to the analysis of land-use and land-cover change in Central Europe (e.g. Bastian and Bernhardt 1993; Hobbs 1994; Ihse 1996; Skĺnes 1996; Pärtel et al. 1999; Zerbe and Brande 2003; Coppin et al. 2004; Zerbe 2004; Bender et al. 2005; Wanja et al. 2007), a detailed reconstruction of abiotic site conditions in historical landscapes such as, e.g., soil water and nutrient conditions has hardly been achieved.

A particular situation for historical landscape reconstruction is given in NE Germany with the Swedish Register Maps which have been drawn around 1700 AD on a scale of about 1:8,300. These historical maps, including comprehensive annotations in textbooks, offer detailed information about settlements, land use, inhabitants, and the property state of land as well as vegetation, abiotic site conditions, and yield. Thus, our study aims to provide a reconstruction of the landscape 300 years ago and its abiotic site conditions, in order to assess the naturalness of

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the historical landscape. This is achieved by the evaluation of the Swedish Register Maps and their description supplements, which in detail describe each mapped landscape unit. Additionally, we integrate landscape-inherent information like relief, soil, and findings derived from macro-fossil and pollen analyses of peat. These historical landscape attributes are compared with the recent state of the landscape as derived from a comprehensive vegetation survey. As a reference, we model a hypothetical natural state which would have developed without human impact. Consequently, we are able to assess the human impact on the landscape level by the "degree of culturalness" (DC) quantitatively and site-specifically for the historical as well as for the landscape of today. The methodology presented here allows us to measure the naturalness of recent and reconstructed historical landscapes. Thus, the hypotheses of our study are

(1) The landscape in NE Germany was more natural 300 years ago.
(2) With help of the Swedish Register Maps, the naturalness, i.e. the degree of culturalness, of a former landscape can be assessed with high precision.
(3) Landscape changes in the past 300 years can at least partially be quantified with our method of landscape reconstruction.

Materials and methods

Study area

Our study was conducted in a landscape situated in NE Germany near the Baltic Sea coast (12°88′ N, 53°99′ E, see Fig. 1) with an area of 2.8 km^2. As typical for Central European pleistocene landscapes formed by the latest glacial period, a wide range of soil nutrient and water conditions exists. The characteristic mosaic of ground moraine, depressions with wet sites, and sites far from groundwater is representative for the NE German lowland (Ehlers 1994; Katzung 2004). The soil consists of more or less sandy clay and peat in the depressions. The climate is humid with an average temperature of 8°C.

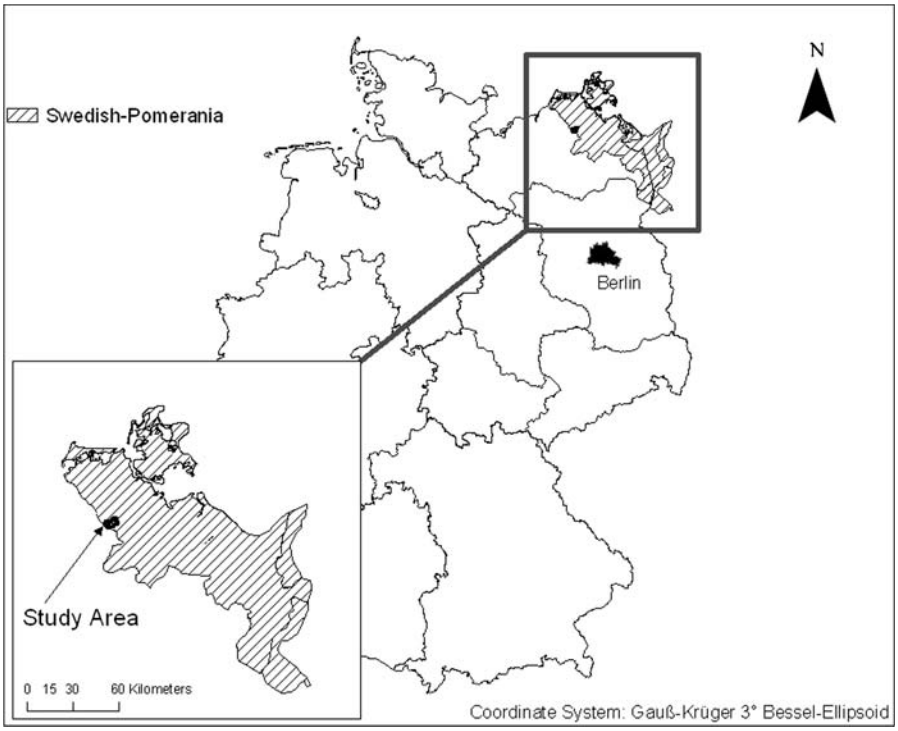

Fig. 1 Study area in North-Eastern Germany: the shaded area shows the part of Pomerania covered by the Swedish land survey 1692–1705

Human impact reaches back to the Bronze Age and is also revealed for the Middle Ages. After the European-wide Migration Period, Slavic people immigrated to NE Germany. However, in our study area only one village was established (see Fig. 2) which is firstly mentioned in 1280 A.D. as "Glowitz" (Königliches Staatsarchiv zu Stettin 1868–1907) which means "cow house" (Trautmann 1949). After the colonization period of the High Middle Ages, almost the whole area with the exception of wetlands was used for agriculture and the forest area had decreased to a historical minimum (Haupt 1940; Hänsel 1998; Mangelsdorf 2001; Barthelmes 2002, see also Fig. 2). This period was followed by partial abandonment in the 14th century.

In 1697, four settlements existed and 30% of the area was agriculturally used. One of the major land uses in the forests showed in Fig. 2c was forest grazing. In the following 300 years, one additional village with nowadays 15 houses was established. The distribution of fields (again) expanded to ca. 45%, especially in the central parts of the study area which had presumably been abandoned in the 14th century and again in the Thirty Years' War (see Beckmann 1999).

Scenario 1: Present-day landscape

From the many possible ways to describe the conditions of the present-day landscape we had to select a method which is simple enough to reconstruct and construct, respectively, the historical and natural states with help of the chosen parameters. Vegetation is considered a useful parameter for an integrative landscape analysis because of its clear relation to abiotic site conditions and habitat function (e.g. Ellenberg 1996). Since the vegetation can only be reconstructed in a very fragmentary manner from the historical records (tree species, sometimes reed [*Phragmites australis*] is mentioned), we need a concept to substitute abiotic and biotic information depending on the available source.

Site conditions derived from vegetation

For the assessment of present-day site conditions we used vegetation forms as a combination of floristically defined vegetation types with related site conditions (see Table 1 and Koska et al. 2001; Timmermann et al. 2006b). The site conditions are

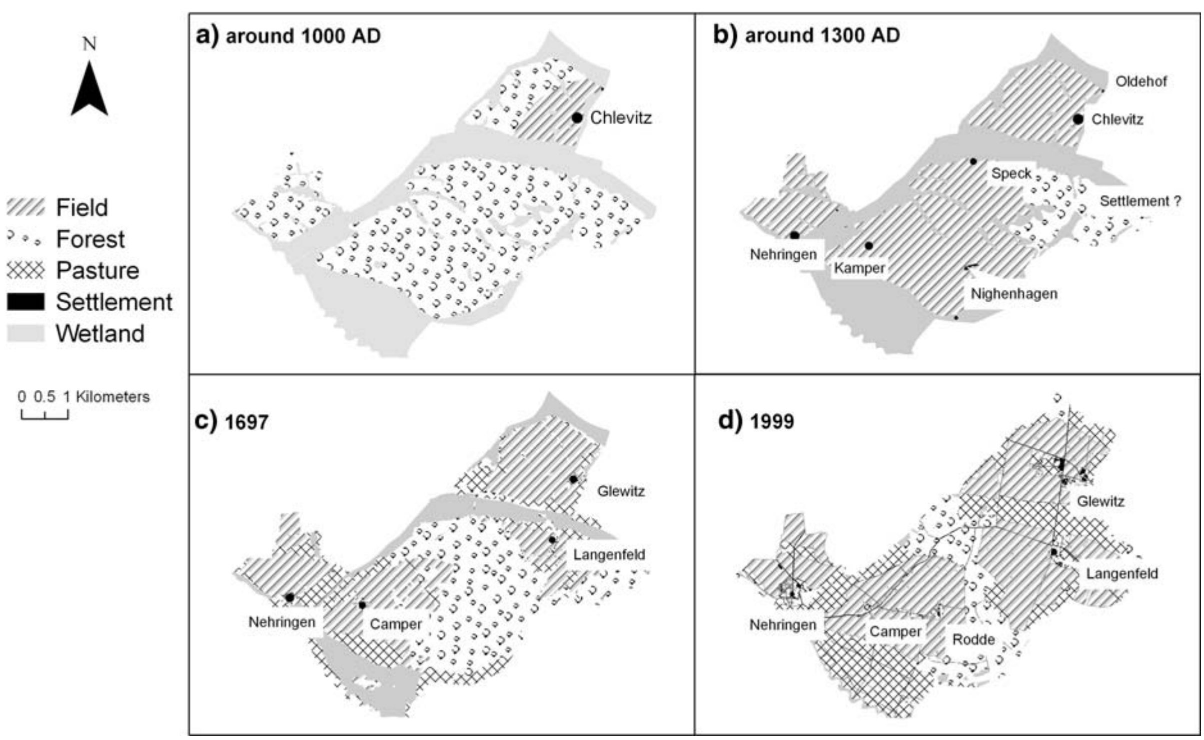

Fig. 2 Distribution of land-use types for the different scenarios

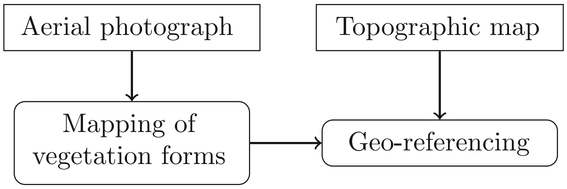

Fig. 3 Flowchart for scenario 1: The present-day state

defined by multiple ecological site factors, namely those with a high explanatory value for the occurrence of specific plant species groups (indicator groups). The factors are graduated due to floristic differences, i.e. the appearance or disappearance of species groups along the gradient (e.g. soil water). Accordingly, the factor classes can also be described by the ranges of the abiotic factor. For example, the moisture class of wetlands can be defined by the long-term annual median of the ground water level. Thus, moisture class 3+ is characterised by a mean annual water median of 20–45 cm below surface (see Table 2). Compared to direct measurements, the advantages of such a classification approach are the compensation of spatial and temporal fluctuations by the plant cover and the much easier application in large areas. The iterative calibration of vegetation and site conditions ensures the selection of appropriate and relevant landscape-ecological factors and their adequate subdivision.

Table 1 Vegetation forms as a combination of floristically defined vegetation types with related site conditions: for biotic and abiotic definitions of factor classes see Koska (2001); Koska et al. (2001); Zeitz and Koska (2001); Succow and Stegmann (2001)

1. Floristic definition:

		Form A	Form B
	Number of samples	16	33
Percolation (P)	*Berula erecta*	**63**	.
	Veronica beccabunga	**19**	*3*
	Nasturtium officinale	**13**	*6*
	Plagiomnium elatum	**25**	.
	Carex paniculata	**75**	*6*
	Scrophularia umbrosa	**63**	.
	Scirpus sylvaticus	**13**	*3*
Topogenic (T)	*Rorippa amphibia*	.	**24**
	Alisma plantago-aquatica	.	**15**
	Rumex hydrolapathum	.	**48**
	Juncus effusus	.	**15**
	Calamagrostis canescens	.	**18**
	Lycopus europaeus	*13*	**39**
	Solanum dulcamara	*6*	**33**
	Iris pseudacorus	.	**24**
	…	…	…

Numbers are the relative frequencies of the species [in %] in the vegetation relevés forming the type.

2. combination of site factor classes:

Factor	Classes
Radiation climate	**shad**ed, **exp**osed
Disturbance	**v**ery **l**ow, **l**ow, **mod**erately, **h**igh, **v**ery **h**igh
Substrate quality	**aqu**atic, **rock**y, **unst**able, penetrable-**st**able
Moisture	6+, 5+, 4+, 3+, 2+, 2-, 3-
Water regime	**P**ercolation, **T**opogenic, **G**roundwater, **I**nfiltration, **per**iodically inundated
Water quality	**omb**rogen, **min**eral, **sal**in
Nutrients	**v**ery **p**oor, **p**oor, **l**ower **m**edium, **h**igher **m**edium, **m**oderately **r**ich, **r**ich, **v**ery **r**ich
Acidity	**ac**id, **med**ium, **alk**aline

Formula to describe a **V**egetation **F**orm (VF):

VF exp vl st 5+ P min r med/alk

= Form A

Table 2 Moisture classes and their abiotic range (Koska 2001)

Scale	Characteristics	
6+	WLm:	140 to 21 cm
5+		20 to 0 cm
4+		0 to −20 cm
3+		−21 to −45 cm
2+		−46 to −80 cm
2−	WD:	<60 l/m^2
3−		61–100 l/m^2
4−		101–140 l/m^2
5−		>140 l/m^2

Abbreviations: *WLm*: long-term annual median of water level (0 = soil surface),*WD*: annual water supply deficiency

In addition to the moisture class, radiation climate (forest or open land), substrate quality (stability of the ground), disturbance degree (frequency of shoot axis damage), water regime (source of water, water emergence), water quality (conductivity), trophic class (nutrient conditions of the soil) and acidity class are considered as site factors with more or less strong influence on vegetation (for further explanations see Succow and Joosten 2001, and Table 1). The number of classes within the factor gradients is different due to their floristic differentiation. For names of factor classes see Table 1.

Most factors are ordinal, like the water supply which ranges from wet to dry. Koska (2001) differentiated 7 degrees of disturbance providing information on successional stages as well as anthropogenic disturbance regimes. We divided the agricultural disturbance into two classes but then combined the successional stages with the corresponding anthropogenic disturbance regime types and finally obtained five classes (for details see Jansen 2005).

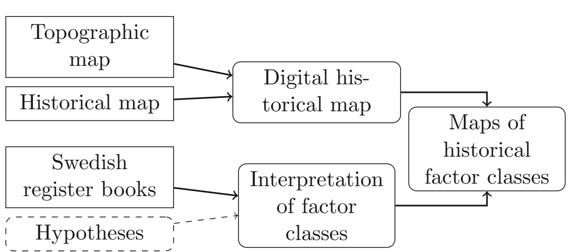

Fig. 4 Flowchart for scenario 2: The historical state of 1697

The present-day conditions are analysed by a field mapping of vegetation forms (Fig. 3). From these, the abiotic site conditions can be derived.

Scenario 2: The landscape in 1697

The landscape of 1697 is reconstructed by the interpretation of historical maps with detailed register books supported by topography and some hypotheses about the human influence (see Fig. 4).

Swedish Register Maps

At the end of the 17th century, the Swedish king Karl XI ordered a land survey of Swedish-Pomerania (see Fig. 1) to recalculate the taxes (Curschmann 1935; Baigent 1990; Asmus 1996). This survey contains a detailed and rather exact triangulation on a scale of approximately 1:8,300 (see Fig. 5) and includes a very precise description of the land, e.g. with regard to inhabitants and property rights as well as to agricultural yields in each specific landscape section. These detailed descriptions enable us to reconstruct the landscape 300 years ago. In addition to the former land use and vegetation, this historical data source allows us to identify the site factors relevant for the distribution of vegetation forms. Maps and descriptions are available free of charge in the World Wide Web (Zölitz-Möller 2007). Since the descriptions are written in the Swedish language, the translation by Wegner (1959) was used for our investigation.

For an area of arable field, for instance, we can derive the following information from the description books: *"Xa: Near the way, better situation, mould mixed with loam, towards the ditch deep and heavy farmland."*

This description can be utilized for a reconstruction of the range of site factors which are related to the vegetation form. The vegetation form concept provides factor classes which are, at least in the case of moisture classes, related to measurable absolute values (see Table 2) and serve as templates for the interpretation. In our example, the description "better situation" and "deep and heavy" is mostly related to the moisture conditions. Taking the whole factor gradient into account and considering the relief, we can divide the described land into an area "near the way" without influence of groundwater but also without drought (moisture class "2−") and an area

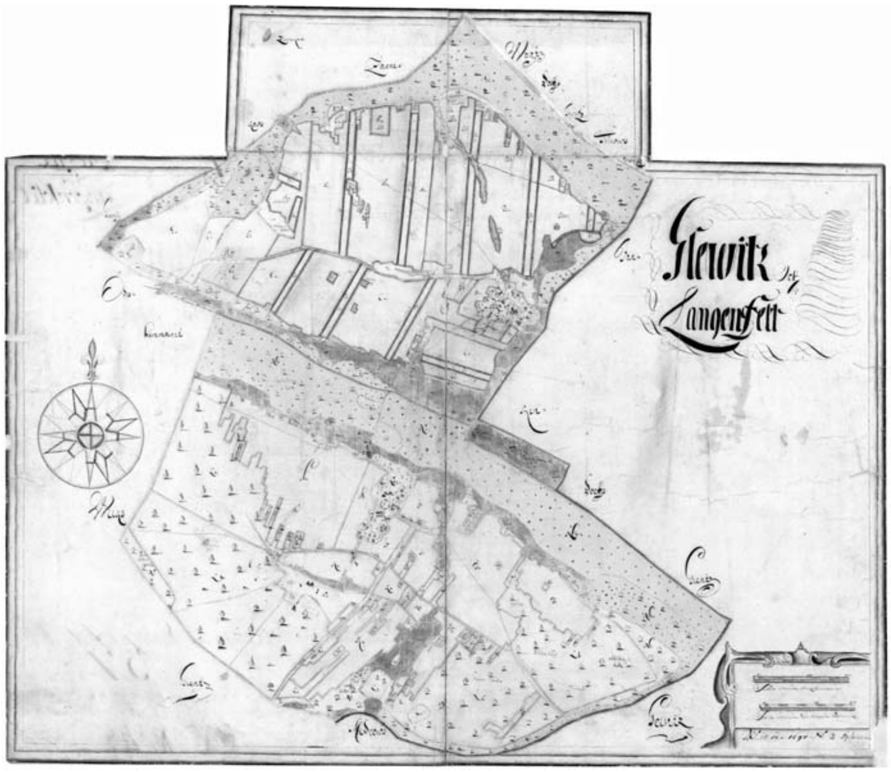

Fig. 5 Swedish Register Map: the maps were measured with triangulation as island maps, which means without higher reference systems but each map uses the points of measurements from the adjacent maps: they show land-use cover and each of the patches has a signature pointing to the associated description

"towards the ditch" with significant influence of groundwater (moisture classes "2+" or "3+").

For every patch, the probability for each factor class was estimated considering all available information from the Swedish Register Maps and if necessary from topography. For the above-mentioned example "towards the ditch", for instance, this means for the moisture class that we assumed a probability of 50% that this patch fits to the moisture class 2+ (long-term annual median water level between −46 to −80 cm below surface, s. Table 2), with 30% probability to moisture class 3+ and with 10% probability to either 4+ or 2−.

Moisture class	5+	4+	3+	2+	2−	3−
Probability (%)	0	10	30	50	10	0

Other sources

The Register Maps prove to be an extensive source of ecological information. However, for factors and areas where information was not sufficient, models had to be developed in order to derive the most probable site conditions.

For acidity and water quality, hypotheses are put forward uniformly for the whole survey area. With regard to nutrient supply, one can find many annotations about the proportion of sowing and crop and of the number of hay carloads in the description books. However, biomass is not only driven by nutrient supply, and the information is specified only for whole land districts. Therefore, hypotheses about the alteration of the (reconstructed) natural conditions induced by the historical land use had to be applied (see Table 4). For details of the models, see Jansen (2005).

Scenario 3: Reconstructed natural conditions of the present-day landscape

We define *Reconstructed natural conditions* (RNC) as the landscape how it would have developed without human impact (see Niemeier 1956; Tüxen 1956; Jansen 2005). Such a reconstruction has to be based on the most stable site factors such as relief and soil substrate (Fig. 6). We used data from the "Reichsbodenschätzung" (Rothkegel and Herzog 1935) to derive a detailed map of soil conditions. Relief and soil types are used to model the groundwater

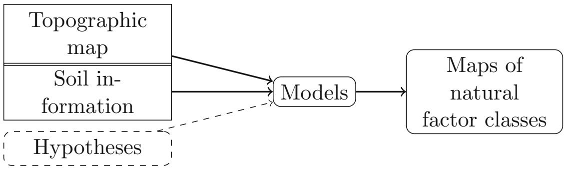

Fig. 6 Flowchart for scenarios 3 & 4: The Reconstructed Natural Conditions (RNC) of 1697 and 1999

conditions (see Fig. 7a). The distribution of peatland is used to calibrate the groundwater model. Also the water regime is modelled from soil type and relief. The nutrient conditions are derived from the soil types using hypotheses about the natural nutrient supply in the given climate based on detailed information by Kopp et al. (1982). For disturbance degree, acidity and water quality, hypotheses are put forward uniformly for the study area. For details of the different models see Jansen (2005).

Scenario 4: Reconstructed natural conditions of 1697

The RNC is time specific, i.e. every time period has its own RNC. However, since the differences between the natural conditions in 1700 A.D. and today are considered rather small due to a more or less similar climate regarding species composition and already well developed soils, the RNC in 1700 and today are considered to be equal.

Degree of culturalness

With the help of the RNC as a reference state, an ecologically defined deviance degree of a site can be described for scenarios 1 and 2. The deviation of the individual factor from the RNC can be used to derive a measure for the distance from nature. For that purpose, the vector GIS layers of scenarios 1 and 2 are spatially joined with scenario 3 = 4 and slivers smaller than 100 sq. m. are purged. Subsequently the factor estimations of the different scenarios can be subtracted from each other for every patch. These differences are weighted and summed up. For all ordinal factors, the level of change is set equal to the difference between classes; for the nominal factor—water regime, change is counted as 1. Accordingly, we can sum up the grade of change for all factors and assess the degree of culturalness (DC) for each area (see Table 5).

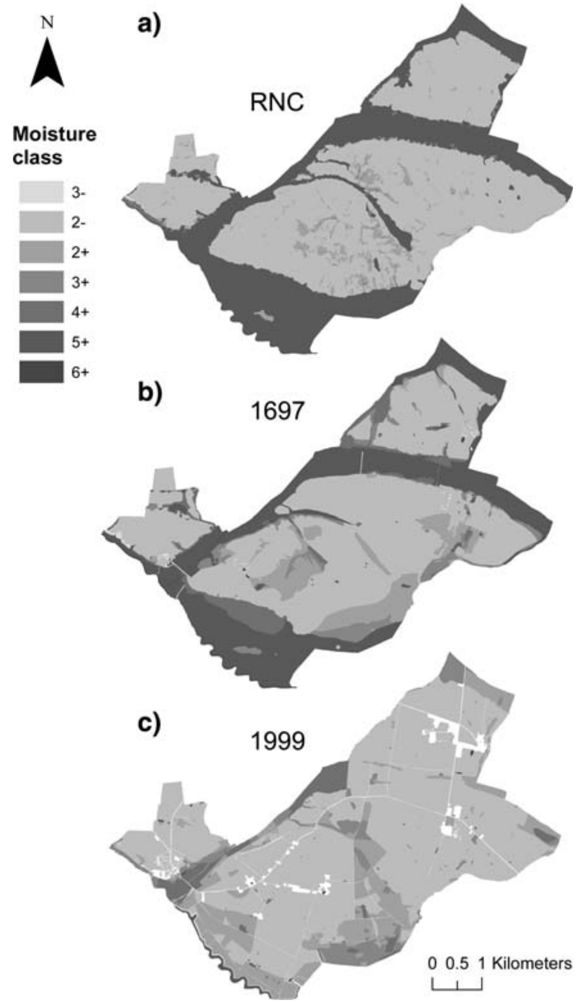

Fig. 7 Distribution of moisture classes under the Reconstructed Natural Conditions (RNC), in 1697 and 1999. For the RNC, it is a hydrological model from relief and soil substrate. For 1697, it is derived from the descriptions of the Swedish Register Maps. The low bogs in the valleys are hydrologically nearly untouched. In 1999, a vegetation survey was carried out. Nearly the whole landscape including the low bogs are leveled to the same medium dry conditions

Error estimation

Such a rather simple summation can only be achieved when the estimation of a specific factor class can be done with 100% probability. As mentioned above, we derived the probability of each factor class for every area to map the uncertainties of estimation. In order to take the variable specificity of the descriptions for the calculation of the factor deviance into account, the probability of deviance between the observed landscape layers is calculated as:

$$P_{d=-n+1}^{d=n-1} = \sum_{i=1}^{n} p_{N_i} * p_{C_{i+d}}$$

for $n \geq i + d \geq 0$ where d is the deviance degree; n the number of factor classes; i the ordinal number for factor class; N the factor in the reconstructed natural landscape (RNC); C the factor in the cultural landscape; p the probability of specific factor class; P the probability of deviance.

The probability of the sum of deviance of all factors can similarly be calculated as the sum of products of the observed factor deviation probabilities. To derive average values for the whole area, we calculate the degree of culturalness as the product of factor deviances until the probability of deviance exceeds 90%, which means that the deviance from nature is with 90% probability at least as high as stated.

Factor weighting

In order to compare the actual impact of the different factors to the degree of culturalness we calculate the area-weighted mean deviance for each factor (see Table 6). In addition to the factors mentioned above, the dominant cultivated plants (for the historical landscape only crop, since the 1960s also seeded grassland) are taken into account as temporal human impact. The degree of culturalness of the historical landscape compared to that of the present-day landscape reveals the change in intensity of human impact.

Results

Water conditions

Figure 7 shows that the soil water condition is one of those site factors which changed most strongly in the landscape. The RNC shows lowland mires covering 32% of the investigation area, which reflects permanently wet conditions on one third of the studied region. In 1697, nearly the same percentage (31%) was revealed. Only some hand-made ditches having a small effect with regard to drainage existed within the arable land (see Fig. 7b). In contrast, in 1999 only 1% of the study area shows a permanently wet moisture class (see Fig. 7c). Consequently, large parts of the former peatland are currently without any groundwater contact (moisture class 2-, groundwater more than 80 cm below surface) due to the intense anthropogenic drainages. Also the wet areas in the arable land run dry except for very small remnants.

If we use the mean groundwater level per moisture class (see Table 2) and if we choose a conservative value of −90 cm as mean for class 2− which is in fact not delimited by groundwater (see Table 2) we can calculate the mean loss of groundwater levels for 1697 and 1999 (see Table 3). The landscape of 1697 shows an overall increase in groundwater level of 2 cm and the present-day landscape shows a loss of water with a value of 56 cm in the lower parts (mainly mires) and 2 cm in the upper mineral parts of the survey area.

Disturbance degree

The early Modern Times farming shows a dominance of low to medium disturbance degrees, i.e. moderate land-use intensities. About one third of the landscape is under the plow. Only 18% of the area, in particular the mires, can be considered as "very low" disturbed. In 1999, the whole peatland is cultivated but, on the contrary, the woodland can be classified as "very low" disturbed (19%).

In 1999, 45% of the survey area is intensively used for agriculture (fields) and meadows occupy 24%. The major percentage of the meadows is intensively used, only 4% is extensively used with a maximum of two cuttings per year or equivalent pasturing. In 1999, high disturbance degrees are prevailing, whereas the moderate disturbance degrees, i.e. the extensive land-use forms of meadows and fields have considerably declined.

Table 3 Groundwater balance, i.e. the change of mean groundwater level compared to the reconstructed natural condition (RNC)

	Overall	Areas ≤3.5 m above sea level	Areas >3.5 m above sea level
1697	2 cm	−2 cm	+5 cm
1999	−23 cm	−56 cm	−2 cm

Trophic situation

The young pleistocene landscape typically has a natural eutrophic state, i.e. 63% of the whole area. In 1697, the anthropogenic nutrient withdrawal (see Table 4) has led to a predominant mesotrophic state (68%). Only 25% is considered nutrient-rich. In 1999 however, 70% of the area is in a polytrophic state due to a very high input of fertilizer. Hardly any sites with less than eutrophic nutrient conditions are present.

Cultivated plants

In 1697, 28% of the area is dominated by cultivation of plants. These are exclusively located on the arable fields which are only managed in two of three years in the agriculture of that period (Küster 1995). In 1999, 68% of the study area is covered by fields and managed grassland.

Naturalness

In 1697, the sum of area-weighted mean of landscape factor deviation is at least DC = 3.4 (see Table 6 and Fig. 8). This, we consider a “near natural state”. Today’s landscape, on the other hand, has—despite of the purely agrarian village structure—an average degree of culturalness of at least DC = 7.7, which we consider “far from nature”.

Table 4 Hypotheses about changes in trophic classes compared to the reconstructed natural conditions for the agricultural land in 1697: the nutrient gradient is divided into 7 classes (see Table 1)

	Max withdrawal	Max gain	Most probable
Fields	−2	0	−1
Fallow fields	−1	1	0
Abandoned land	−1	0	0
Village area	−2	1	−1
Meadows/pastures	−1	0	−1
Woodland pasture	−2	−1	−1
Woodland	−1	0	0
Standing water	−1	+1	0
Peatland (unused)	0	0	0

Withdrawal is caused by harvesting and gain by fertilization. For example, on arable land a naturally rich soil will most probably end up in moderately rich conditions

Table 5 Degree of culturalness as the sum of factor deviances

Change in factor classes	Deviance range
Radiation climate	(0–1)
+Disturbance degree	(0–4)
+Substrate quality	(0–1)
+Moisture class	(0–6)
+Water regime	(0–1)
+Water quality	(0–2)
+Trophic class	(0–6)
+Acidity class	(0–2)
+Dominant crop	(0–1)
Degree of culturalness “DC”	Max = 24

The rate of change per factor is evaluated as equal with regard to the class difference between RNC and the considered scenario (1 or 2): if, for instance, the natural moisture class is 5+ (see Table 2 for explanation) in RNC and 2+ in the considered scenario, the deviance degree is 3; for the nominal factor water regime, an observed change, no matter in which direction, is counted as 1. The highest possible deviance from the RNC is 24

Table 6 The area-weighted mean of factor deviances shows the relative importance of the different factors in the different scenarios for the resulting deviance degree

	1697	1999
Radiation climate	0.5	0.7
Disturbance degree	1.4	2.5
Substrate quality	0.01	0.2
Moisture class	0.5	1.1
Water regime	0.2	0.4
Water quality	0	0
Trophic class	0.5	2.1
Acidity class	0	0
Dominance of crop	0.3	0.7
	3.41	7.7

Discussion

The change of site conditions

The high percentage of lowland mires in the RNC is due to the low altitude above sea level (≤ 20 m a.s.l.) and only few drainage systems which is typical for the geologically young landscape of NE Germany (Kowatsch 2007). In 1697, some drainage systems were already established but have only little effect. Table 3 shows a slight increase of the groundwater

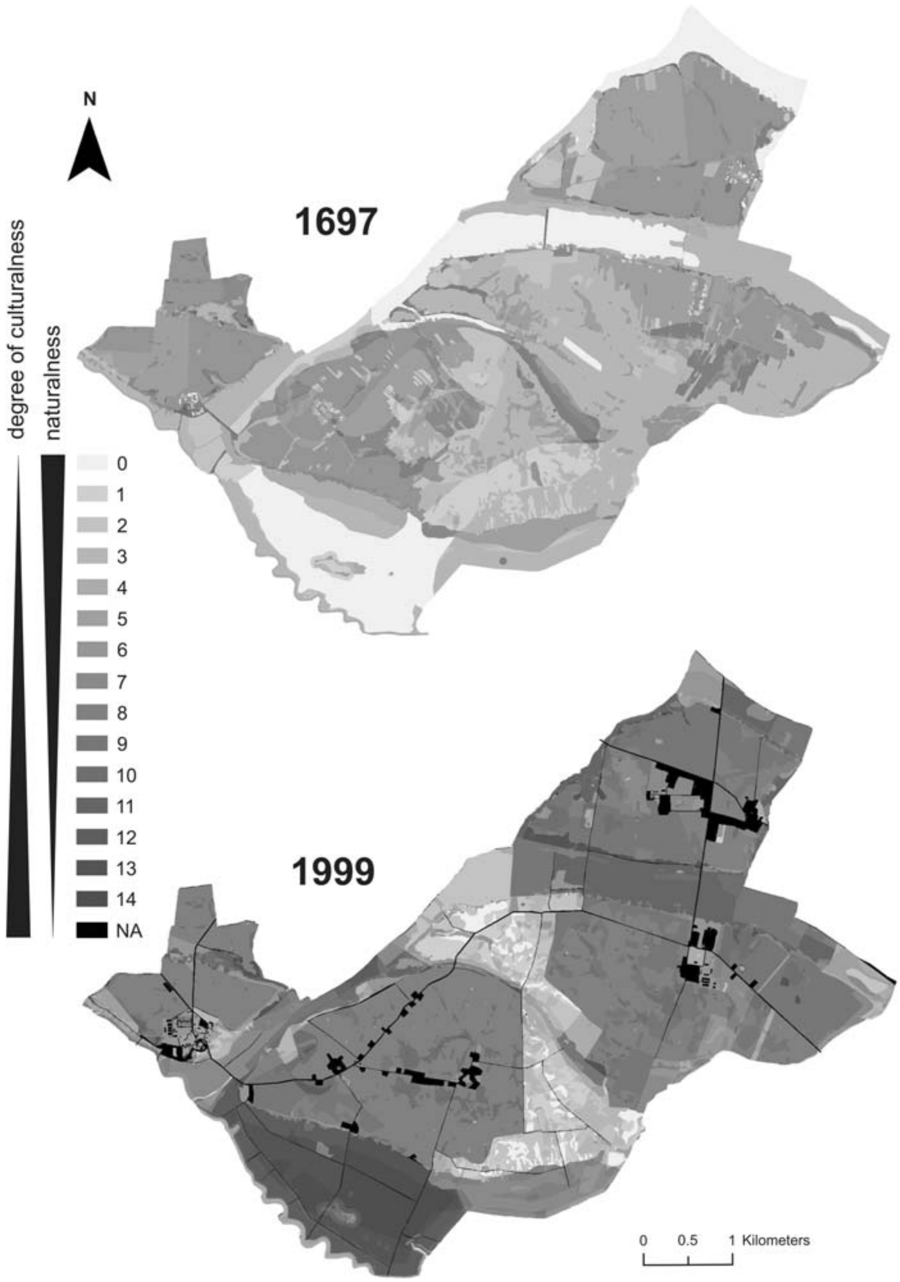

Fig. 8 Deviance from nature in 1697 and 1999. The dominance of an intermediate degree of culturalness as well as a high heterogeneity can be seen in 1697. High degrees of culturalness are predominant in 1999. Peatlands, the most natural sites in 1697, are nowadays the sites which show the highest degree of culturalness. The mineral woodlands currently are islands of naturalness. NA denotes for not available data

level of 2 cm, which reflects the increased water balance of the landscape due to major deforestation in the region. The present-day landscape suffers from a strong decrease of the groundwater table: approximately 23 cm relating to the whole area and an average value of 56 cm in the lower parts caused by the massive drainage of the peatlands.

Disturbance is one of the main driving forces of biodiversity (Pickett and White 1985; White and Jentsch 2001; Jentsch 2004; Buhk et al. 2007). In 1697 as well as in 1999 approximately 20% of the area is undisturbed (Disturbance degree = 0). However, completely different habitats were not exposed to strong human impact, i.e. peatland in 1697 and woodland, mainly on mineral soils, in 1999. For the remaining 80% of the landscape, disturbance has changed dramatically with regard to both intensity and frequency. Medium disturbance degrees decreased and high disturbance degrees increased over time.

The changes in nutrient supply are considered the most important factor influencing biodiversity in the historical and present-day landscape. Higher supply of nitrogen or phosphor leads to lower species richness (e.g. Stevens et al. 2004; Wassen et al. 2005). The historical landscape was exhausted by a severe nutrient withdrawal, because harvesting and grazing removed much more nutrients than droppings and dung could give back. The application of mineral fertilizer and atmogenic nutrient depositions have nowadays led to a much higher nutrient level compared to the historical landscape.

Data quality

Spatial, temporal, and textual uncertainties in a historical analysis can be counteracted by fuzzy set theory (Zadeh 1965; Burrough and McDonnell 1998; Leyk et al. 2005) but it would be necessary to develop uncertainty models (Plewe 2002; Leyk and Zimmermann 2007) to model the uncertainty.

The *mapping units* of the Swedish Register Maps are primarily units of land-use management and ownership. Consequently, they reflect a considerable spatial uncertainty for the site ecological characteristics. Nevertheless, the Swedish land surveyors have been the leading cartographers of their time (Curschmann 1935). Due to the high topographic precision of the historical maps, the absolute topographic uncertainty is low. Furthermore, there are no references from which to derive uncertainty models (Leyk and Zimmermann 2007). Therefore, we use the relief to determine sub-patch borders if necessary but without fuzziness.

Time is considered as a discrete variable in this survey because after 1697 A.D. no data as informative as the Swedish land survey are available. The Prussian maps, the so-called “Urmesstischblätter” (Reichsamt für Bodenschätzung 1827–1837) for instance, were laid out on a scale of 1:25,000 and reflect only land-use types and some information about drainage.

The *textual imprecision* of the map source could only be handled by estimations. For each factor, all available information from the maps, such as descriptions, relief, substrate, and neighbouring patches were considered and probabilities for each factor class estimated.

The quality of information for the reconstruction of the different site factors from the Swedish Register Map is heterogeneous. Degree of disturbance, radiation climate, and the dominance of cultivated plants can easily and with great certainty be deduced from the historical maps. The moisture class can be interpreted from the descriptions in a more or less confident way. For the water regime and water quality, it can be suggested that situations differing from the natural state (for instance spring mires, salt water springs, etc.) would have been recognized in the survey or can be reconstructed from the present evidence (e.g. percolation mires from the peat soil profiles (Succow and Joosten 2001)). To a lesser extent, this also holds true for the soil pH. Acidity as an important factor for plant productivity was unknown by the land surveyors and is therefore not mentioned in the descriptions. Nevertheless, acidic sites would most probably have been mentioned because of their low productivity. Additionally, the decision between (sub-)neutral and calcareous sites can only be revealed by bioindication if the nutrient status is not too high (Koska 2001). In the RNC, the primary calcareous moraine substrate would have been leached (in particular on woodland sites) in the past 10,000 years to an extent that no explicit calcareous condition can be expected in either 1697 or 1999. However on hills, due to erosion under present-day as well as historical land use and subsequent capped soils calcareous conditions can prevail (Manthey 1998). For the historical as well as for the present-day landscape, the extent of calcareous sites is difficult to estimate. Finally, the whole area was considered to be sub-neutral in all time layers and possible differences are only anticipated by an accordant uncertainty value.

Maybe the most uncertain factor is the nutrient supply for vegetation. There are a lot of comments in the description books about substrate quality and yield in relation to sowing. However, biomass is also highly dependent on other factors like moisture and most of the yield information has only been recorded for whole districts. Thus, it is difficult to derive the nutrient supply from the historical survey. We decided to use hypotheses about the deviance from the nutrient status of the RNC as long as no better information is achievable.

Deviance from nature

One of our major objectives was to model the degree of deviance from the natural state for a present-day landscape and its historical state 300 years ago. Among the approaches to determine a degree of naturalness, the concept of hemeroby (Jalas 1955; Blume and Sukopp 1976; Kowarik 2006) was increasingly debated in the past decades, at least in Central Europe. It is mostly based on expert classification of the degree of human impact on vegetation types, biotope types, or land-use types, respectively (Kowarik 2006; Rühs et al. 2006). Only a few studies have been carried out to determine hemeroby by more or less precisely quantifying the human impact on soil, vegetation, etc. (e.g. Kim et al. 2002; Fu et al. 2006). Beyond the difficulties of expert systems we have to face the fact that vegetation cannot be reconstructed directly for the historical landscape.

The reconstruction of soil types is a promising approach (Lorz et al. 2000) but has no direct relation to flora or fauna. Vegetation forms like the one we used in our approach have to be reconstructed indirectly. But since we had to reconstruct the driving factors for the vegetation forms we could then use these factors to calculate the degree of landscape change (scenarios 1 and 2) directly. For the assessment of naturalness, reversible as well as irreversible changes should be considered. It makes no sense to ignore the most significant human impacts like erosion or hydrological changes just for reasons of practicability.

The reconstruction of the historical landscape and human impact is necessary to understand the present-day situation. Throughout Europe, a high degree of naturalness often is an objective of nature conservation or ecosystem restoration (Zerbe 2002; van Andel and Aronson 2006). In restoration ecology, for example, the identification of restoration objectives is crucial for a successful ecosystem restoration (Zerbe et al. 2009).

Most of the endangered plant species of Europe grow in habitats which have been utilized and changed by men (e.g. Ellenberg 1996; Ludwig and Schnittler 1996). An historical comparison of landscape scenarios like the one presented here can help to identify the conditions under which alpha and beta biodiversity could be increased. The concept of Degrees of Culturalness can, for instance, be applied within nature protection guidelines, on the one hand with regard to specific factors (e.g. "A deviance of moisture classes not more than 3 should be achieved.") or on the other hand to the whole DC ("Not more than 6 degrees of deviance from nature are allowed in a specific protected area."), no matter which factor is deviating.

With regard to the calculation of the Degree of Culturalness from the observed factor deviances, we also can derive other methods. For instance, we could equalize the potential impact of every factor to DC. We consider the classification of the continuous abiotic factors into more or less discrete classes by floristic means to provide a suitable indicator for specific anthropogenic landscape changes.

The sum of the factor deviances reveals that the culturalness of the modern landscape is twice as high as 300 years ago. If we focus on the area-weighted mean of single factor deviances (see Table 6) we can identify the degree of disturbance as crucial for the increase in deviance sum. Despite the fact that the highest possible deviation for a certain factor is theoretically within the moisture class (see Table 5), the highest absolute changes result from anthropogenically induced vegetation damage by ploughing and grazing. Also, the mean deviance of trophic classes exceeds 2 classes in the modern landscape. In the agricultural landscape of 1697, the trophic exploitation may have been underestimated (see Table 4), so that the historical deviance may be even higher. In NE Germany, the percentage of open land without forest cover is more or less equal in 1700 and today (Seidl 2006). The deviances of moisture class, water regime, and the dominance of cultivated plants today are twice as high as 300 years ago.

As a further step, the factors could be weighted according to their reversibility. Disturbance is considered highly reversible. Water and nutrient supply are more stable transformations or even irreversible.

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