

A Multisource Approach to Verify a Forest as a Reference of Natural Conditions in an Intensively Used Rural Landscape (Uckermark, Ne Germany)

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Abstract

Background

The sharp decline in near-natural areas worldwide is undisputed, but the consequences of this decline, apart from the loss of biodiversity, cannot be fully assessed. Biotic components of a landscape are usually more easily assessed than the abiotic components, since biotic components are often more easily detectable. A forest of (semi)natural stocking was selected in the northeastern part of Brandenburg (northeast Germany) to check whether it can serve as reference site for near-natural conditions or not. Analyses of archival sources and historic maps as well as field investigations were combined to reconstruct the dynamics of vegetation and soil as far back in time as possible.

Results

Palynological data from nearby sites provide evidence that the investigated area has been forested for several thousands of years and has hardly been structurally influenced by humans in the last 450 years. This evidence together with historical maps of tree species composition allows us to infer that the specific forest has been very close to a natural state for at least 250 years. Soil investigations support this conclusion, since a soil inventory, field studies on two catenas and corings at selected depressions rarely show signs of anthropogenic erosion and related colluviation. Parts of the area were cleared in prehistory, but near-natural soils have been preserved in other parts.

Conclusions

The area with these undisturbed parts is regarded as an ideal reference site. With this study, we show that using a multi-source approach it is possible to find potential reference sites and that such an approach is applicable in other regions.

Background

With the ongoing growth of the world population, intensive land use in extensive areas has become a global phenomenon, and natural or near-natural terrestrial ecosystems are diminishing (Foley et al. 2005; Sabatini et al. 2020). Even in sparsely populated landscapes, evidence of past land use has been found, such as traces of Neolithic farmland in the boreal zone of Northern Europe (Alenius et al. 2013) or of 'field systems' in the Amazonian forests (McKey et al. 2010; Maezumi et al. 2018). Densely populated regions such as Central Europe seem to lack any near-natural sites (Moss et al. 2003). Even peripheral sites of this area, such as the famous Białowieża Primeval Forest in eastern Poland and western Belarussia, have demonstrated to be impacted by land use in the last two millennia (Jaroszewicz et al. 2019).

There are different approaches to obtain an idea of the natural or near-natural state of ecosystems as references for ecological/environmental change. Such approaches include the concept of the potential natural vegetation (e.g., Zerbe 1998), the reconstruction of past vegetation (e.g., Cogbill et al. 2002), creation of indices for biological/ecological integrity or naturalness (e.g., Machado 2004; Whittier et al. 2007), and detection of reference sites (e.g., Hughes et al. 1986; Clewell and Aronson 2013).

The potential natural vegetation (PNV) is defined as the hypothetical state of vegetation after human influence has ceased, assuming constant climatic conditions. PNV was presented in an overview map (scale 1:1,000,000) for Europe (Bohn et al. 2000) and with higher spatial resolution for numerous regions (e.g., the Netherlands by Stumpel and Kalkoven 1978; Bavarian Alps by Reger et al. 2014).

A similar, but not hypothetical approach is the reconstruction of vegetation before human intervention using historical and paleo-ecological sources (Birks & Birks 1980; Rackham 1989; Batek et al. 1999; Bickford and Mackey 2004; Cogbill et al. 2002; Jansen et al. 2009; Colombaroli et al. 2013; Mrotzek 2015). Such investigations provide information on pre-impact vegetation for the restoration of near-natural ecosystems (Bolliger et al. 2004; Pollock et al. 2012; Conedera et al. 2017).

Biological integrity is defined as the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of a region (Karr and Dudley, 1981). It is usually measured by key attributes, such as plant or animal species, but also by compositional, structural and functional indicators (Wurtzebach and Schultz 2016).

The reference concept has been developed in restoration ecology and aims at concrete representations of ecological references or reference sites, supported by quantitative models (e.g., Brudvig et al. 2014; Clewell & Aronson 2013; Pollock et al. 2012). There is no explicit definition for an ecological reference or a reference site, but rather general statements are made such as "ecosystems in self-organised condition" or "intact ecosystems". McDonald et al. (2016) provide a definition that very strongly focuses on concrete projects. According to this definition, "a reference ecosystem is a model characteristic of the particular ecosystem that informs the target of the restoration project" (McDonald et al. 2016, p. 11). In this study, we followed the PNV and the reference concept. Unlike McDonald et al. (2016) we further specify references as ecosystems or sites that have been proven to be subject to no or very little human interference or intervention (Nielsen et al. 2003).

We used a spatio-temporal top-down approach by focusing on long-term vegetation development (using palynology) and PNV (using published maps) on a large (regional) scale and then reconstructing land-cover development for the water catchment area in which the forest is located (sub-regional scale). On a local scale, we reconstructed the forest and stand development back to about 200 years using historical maps and a forest database as well as mapping of archaeological finds (back to several 1,000 years), and used palynological reconstructions from a nearby forest as a reference for the past 6000 years. In addition, we investigated soil catenas at selected sites of the targeted forest area. With this approach we want to show how reliable reference sites can be found with the help of independent sources and present an approach that can also be applied in other regions.

Material And Methods

Study area

The Kiecker forest (53°22'N, 13°36'E; Figs. 1, 2) has been a nature reserve since 1992, designated to protect near-natural deciduous tree vegetation with high biodiversity amidst an intensively used "agricultural steppe" (District Administration Uckermark 2017). It is not strictly protected (= IUCN category I and II) as partial cutting and salvage logging is allowed. The forest has a size of 261 ha. The main forest vegetation is composed of beech (*Fagus sylvatica* L.) covering approximately 60% of the forest area, followed by oak (*Quercus robur* L.) and birch (*Betula pendula* L.) with approximately 9 and 6% coverage, respectively, resulting in the main vegetation type of Melico-Fagetum according to Hofmann and Pommer (2005). The remaining area is covered by coniferous tree species (approximately 17%) and other tree species (approximately 8%). Additionally, some small water areas and mires with reed and sedge vegetation occur in glacial kettle holes.

The climate of the region can be classified as temperate humid. The study area is part of a transitional zone from subarctic to subcontinental climate conditions (Hendl 1994). The local weather station at Feldberg/Mecklenburg-

Vorpommern, approx. 10 km to the southwest of Kiecker, records a mean annual air temperature of 7.7 °C and a mean annual precipitation of 611 mm a⁻¹ in the measuring period 1961–1990 (<http://www.pik-potsdam.de>).

The terminal moraine of the Weichselian (i.e., last Glacial) Gerswalder Staffel forms the geological and geomorphological setting of the study area (Lippstreu et al. 1997). The relief is undulating with several pronounced hilltops, rather steep slopes and closed depressions, having an elevation range between 89 and 127 m a.s.l. The sediments on the surface mainly consist of sand-covered till, boulder layers and glaciofluvial sand. Peat locally occurs in depressions. The soil cover is dominated by Albic Luvisols and Arenosols/Cambisols supplemented by Stagnosols, Gleysols and Histosols, which is a soil pattern typical for morainic sites in the region (Sommer et al. 2008; Deumlich et al. 2010; Janetzko and Schmidt 2014). In contrast with the intensive agricultural land surrounding the forest (van der Meij et al. 2017; Kappler et al. 2018; van der Meij et al. 2019) and even with other forested sites in the region (Dieckmann and Kaiser 1998; Kaiser et al. 2002; Küster 2014; Calitri et al. 2020; Kaiser et al. 2020), only marginal traces of past soil erosion have been detected at Kiecker so far.

The Kiecker forest belongs to the catchment of the Quillow River, which originates in Lake Parmener See on the southwestern border of the study site. The Quillow catchment (approximately 16,094 ha) can be regarded as an original assemblage of undrained (sub) catchments, which were connected by artificial ditches probably no earlier than the 13th century AD, draining the catchment since then to the Ucker River (Enders 1992). In general, the study area represents a site that is very typical for the morainic landscape of the region.

Vegetation data from palynological records (regional and local scale)

Although a number of peat-filled depressions and thus potential sedimentary geo-bio-archives exist in Kiecker forest, a local pollen analysis has been discarded, as there was too much evidence for disturbance of the deposits. Most of the depressions were drained in the 19th/20th centuries, which led to the destruction of the uppermost decimetres of peat and thus of the pollen records for the last centuries. Instead, a diagram from a small kettle hole mire in the Conower Werder forest serves for information on local forest dynamics. Conower Werder forest is situated only 11 km southwest and very well comparable to Kiecker forest in terms of site conditions, current vegetation (Melico-Fagetum), and knowledge on land-use history. To use a pollen diagram from a different site bears the potential of misinterpreting the development in Kiecker forest. However, both the palynological data and the local land-use history, including nearby glass production in the 18th century, give no evidence for serious differences between these localities.

The palynological record from Lake Carwitzer See (Mrotzek 2017) provides the regional vegetation development. The record represents the vegetation in a radius of approximately 50 km (see Theuerkauf et al. 2013) and therefore covers Kiecker forest that lies 10 km northeast of Lake Carwitzer See. Pollen analysis was carried out on 18 peat samples from Conower Werder and 32 sediment samples from Lake Carwitzer See. Preparation (cf. Fægri and Iversen, 1989) of the pollen samples (0.25 ml volume) included addition of one Lycopodium tablet, treatment with 10% HCl, 20% KOH, sieving (120 µm), acetolysis (7 min), and HF digestion (three days in a shaker). Samples were mounted in silicone oil. Counting was carried out at 400-x magnification. Samples were counted up to a minimum pollen sum of 100, with some exceptions. Pollen identification and nomenclature followed Moore et al. (1991).

Regional vegetation was reconstructed from the Carwitzer See record by using the REVEALS model to obtain land cover percentages for the taxa (Sugita 2007; Theuerkauf et al. 2016; calculated with REVEALSinR function at disqover.botanik.uni-greifswald.de/revealsinr/, parameters: PPE, MV2015, distribution model LS). The local vegetation reconstruction from the Conower Werder pollen record was carried out with the MARCO POLO model to gain land cover

percentages for the taxa (Mrotzek et al. 2017; calculated with MARCO POLO R-function at disqover.botanik.uni-greifswald.de/marco-polo/, reference data: Carwitzer See record, r-values: from Mrotzek et al. 2017).

Land-cover data from maps (sub-regional scale)

For the Quillow catchment and surrounding area of the Kiecker forest land cover data were obtained from both historic maps (for the time phases 1767, 1826, 1890, 1957, 1985; for some details see Chap. 2.4) and a current topographical map (2010). The oldest reliable map was produced between 1767 and 1787 by the Count von Schmettau (Crom 2013). These map sheets are available in rectified form and provide much information about land use at that time (Wulf and Groß 2004; Herrigel and Groß 2014). The next most recent maps are the so-called Ordnance Survey Maps (or Measuring Table Sheets), which were produced between 1820 and 1872 (Krauss 1969). The subsequent map of the so-called Prussian Land Survey (1875 to 1912, Albrecht 2004). Both, the 1957 and 1985 maps are precise topographical maps of more modern time. All maps, provided by Landesvermessung und Geobasisinformation Brandenburg, comprise scales in range 1:50,000 to 1:25,000. After geo-referencing and digitalization of map contents, the data files were analyzed using the ArcGIS computer program.

Tree species composition reconstructed by maps and a forest database (local scale)

Some information on tree species can be obtained from the maps of about 1780, 1820 and 1880, but the information is not sufficient for a comprehensive representation. We have used the 2009 biotope type mapping of the State of Brandenburg, which is available on a scale of 1:10,000 (Zimmermann 2003 and 2007; LUGV 2013) for the most actual time. However, to obtain a clear representation of tree species at the local level as far back in time as possible, we used also the so-called Forest Data Store of the State of Brandenburg from 2013 (Redmann and Regenstein 2010); here the data store in its basic structure is presented. The data store is designed to automatically update basic data such as age and height of trees). We chose 120 years as a tree age limit to show the distribution of the main tree species around 1880/1890 over the largest possible area (approximately 50%). In order to get enough single trees over the whole forest area, we had to limit tree age to 120 years, because even older trees are rare and so scattered that it is not possible to draw conclusions about dominant tree species. Additionally, we chose 80 years as another tree age limit to produce a map for around 1930 to compare it with the forestry management map from 1937. This forestry management map gives the exact distribution of the main tree species down to the level of the subdivisions (smallest forestry unit, characterized by more or less uniformly structured trees of the same age). Another forest district map with the same resolution dates to 1 January 1979.

Information on archaeological finds (local scale)

Archaeological data, reflecting the prehistoric and historic settlement and potential land use of the study area, were obtained from the state archaeological survey (Untere Denkmalschutzbehörde 2016, unpublished data) and from the literature (Schulz 2009). The digital data were visualized and analyzed for a landscape window of 5 km x 5 km with the Kiecker forest in the center using the QGIS computer program. Attribution of archaeological finds follows both functional and cultural (i.e. chronological) features.

Soil data (local scale)

Soil data are available for Kiecker from an already existing soil map (from 2009; LFB 2017) and from numerous ($n > 70$) point data sources (corings and soil pits) originally aiming to obtain site information for forest management (LFB 2017). Furthermore, in the southern and central part of Kiecker, a soil survey was performed within this study to characterize the local soil cover and to use soil morphology as a proxy for potential past soil erosion following forest clearing and agriculture (Schulz 2017). Therefore, 32 soil profiles were recorded, including the preparation of two soil

catenas, which each consist of three profiles along a slope. These two catenas were investigated in order to characterize local toposequences in detail. The site selection is based on the available soil mapping data, the relief structure and the presence of old tree stands. Furthermore, we paid particular attention to depressions and footslopes, screening these sites for colluvial deposits by means of auger corings (n = 20).

Soil research in this area is based on the German classification standards "KA5" and "SEA95" (Schulze 1996; Ad hoc-AG Boden 2005). Classification of soil types follows the international IUSS Working Group WRB (2015) standard.

From six profiles and a total of 33 samples, soil analyses were performed on the matrix < 2 mm (Supplement 1) to assist in the designation of sedimentary facies and soil horizons. For grain size analysis, samples were air dried and hand-crushed. If present, organic matter and carbonate were removed using 30% H₂O₂ and 10% HCl, respectively. Grain-size distribution was estimated in a laser particle size analyzer using laser diffraction spectroscopy (HORIBA LA-950). CaCO₃ was estimated as total inorganic carbon (TIC). It was calculated as total carbon minus total organic carbon (TOC), which was measured by elemental carbon analysis (Vario EL elemental analyzer). Soil pH was analyzed potentiometrically in 0.01 M CaCl₂ (soil:solution ratio = 1:5).

Results

Palynological records (regional and local scale)

The regional vegetation (Fig. 3) was dominated by forests for the past 6000 years until around 450 years ago. Early (mid-Holocene) forests consisted of lime (*Tilia*), ash (*Fraxinus excelsior* L.), oak (*Quercus*) and pine (*Pinus*). Since the understory shrub hazel (*Corylus avellana* L.) shows stable proportions, at least part of the forests must have formed relatively open stands. Beech (*Fagus*) started to invade the region around 4000 cal. BP and was the dominant vegetation covering up to 40% of the landscape after 2200 cal. BP. Since this time, hornbeam has also been present at 5–10%. Pine and oak maintained a presence at 5–10% as well, whereas all other tree species occurred only sparsely (Fig. 3).

Around 6000 cal. BP, open land vegetation covered 10% of the region consisting of some herbs and mainly wild grasses (Poaceae) that are associated with natural open vegetation, such as reeds (*Phragmites*) growing on lake shores and peatlands. Only after 5500 cal. BP, human activity is evidenced by anthropogenic indicator herb taxa (*Plantago lanceolata* L., Cerealia) supported by the increase in grass proportions. Starting with low intensity in the Neolithic, human impact became stronger from around 3600 cal. BP onwards with Bronze Age settlement activities (Schoknecht 1997). After 2200 cal. BP, forest cover increased until it reached pre-settlement values around 1000 cal. BP. Then, open land expanded again due to Slavic settlement and German colonization. Since 400 cal. BP, open land cover reached its highest values of more than 50% with a high proportion of arable fields indicated by cereal pollen. Pine became a dominant forest component either as a pioneer tree on devastated land or later as a tree planted by forestry. The cover of deciduous trees (including beech) has dramatically declined.

(A) of the Carwitzer See (regional scale) and (B) the Conower Werder (local scale).

The local forest development of Conower Werder follows the general regional succession. From 5800 cal. BP onwards, lime dominated the forest stand with ash, oak and hazel as further components. The shift to beech dominance of more than 95% started relatively late at only around 2400 cal. BP but took place quickly and dramatically. There is low human impact indicated by herbs and grasses. Only in the period between 1300 and 400 cal. BP (650–1550 CE), the share of herbs and hazel reaches up to 30% what hints to open conditions in a normally light-limited beech stand.

Land-cover changes in the Quillow catchment (sub-regional scale)

The analysis of land-use data obtained from cartographic sources shows a marked increase in arable land in the Quillow catchment from 55% in 1767, to 68% in 1826, and to 79% in 1985. However, the Kiecker forest has remained constant in its present shape. In the same period, the forest cover decreased in the catchment from 25–10% (Table 1). Transformation into arable land particularly took place in the western part of the catchment, where a forest area intermingling with grassland was cleared at the end of the 18th and over the course of the 19th century (Fig. 4). At the same time, the number of small settlements (usually outlying estates) and of industrial and domestic infrastructures (e.g., glassworks, tarn and charcoal kilns, roads, mills, melioration ditches) increased (Schneider 2014). As is clear from historical research, the clearings were transformed into agricultural land as part of the regional recultivation after the Thirty Years' War in the first half of the 17th century (Enders 1992; Bayerl et al. 2008).

Before the 18th century, historical and archaeological data, as well as, to a certain extent, palaeobotanical data (see Sect. 3.1), allow only generalized considerations about regional land-cover dynamics. Very sparsely populated during the final Paleolithic and Mesolithic (Terberger et al. 2004; 2015), the region underwent complex cultural landscape dynamics since the early Neolithic, with the first agriculture in the eastern part of the catchment around 7000 years ago (Kulczycka-Leciejewiczowa and Wetzel 2002). All subsequent prehistoric periods are proven in the whole catchment by archaeological records (Schulz 2009), indicating agricultural economies in that time. Depending on the respective subsistence strategy and the population number, the share of forest, grassland and arable land has changed over the millennia. In the late 12th and 13th centuries, the German colonization of that area took place, drastically increasing the population and the land required for agriculture and thereby widely deforesting the Uckermark region, including the Quillow catchment (Enders 1992; Kirsch 2004; Schulz 2009). Several phases of severe economic decline (e.g., late medieval agrarian crises including the Plague and the Thirty Years' War) and recovery followed, always accompanied by land cover changes. Forest pasturing, hunting, beekeeping and keeping the forest as a potential resource for wood might have at least indirectly influenced the vegetation dynamics in the Kiecker as well. Currently, nearly the whole Quillow catchment is dominated by intensive industrial agriculture, which is characterized by high crop yields contrasted with serious environmental threats (e.g., eutrophication, contamination of groundwater, soil erosion, loss of biodiversity; Lischeid et al. 2018).

Data on the main tree species around 1780, 1890 and 2010 for the entire Uckermark are already published (Wulf et al. 2017). For comparison, these data together with data for the Quillow catchment area and the Kiecker forest are shown in Table 2.

Tree species composition (local scale)

Since the Kiecker is a remnant of the formerly much larger Fürstenwerdersche Heide forest, a brief overview of the changes in forest cover is given first. The border of the Fürstenwerdersche Heide cannot be identified on the oldest map from about 1780. The border was determined with the help of manor and district boundaries, as well as research results on the settlement history and descriptions of the forest area (Stockmann 2015). The land cover change was presented on a precise scale (1:50,000) in three time intervals (Stockmann 2015) and illustrates the dramatic decline of the former forest area (Fig. 5). Table 3 shows that only approximately one-third of the original forest area has been preserved, while arable fields prevail with two-thirds of the area and grasslands cover approximately 15% of the former forest area.

(A) from 1780 to 1820, (B) from 1820 to 1880 and (C) from 1880 to 2010.

To illustrate the changes between 1780 and 2010 in a clearly perceptible manner, only the changes in forest cover compared to other land use (including arable fields, grasslands, water bodies and settlements) from 1780 to 1820, from 1820 to 1880 and from 1880 to 2010 are shown above (Fig. 5).

All data in Table 4 refer to the actual total area of 261 hectares for comparability. Since for 1890 and 1930 only trees over 120 and 80 years of age were taken into account, approximately 45% and 67% of the total area is covered by the Forest Data Store (FDS). However, it becomes clear that beech has been the dominant tree species for at least 130 years. With the information on beech wood-demanding glassworks around 1750–1800 (Wendt 1968; Friese and Friese 1992), we can extend the period back 100–150 years, totalling 230 to 280 years. The FDS data for 1930 cover only approximately one-third of the area, so that comparability with the 1937 map is limited. Basically, the values of the FDS remain below those of the map, but the relations among the tree species are very similar, with the exception of the three coniferous species (Table 4).

A close look at the current Kiecker forest shows that the majority of the forest area is an ancient deciduous forest dominated by beech, while other main tree species are limited to comparatively small areas, except in the northernmost part of the forest (Fig. 6).

Archaeological finds (local scale)

In addition to a few Mesolithic and Neolithic finds and settlements/burials, a rather large number of settlements and burial mounds from the Bronze Age have been recorded inside and immediately outside of Kiecker (Fig. 7).

Remarkably, such burial mounds ($n = 25$) occur in all parts of Kiecker, certainly indicating local forest clearing and probably agricultural land use during the Bronze Age. Even in subsequent prehistoric periods (Pre-Roman Iron Age/Roman Age), the surroundings of Kiecker, at a minimum, were settled and used for agriculture and metallurgy.

The first mentions of the adjacent villages of Parmen (1302 AD), Weggun (1331 AD) and Raakow (1373 AD) in the 14th century AD (Enders 2012) indicate late medieval colonization, agriculture and further land use of the immediate surroundings of Kiecker. All the village names have a Slavic word stem, referring to an already earlier, i.e., at least late Slavic (10th-13th centuries) settlement period, which has been proven even for the wider surroundings (Kirsch 2004). Thus, surrounded by agricultural land and villages, Kiecker was surely impacted by human activities in the last millennium to a certain extent.

Soil catenas (local scale)

Both investigated sandy slope catenas primarily consist of glacial diamictons (till) overlaid by loamy-silty cover sands (German: 'Geschiebedecksand', Helbig 1999; 'Kryosand', Ad hoc-AG Boden 2005), which are locally underlain by glaciofluvial sand (Supplement 1, Figs. 8 and 9). This sediment association, together with the strongly undulating relief, is typical for terminal moraine sites in the region. Dry, natural soil formation of such sites tends toward silicate weathering/brunification forming Arenosols/Cambisols and toward clay illuviation forming Albic Luvisols. Even combined pedogenic processes at the same site occur. The vegetation of both slopes consists of old-growth beech forest, including some ca. 150- to 200-year-old tree individuals.

Catena 1, with a length of 70 m and a relative height of 13 m, shows on the lower slope a soil profile (KIE-2) with a complete appearance of the expected soil horizons and related thicknesses (Albic Luvisol; Figs. 2F, 8, 9A). In contrast, both the top and the depression positions show clear modifications of the anticipated soil morphology. A Stagnic Luvisol is formed on the top, whose potentially occurring upper horizons (Bv, Al) are widely lacking (Figs. 2E, 8). The decalcification depth of only 70 cm is considerable compared to the ca. 100–120 cm depth found in other dry-site Luvisols in the region (Kühn et al. 2015; van der Meij et al. 2017). Both observations indicate a reduction of the profile depth by erosion of ca. 30–50 cm. In the depression, a ca. 30 cm-thick layer of silty colluvial sand covers a buried soil (Colluvic Stagnosol; Figs. 2G, 9A), indicating past input of eroded sand from the slope section above.

Catena 2, with a length of 90 m and a relative height of 15 m, generally shows similar soil profiles (Luvisols, Arenosols/Cambisols; Figs. 8, 9B) but lacks morphological signs of soil erosion or aggradation as described for catena 1.

From a soil analytical perspective, the contents of organic carbon in the 10 to 20 cm-thick humic topsoil horizons (Ah) are in part rather high (up to 8%; Supplement 1), referring to a long-lasting period of organic matter enrichment by continuous forest vegetation. Correspondingly, the pH values are very low (pH 3.3–3.6), which indicates strongly acidic soil conditions caused by the long-term turnover of organic substances.

Auger corings in several depressions and at footslopes around the catenas show that only a minority of 2 of a total of 20 corings show thin sandy colluvial layers (below 10 cm each). Furthermore, small charcoal pieces in the colluvial sands indicate past wood burning.

Discussion

Long-term presence of beech forests – palynological, archaeological, historical and present-day vegetation evidence

The postglacial vegetation development of the nearer surroundings of the Kiecker forest, derived from the pollen record of lake Carwitzer See, corresponds very well with other records in the region (Müller 1967, Jahns 2011, Strahl 2005). Beech started to invade forests that were composed of lime, oak, ash, elm, hazel and pine since 4000 years ago. It dominated the forests since more than 2000 years. The dominance of beech is proven for the Conower Werder already around 2400 cal. BP and lasts until today (Fig. 3). Almost pure beech forests therefore represent the natural vegetation at Conower Werder. Due to the similar site conditions and history of both forests, they most likely have been present for a long time at Kiecker forest as well.

A further hint to the long-term presence of beech is the presence of glassworks in the 18th century which is known from archaeological and written sources for Kiecker forest and Conower Werder. (see overview of former glassworks in Schneider et al. 2019). As a rule, much of beech wood was needed to operate the glassworks, therefore to conclude beech occurrences from glassworks is obvious and has been proven by various studies for the northern eastern Germany (Friese and Friese 1992, Endtmann 1998, Enders 2012).

The rather high percentage of preserved old beech trees in the Kiecker area and the palynological evidence of a low human influence during the last 450 years at Conower Werder (Fig. 3) underline the fact, proven by historical maps that this is an ancient forest (Hermy et al. 1999). Kiecker Forest is not a single case. There are many similarities with the 'Grumsiner Forst' located about 50 km southeast of the Kiecker Forest, which has been in existence continuously for at least 400 years, is also dominated by beech, and probably originated largely from natural regeneration (Pagel 1970, Luthard et al. 2004). A further example is the 'Heilige Hallen' forest reserve, located about 15 km southwest of Kiecker.

Here, beech regenerated in the late 18th century after cessation of forest use by wood extraction and pasturing (Mrotzek 2014).

In the wider region, however, drastic former land cover changes in near-natural areas, even in ancient forests, can be detected repeatedly. For instance, the UNESCO World Heritage Site 'Serrahn' with its ancient beech forest, part of the Müritznational Park lying 25 km to the west of Kiecker, has been used for arable farming in the past. A study of sediments and soils from Serrahn revealed periods of intense land use resulting in soil erosion, particularly during the medieval period around 1000 to 500 years ago (Dieckmann and Kaiser 1998; Küster 2014; Kaiser et al. 2020). During these periods, pollen data clearly indicate that beech went locally extinct but recovered after abandonment of the area (Theuerkauf 2015).

Forest continuity derived from archival sources and maps

The map of 1890 (Fig. 6) shows the dominance of beech stands some 80 years after the concession for a glassworks was granted. The period is probably too short to presume that another tree species was dominant in the meantime, since it takes several decades for such a stand structure to emerge. Additionally, the following forest maps from 1937 and 1979 show large parts of the Kiecker forest dominated by beech (Geiges-Erzgräber 2016). The results fit seamlessly into the results of the nearby pollen analyses (Fig. 3) and support the fact that a near-natural beech stand has survived here for centuries. Evidence for this assumption can be found in Enders (2012), where it is mentioned for 1751 that the former owner Count von Schwerin sold large parts of the forest to the Mecklenburg Lord Steward von Wenderin for his glassworks. Elsewhere in Enders (2012), the reference is given that the Count of Schwerin received a concession to build a glassworks in his forest district in 1810. For this purpose, a file in the main archive of the State of Brandenburg (Brandenburgisches Landeshauptarchiv = BLHA) documents for the whole Fürstenwerdersche Heide forest beeches and oaks on the higher parts and birches and alders (*Alnus glutinosa* (L.) Gaertn.) in the lower parts (BLHA, Signature 2A I HG 692). Beech was most likely the dominant tree species because the glassworks of the region mainly used beech and softwoods (Parchmann 1921; Voß 1993). Due to the general high demand for wood, only oak stands were spared at that time, while vigorous beech trees were cleared (von Oeynhausen 1905; Friese and Friese 1992). Beech was used as fuel for the glassworks because it has a high calorific value, develops many embers and thereby generates an even, long-lasting useful heat and tolerates the ash-rich sand admixture for glass production (von Oeynhausen 1905).

However, the high number of Bronze Age burial mounds and other archaeological evidence shows (Fig. 7) that at least some parts of the Kiecker forest have been cleared or drastically thinned out during prehistory. This finding applies likewise for the medieval and early modern period, when nearby villages at only 1 to 2 km distance (Parmen, Raakow, Weggun) may have used Kiecker, for instance, for timber and firewood harvesting, as well as forest pasture. The remaining forest could have been woodland with older individual trees, many shrubs and a grass-rich ground cover. After cessation of this extensive use, dense tree vegetation recovered, resulting in the present-day beech-dominated forest.

Soils and sediments as proxies for past land-use dynamics

In general, pedological research in the Quillow River catchment has shown that this area is heavily impacted by past and present soil erosion (Sommer et al. 2008; van der Meij et al. 2017; Heinrich et al. 2018; van der Meij et al. 2019). The oldest colluvial deposits date back to the Late Bronze Age. Most datings, however, cluster within the last 600 years with a peak in the last 200 years, ascribing the main phase of soil erosion to the recent past (Kappler et al. 2018). However, for the Kiecker forest, both the areal soil inventory for forest management (LFB 2017) and our local survey at catenas 1 and 2, as well as the auger corings at selected depressions, reveal a widely near-natural status of the soil

cover. This finding means that the near-natural soils typical of this landscape (mostly Albic Luvisols and Arenosols/Cambisols at dry sites and Stagnosols and Gleysols/Histosols at wet sites; Sommer et al. 2008; Janetzko and Schmidt 2014; Felix-Henningsen 2017; Kaiser et al. 2020) are widely preserved, rarely showing signs of human-induced erosion and related aggradation. Thus, a spatially complete clearance of this site with very drastic change in the land cover, in the extreme case a transformation into arable land, can be excluded for the past. From this perspective, Kiecker forest is very suitable as a reference site because it reflects the natural site conditions of a morainic landscape typical for this region. In terms of hemeroby (i.e., 'naturalness'; Hill et al. 2002; Kowarik 2006), the soil cover of Kiecker reflects an oligo- to meso-hemerobic state (Lorz and Opp 2000; Hornschuch and Riek 2009a and b).

Critical reflection on sources and methods

With a research question as local as this one, the most critical aspect is the spatially explicit allocation of the data and information used. This aspect applies to the evaluation of the palynological analyses and to the written and graphic archival sources for vegetation development. Palynological analyses depend on the existence of suitable archives (e.g., mire, lake, soil). If there is any archive available, it should be (i) close to the site of interest, (ii) as small as possible, and (iii) preferably untouched by drainage/desiccation. Point (i) can be complicated, as the position of existing archives might not be ideal or the localization of an undisturbed area might require an analysis of several sites that is not feasible. In such cases, the gaps can be filled with other methods. The point (ii) requirement might limit the precision of the analyses, as, e.g., the deposits of a small basin of only ~ 30 m diameter mainly reflect the vegetation in a radius of up to several hundred meters. Smaller basins would be more precise but are very rare, and larger basins lack the needed spatial precision. In general, basic requirement for a meaningful use of the pollen archive is an undisturbed record (point iii), i.e. the exclusion of potentially pollen-destroying drainage. Due to anthropogenic drainage, the most recent and, in this case, most interesting deposits are particularly affected. In the case of the Kiecker most of the small glacial kettle holes were drained by ditches in the 19th/20th centuries, as is often the case elsewhere in the region (Couwenberg et al. 2001; Kaiser et al. 2012).

There is no question that our study area is potentially dominated by beech forests (Bohn et al. 2000; Hofmann and Pommer 2005; Krausch 2008; Leuschner and Ellenberg 2017), so it remains to be examined to what extent back in time this vegetation type can be proven. In our case, the oldest historical evidence for beech occurrence in recent times is the reference to glassworks, which consumed high quantities of calorific fire wood, particularly beech. We estimate extensive stocks for profitable processing. In general, local glassworks were operated for 12 years and consumed approximately 2000 to 3000 solid cubic meters of wood per year (equivalent to 3000 to 5000 cubic meters of stacked wood), which means 20 to 30 ha of forest area per year (Wendt 1968). Even with only 10 years of glassworks operation time, 200 to 300 ha of forest area must have been present in total for exploitation. Apart from the location of the glassworks (on the original Ordnance Survey Map from 1826 the "Kleiner und Großer Glasort" shown on the northwestern edge of Lake Parmener See near the village Parmen, Fig. 1C), the spatial extent of the beech forests remains uncertain.

The second-oldest evidence is provided by regional historical maps, which often give relatively rough spatial information, but together with forest inventory maps, provide reliable results. In addition, there is the FDS, which allows a retrospective view of approximately 50% of the area back to around 1890. This source is especially reliable because the data are based on former field visits in the 1970s. The updating of the data has been automatically performed for several years now. Therefore, a current on-site check is advisable, as very old trees may no longer be present.

The traces of local soil erosion and related colluviation detected in catena 1 (Figs. 2E, 2G, 8, 9A) and in two of the 20 auger drillings might have been caused by human impact, as mentioned above. However, even natural forest dynamics

are capable of forming ultralocally eroded soil profiles and colluvial sediments. As both regional (von Oheimb et al. 2007) and supra-regional (Samonil et al. 2014) research has proven, windthrow/uprooting has to be considered as an important geomorphic-pedogenic factor in ancient/old growth forests. We also take it into account for Kiecker forest. Finally, direct (modern) human influence on the relief and soils at Kiecker is locally detectable, particularly in the form of ditches used for the drainage of kettle holes, colluvial fans poured from the surrounding fields and forest road construction.

Conclusions

Reference sites or terrestrial sites that are largely unaffected by humans are non-renewable natural resources that must be maintained (Sabatini et al. 2020). Reference sites are necessary in order to carry out impact assessments of anthropogenic interventions as comprehensively as possible and are therefore an indispensable basis for the concretization of sustainable land use. Without sustainable land use, the basis for human survival is questionable, which is reflected in the formulation of soil protection laws and the UN sustainability goals. The search for reference sites is thus not a purely scientific end in itself but makes an important contribution to land use that ensures the preservation of the basis of life (Sabatini et al. 2020).

Our study proves the successful search for reference locations with the help of different independent sources or research approaches and the presentation of complex data/information acquisition in a clear scheme. We found direct and indirect evidence for the long-term continuity of the Kiecker forest and its near-natural tree species composition and soil development. Direct evidence in this study includes maps of different ages together with the forest inventory data showing spatially explicit tree species cover data. Indirect evidence includes the rare archaeological finds in the forest area that indicate former settlement. We also assume that such an obvious phenomenon cannot be explained by gaps in research, especially since several finds have been found in the greater vicinity. Thus, we could show that it is possible to find reference sites. However, the proof requires a significant expenditure of time and staff with different expertise (Table 5), and for the clarification of local facts often the inclusion of unpublished or so-called grey literature published facts, which then receive a special importance.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and material

The datasets generated and/or analysed during this study are not publicly available due to restrictions on the publication of digital geodata by the 'Landesvermessung und Geobasisinformation Brandenburg' (license is available at ZALF) but are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contribution

All authors listed have materially participated in the research presented in this manuscript. MW, AM and KK have made a substantial, direct and intellectual contribution to the work, while MW led the writing of this article, with KK and AM co-writing sections of the paper. All authors have approved the final manuscript.

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Tables

Table 1

Land cover in the Quillow river catchment from 1767 to 2010. The changing in the total land cover generally depends on the precision of the map source.

	1767		1826*		1890		1957		1985		2010	
	ha	%										
Arable field	8,757	55	9,897	68	12,286	76	12,455	77	12,683	79	11,594	72
Forest	3,907	25	2,054	14	1,343	8	1,529	9	1,568	10	1,707	11
Grassland	1,405	9	696	5	527	3	969	6	611	4	1,355	8
Wet/ Peatland	1,050	7	1,281	9	1,225	8	391	2	349	2	436	3
Others	770	5	545	4	713	4	751	5	883	5	1,002	6
Total	15,889	100	14,473	100	16,094	100	16,095	100	16,094	100	16,094	100

*For 1826 the value of total land cover is lower because of missing data in the north-western part of the region.

Table 2

Main tree species distribution of the past and at present in the Uckermark (UM), Quillow catchment and Kiecker (empty cells = no data).

	1780			1890			2010		
	UM [%]	Quillow [%]	Kiecker [%]	UM [%]	Quillow [%]	Kiecker [%]	UM [%]	Quillow [%]	Kiecker [%]
Deciduous forests	12.4	10.0		3.4	3.2	41.4	6.9	3.8	80.4
Alder/birch	0.8	0.1		0.3	0	1.6	2.3	1.1	10.9
Pure beech	2.6	0		0.3	0.3	35.2	3.1	1.9	60.1
Beech/oak	7.8	8.3		2.4	2.5		0.1	0.1	
Pure oak	1.2	1.6		0.4	0.4	4.6	1.4	0.7	9.4
Mixed forests	1.4	0		3.8	1.6		0.8	0.1	
Pine/beech	0.1	0		0.5	0		0.6	0.1	
Pine/oak	1.3	0		3.3	1.6		0.2	<0.1	
Coniferous forests	8.8	3.0		14.4	2.4	3.7	14.4	2.6	13.0
Pure Pine	8.8	3.0		14.4	2.4	2.1	14.4	2.6	6.4
Non-forest and other areas	77.4	73.4		78.4	92.8	54.9	77.9	93.5	6.6

Table 3
Change of land cover on the former area of the Fürstenwerdersche Heide forest.

Land cover	1780 [ha]	%	1820 [ha]	%	1880 [ha]	%	2010 [ha]	%
Forest	1187.2	90.1	648.8	49.2	399.7	30.3	409.9	31.1
Arable field	10.1	0.8	529.0	40.1	816.8	62.0	607.8	46.1
Grassland	117.9	8.9	116.8	8.9	48.7	3.7	199.1	15.1
Others	2.4	0.2	23.0	1.8	52.4	4.0	100.8	7.7
Total	1317.6	100	1317.6	100	1317.6	100	1317.6	100

Table 4
Main tree species in the Kiecker forest in about 1890, 1930, 1937 and 2010.

	ca.	1890	ca.	1930	ca.	1937	ca.	2010
Tree species	ha	%	ha	%	ha	%	ha	%
Deciduous								
Beech	91.9	35.2	110.2	42.2	136.8	52.4	156.9	60.1
Oak	11.9	4.6	24.6	9.4	35.0	13.4	24.4	9.4
Birch	3.8	1.5	7.6	2.9	11.4	4.4	9.8	6.4
Ash	0.2	0.1	2.6	1.0	3.3	1.3	6.5	2.5
Hornbeam	0.04	0.02	0.04	0.02	2.9	1.1	0.04	0.01
Alder	no data		1.1	0.4	8.2	3.1	5.3	2.0
Coniferous								
Pine	5.6	2.1	11.8	4.5	22.7	8.7	16.7	6.4
Spruce	3.1	1.4	6.1	2.3	23.1	8.8	9.2	3.5
Larch	0.5	0.2	3.7	1.4	no data		8.0	3.1
Others	no data		6.4	2.4	no data		10.3	3.9
No data	143.4	54.9	87.0	33.3	no data		13.8**)	5.3
Total	117.64	45.1	174.03	66.7	243.4*)	93.3	261	100

Table 5 Overview of data sources, their information and accuracy as well as accessibilities and time investment as experienced from our studies in northeastern Germany.

Looking back	Sources	Information	Accuracy	Accessibilities	Time investment
up to 150 yrs	Forest inventory data	Tree stands, areal extend	High; detailed data for whole forest area, more detailed for subsections	Moderate; data only available for scientists and via official request	Weeks for provision of data, only days for data processing
up to 350 yrs	Historical maps	Areal extend	High to low: mostly whole forest area, older maps may lack accuracy and resolution	Easy; reprints mostly available via public platforms of national institutions	Days to weeks for research, provision of reprints, digitisation of maps
up to 800 yrs	Archive documents (e.g. place names, title deeds, glass production)	Scattered information on diverse matters (plants, management, property)	(Rarely) high to low: sometimes vague descriptions, localization may be critical	Easy to moderate; needs research in internet, libraries and public archive	A few days to weeks
up to 8000 yrs and more	Archaeological finds	Historic and prehistoric land use	depends on the intensity of exploration, mostly exact locations	Moderate; data on request from monument protection authorities	Weeks
	Palynological records	Vegetation development, land use	depends on availability of archives (the closer the better) and their spatial resolution	Difficult; availability of archives, expertise for sampling and time-consuming analyses	Weeks to month
	Soils and sediments	Soil development, land use activities	exact location of single small spots, spatially extended by multiple spot	Difficult; requires at least two experts for time-consuming field	Weeks
			Investigation (e.g. catena, grid)	work, laboratory analyses	

Figures

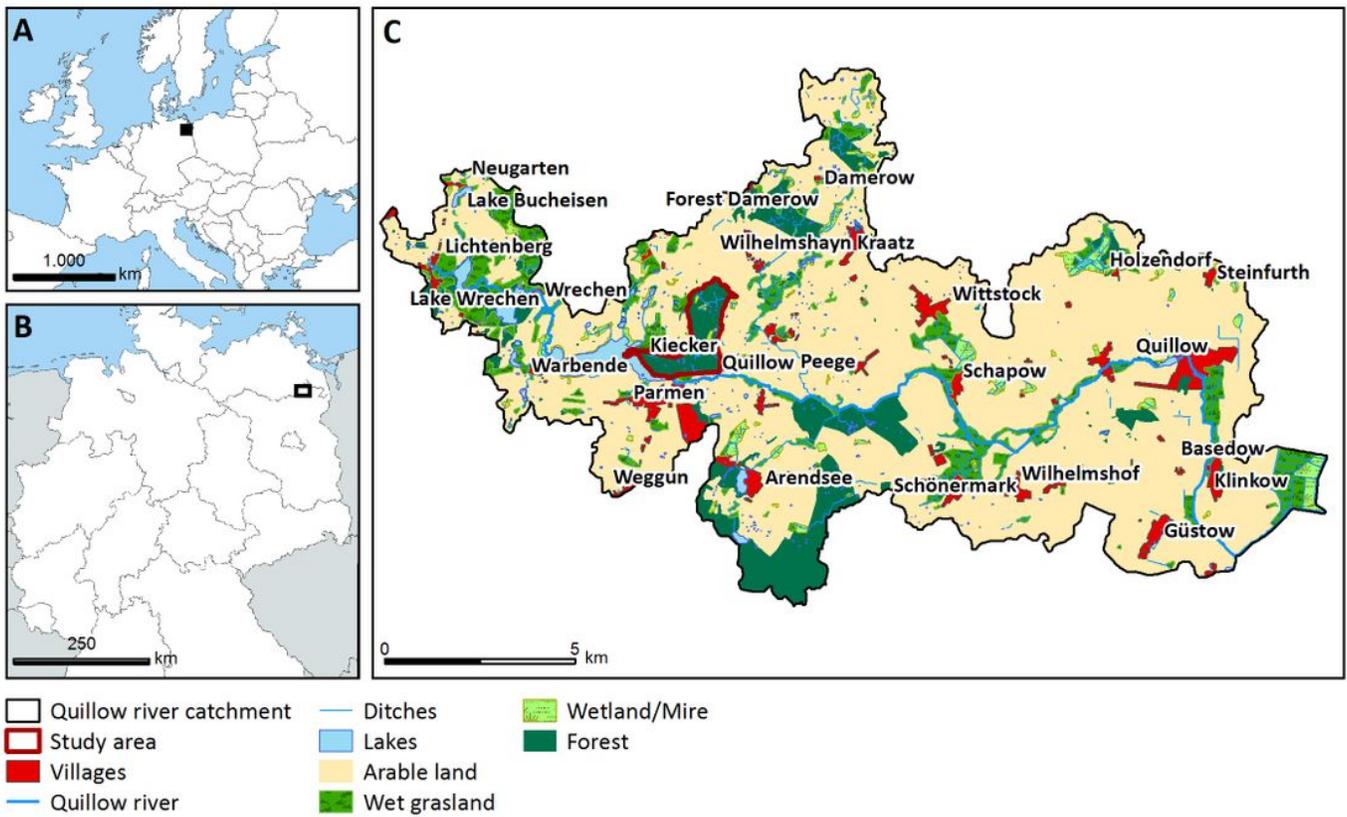


Figure 1

Location of study area. (A) location in northeast Germany, (B) location in northeast Brandenburg and (C) shown in detail (Kiecker forest red bordered), within the Quillow catchment. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

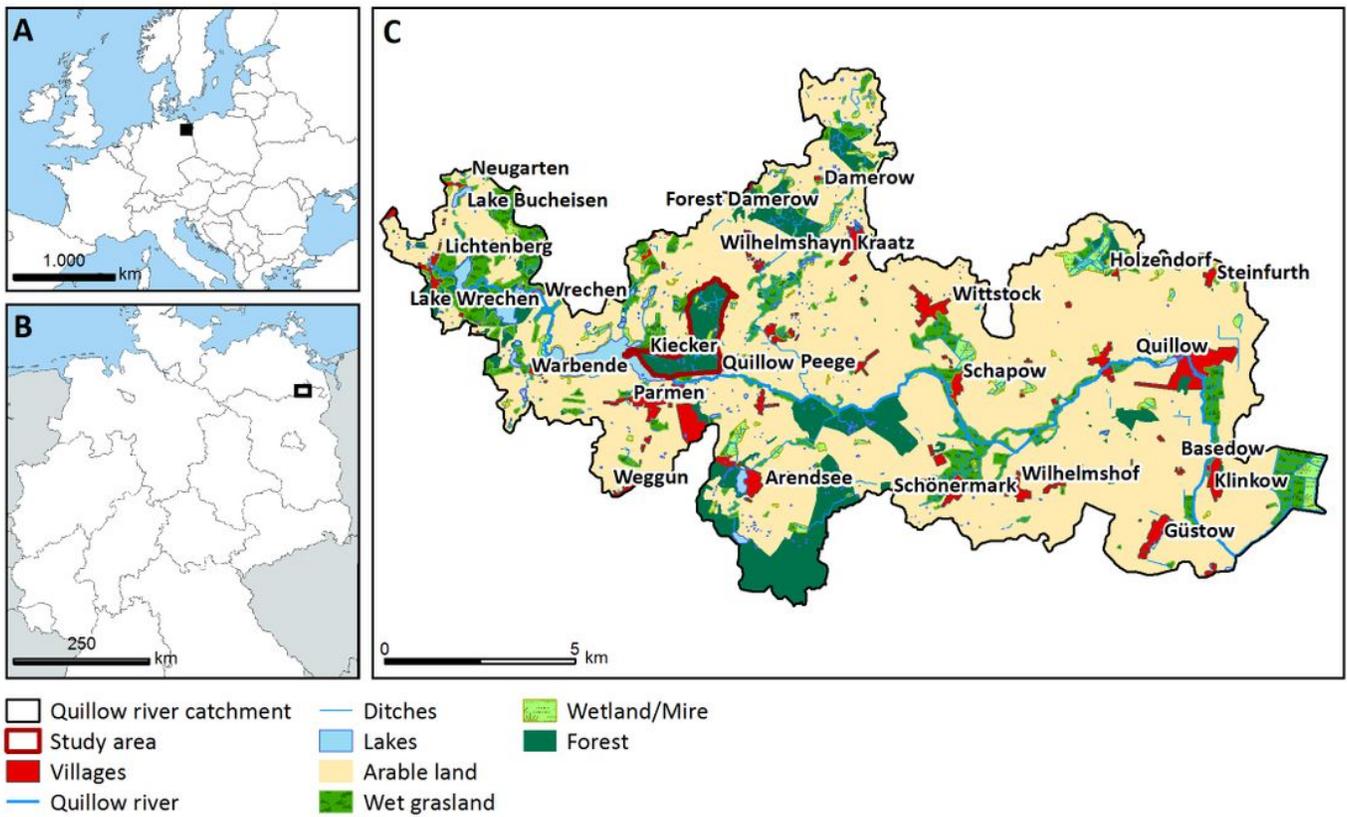


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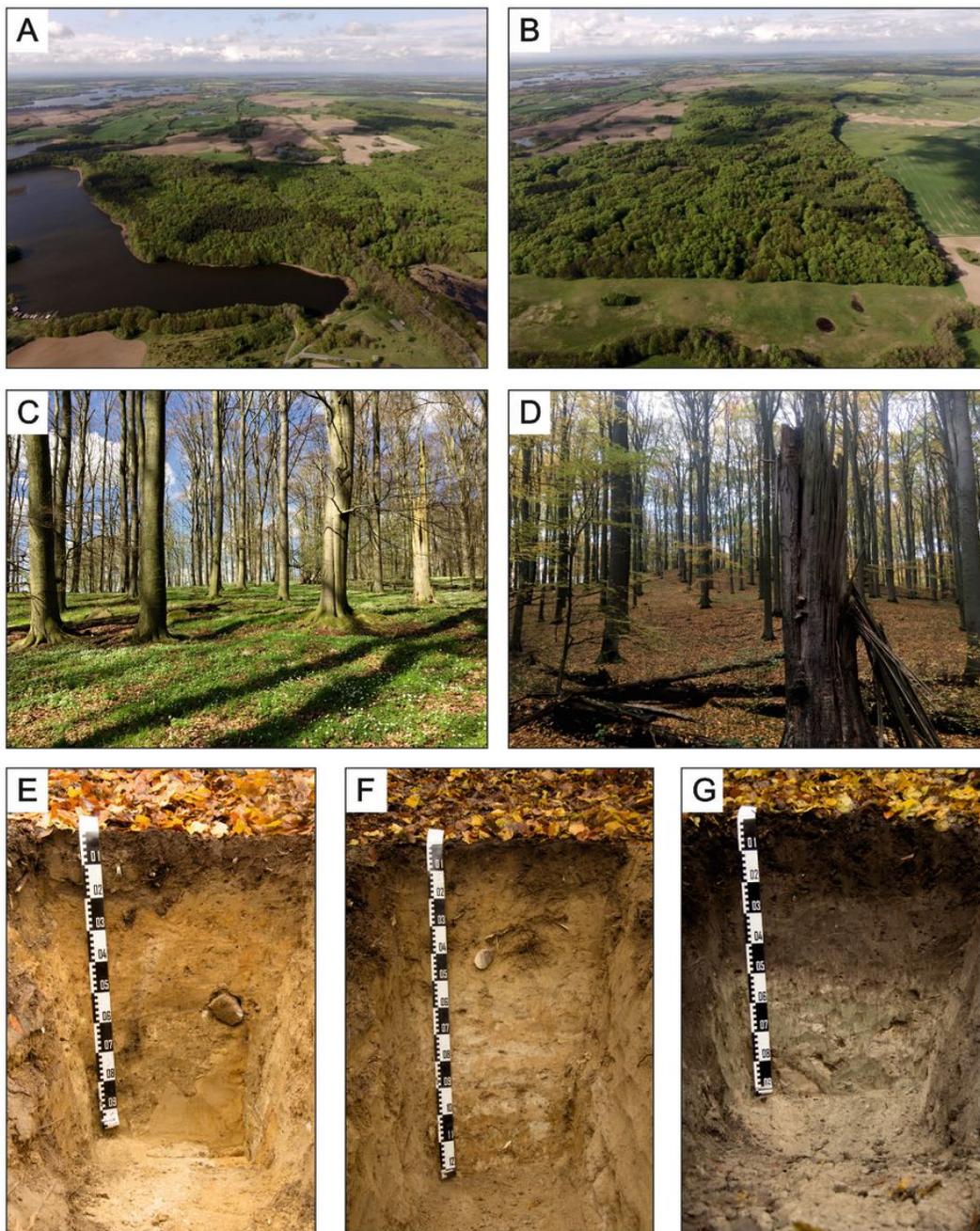


Figure 2

Photos from the study area. (A) Aerial photo from the southern part, (B) from the part extending from south to the north, (C) spring time in a typical beech forest, (D) autumn time in a typical beech forest, (E) profile of a Stagnic Luvisol, (F) profile of an Albic Luvisol and (G) profile of a Colluvic Stagnosol.

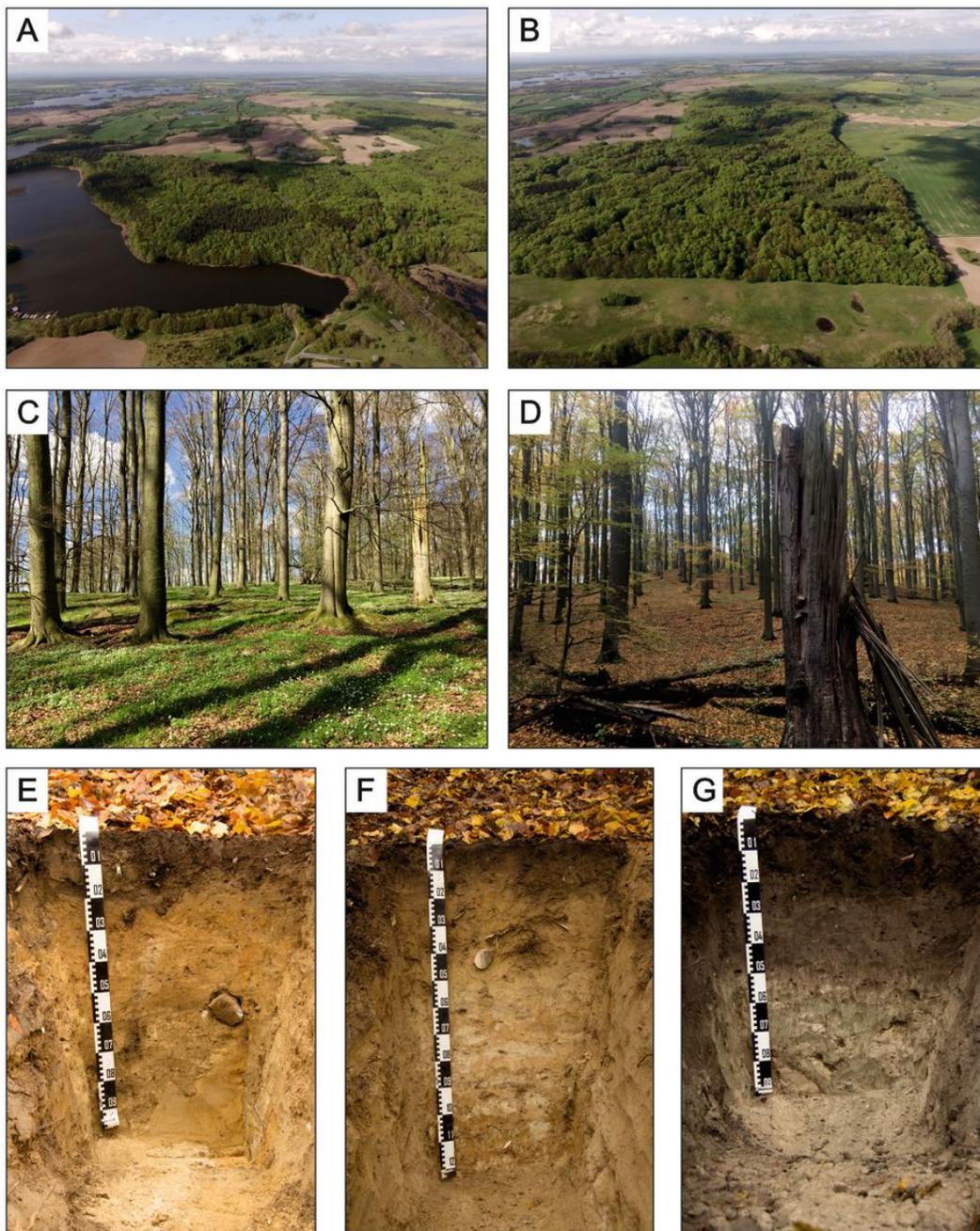


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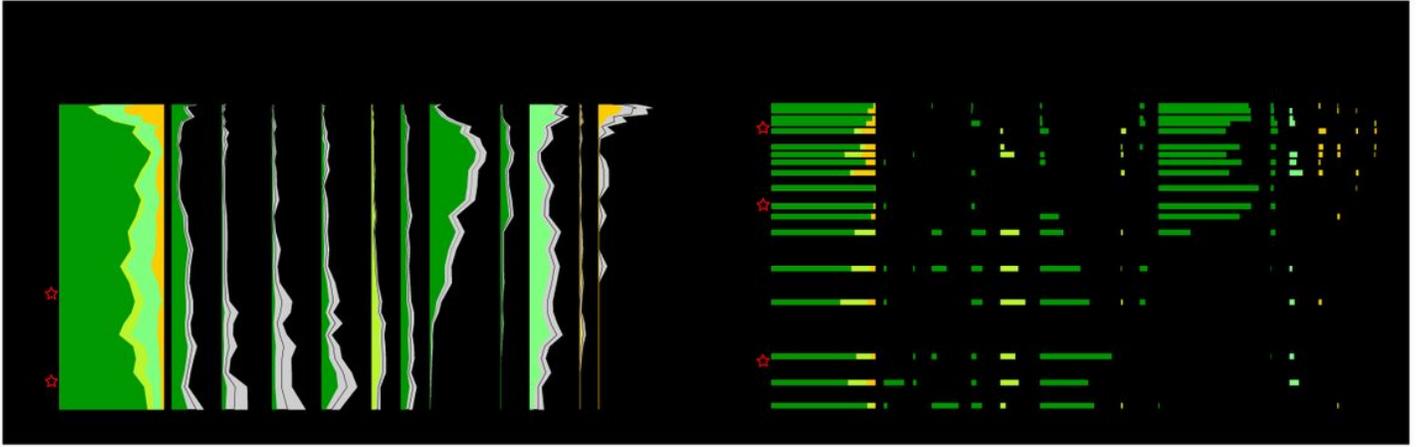


Figure 3

Palynological records. (A) of the Carwitzer See (regional scale) and (B) the Conower Werder (local scale).

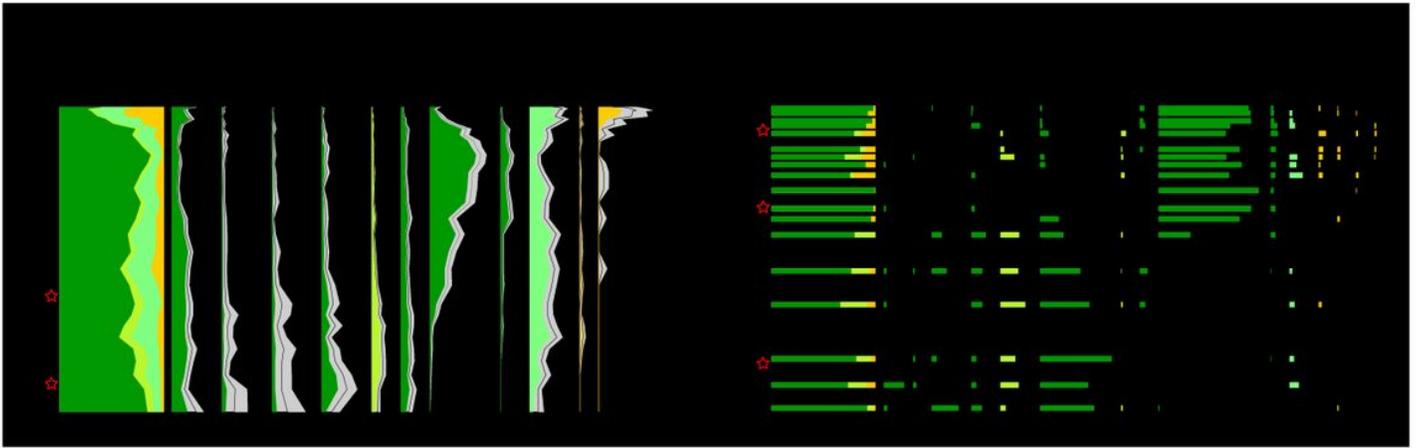


Figure 3

Palynological records. (A) of the Carwitzer See (regional scale) and (B) the Conower Werder (local scale).

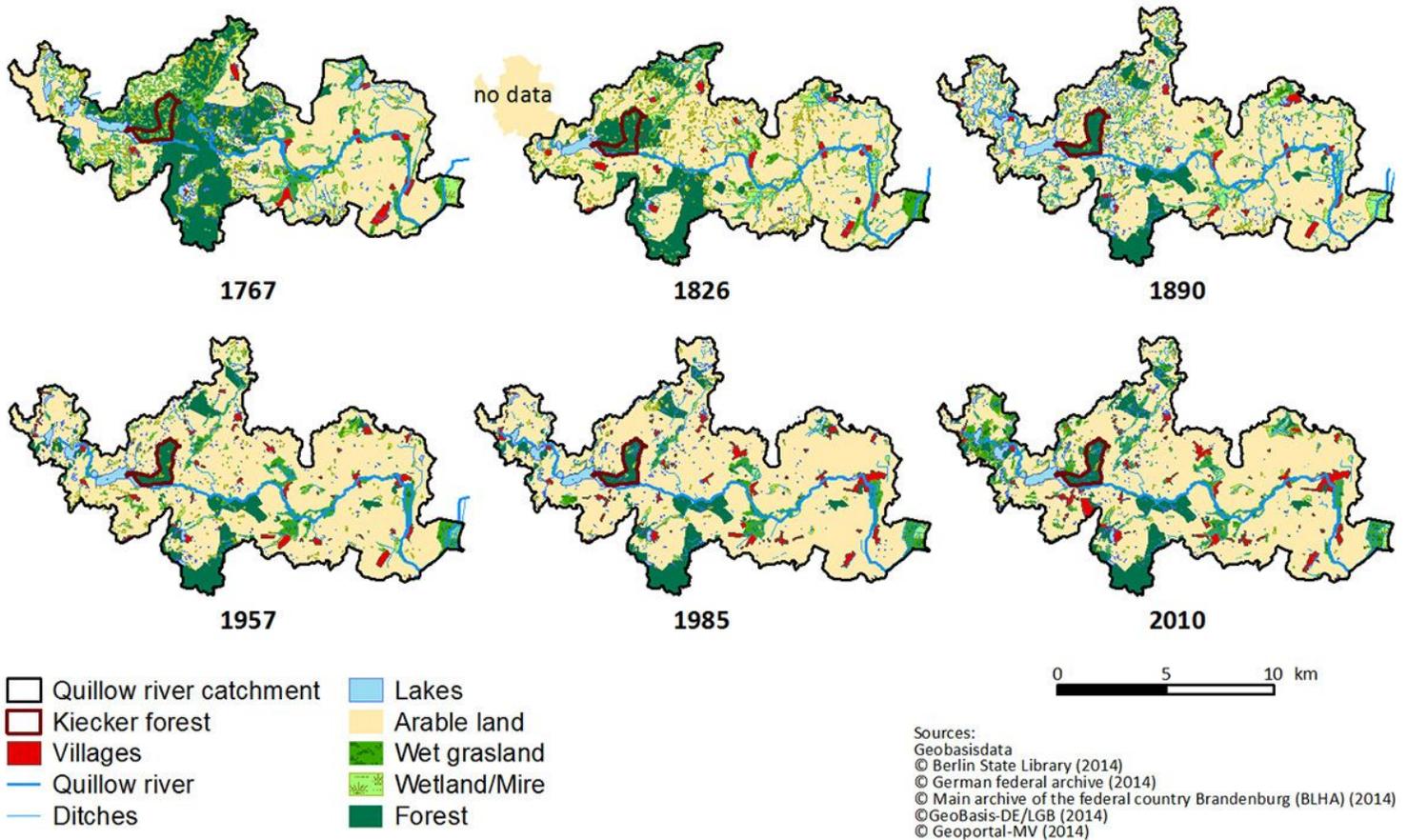


Figure 4

Land-cover changes in the Quillow catchment from 1767 to 2010. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

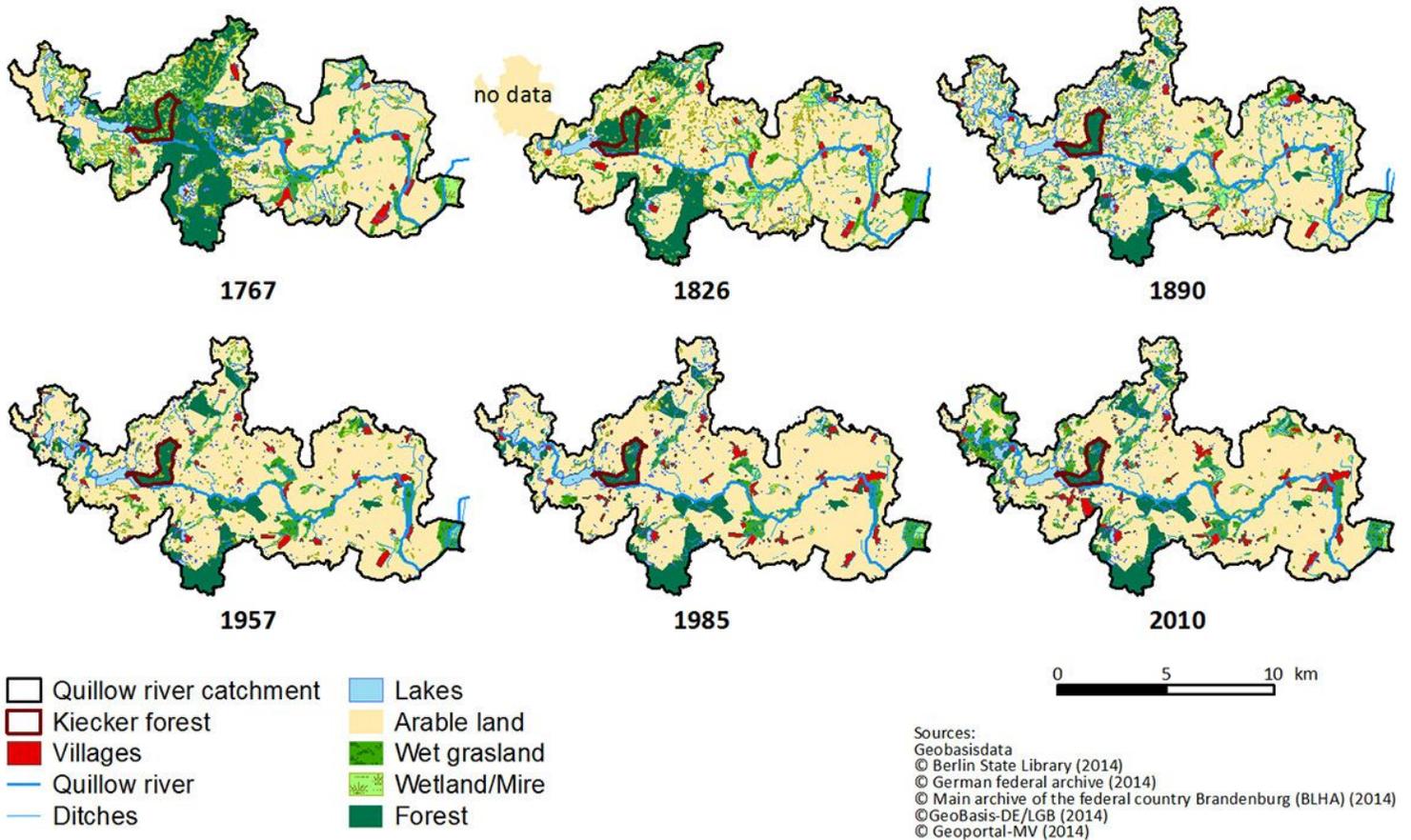


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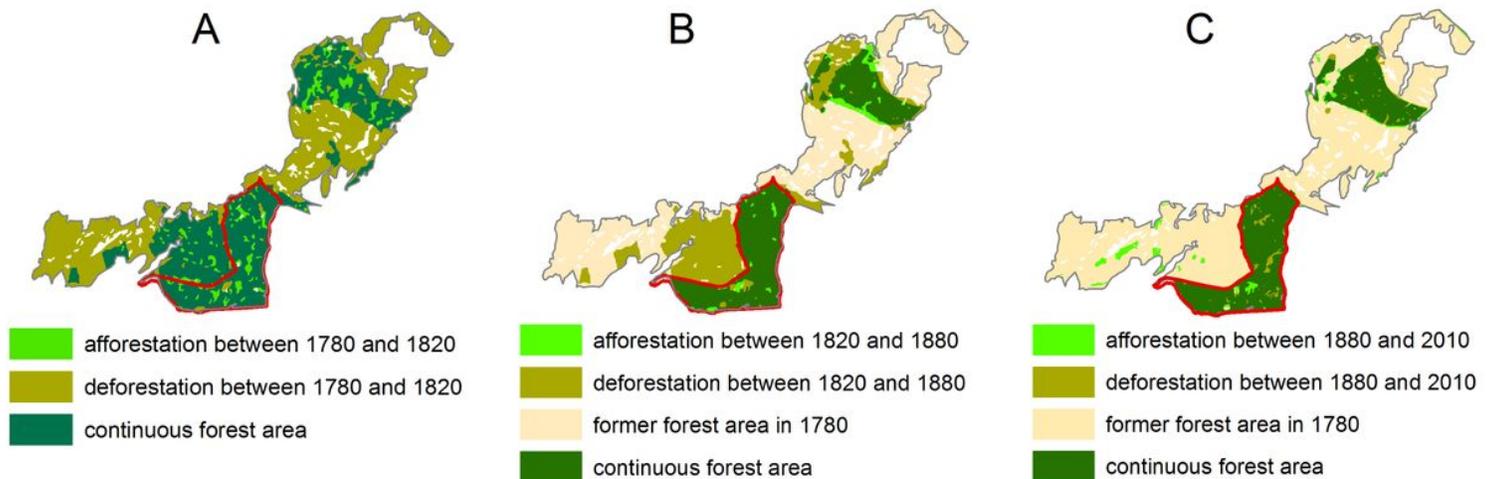


Figure 5

Land-cover changes of the former Fürstenwerdersche Heide. (A) from 1780 to 1820, (B) from 1820 to 1880 and (C) from 1880 to 2010. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country,

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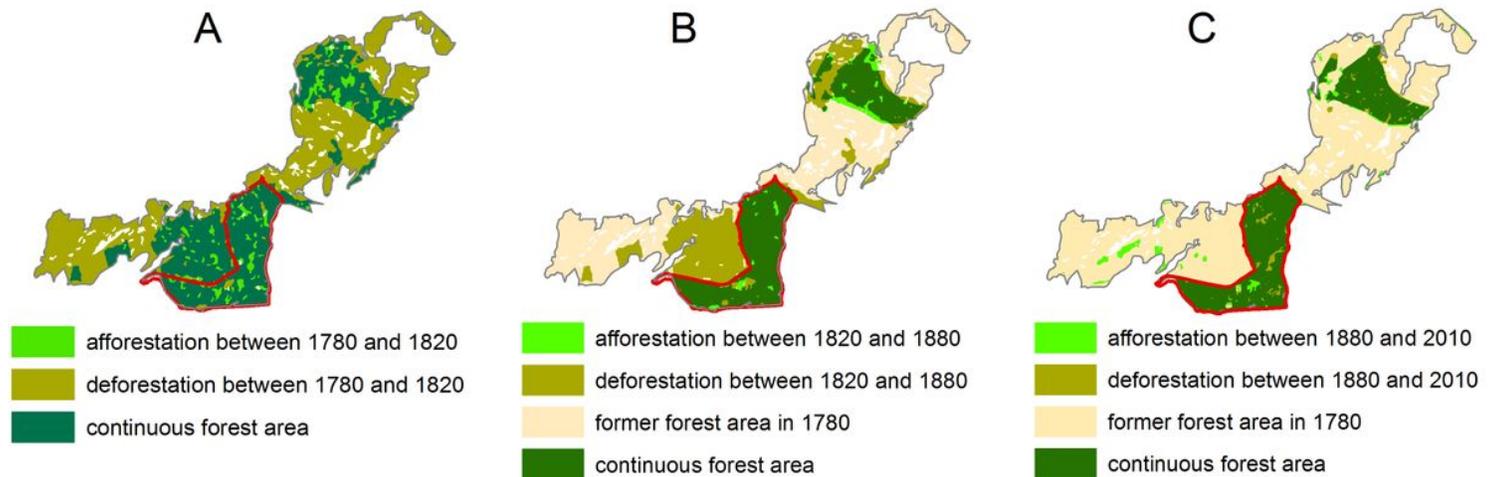


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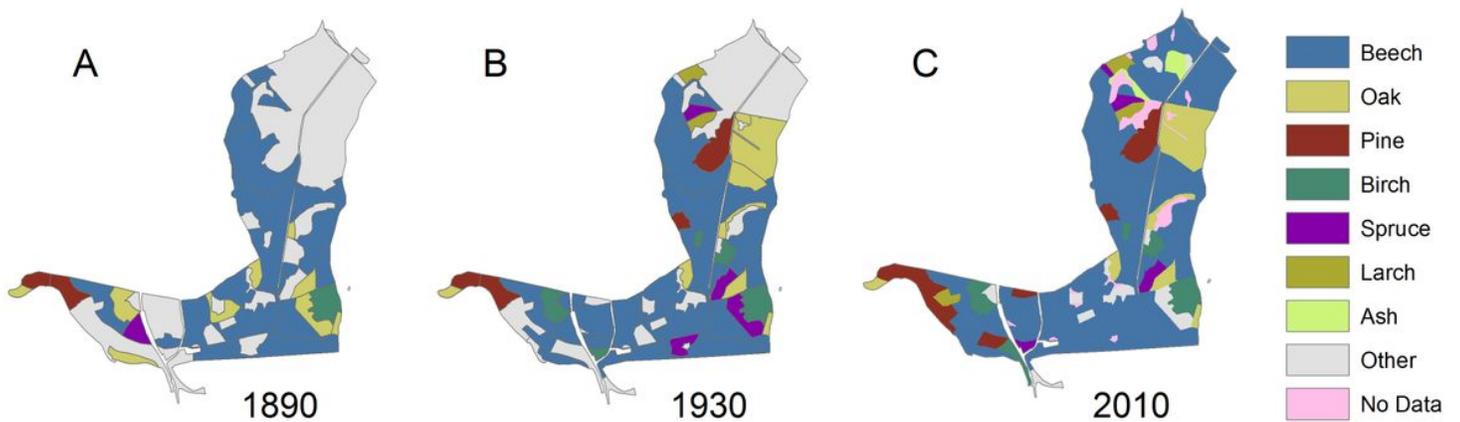


Figure 6

Dominant tree species and their distribution in the Kiecker forest. (A) in 1890), (B) in 1930 and (C) in 2010. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

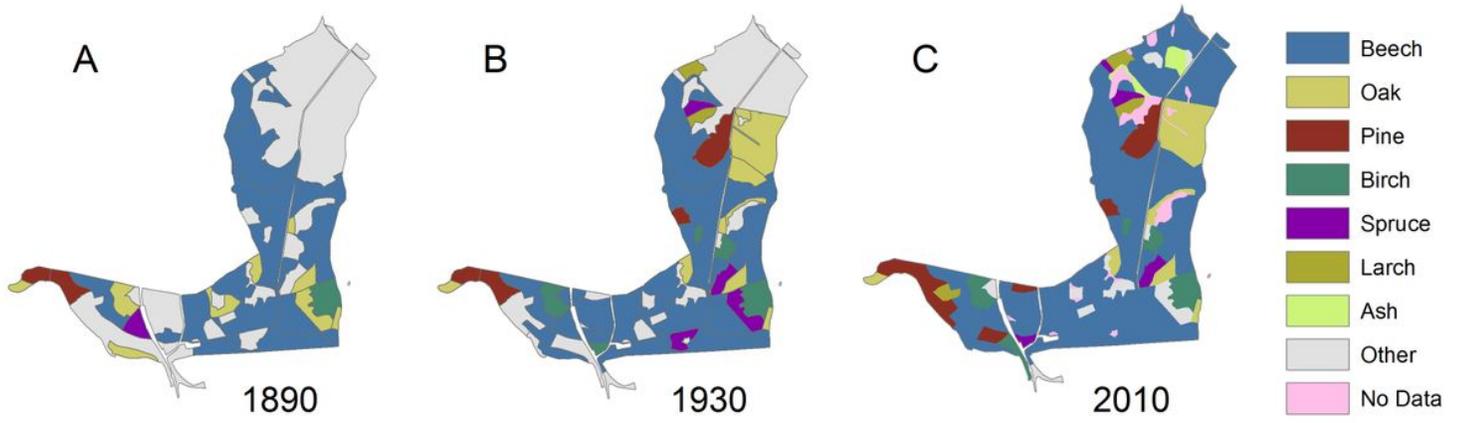


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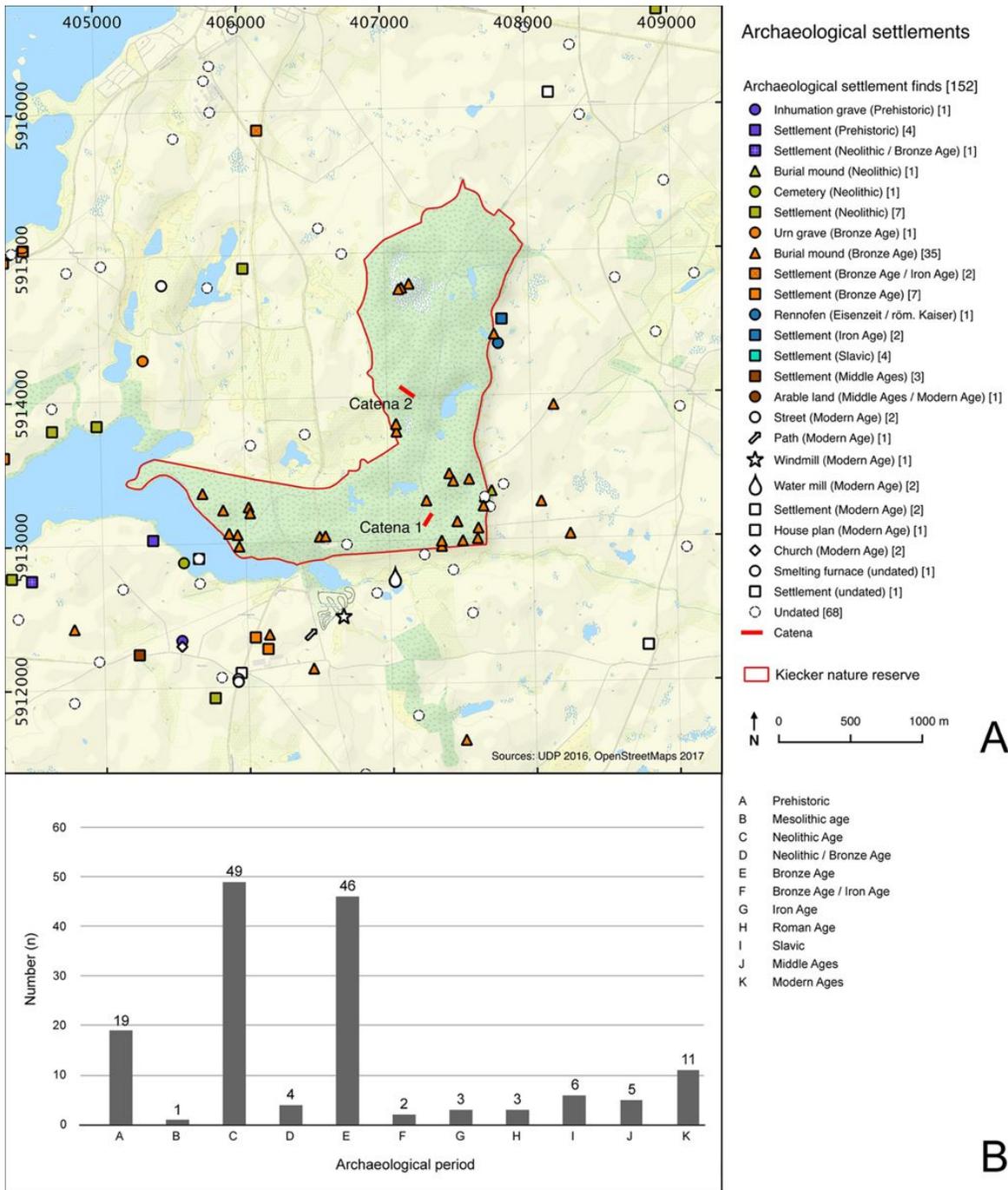


Figure 7

Archaeological settlement finds. (A) in the immediate vicinity of the Kiecker forest and (B) their number for the different ages. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

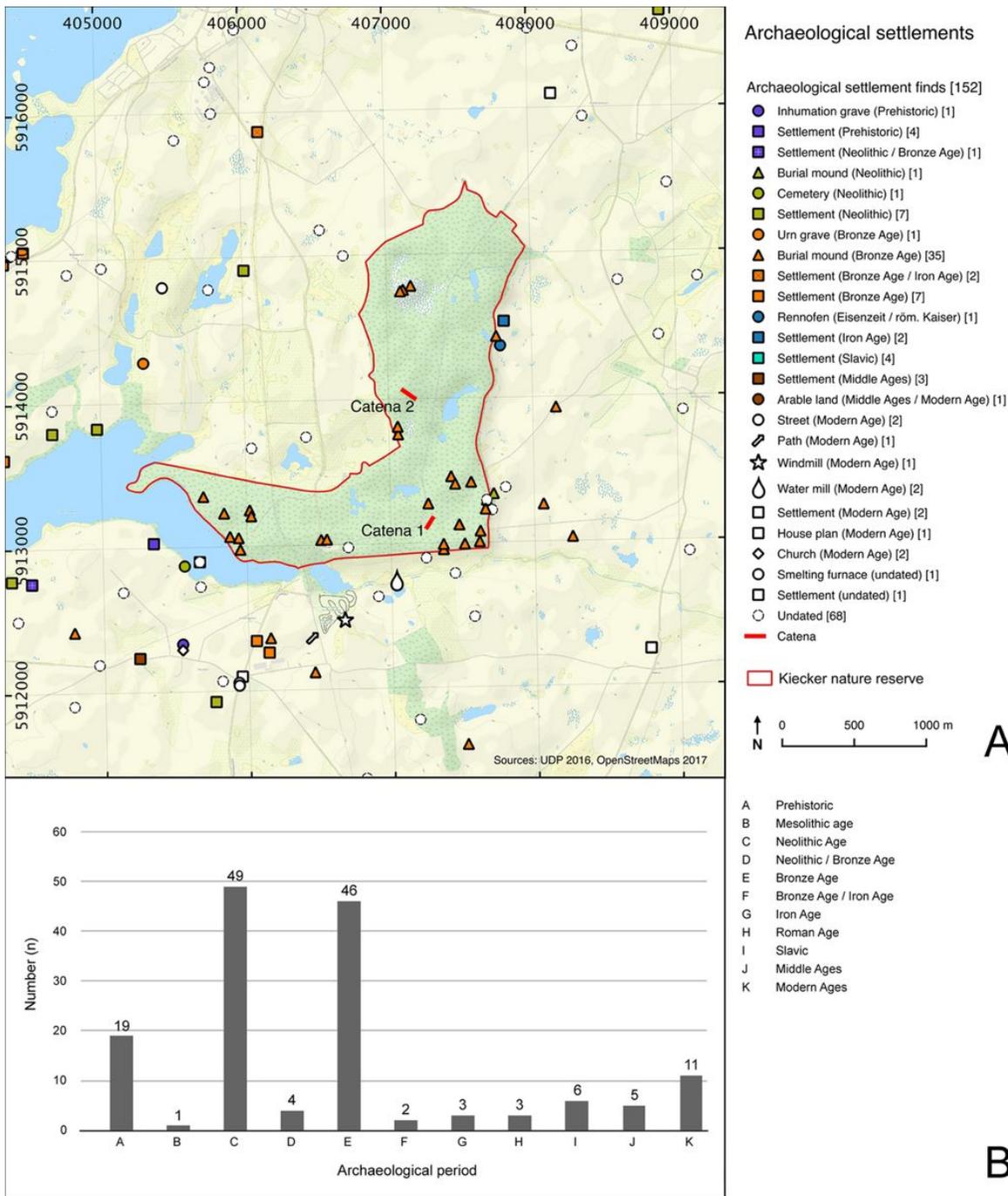


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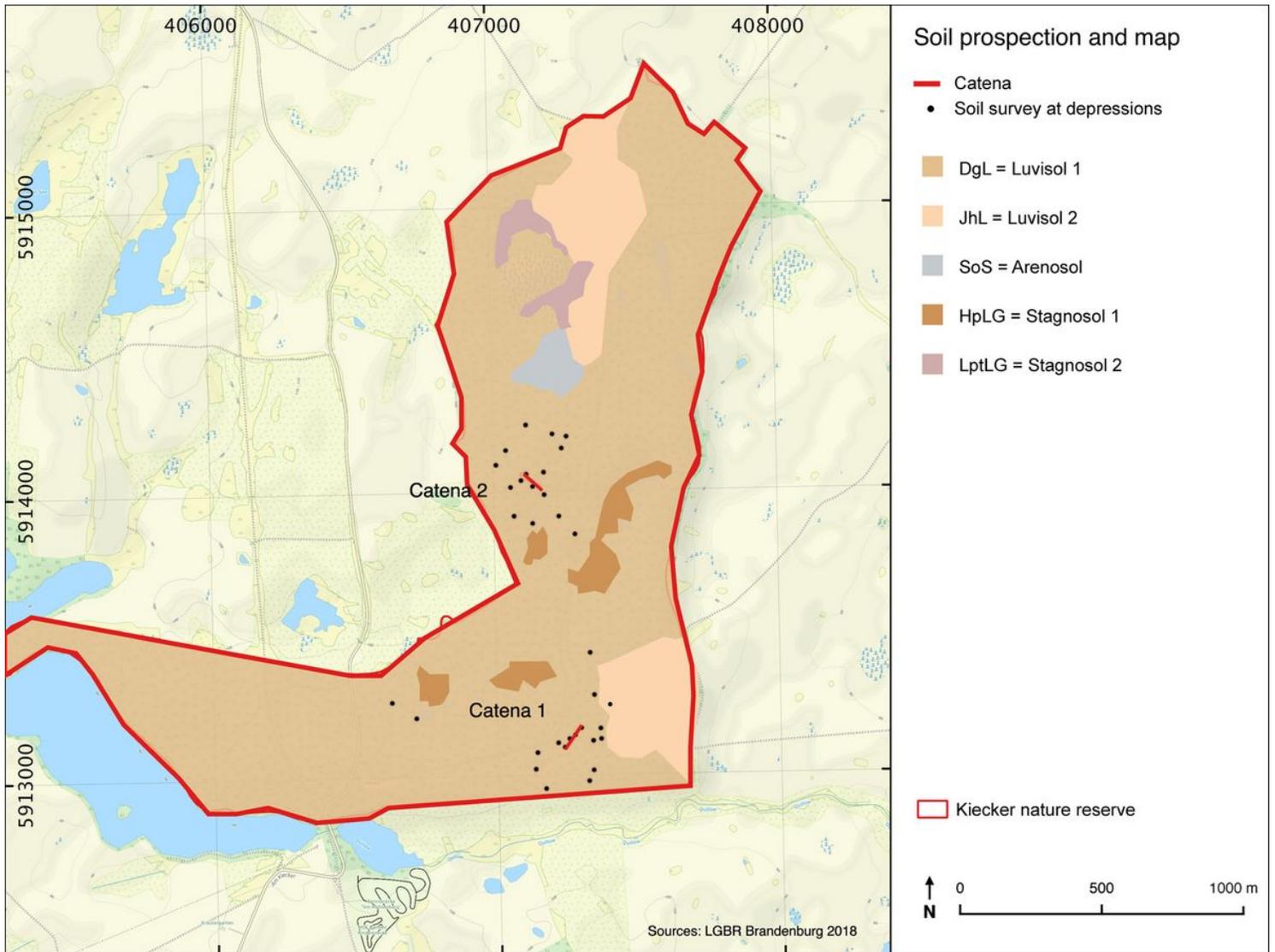


Figure 8

Map of soil types and location of the two catena and soil surveys. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

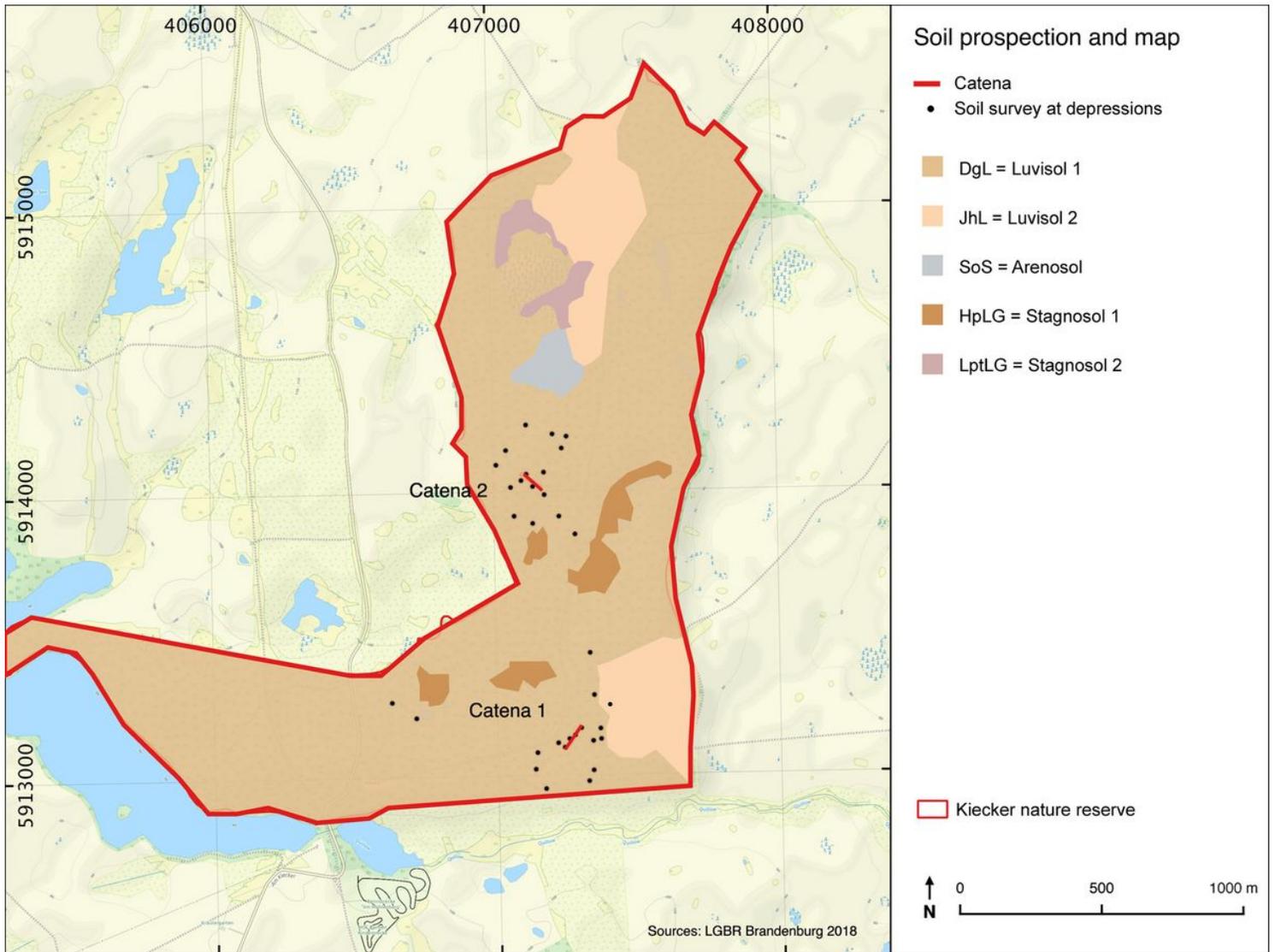


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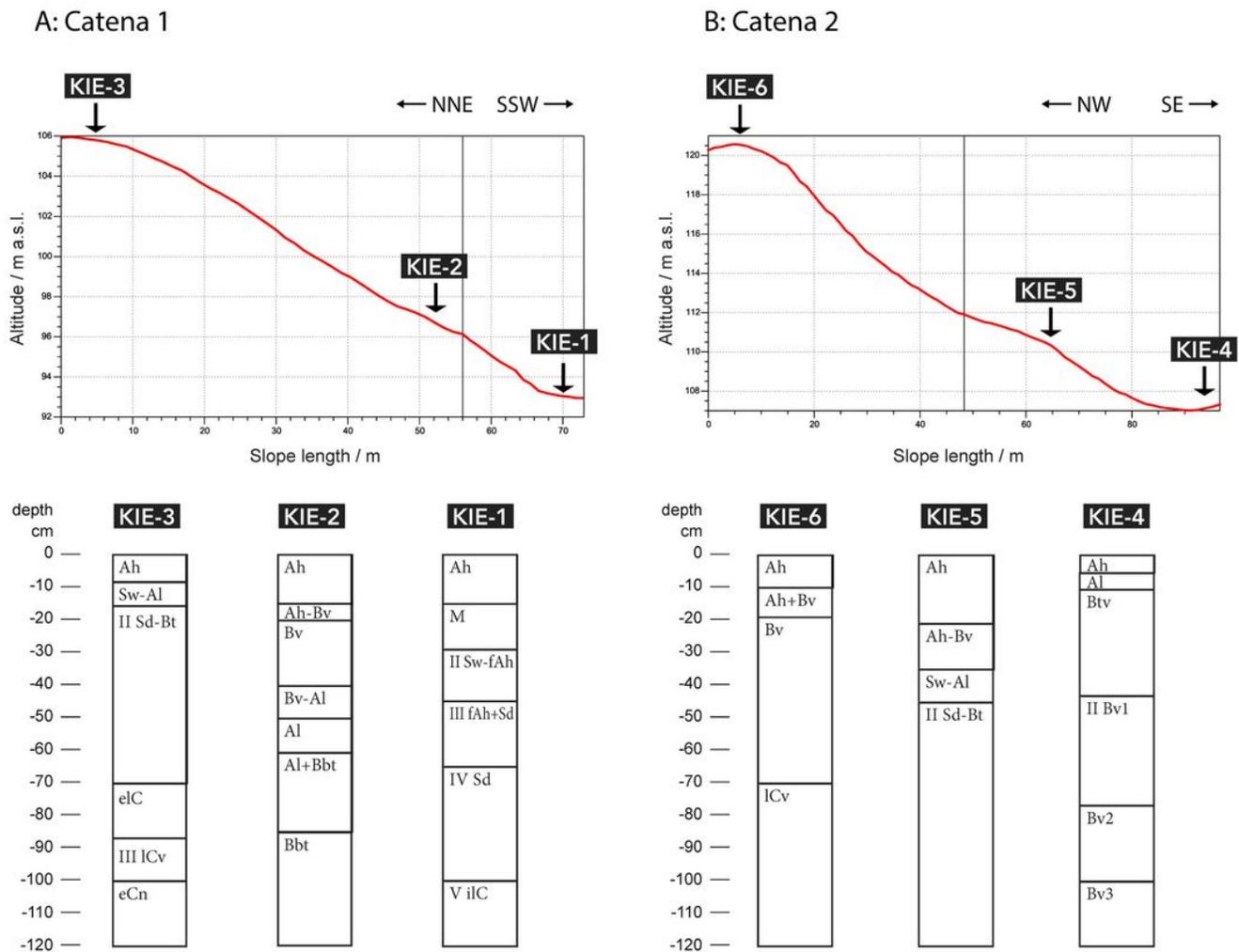


Figure 9

Scheme with soil profiles of (A) catena 1 and (B) catena 2.

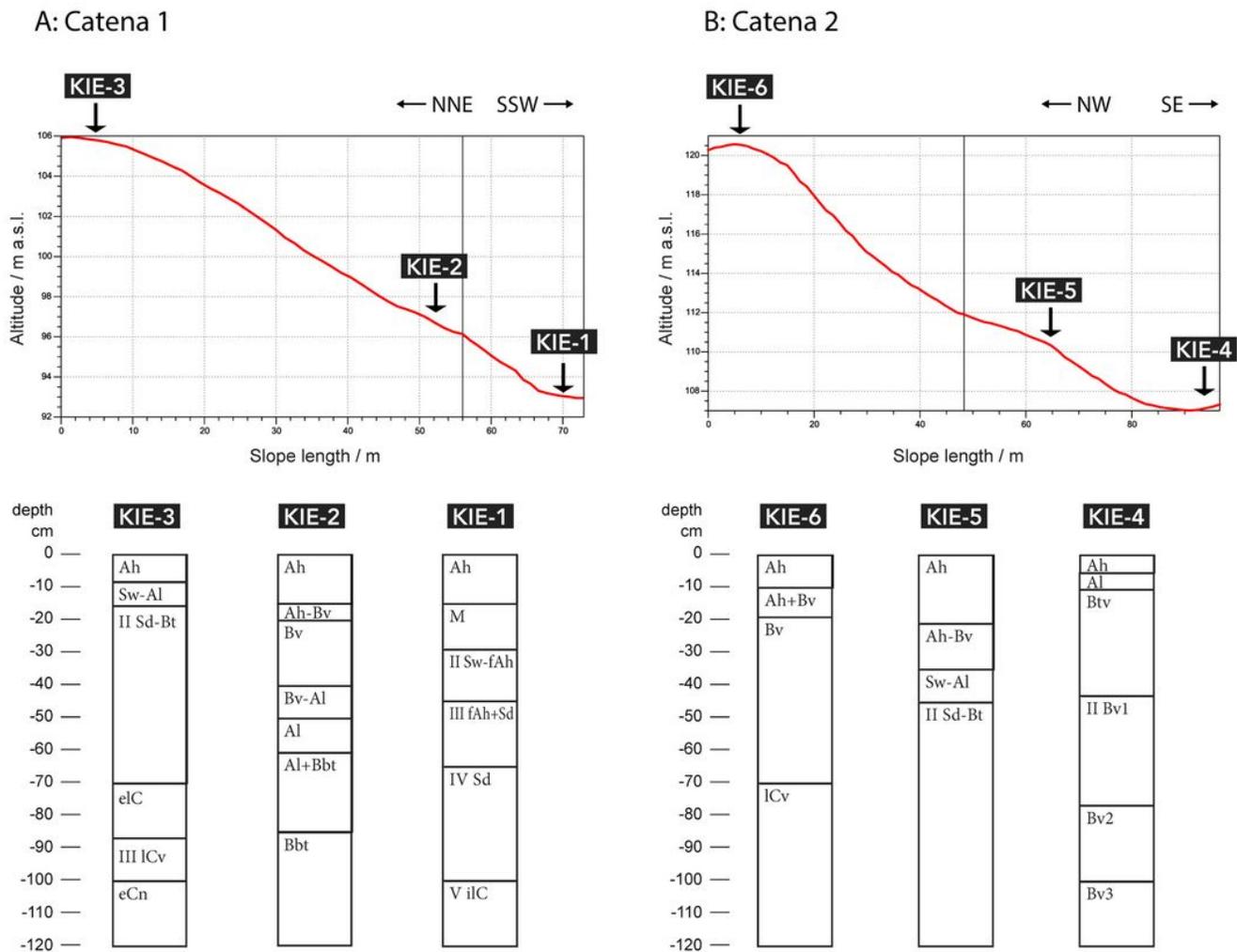


Figure 9

Scheme with soil profiles of (A) catena 1 and (B) catena 2.

Supplementary Files

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