Validation of Medium-Scale Historical Maps of Southern Latvia for Evaluation of Impact of Continuous Forest Cover on the Present-Day Mean Stand Area and Tree Species Richness

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Abstract

Medium-scale historical maps are often the only cartographic source of former forest area distribution on a regional level. In conjunction with a database of the current distribution of species or functional traits, maps may be valuable tool for studying the impact of previous land use on ecosystems. In this study a heterogeneous set of historical maps was used to reconstruct the multi-temporal pattern of the forest area in a moderately forested region (5,180 km^2) of southern Latvia during the last 220 years. Changes in the total forest cover were assessed in four time slices and compared with available historical statistical data. To validate the obtained multi-temporal data for ecological studies, the impact of continuous forest cover on the present-day mean stand area and tree species richness derived from the forest inventory database of 94,886 stands was quantified by bivariate and regression analyses. We found no significant impact of inaccuracy of the historical maps on the entire forest continuity pattern of the study area. In particular, the diversity metrics dependencies on the forest continuity can be described by quadratic regression models with coefficients of determination close to one. We also found that the mean stand area is for about 18% larger in woodlands with longer forest continuity irrespective of the forest type. The older woodland the less difference was found between boreal deciduous and nemoral deciduous forests in terms of tree species richness.

Keywords: forest continuity, historical maps, mean stand area, nemoral deciduous forests, tree species richness, Zemgale

Introduction

An understanding of land-use history is critical in evaluating of nature conservation strategies, for fostering methods to sustainably use natural resources, and for interpreting modern landscapes (Foster et al. 1998, Eriksson et al. 2010, Szabo and Hedl 2011). In forest ecology, the main goal of historical land-use studies is to identify ancient woodland, i.e. areas that had continuous forest cover for a certain period (Peterken 1996). The threshold date for a forest to be regarded as ancient is the date of the oldest map that clearly depicts the forest pattern (Hermy and Verheyen 2007). Ancient woodlands are essential for environmental sustainability as they provide habitats for certain species of plants and animals (Wulf 1997, Hermy and Verheyen 2007, Sikorska et al. 2008, Orczewska 2009a), and mitigate climate change through increasing carbon sequestration and storage (Koerner et al. 1997, Bossuyt et al. 1999, Orczewska 2009a). Therefore, the identification of ancient forests and prevention of their deforestation are two of the most urgent needs of forest management.

The main methods used to reconstruct past land-use patterns are analyses of pollen, soil and field evidence, inventories of indicator species, studies of written archival sources, as well as analyses of historical maps and aerial photographs (Egan and Howell 2001). Historical maps are the most comprehensive source of spatial distribution of former land cover and land use. Relatively accurate maps on different scales have been available since the 18th century for almost the whole of Europe (Orczewska 2009b, Skaloš et al. 2011). Handling and analysing such maps using Geographic Information Systems (GIS) is relatively easy, efficient and less time-consuming than performing field studies (Wulf et al. 2010) and could thus be widely applied in various kinds of forest management planning. For example, mapping forests with different duration of continuous forest cover could be useful for setting priorities for afforestation plans because the proximity of ancient woodlands might serve as sources for forest species to colonize recently created forests (Orczewska 2009a).

However, heterogeneity of historical maps of different origins and scales may present some problems: 1) the accuracy of cartographic sources varies greatly (Stäuble et al. 2008) since mapmaking has constantly developed during the studied period. Use of GIS can improve the applicability of old maps for regional level research (Kramer et al. 2011). Vectorized historical maps can, however, give the false impression that the spatial patterns on the maps are very accurate, thus they should not be used without understanding the limitations of the original cartographic sources; 2) the dating of some of the features depicted on a map may not be related to the date of its issue; a field survey of regional forest patterns may take several years, and could be complemented by data from older maps, estate surveys and questionings (Kavacs 1994) ; 3) definitions of forest tend to differ according to time period and type of maps. The last problem especially affects maps that were made for economic purposes, e.g. land cadastral maps, as they tend to have been based more on existing land-use principles (Raet et al. 2008). The definition of 'forest' used by military cartographers might be more unambiguous as objects on military maps have strategic importance. Land, where tree vegetation dominates, is treated as a forest in military cartography, because any type of forest cover may influence the movement of military units.

Despite the difficulties, in practice, maps are often the only historical source of information about the spatial distribution of natural objects in the past and are already successfully used for former land-cover and land-use studies (Kienast 1993, Reithrnaier 2005, Grossinger and Striplen 2007, Gimmi et al. 2011). The overwhelming majority of studies dedicated to clarifying the impact of forest history on current ecological parameters such as the understory vegetation or the carbon stock, have been performed on one single site (Molinari et al. 2005, Barbier et al. 2008, Wäldchen et al. 2013). An advantage of such stand-level studies is that it is easier to find the contours of old and recent forests using evidence from historical materials or field observations. However, the results of such studies depend on site characteristics, which is why contradictory results are reported for different places (Wulf 2003, Verheyen et al. 2003, Barbier et al. 2008). The effect of site can be minimised by accumulating results from studies of different stands with similar forest continuity, or by performing analysis on a regional level. Numerous regional studies have already been carried out to evaluate and describe the forest cover from medium-scale historical maps (e.g. Orczewska 2009b, Skaloš et al. 2011, Mikusinska et al. 2013, De Keersmaeker et al. 2015), while no study, to our knowledge, has evaluated the impact of forest continuity on present-day ecosystem parameters on a regional level. Moreover, applicability of historical maps in previous studies is usually assumed as a postulate, and no quantitative description was applied to prove this approach.

In this paper we address the problem of validity of heterogeneous historical data in ecological studies by using a set of historical maps to reconstruct the development of the forest area over the last 220 years in Zemgale, a region of Latvia with the same economic and political history. Firstly, the forest area at four different time points since the end of the 18th century was calculated and compared with available historical statistical data for the study region. Secondly, woodlands with different forest continuity were localized to find out the impact of continuous forest cover on two present-day diversity metrics: the mean stand area (i.e. the inverse of stands density) and tree species richness. If the maps are not valid representations of the historical forest cover, noisy and hardly interpretable dependencies will be obtained, since any systematic bias is unlikely for the whole set of different historical maps. We hypothesized that 1) the total forest cover obtained from medium-scale historical maps does not contradict to available historical statistical data; 2) any unknown factors related to imperfection of the historical maps do not significantly distort dependencies of the diversity metrics on the forest continuity.

Materials and methods

Study area

The Zemgale region (lat. 56°N, long. 23°E) located in an agricultural region in the south of central Latvia (Figure 1) is about 5,178 km^2 in size. Forest covers about 31% of the landscape (State Forest Service 2010). The study area includes Bauska, Jelgava and Dobele administrative districts. Most of Zemgale is a plain 20 to 60 m a.s.l., except the western part, where the elevation is 60 to 150 m a.s.l. The study area is located in the transition zone between boreal and nemoral forests, the so-called hemiboreal vegetation zone (Ahti et al. 1968). Areas of sandy soil in the north and north-east of Zemgale are covered with *Pinus sylvestris* L. dominated boreal forest tracts (Figure 1). *Picea abies* L. H. Karst. stands are more common on mesotrophic soils in the western part of Zemgale. Stands with thermophilous, nemoral deciduous tree species *Quercus robur* L., *Fraxinus excelsior* L., *Tilia cordata* Mill., *Ulmus glabra* Huds. are scattered in the central

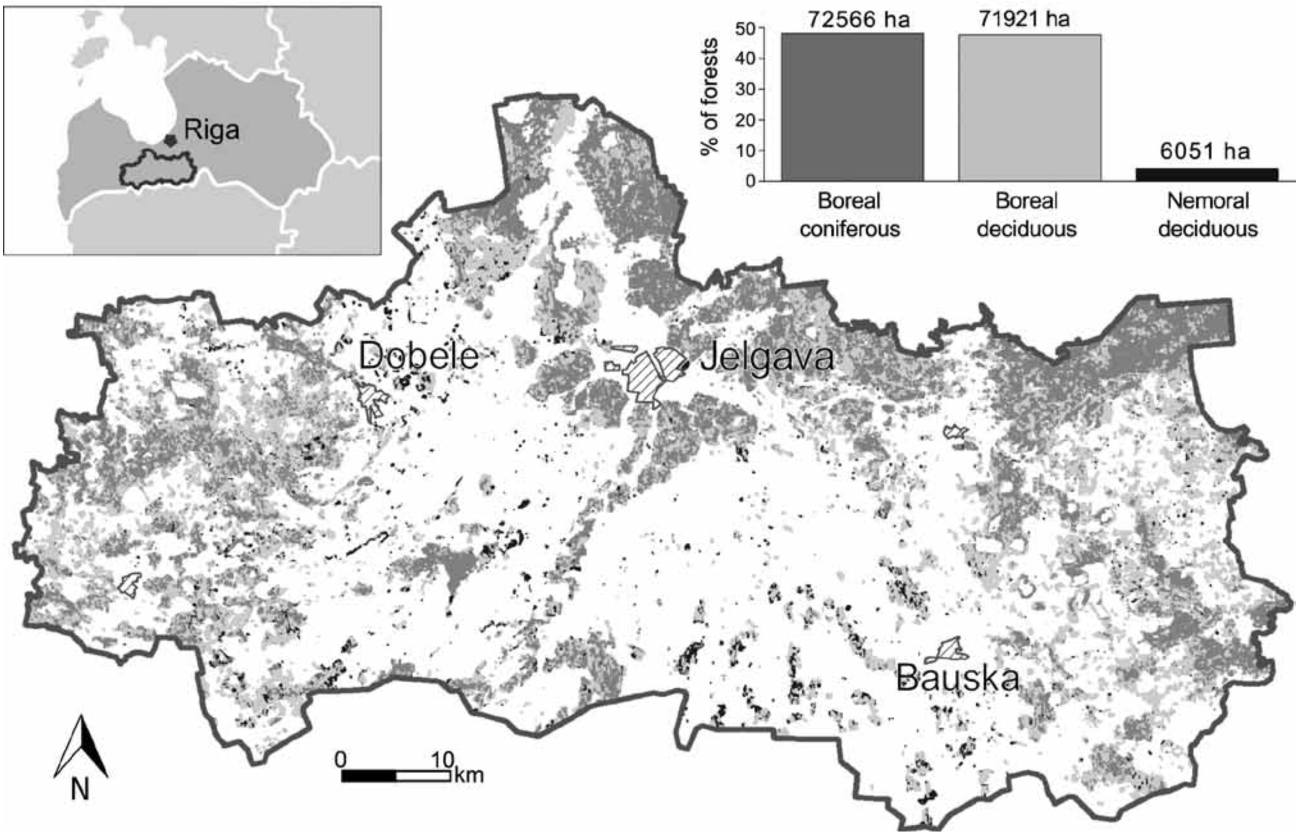

Figure 1. The spatial distribution and the proportion of the forests by forest types in the study area in 2010. The location of the study area in Latvia is shown in the upper-left panel

and southern areas on eutrophic soils. Early successional, boreal deciduous tree species *Betula pendula* Roth, *Populus tremula* L., *Alnus incana* L. Moench. and *Alnus glutinosa* L. Gaertn. are common over the whole study area.

Before agriculture became widespread (until ca. 500 AD), lowlands of Zemgale were covered by nemoral tree species, especially *Quercus robur* (Galeniece 1959). Historic records indicate that when the German crusaders arrived in the 13th century, Zemgale *(Semigallia)* was still mainly covered with forests (Zunde 1999). From 1290 to 1562 the territory of Zemgale was a part of the ecclesiastical state *Terra Mariana* (also known as Livonia) as a principality of the Holy Roman Empire. After the Livonian War, it became a part of the Duchy of Courland and *Semigallia* with its capital in Jelgava (*Mitau*). It is known that in the Duchy forest resources were intensively explored providing timber for shipyards and smelters (Zunde 1999). Later, in 1795, it was incorporated into the Russian Empire, but Zemgale remained dominated by the local German-speaking minority until 1919. Since the 19th century, the depopulation (Skujenieks 1938) of rural land due to industrialization led to the afforestation of Zemgale. These processes were intensified in a series of wars, of which the most destructive was World War I. Shortly before World War II, the region was incorporated into the Soviet Union, and remained under that rule until the Republic of Latvia was re-established in 1991. With the re-independence of Latvia in 1991, land claims of former owners led to more agricultural lands being abandoned, resulting in rapid afforestation (Penēze et al. 2009, Lūkins and Nikodemus 2011).

Historical maps

In this study we used medium-scale (1:75,000 - 1:300,000) historical maps from three cartographic sources (Table 1) to reconstruct the historical forest distribution in Zemgale every 50-100 years from 1790 onwards. The maps are digitalized copies from the authors' private collections, and cover the whole study area. The exact or estimated final year of the cartographic survey was used to date the forest distribution on each of the map.

The Courland map (*Karte von Kurland von C. Neumann*) is the oldest source for the forest area distribution in Zemgale (Table 1, Figure 2a). This semi-topographical map was first published in 1833 in Jelgava. The exact date and the circumstances of survey for this map are unknown (Kavacs 1994). We consider that the forest area distribution on the Courland map was established before 1790, since the contours of the Golf of Riga, as well as the style and contents of the map are similar to those in the Atlas of

Table 1. Characteristics of the maps used in the study

Map name	Ed.[1]	Survey[2]	Scale	Geod. points[3]	Survey. accuracy (m)[4]	Drawing accuracy (m)[5]	Min. forest patch (ha)
Courland map	1833	ca. 1790	1:296 000	506	1265	178	9
3-verst map	1865	ca. 1860	1:126 000	629	546	76	0.6
Latvian army map	1924	ca. 1910	1:75 000	-	-	45	0.3
Forest inventory map	-	2010	1:10 000	-	-	6	0.1

[1]The date of the first edition of map sheets. [2]The survey date indicates the year, when the forest distribution had become fixed. [3]The geodesic points were used to link the oldest two maps to the Latvian army map and optimized for local accuracy through spline transformation. [4]The root-mean-square error after the 1^{st} order transformation was used to estimate the surveying accuracy before the spline transformation. [5]The drawing accuracy of the real world is derived from the scale by assuming a drawing accuracy of 0.6 mm on the map.

Livland (*Atlas von Liefland*, a map of an adjacent region published by Ludwig August Mellin in 1791). The Courland map differs markedly from the later ones made by Russian cartographers after 1790, e.g. a detailed military map along Russian-Prussian border (1799), a special map of Western Russia on a scale of 10 verst per inch (1821-1839) and a special map of Livland (1839). The survey for the Courland map may have been even earlier, because the Ozoldarzs, a 19 ha old oak-dominated forest patch (marked in Figure 2 with arrows), is absent on the map. It was planted in about 1776 (Ikauniece et al. 2012). The delay in publishing the Courland map could be due to the tension between the German administration and Russian authorities at that time. The issue of the Atlas of Livland in Germany provoked the arrest of Count Mellin and the issuing of a special decree by the Russian Tsar Pavel I banning the publication of maps of the Russian Empire abroad.

The 3-verst map of the Russian Empire (The military topographical map of the European Russia) is the second source for estimating the forest area distribution in the study area (Table 1, Figure 2b). The preparation for this map started in 1845. The sheets of the 3-verst map used for our study are dated by 1865, but only administrative boundaries were updated and railways added that year (www.maps4u.lt. 2013). We therefore estimated the final mapping of the forest area in Zemgale took place as late as 1860.

The Latvian army map (Table 1, Figure 2c) was published in 1924-1931. For Zemgale this map was reproduced from the Russian Empire 2-verst map on a scale of 1:84,000 (Kavacs 1994), based on a survey before 1910. The advantage of the Latvian army map is that it is available georeferenced for the whole study area. To vectorize the forest area distribution, we also used some original sheets of the 2-verst map and some sheets reproduced from it by the German Army and the Red Army (RKKA).

Georeferencing and estimating accuracy of historical maps

The digital copies of sheets of the Courland map and the 3-verst map were georeferenced in ArcGIS software (ESRI 2011) to the Latvian Army map using territorial

Figure 2. Examples of maps used in this study: A) Courland map (issued 1833, surveyed in ca. 1790); B) 3-verst map of Russian Empire (issued 1865, surveyed in ca. 1860); C) Latvian army map (issued 1927, surveyed in ca. 1910). The arrows show the location of the Ozoldarzs, which was planted in 1776

features such as castles, palaces, manors, churches and stone bridges as ground control points. More than 500 control points were identified on the Courland map for the whole study area, and more than 600 on the 3-verst map (Table 1). We used spline transformation to improve the local accuracy of the maps (Kramer et al. 2011). To estimate the local accuracy of the Courland map and the 3-verst map before the spline transformation, we used the same control points moving sheets of the maps so that residual errors between all pairs of control points on the maps, of which the Latvian Army maps are considered to be the most exact, would be minimal (1st order transformation). The root-mean-square sum of all the residuals, indicating the mean mismatching between a pair of control points, was proportional to the local inaccuracy of a less accurate map. The maximum accuracy of the maps after the spline transformation was limited by the drawing accuracy. It was calculated for a particular map scale, S, as $\Delta w/S$ by assuming forest contours width, $\Delta w = 0.6$ mm, on each map. The third way to estimate a map accuracy we used involves finding the smallest forest patch area depicted on the map. The results of these estimates are shown in Table 1.

Present-day data

The present-day data (2010) on the forest area distribution, stand area, and tree species composition were taken from the State Forest Service (SFS) forest inventory database (State Forest Service 2010), which contains records of forest land with the GIS database (Forest inventory map, Table 1). The database provides information summarized in more than 120 attribute fields on both state and private forests. Unlike many European countries, where total forest inventories are performed on a statistical inventory basis (Brack 1997), in Latvia about 97 % of the forests are divided into stands: management units of similar growing conditions, tree species proportion, density and age (see an example in Figure 3). According to the forest management principles adopted in the 1920s, the data were obtained by surveying each stand once every 10 to 20 years, followed by a limited check of data between stand-wise inventories. The minimum area that can be designated as a stand is set to 0.1 ha, although the mean stand area in Zemgale is 2.1 ha (State Forest Service 2010). For the study area, the database contains a total of 94,886 stands, from which 39,875 are boreal coniferous forest stands, 51,475 are boreal deciduous forest stands, and 3,536 are nemoral deciduous forest stands.

Forest continuity map

Contours of forested areas traced on the historical maps were vectorized in ArcGIS software (ESRI 2011) to a set of polygons, which were dated according to the estimated final year of a corresponding survey (Table 1). By projecting historical polygons onto polygons of present-day forest stands, we assigned to each stand new attributes, which showed whether the stand was inside of any forest polygon from a historical map. In case the stand was partially intersected with a historical forest polygon, it was split into previously forested and non-forested parts. Therefore, a new more granular map of current forests was produced, where presence or absence of forest cover at each of the three time points was attributed to all polygons. Polygons with area less then 0.1 ha were disregarded for further analysis. We obtained a detailed map showing the forest continuity by dividing forests into four classes: 1) ancient forests, woodlands with forest continuity more than 220 years (forest cover in 1790, 1860, 1910, and 2010); 2) woodlands with continuity 150-220 years (forest cover in 1860, 1910, and 2010); 3) woodlands with continuity 100-149 years (forest in 1910 and 2010); and 4) recent forests, woodlands forested continuously for less than 100 years (forest cover in 2010 but not forested in 1910). For additional analysis of the forest continuity

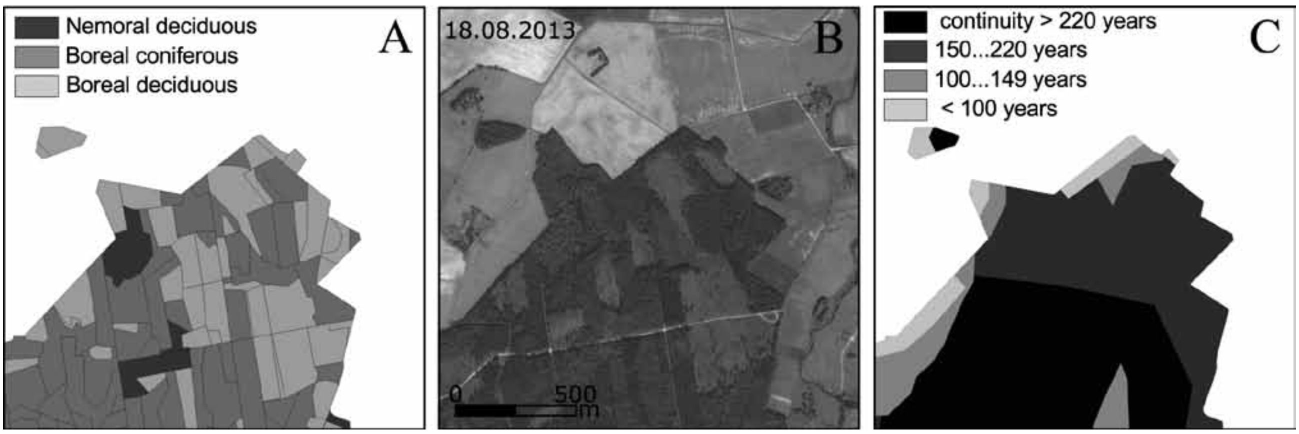

Figure 3. A) An example of the Forest inventory map of a forest patch near Platone village. B) NASA satellite image of the stands structure (Google Earth, 2013). C) The forest continuity map of the forest patch

pattern, the study area was manually subdivided by elevation and proportion of present-day forest cover in four ecoregions: forested lowland (> 50 % of forests, < 60 m a.s.l.), open lowland (< 10 % of forests, < 60 m a.s.l.), mosaic lowland (10-50 % of forests, < 60 m a.s.l.), and mosaic highland (10-50 % of forests, > 60 m a.s.l.).

Data analysis

Firstly, total areas of forest cover, as well as forest areas with different forest continuity, were calculated in four time slices using standard GIS functionality. To analyze deforestation during a period between two successive time horizons, total area of forest polygons that were depicted on the previous map and disappeared on the next map was calculated and divided by number of years in the period. Similarly, total area of forest polygons that were depicted as open lands on the previous map was used to calculate afforestation during the corresponding period.

Three forest types according dominant tree species were analysed separately: (1) boreal coniferous *Pinus sylvestris*, *Picea abies;* (2) nemoral deciduous *Quercus robur*, *Fraxinus excelsior*, *Tilia cordata*, *Ulmus glabra;* (3) boreal deciduous *Betula pendula*, *Populus tremula*, *Alnus incana*, *Alnus glutinosa*. One dominant tree species from the 20 available was defined in the SFS database for each stand as that making up the largest tree volume.

The number of tree species in each of 94 886 stands was extracted from the SFS database taking into account all tree species including ones of individual trees. It should be noted that according to forest management practice in Latvia, only one tree species is intentionally planted in one stand until now, while other species have seeded naturally. The arithmetic mean value of tree species richness per hectare and mean stand area with standard errors were calculated for each forest type and for each forest continuity class by applying the 'select by location' method of ArcGIS to stands within or intersecting a forest continuity class. The mean stand area (an inverse of stands density) indicates a diversity of particular forest subareas with similar light transmission, humidity, fertility and tree species composition, and consequently, with similar forest-dwelling species pool, i.e. it is related to diversity of habitats in forests.

Though the forest continuity is a continuous variable, its real values were hardly estimated because any new forest area on a map had been appeared during a period, which is unknown for the very first map and varies for the later maps. Therefore, for bivariate and regression analyses we made an approximation of the real forest continuity by an equidistant successional series. To quantify distortion (i.e. deviation from a simple trajectory) of the metrics dependencies on the forest continuity, they were fitted with quadratic regression models, and the coefficients of determination (multiple *R*-squared) were obtained using R programming language (R Development Core Team 2014). To quantify relationship between the diversity metrics and the forest continuity, the Spearman correlation was calculated for the pairs of the variables.

Results

Temporal pattern of forests

Changes over time in the forest area of Zemgale for the four time horizons 1790, 1860, 1910, and 2010 are plotted in Figure 4a. The overall percentage of forest cover during the study period remained within 27 % ± 4% of the study area with peaks in 1860 and 2010. Contributions of the time horizons (grey colours in Figure 4a) to the present-day forest area were nearly similar, which were 25 %, 23 %, 16 %, and 36 % for years 1790, 1860, 1910, and 2010, respectively. Area of forest cover that presented on the same place since a certain time horizon decreased along the time axis in exponential-like trajectories, which means that new woodlands became deforested more quickly than older ones. Indeed, only 25% of the areas deforested from 1860 to 1910 were presented as a forest in 1790; another 75 % were afforested after 1790. From the areas deforested from 1910 to 2010, only 9 % had continuous forest cover since 1790, 28 % since 1860, and 63 % since 1910. Land-use turnover over the last 100 years has decreased approximately twice in comparison with the previous periods (Figure 4b).

Spatial pattern of forest continuity

Woodlands with different continuity of forest cover were unevenly distributed between forested, open, mosaic lowlands, and mosaic highland ecoregions (A, B, C and D in Table 2, Figure 5). Large forest tracts in ecoregion A formed a dense matrix of mostly ancient coniferous *Pinus sylvestris* dominated forests with adjacent recent forests dominated by boreal deciduous tree species. Ecoregion B on Zemgale plain in the southern and central part of the study area is characterized by fertile soils and intensive agricultural activity forming an open landscape pattern with scattered old deciduous forest patches. Evenly scattered woodlands of different forest continuity characterized ecoregion C in the western part; such a mosaic pattern formed on the western side of the East Curonian upland with elevations from 60 to 150 m a.s.l. High proportion of recent forests dominated by boreal deciduous tree species has been found in ecoregion D in the eastern part of Zemgale. The both mosaic landscapes were characterized by the lower mean stand area and mean tree species richness (Table 2).

Mean stand area and tree species richness

The mean stand area is positively correlated on forest continuity for all forest types (Figure 6a), while the

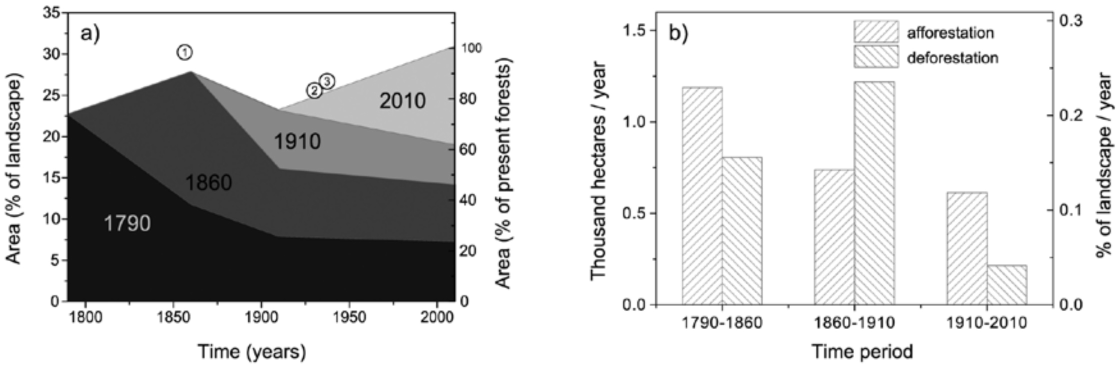

Figure 4. a) Changes over time in the forest area in Zemgale in the four time horizons: 1790, 1860, 1910 and 2010. The percentage of the total study area is shown on the left y-axis, while the right y-axis shows the percentage of the current forest. Gradation of colours indicates proportions that have had continuous forest land use since: 1790, 1860, 1910 or after 1910. The numbered circles depict proportions of forest cover from available historical data for Dobele and Bauska districts (Орановский 1862, Švābe et al. 1934). b) Afforestation and deforestation rates during the three study periods

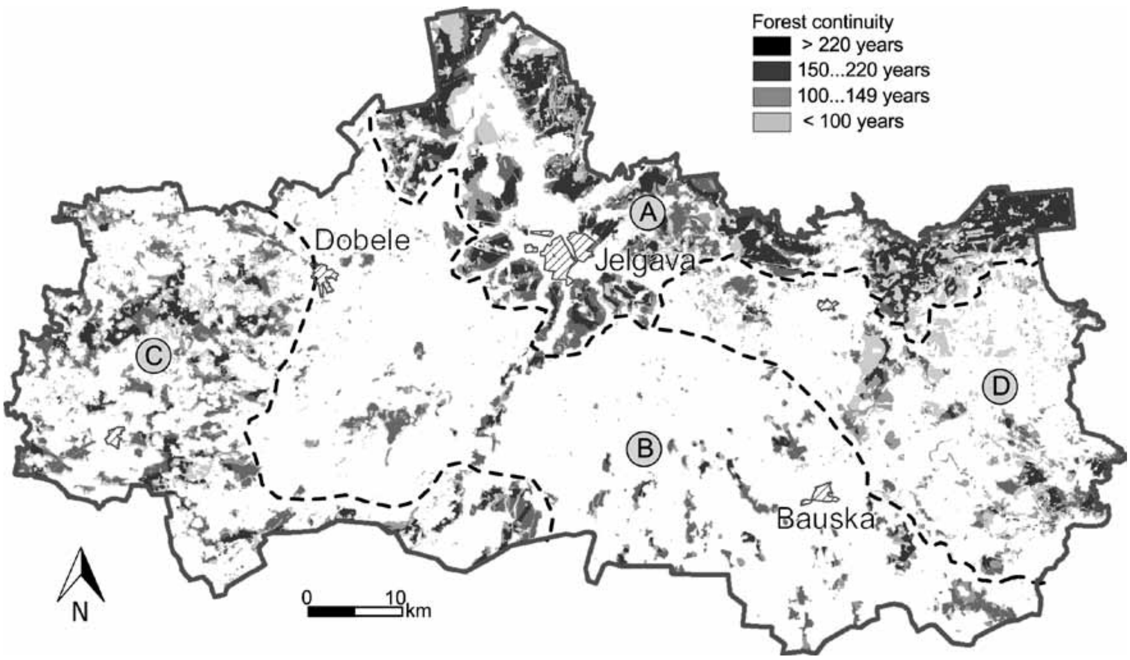

Figure 5. Spatial distribution of woodlands, divided into four classes according to the forest continuity. The capital letters and dashed lines indicate ecoregions

correlation is more pronounced for deciduous tree species ($\rho_{s.cor} > 0.16$, p-value < 0.0001). The mean stand area was for about 18% larger in woodlands with longer forest continuity irrespective of the forest type. The tree species richness was also found positively dependent on the forest continuity in stands with dominant boreal deciduous tree species ($\rho_{s.cor} = 0.15$, p-value < 0.0001, Figure 6b). The tree species richness of the nemoral deciduous forests was about for 35% (for all continuity classes) higher than that of the coniferous woodlands, and both these forest types had weak correlation with the forest continuity (p-values: 0.99 for coniferous and 0.04 for nemoral deciduous forests). All the presented dependencies fitted with simple quadratic model showed determination coefficients R^2 close to 1, i.e. they were not statistically distorted.

Discussion

Validation of historical maps for multi-temporal analysis

When dealing with historical maps, especially produced before the 19th century, a question may arise about their validity for scientific applications since such maps are not obviously trustworthy. First of all, they should be supported by other historical data. The available historical statistical forest cover data of Bauska and Dobele districts (see Figure 4a, circles 1-3, Орановский 1862, Švābe et al. 1934) are consistent with our map-based analysis of forest cover: in 1856, the forest area in Bauska and Dobele districts was 30.3% (circle 1), in 1929 - 25.3% (circle 2), and in 1931 - 26.2% (circle 3). The discrepancy can be explained by the incomplete overlap of the administrative units in the study area during the different time periods: the Bauska and Dobele districts had different borders in the 18th and 19th centuries but in the 20th century, the Jelgava district became a separate unit. These changes in the forest cover during the studied period can be explained by soils interacting with political, economic and social factors in Zemgale (Fescenko et al. 2014).

Another evidence of the maps reliability is that the ecoregion with the highest percentage of the ancient forests (see A in Table 2, Figure 5) is *Pinus sylvestris* dominated, which confirms the link between forest continuity and coniferous forests (Eriksson et al. 2010, Tērauds et al. 2011). Such woodlands grow on land that is not suitable or profitable for agricultural use, thus it is reasonable to expect that they have much longer forest continuity than the 220 years.

The forest continuity derived from the historical maps and linked to diversity metrics provides itself a validation test of the maps: the smooth and simple curves of the dependencies (see Figure 6) exclude any significant impact of cartographic inaccuracy on the obtained forest cover distributions. Heterogeneity of maps is not necessary a drawback. Conversely, it randomizes any systematic errors due to cartographic methods excluding their impact on the analyzed historical land-use pattern. Local inaccuracy of medium-scale historical maps is also mostly random; consequently, its impact on analyzed properties decreases inversely with size of a region. The undisturbed dependencies can be due to the fact that the local inaccuracy/study area ratio of different cartographic sources becomes compatible for the scale of 5,000 km^2, making the maps useful for multi-temporal analysis.

Table 2. Diversity metrics and forest cover by forest continuity classes in ecoregions of Zemgale

Ecoregions	*	Forest cover (% of landscape)	Mean tree species richness (species/ha)	Mean stand area (ha)	Forest continuity >220 years (%)	150..220 years (%)	100..149 years (%)	<100 years (%)
Forested lowland	A	67	2.82	1.65	38	20	10	32
Open lowland	B	9	2.77	1.56	6	20	22	52
Mosaic highland	C	36	2.71	1.33	12	22	19	47
Mosaic lowland	D	39	2.47	1.18	5	12	17	66

* The ecoregions are marked in Figure 5 by capital letters. Values of the mean tree species richness and mean stand area are given with standard error less than 1 %.

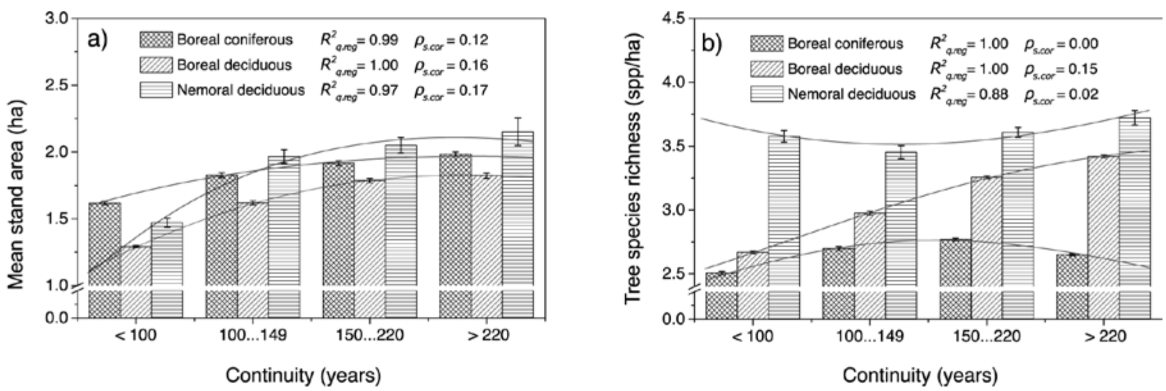

Figure 6. a) Mean stand area by forest types vs. forest continuity. b) Mean tree species richness by forest types vs. continuity. The solid lines are quadratic regression models. Error bars designate the standard error. Coefficients of determination, R^2, for quadratic regression models and Spearman correlation coefficients, ρ, are shown for each forest type

Forest continuity versus mean stand area and tree species richness

Our analysis reveals a positive dependence of the mean stand area on forest continuity, which evidences of a greater fragmentation of stands within post agricultural forest areas (Wagner et al. 2000). This could be explained by various human activities before and during the gradual process of afforestation (Lunt and Spooner 2005), while long-term forest cover tend to eliminate human traces as the stands in the long run take on the pattern formed by abiotic factors, such as soil or relief (Turner 2005).

The study shows a monotonous increase of tree species richness with forest continuity of boreal deciduous stands. We explain it by fertility of the soil, which supports tree species diversity (Rosenzweig and Abramsky 1993, Austin et al. 1996). The boreal deciduous tree species are early successional (pioneer) species, which easy colonize unforested areas due to their ruderal life-history strategy (Brzeziecki and Kienast 1994). Such areas usually are not favourable for germination and growth of competitive nemoral tree species (Brzeziecki and Kienast 1994), allowing the boreal deciduous tree species to form dense homogeneous stands (Aosaar et al. 2011). In a long term, i.e. over several stand rotation periods, forest soils become more fertile due to the increased stock of organic matter (Gimmi et al. 2013), which provides new niches for competitive tree species (Chesson 2000), and the diversity of boreal deciduous stands increases reaching the tree species richness camparable with nemoral deciduous stands (see Figure 6b, >220 years). Previous studies of plant species richness have also shown monotonically increasing dependence for a 60-year successional series (Inouye et al. 1987), and increasing then flattening out with no apparent decrease dependence for a 250-year successional series (Nicholson and Monk 1974). The humpbacked species richness-curve (according to Tilman and Pacala 1993) would have a place if a few highly competitive species monopolize all of the resources, when productivity of forest soil becomes higher (Graham and Duda 2011). Our study has obtained such dependence only for coniferous forest stands, where small decrease of tree species richness occurred after 220 years of continuous forest land use. The dominance of coniferous tree species indicates that such forest communities occur on poor and mesotrophic soils with a limited possibility to host large number of species. Meanwhile the tree species richness of nemoral deciduous forests has neither increasing nor decreasing parts, which can be due to either the insufficiently long studied period, or depressed competition ability of nemoral tree species on the northern border of the nemoral vegetation zone. Besides, widespread nemoral forests, known from the historical records, developed through the interactions of forest ecosystems with herds of wild or domestic ungulates, (Vera 2000) which today practically no longer exist.

Proposed forest management for best biological value

In Zemgale, as in many other regions of Europe, nemoral forests have become rare due to competition with agriculture for fertile soils (e.g. Wulf et al. 2010). Today, the high ecological value of such forests is recognized, pointing to the need to preserve or restore those (Schweitzer et al. 2014). However, in forest management direct afforestation with nemoral tree species requires a fertile land favourable for agricultural use (Valtinat et al. 2008, Ikauniece et al. 2013). Alternative of restoration is, therefore, to promote the natural transformation of early successional forest dominated by *Populus tremula, Betula pendula, Alnus incana* to nemoral forests with high biological value. The boreal deciduous tree species can be used as nurse plants (Ren et al. 2007) facilitating the growth and development of target plant species (i.e. nemoral deciduous tree species), as they prepare benign microhabitats more favourable for seed germination and/or seedling recruitment than depleted agricultural lands or clearings. Similarly, early successional nurse shrubs in Mediterranean region had facilitative effect on the establishment of late-successional woody species (Gómez-Aparicio et al. 2004). A hundred and more years old stands, which are currently dominated by boreal deciduous tree species, should be given priority as primary sources of nemoral forests, and therefore appropriately managed. We believe that cautious thinning and single stem management (Boncina 2011) will facilitate the process of formation of nemoral deciduous forests, while clear cutting with reforestation, which is still widespread in Latvia, impedes their formation by slowing down the process of soil organic matter accumulation (Callaway 1995).

Conclusion

We have shown that the heterogeneous medium-scale historical maps provide consistent information on the historical forest area pattern at the scale of 5,000 km^2, and that noone unknown factor related to imperfection of such maps significantly distorts dependencies of the diversity metrics on the forest continuity. Such regional studies, based on medium-scale maps, diminish the effects of the specific sites and can be particularly useful in areas, where other sources of information are lacking. They could, therefore, be extremely useful to test ecological hypotheses (Eriksson et al. 2010) and to guide future research, restoration and conservation activities (Egan and Howell 2001, Lunt and Spooner 2005). In particular, our map-based study has shown for Zemgale region that: 1) turnover rate between forest and agricultural land-uses is more rapid in recent woodlands than in ancient ones; 2) the mean stand area is larger in woodlands with longer forest continuity regardless to the forest type; 3) the tree species richness of the coniferous woodlands is lower than that of the nemoral deciduous forests, while in the both forest types tree species richness is weakly dependent on the forest continuity; 4) the tree species richness in stands dominated by boreal deciduous (early successional) trees positively depends on the forest continuity, and they regain the properties of nemoral deciduous forests in terms of tree species richness if forest cover lasts over two centuries.

Our results may promote the interests of ecologists and forest managers in using historical maps to identify and protect ancient forests, to estimate carbon stocks in forests, as well as to attract attention to a value of early successional forests with long continuity. Further research will be conducted to study the links between the forest continuity and protected areas, as well as the response of forest habitats, species and functional traits on land-use change.

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