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Zonal assessment of environmental driven settlement abandonment in the Trans-Tisza region (Central Europe) during the early phase of the Little Ice Age

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1. Introduction

1.1. Medieval settlement abandonment

Environment as a ‘protagonist’ in social and economic transformations became a focal issue of palaeoclimatological and historical discourse (McCormick et al., 2007; Campbell, 2010; Luterbacher and Pfister, 2015; Putnam et al., 2016). Still, it is only a small minority, who have considered the impact of medieval climate and environmental change on medieval settlement patterns (Utterstrom, 1954; Kaniewski et al., 2012; McCormick et al., 2012; Xoplaki, et al., 2015). Mainstream historiography discusses epidemics, migration and economic transformation as the underlying reasons for massive settlement desertion and nucleation processes in medieval Europe (Abel, 1980; Dyer, 2010; Curtis, 2013). Dyer’s (1982) observation that the most significant concentration of abandoned late medieval villages in England was noticeable in ‘low-lying valleys and clay plains’ highlighted the necessity of taking into account of hydroclimatic and landscape aspects. Yet, the author ignored climate as a causative factor behind long-term settlement changes. In the case of Wharram Percy, one of the most thoroughly investigated villages in the North-East of England, however, Beresford and Hurst (1990) hypothesized that deteriorating environmental conditions led to its first wave of desertion in the early 14th century (c.). Subsequently, Galloway and Potts’s (2007) reconstruction referred to raising flood vulnerability and settlement abandonment among 13th–15th c. communities living on the Thames bank. Nicholas (1992) observed a similar phenomenon with regard to deserted parishes in late medieval Flanders. Regarding settlement changes in Central Europe the late medieval period was characterized by dynamic processes. It was the age of expansion to the highlands (Gojda, 2005) and the nucleation of settlement patterns. Some densely populated plains, e.g. the Great Hungarian Plain (GHP), saw massive abandonment (F. Romhányi, 2017). To illustrate the magnitude of the regional process, the number of settlements in Germany dropped by some 25% between AD 1350–1450 (Abel, 1980).

Focusing on the study area, it is the Mongol invasion (1241-42), internal migration and urbanization that are generally blamed for the massive settlement abandonment. The earliest study looked at plague and the policies of feudal lordships as the most influential agents behind late medieval settlement desertion in the southern Hortobágy (Zoltai, 1925). Nevertheless, contrary to the overall European picture (Campbell, 2011) no evidence has so far been found to support the idea of a severe plague-induced population reduction in 14th c. Hungary. One of Zoltai's disciples interpreted settlement abandonment in this region as a migration phenomenon within the framework of late medieval land use and economic changes (Balogh, 1953). He concluded to the controversial result that the asymmetries of settlement desertion and concentration were determined by different pedological features when the focus of 13th c. agricultural activity shifted from animal husbandry to plant production (Gábris and Túri, 2008; Gyulai, 2010).

Fig. 1. Study area and the sites of analysed plant macrofossils

1.2 Objectives

Our analysis started from the premise that besides social conditions, it was two environmental factors – flood proneness and potential biomass production – that determined the settlement patterns of pre-industrial temperate lowland societies without navigable waterway networks and water management systems the most (Braudel, 1949). The point that rising water levels and increasing flood vulnerability in the humid periods of the LIA led to a vertical displacement of the settlement pattern in the studied Trans-Tisza Region – similarly to the Atlantic Coast (Grove, 2004), in the valleys of the Thames (Galloway and Potts, 2007), the Danube (Kiss and Laszlovszky, 2013), the Maros (Vadas, 2011) and the Volga (Panin and Nefedov, 2010) – was statistically confirmed in an earlier analysis (Pinke et al., 2016). So, we hypothesized that early LIA hydroclimatic changes increased flood levels of lowland landscapes and significantly narrowed the extension of areas suitable for settling. Consequently, we assumed that deserted settlements – on average – may have been situated lower than permanent ones. We also assumed that the spatial connection between the topographic position of settlements and potential biomass production is demonstrable by statistical tools. In other words, areas highly suitable for cropland farming possessed higher population and settlement density than areas unsuitable for farming within the study area. Third, we presumed that if hydroclimatic changes increased water levels, they must have changed not only the extension and vertical position of settlement patterns, but also the plant composition of the landscape.

2. Spatio-temporal framework

Botanically, the studied 4128 km² plain of East-Central Europe belongs to the forest-steppe belt (Magyari et al., 2010). Climatically, the oceanic, the continental and the Mediterranean effects meet over the region (Pécsi and Sárfalvi, 1964). The mosaic structure of the landscape was characterized by a late Pleistocene and Holocene fluvial system, deeper floodplain basins and relatively elevated relief elements, such as river levees, loess plains and sand ridges, suitable for human habitation and cultivated since the Neolithic (Jankovich et al., 1989). Since the paper focuses on the spatial connection between social, geomorphological and hydroclimatic structures, physical geographical microregions were considered to be a suitable framework (Dövényi, 2010). The same microregional scale was applied when creating the ‘Vegetation-based landscape-regions of Hungary’ (Molnár et al., 2008) and it can also be a potential basis for reconstructions of historic landscape character.

A dendroclimatic analysis revealed that the long-term fall of summer temperatures in the eastern Carpathians began in the mid-13th c. (Popa and Kern, 2009). Albeit the beginning of the LIA in Central Europe is clearly dated to the period between the mid-13th and the early 14th c. (Holzhauser et al., 2005), the magnitude of change and its interpretation is disputed by climatologists (Matthews and Briffa, 2005). As for the hydroclimatic proxies and interpretations, there are only scarce reliable data at hand from the Carpathian region (Kern et al., 2016). A palynological reconstruction suggests that the 11th and the 13th centuries may have been the two driest centennial periods in the past two Millennia (Sümegi et al., 2009). The European drought database also indicates an extremely long drought in 11th–12th c. North-Central Europe (Cook et al., 2015). The overall picture of the 13th c., however, demonstrates a transforming hydroclimatic regime, which is supported by archaeological observations referring to the inundation of late 13th c. settlements around Lake Balaton (Hosszú, 2011; Pálóczi Horváth, 1993). Natural proxies and historical sources indicate a dramatic turn in the first years of the 1300s (Dobrovolný et al., 2015), when an extraordinarily wet episode induced a Malthusian crisis in Europe (Lucas, 1930; Le Roy Ladurie, 1971; Vadas, 2010). The extremity of the early LIA climate regime is indicated by the fact that the second third of the 14th c. saw not only enormous inundations and wet periods with weak crop yields, but also severe droughts (Brázdil and Kotyza, 1995; Campbell, 2010). In the spatial pattern of the initial phase of the LIA, climate deterioration in the Low Countries (today Benelux countries), eastern France, western Germany, Switzerland and northern Italy began in the second third of the 14th c. (Pfister, 1998). In Scandinavia and Greenland, however, a major cooling was documented as early as around 1200, whereby opportunities for grain production dwindled (Matthews and Briffa, 2005). Atlantic coast settlements were hit by violent tempests and coastal flooding from the first decades of the 13th c. (Lamb, 1965).

Besides reconstructions based on biological indicators, the above mentioned results of interdisciplinary archaeological surveys also refer to increasing water levels of water bodies in a number of cases in Europe. In North America a ‘shift away from a marked dependence on agriculture to a heavier emphasis on hunting’ in the Upper Mississippi region from the 13th c. has been interpreted as a climate driven phenomenon (Griffin, 1961, pp. 710–711). The North American Drought Atlas indicates megadroughts in the late 13th c. The first quarter of the 14th c., however, saw positive precipitation anomalies that shrank the size of dry areas in Western North America (Cook et al., 2004). Megadroughts and floods were blamed as environmental factors for the massive late 13th c. abandonment of the settlements in the regions of the San Juan Basin, the Mesa Verde in Western North America (Gumerman et al. 2003; Glowacki, 2015; Monastersky, 2015). Kidder et al. (2008) also concluded that inundations were decisive in the 11th–13th c. transformation of the settlement pattern in the southern region of the Mississippi River Alluvial Plain.

2.1. Hydrological fluxes affecting the settlement pattern of the Great Hungarian Plain

Securing a steady surface free from flood hazard was one of the most substantial aspects of site selection for pre-industrial lowland communities (Braudel, 1949). Most of these settlements, however, lay on the edge of aquatic and terrestrial habitats to have benefit from ecosystem services (Turner et al., 2003). The fact that 92.3% of archaeological sites in the study area representing settlements had waterside positions (Fig. 2) strongly supports this statement (Pinke et al., 2016).

Fig. 2. Settlement traces situated in waterside position. Legend: 1 – abandoned meander; 2 – natural levee; 3 – point bar / swale; 4 – late medieval archaeological site; 5 – high medieval archaeological site; 6 – recent settlement

Regarding the hydrological conditions of the catchment, rivers show their highest water levels between March and June. Before the 19th c. river regulations the runoff peak pushed an enormous water mass into the floodplains almost every year. In the first phase of the LIA, when climatic conditions were changing dramatically, settlements were mushrooming by the thousands in the upper catchment of the Tisza. Along with this process tens of thousands of square kilometres of virgin forests have been destroyed between the 13th and 15th centuries (Szabó, 2005).

Fig. 3. Estimated magnitude of the 20th century surface subsidence in the Great Hungarian Plain (Timár, 2003)

Timár's thesis (2003) discussed the permanent subsidence of certain surfaces of the GHP. Especially in the neighbourhood of the study area (Fig. 3) flood vulnerability has definitely risen over the past century. In summary, climate change, upper catchment deforestation, surface subsidence and the medieval erosion of stream levees, sedimentation of streambeds and floodplain basins (Hoffmann, 2013) may have amplified the flood proneness of lowlands during the first phase of the LIA.

3. Zonal analysis of the historic landscape

Setting up zonal categories for the classification of environmental and social factors is a wide-spread approach in researching spatial processes of societies (McHarg, 1992). There are two examples that inspired and supported this study particularly. One is the 'Ecotype-Based Land Use Analysis of Hungary' (Centeri et al., 2006), which established the zonal selection of areas highly suitable for cropland farming and afforestation in the National Spatial Plan of Hungary. The procedure measured the physical, chemical and hydrological conditions of soils, their lime content and climatic conditions over a 100x100 m grid and established three categories of agro-ecological suitability (weak, medium and excellent), which were adopted in our examination. It is to be emphasized, however, that soil conditions may have changed significantly since the Middle Ages (Bockheim et al. 2005). For example, due to the 18th–19th c. river regulations water fluctuation became more extreme, water table and moisture content of soils lowered, making the landscape more prone to drought. Desiccation of hydromorphic soils – in this area mostly meadow and moor soils – and the effect of climate change led to the alteration of chemical and water condition of soils, as well as their salinity and biomass production (Lechner, 1867; Antal et al., 2000). Considering these points, projecting recent soil and climate conditions and suitability categories back to the early LIA should be done with due care. The other example is historic landscape characterization that evolved from landscape archaeology in Britain and spread over Europe (Clark et al., 2002). This method focuses on mapping and interpreting landscape components (soil, vegetation, archaeological sites, settlement pattern, etc.) and the spatio-temporal relations among their patterns (Roberts and Wrathmell, 2000).

This study classified two environmental aspects of the landscape (geomorphology and agro-ecological suitability) in relation to settlement stability. As a first step, geomorphological classification distinguished three zones (riparian zones, deep floodplains and sand plateaus) based on the dimension and the density of the most typical fluvial and aeolian micro- and mesoforms (oxbow lake, deep floodplain basins, natural levee, ridge, etc.) (Leopold et al., 1995), using a geomorphological database (Gábris and Nádor, 2007; Timár and Gábris, 2008; Gábris et al., 2012) and the SRTM 90x90 m elevation model (nasa.gov; Farr et al., 2007).

In the next step the spatial distribution of settlements and their abandonment was assessed on the basis of archaeological and written evidence (Ecsedy et al., 1982; Jankovich et al., 1989; Györffy, 1963, 1987; Engel, 2001). As a major source we used the data and polygons of cemeteries, churches and settlements of the GIS database of the Hungarian National Office of Cultural Heritage (henceforth: GIS database). According to estimations 66-90% of the entire medieval settlement network is represented in the GIS database with relatively high regional variations.

The periodization of archaeological sites is predominantly based on ceramic finds that split them into two major categories: High Middle Ages (henceforth HMA) (971–1301) (n=377) and Late Middle Ages (henceforth LMA) (1301–1541) (n=209). Historico-archaeological periodization of the HMA and the LMA in Hungary is based on historical events, which essentially cover the Medieval Climatic Anomaly (MCA) (9th–mid-13th c.) and the initial phase of the LIA (late 13th–mid-15th c.) in the region (Holzhauser et al., 2005). This provides an opportunity to compare the settlement patterns of the MCA and the early LIA. Where periodization was ambiguous, or there was continuous occupation the GIS shows a third category – the Middle Ages (MA) – merging the HMA and the LMA. This implies that this group is to be interpreted as a composite group of the HMA and LMA sites, which, according to our hypothesis, also means that its features (e.g. elevations) will differ from those of the HMA group's. Then, we defined permanent, deserted and uninhabited settlement suitability zones within the geomorphological zones. Permanent zones were those, where settlements occurred in both archaeological periods. Since the concentration of the settlement pattern in the High and Late Middle Ages led to a presumably significant, but hardly quantifiable rarefaction of settlements, areas where the number of the settlements merely decreased – however dramatic their decline was – were classified as permanent zones. Areas where HMA sites did exist, but LMA+MA ones were either completely missing or there were only very few and usually temporary ones were defined as deserted zones. Areas where there were neither HMA nor LMA+MA sites were defined uninhabited. Desertion may be understood as a response to a challenge that surpassed the tolerance of communities, deserted zones may also be interpreted as a category of vulnerability.

Finally, by projecting settlement suitability zones onto agro-ecological suitability categories, socio-ecological habitat types were set up (Fig. 7). To trace spatio-temporal changes, the size and the elevation means of the archaeological site groups of the HMA and the LMA+MA were compared in every zone and habitat-type. The elevation of an archaeological site was defined at its lowest point in metres above Baltic Sea level (m) derived from the contour lines of a 1:10 000 topographic map (fomi.hu). Shapiro-Wilk normality test, F-test and visual inspection of histograms show that elevation data distributions deviate from normality and their variances skewed unequally. The differences between stochastic equality of elevation data groups were checked by Brunner–Munzel test using *lawstat* package for R 3.2.4 Revised version (Hui et al., 2008). This method allows the analysis of non-normal distributions and unequal variances. The differences between the ratios in the composition of socio-ecological habitat types were tested for significance using Chi-squared test applying the *Rcmdr* package (Fox, 2005). The relationship between the extension of agro-ecological suitability categories and the number of settlements in the stable and deserted settlement suitability zones of the five microregions was analysed using linear regression model and the normal distribution of residuals with the Shapiro-Wilk test of the *Rcmdr* package.

3.1. Archaeobotanical data and method

Given that only limited pollen evidence suitable for paleoecological reconstructions has been found and dendrological samples are not available in the low-lying areas of the Pannonian Basin, archaeobotanical data are of particular importance. Despite some important achievements in estimating vegetation composition of past open lands, vegetation reconstruction on grasslands or steppe forest biomes based exclusively on pollen is rather problematic (Sugita, 2007; Fyfe et al., 2012; Davis et al., 2014). A substantial size of macrofossil sample, however, may represent all important vegetation types of the landscape (Aarnes et al., 2012; Birks, 2013; Gaillard, 2013). Since plant macrofossil remains are available only from three sites within the study area, we extended the scope of paleobotanical analysis to a ca. 40,000 km^2 area of the GHP (Fig. 1; Tables 7, 8 and 9). This way, we were able to analyse a macrofossil assemblage of the Hungarian Archaeobotanical Database (Gyulai, 2010; Pinke et al., 2015) from 55 sites dating from the studied period (late 10th–mid-16th c.). The periodization of the macrofossil remains is based on the traditional archaeological method (pottery and coin chronologies) just like in the case of the analysed settlements. This nomenclature, however, includes an early HMA (late 10th–mid-13th c.) and a late HMA (second half of the 13th c.) group – making the chronological reconstruction of ecological changes in the landscape more precise. Though remains have no ^{14}C dating, identical periodization of archaeological sites of settlements and macrofossils provides a good opportunity to compare the changes in their spatio-temporal compositions. As to ^{14}C dating, however, it may not provide any major advance in chronology, since the calibration uncertainty for samples of the last 7–800 years could hardly give more accurate chronology than their archaeological periodization.

To estimate the temporal changes in the composition of plant remains, three sets of categories representing the ecological demands and tolerance of certain taxa were used. The first step of our assessment was habitat categorisation of the species (Jacomet et al., 1989). Their habitat types were classified into arid, general and humid categories for both domesticated and non-domesticated species. Plant groups not classifiable from the aspect of ecological conditions were excluded from further investigation. Besides Jacomet's classification, Borhidi's (1995) relative moisture categories ('ecological indicator values') were used to describe the differences between the studied periods with regard to the occurrence of non-domesticated plant species. Borhidi's system was adapted from Ellenberg (1974) to the Pannonian biogeographical region. Following Borhidi's interpretation concerning moisture figures low, general and high categories were established. We assumed that changes in the proportion of species indicating the extreme (arid and humid) and the general categories of habitat types refer to altered environmental conditions. To avoid biased interpretation of the ratios of the number of remains, only the occurrence of taxa was recorded and the number of taxa occurring in particular habitat, moisture categories was compared using Chi-squared test.

4. Results

4.1. Connections between geomorphological conditions and the stability of the settlement pattern

The results show that riparian zones had the most permanent settlement pattern. Differences among the elevations of natural levees and thalwegs proved averagely ca. 1.7–2 times higher than the levels of the uninhabited or deserted zones. Uninhabited zones occurred in the deep floodplain and sand plateau zones (Fig. 4; Table 1, row 2), where only some small archaeological sites, such as remains of isolated hamlets and seasonal dwellings were traceable.

Fig. 4. Settlement suitability zones in the study area

Deserted zones appeared in two geomorphological settings: in low levees enclosed by flood zones and in low-lying areas of high and wide riparian levees bordering deep floodplains. No other zone preserved the picture of dispersed and relatively dense pattern of HMA sites as clearly as the deserted zones (Table 1, rows 1 and 3).

Table 1 Archaeological site density, percentage of HMA archaeological sites in settlement suitability zones and the area of settlement suitability zones

	Archaeological site density	Archaeological sites (HMA)	Area
	Number of sites/10 km^2	%	%
1. Permanent	2.5	56.0	39.2
2. Uninhabited	0.1	3.7	47.1
3. Deserted	2.9	40.3	13.7

Comparison of the elevation means of archaeological sites, the HMA and LMA+MA site groups of permanent zones showed significantly higher elevation means than the deserted areas (Fig. 5). Additionally, the LMA+MA site group was situated, on average, significantly higher than the HMA group within the permanent zones. On the one hand, it means that settlement suitability zones that were densely populated in the HMA and deserted by the end of the 13th c., were situated lower on average than permanent population zones. On the other hand, this result shows that the elevation levels of settlements rose significantly from the HMA to the LMA.

Fig. 5. Density, means and standard errors of tested archaeological site elevations (MASL) in settlement suitability zones. Table below: differences between the elevation means of archaeological site groups and Brunner–Munzel test results. ΔMASL=differences between elevation means; df=degrees of freedom; p=test result

4.2. Connections between agro-ecological suitability and the stability of settlement patterns

Table 2 demonstrates considerable differences among settlement suitability zones with regard to agro-ecological suitability. For instance, the proportion of areas with excellent agro-ecological suitability was 1.5–2 times higher in the permanent zones than in the other two settlement suitability zones (Table 2; Fig. 7). Chi-squared test results showed a significant difference ($p<0.01$) in the agro-ecological composition of the three agro-ecological suitability zones (Table 2, rows 2 and 4).

Table 2 Percentage of the three agro-ecological categories (AEC) and archaeological sites (AS) in settlement suitability zones

		Weak		Medium		Excellent	
		AEC	AS	AEC	AS	AEC	AS
1.	Total area	28.1	14.5	48.4	54.9	23.5	30.5

2.	Permanent	23.7	13.3	45.3	50.5	31.0	36.2
3.	Uninhabited	30.7	13.0	49.5	47.8	19.9	39.1
4.	Deserted	31.6	17.6	54.9	66.7	13.5	15.8

Table 2 refers to the fact that as opposed to areas with weak agro-ecological suitability excellent areas attracted settlements in greater proportion than their spatial ratio. It is partly this spatial relationship that has been revealed by linear regression results too (Table 3).

Table 3 Linear relationship between the extension of socio-ecological habitat types and the number of their settlements by historico-archaeological periods

	Weak	Medium	Excellent	Weak	Medium	Excellent
		R^2			p	
LMA+MA	0.60	0.57	0.50	0.01	0.01	0.02
HMA	0.14	0.67	0.04	0.29	<0.01	0.60

Fig. 6. 3D scatterplot of multiple regression between medium and excellent settlement suitability zones and the number of LMA+MA sites

The findings of the regression analysis also suggest that groups of the noticeably more dispersed HMA settlements indicated a significant relationship exclusively with the extensions of areas with medium agro-ecological suitability (Table 3). Conversely, the number of lower and more concentrated LMA+MA site groups showed significant relationship with the extensions of two agro-ecological categories (Table 3). Multiple regression test indicates that the spatial dispersion of HMA sites was determined only by areas with medium agro-ecological suitability. By contrast, dispersion of LMA+MA sites showed a strong linear relationship with the extension of areas with medium and excellent suitability (R^2=0.78; df=7; p=0.02) (Fig. 6).

Fig. 7. Combinations of agro-ecological suitability categories and settlement suitability zones: habitat types

4.3. Changes in the medieval composition of archaeobotanical remains

When categorizing taxa by ecological conditions, we see that the ratios of species from arid and humid habitat types are practically equal in the HMA and in the LMA (Table 4). However, the proportion of species with high moisture demand increased significantly from the early HMA (11th–mid-13th c.) to late HMA (second part of the 13th c.) ($X^2=5.6$; df=1; $p=0.02$). This transformation takes place simultaneously with the MCA-LIA transition (Holzhauser et al., 2005; Popa and Kern, 2009). Along with this trend, the ratio of species of arid habitat types did not change significantly (Table 4).

Table 4 Taxa of archaeobotanical remains from the examined 55 archaeological sites classified in Jacomet's et al.'s (1989) habitat types

Habitat type	Humidity	Early HMA	Late HMA	Non-divided HMA	Merged HMA	LMA
1.1 submerse aqueous plants	humid	0	2	0	2	0
2.1 reed habitat	humid	2	6	2	9	5
2.2 high sedge habitat	humid	2	6	2	6	7
2.3 watershore pioneers	humid	1	5	3	5	8
3.1 marshland plants	humid	3	15	0	16	14
3.2 wet perennials	humid	0	3	2	3	4
2./3 diverse waterside plants	humid	2	3	0	4	5
4 wet forest	humid	2	2	0	3	6
4.1 wet fragmented forest	humid	0	1	0	2	2
4.2 grove forests	general	2	3	2	4	9
5 fresh and light mixed forest	humid	0	2	0	2	2
6 shady forest	general	0	2	0	2	4
7.1 cleared forest, shrubby	general	0	3	1	3	7

habitat						
7.2 general forest side association (general)	general	2	3	2	5	11
7.3 general forest side association (arid)	arid	1	1	0	1	4
8.1 wet meadow	humid	3	18	6	18	19
8.2 general meadow habitat	general	17	36	13	39	40
8.3 arid meadow and rocky grass	arid	3	13	10	17	15
9.1 cultivated plants	general	16	44	0	47	55
9.2 root or spring weed	general	7	13	2	13	11
9.3 cereal or autumn crop weed	general	18	33	23	41	51
10.1 humid ruderal habitat	humid	3	12	4	12	16
10.2 general ruderal habitat	general	16	25	15	28	30
10.3 arid ruderal habitat	arid	6	10	6	13	7
Number of taxa		106	261	93	295	332

As for the evaluation based on Borhidi’s (1995) ecological indicator system showed that the proportion of plants with extreme values did not change significantly. Considering moisture demand, a trend-like increase in the ratio of species with high demand (Table 5, rows 7–9) and of aquatic plants (Table 5, rows 10–12) can be observed in the second half of the 13th c. Numerous aquatic species could be documented for the late HMA such as: *Bolboschoenus maritimus, Carex lasiocarpa, C. riparia, C. rostrata, Ceratophyllum submersum, Eriophorum vaginatum, Potentilla. palustris, Rhynchospora alba, Rumex hydrolapathum, Schoenoplectus mucronatus, Trapa natans* and *Typha angustifolia*.

Table 5 Distribution of the medieval archaeobotanical taxa within Borhidi’s (1995) relative moisture categories

		Early HMA	Late HMA	Non-divided HMA	Merged HMA	LMA
1. Plants of extremely dry habitats or bare rocks	arid	0	0	1	1	0
2. Xero-indicators on habitats with long	arid	5	9	5	10	9

dry period						
3. Xero-tolerants, but eventually occurring on fresh soils	arid	11	26	17	34	42
4. Plants of semidry habitats	general	26	61	30	65	67
5. Plants of semi-humid habitats, under intermediate conditions	general	20	37	17	42	55
6. Plants of fresh soils	general	8	18	9	20	27
7. Plants of moist soils not drying out and well aerated	humid	6	23	4	23	25
8. Plants of moist soils tolerating short floods	humid	5	12	4	13	15
9. Plants of wet, not well aerated soils	humid	3	15	2	16	19
10. Plants of frequently flooded soils	humid	4	9	3	13	8
11. Water plants with floating or partly emergent leaves	humid	0	1	0	1	1
12. Water plants, most wholly submersed in water	humid	0	1	0	1	0
Number of taxa		88	212	92	239	268

4.4. Case studies

4.4.1. Southern Hortobágy

No microregions illuminate the severity of late medieval settlement abandonment of the GHP and the differences of geomorphological and soil conditions in permanent and deserted zones so unequivocally as the Hortobágy microregion. Relatively high elevation differences (1.5–3.5 m) and the number of oxbow lakes in its northern part define this area as a riparian zone. There are only slight differences between thalwegs and levees (1–2 m) and a few banked up oxbow lakes that make contrast between the southern and northern parts of the landscape. As opposed to the north where settlement density grew spectacularly, the relatively low natural levees of the Hortobágy River and the Árkus Brook in the south saw a severe drop in the number of archaeological sites (Fig. 4). This rapid depopulation is also reflected in written documents (Módy, 1972). There, only a narrow strip of levees bordering the landscape from the south-east was selected as a permanent settlement suitability zone where two settlements

(Újváros and Nádudvar) remained inhabited and developed into market towns by the early Modern Age (Fig. 4). Apart from some scattered and small hamlets, most of southern Hortobágy (ca. 1000 km^2) eventually became deserted land (Fig. 7).

The difference between the agro-ecological suitability in the permanent and the deserted or in the permanent and the uninhabited zones of the two parts of the microregion is also conspicuous and statistically significant ($X^2=84.6$; df=2; $p<0.01$) (Table 6). The ratio of excellent agro-ecological areas in the zone of permanent settlement pattern in the Hortobágy was 2.5 times higher than in the deserted and uninhabited zones. Conversely, the deserted and uninhabited zones of the microregion were dominated by areas with low agro-ecological suitability.

Table 6 Percentage of agro-suitability categories in the southern and northern parts of the Hortobágy microregion

	Southern Hortobágy, %	Northern Hortobágy, %
Excellent	20.0	30.8
Medium	36.3	48.9
Weak	43.7	20.2

4.4.2. Abandoned low levees and the edge of riparian zones

Low and narrow levees were typical geomorphological formations within deserted areas. One of them is the Ösvény levee, western and eastern parts of which are separated by a relatively sharp ca. 1 meter high scarp. In the western part, all but one settlements were deserted before AD 1300, and the only remaining village – Ösvény 85.4m – also became a ghost settlement by the end of the 14th c. (Fig. 7). The late 18th c. map of the First Military Survey of the Habsburg Empire (1763-1787) depicted a water covered floodplain in the place of the once dense HMA settlement structure in the western levee. Darásülése, a small hamlet lying in the border zone between the western and eastern parts, was abandoned in the HMA (Ecsedy et al., 1982) (Fig. 4). The highest elevation of its polygon (86.3 m) protrudes only 1.3 m above the thalweg of the stream bordering the village. This relatively small difference is likely to have made the settlement highly vulnerable to floods. Császárülése, identified 1.7 km to the east, situated at 87.0 m (Ecsedy et al., 1982), was deserted probably before AD 1480. Káta, an abandoned village with an elevation of 86.5 m was found on the flood prone edge of the riparian zone, may have been deserted before the beginning of the 15th century (Ecsedy et al., 1982). The neighbouring Pázmány, situated only 1 m higher, survived until the end of the late 17th c. when the Ottomans destroyed the village (Fig. 4). The reason why Császárülése, Darásülése and Káta were abandoned remains unknown, but they might have been exposed to inundations to a different degree, due to the small differences (0.7 and 1 m) in their elevations. Thus, the relative stability of Császárülése and Pázmány may not be accidental. Another point is that these settlements lay closer to the permanently inhabited eastern part of the levee, which possibly provided more favourable road access.

4.4.3. Permanent settlement pattern on the edge of sand plateaus

An example of the functional relation of residents to ecological conditions was unearthed on the edge of one of the sand plateaus and the Tisza River (Horváth, 1970). The excavated finds of village Örvény and the structure of the settlement revealed two communities within the village with different lifestyles, sharply reflected by their different habitat types. The tools found in the houses of the riparian part (nets, fish hooks, arrows and a few agricultural tools) refer to a uniform fishing and hunting lifestyle. Agricultural tools, grain pits and stone ovens, however, point to arable farming as the livelihood of the other part of the community whose houses crept up the sand plateau (Laszlovszky, 1991). The map of the First Military Survey clearly demonstrates that the settlement pattern around the frontiers of the sand plateaus was similar to its medieval precedent (Fig. 4 and 7), and also that the internal parts of the plateaus were cultivated.

4.4.4. The monastic network

The medieval monastic network of the investigated area was loose and underdeveloped. It comprised five abbeys in the HMA: Bűd (first mentioned: 1239), Zám (1220), Ohat (1220), Tomaj (1322) and Szerep (1283) (Fig. 4). As for the overall evolution of the monastic network in the GHP, archaeological investigations revealed that most monastic sites were established much earlier than their earliest references in the documents (Mesterházy, 1969, 1970; Németh, 1997; F. Romhányi, 2000). Similarly to the dynamics of the reconstructed settlement desertion, the above mentioned monasteries were all abandoned before AD 1350. Although several monastic orders had lands within the study area, in the late medieval period there were no monastic institutions settled here. There was only one failed attempt of Pauline Hermits, who tried to found a monastery in Kenderes (1453), which lasted for two decades.

5. Discussion

Relying on the zonal and statistical analyses of archaeological sites as well as on the evaluation of plant remains, our study provided evidence for systematic changes on a broader landscape scale. Besides this contribution, by combining different datasets on a GIS platform, we were able to trace the impact of various environmental factors on medieval settlement structure. Firstly, a significant shrinkage of the area of habitation was observed in the initial phase of the LIA (late-13th–mid-16th c.) (Fig. 4; Table 1). Settlements affected by depopulation lay mostly in the area of low levees, marsh islands and in the low margins of fluvial ridges. Comparing the elevation means of archaeological sites, settlement locations in the permanent zone proved significantly higher than those of deserted areas (Fig.4 and 5). The zonal analysis also showed that within the permanent settlement zone HMA sites were situated lower than LMA+MA sites (Fig. 5). The significantly lower elevation means of the HMA settlements undoubtedly imply higher flood vulnerability.

The shrinkage and vertical displacement of inhabited areas and the significantly growing proportion of plants with humid environment tolerance (especially species of aquatic habitats) during the second half of the 13th c. indicate parallel processes in human and natural structures (Table 2, 4 and 5; Fig. 5). Although late 13th c. deforestation in the upper catchments surely increased the extension and flood vulnerability of water covered areas in the lowlands, it is chiefly the long-term transformation of the hydroclimatic regime that drove the permanent expansion of water bodies. Since ‘hydroclimatic conditions of the region remain even more poorly quantified’ (Cook et al., 2015; Kern et al., 2016), it is a substantial contribution of this paper that we could illuminate a short but crucial transition phase in the overture of the LIA. This late 13th c. period spanning only a few decades is important not only from a climatological aspect, but also as a period of great social transformations. The newly explored, hydro-climate driven settlement abandonment was accompanied by the enormous internal migration process that took place in the Hungarian Kingdom (Makkai, 1990). This dynamism justified the hypothesis concerning the pulsation of pre-industrial waterside settlement patterns lacking water management systems. Our observations also confirmed the supposition that human settlement pattern, as those of other communities living on the edge (Murray-Wallace, 2013), can be interpreted as indicators of hydroclimatic water level changes. The reconstructed late 13th c. transformations in the composition of plant remains and settlement structure signal not a mere transitional change, but a ‘longue durée’ structural transformation of the landscape. It is the prologue of the new cultural landscape phase that lasted until the 19th c. modernization, or – in a climatic context – until the end of the LIA. Its most characteristic features were the expansion of humid habitats and – from the point of view of land use systems – the growing significance of extensive animal husbandry as well as the growing diversity of domesticated plants. The increasing share of rye (a cereal with the greatest resistance to humidity and cold) also seems to be a substantial element in the cultural landscape from the late 13th c. (Gyulai, 2010). Table 1 suggests that uninhabited and deserted zones account for ca. 60% of the study area – and we estimate a similar ratio for the entire 110.000 km^2 of the GHP. The extension of this area where seasonal inundations supplied relatively high grass yields helps understand how the Kingdom of Hungary became a top player in European cattle trade by the 15th c (Blanchard, 1986).

The transformation of the settlement pattern could be observed not solely in deserted zones, which occupied 13.7% of the study area (Table 1), but also in the permanent zone. We have only insufficient evidence at our disposal to trace the causes behind the nucleation process that crystallized a fairly steady and sparse settlement structure. Having examined the geomorphological conditions in permanent settlement suitability zones we may conclude that hydrological changes might also be in part responsible for the nucleation process in this settlement pattern. Interestingly, a considerable similarity appears between the patterns of depopulation of the British Midlands and the Hungarian Great Plain during the LMA. Dyer (1982) says that the highest concentration of abandoned settlements in Britain was detected in low lying plains and valleys with clay soils. Soils with high clay content and with low or extremely low water absorption capacity are characteristic in floodplains just like in the deserted zones of our study area.

The presented agro-ecological zone approach illuminated another explanatory factor behind the stability and instability of settlement patterns. The results showed that the ratios of agro-ecological categories within permanent and deserted zones differed significantly (Table 3). They also revealed that the excellent zones attracted people to settle down in higher proportions than the weak zones (Table 2). A relevant point is that surface elevation and exposure to hydrological effects influenced the physical and chemical conditions of soils, consequently, there is a potential correspondence between the geomorphological and agro-ecological features. The disclosure of such interaction systems needs more complex interdisciplinary investigations (Deák et al., 2011). Archaeological and written sources recorded a great number of fishing and pastoral communities (e.g. farmstead settlements) in deserted zones (Jankovich et al., 1989; Györffy, 1963). Farming activities of these high medieval communities were less dependent on agro-ecological suitability for arable farming. Testing the interrelations of the extension of socio-ecological habitats and the number of settlement traces by the linear model sharp differences appeared in coefficients of the two studied periods. This result also suggests that the issue of agro-ecological suitability in high medieval farming did not bear such importance as in the LMA. The synchronism between historico-archaeological evidence and the statistical test result confirms the potential effectiveness of classifying the area into agro-ecological habitat types when researching the evolution of settlement patterns.

The frequent occurrence of dispersed settlements in the low-lying areas suggests that their population is likely to have swarmed out to flood risk areas in arid periods. Most of this process took place between the 10th and the early 12th centuries, as shown by archaeological evidence recovered just north of the study area (Méri, 1952). Their abandonment may be related to various events and processes. Some argue that it was the Mongol Invasion (1241-1242) (Györffy, 1987), however, the majority of settlements in the central and eastern parts of the study area lost their population only by the end of the 13th c. (Módy, 1972). There is no doubt that the almost complete disappearance of farmstead settlements ended by the 14th century and this supports the argument that desertion was a response to political turmoil, internal migration and the reconfiguration of the feudal agrarian system. In contrast to these points, we concluded that low-lying areas saw massive abandonment due to hydroclimatic changes as early as in the 13th c.

As illustrated by the case study on sand plateaus (Section 4.4.3), environmental conditions appear as strong determinants regarding rural lifestyles, which could be configured in complex ways within the spatial units of settlements. Not only did the elevation of these plateaus provide constant flood protection for people, but their medium and excellent soils also provided favourable conditions for settling (Fig. 7). Yet, it is only their narrow riparian edge that proved suitable for occupation and their internal zones remained almost totally uninhabited during the MA. (It is presumably the relatively deep water table of these plateaus – as a limitation to access freshwater – that made these areas less favourable for settling). The ecological and geomorphological border of the plateaus, however, functioned as a sharp socio-ecological dividing line in terms of economic strategies and land-use of riparian settlements like Örvény.

As a consequence of the massive settlement abandonment all the early monastic sites were deserted on the GHP before 1350 AD (Section 4.4.4). The Mongol invasion (1241–1242 AD) supposedly affected these institutions. Most of them attempted to re-establish themselves, however, none of them succeeded. The vanishing monastic network reflects the regionally decreasing population density in the LMA, which stands in sharp contrast with the contemporary expansion of mendicant monasticism in Hungary and in Central Europe in general (F. Romhányi, 2016). While local monastic sites were abandoned, this loosely settled area remained attractive for some other monastic communities as an agricultural resource (animal husbandry), which continued to be interested in possessing lands in the area.

6. Conclusions

In certain regions of Western Europe massive settlement abandonment seems to occur in conjunction with conversion between dominant land use forms – from croplands to pastures (Curtis, 2013). As a consequence of rapidly rising wages (driven by the 14th c. demographic crisis) and urbanization pressure, as well as of deteriorating environmental conditions, arable farming lost its profitability, while the rising demand for wool created more demand for pastures (Campbell, 2010). This did not always happen at the same time. At Wharram Percy, for example, manorial lands were turned into pastures around the early 16th c. Le Roy Ladurie and Pesez (1965) argued that in France, contrary to England, it was not the process of enclosures that forced people out of their lands and led to the desertion of villages, but settlement abandonment happened before these lands were converted to pastures. As for Hungary, the first document that undoubtedly refers to enclosures, dates back to 1494. Therein, John of Corvin as the landlord of Sziget – a village situated only a dozen kilometres to the east of Hortobágy –, regulated the rights of ownership and the forms of land use in order to secure grazing rights and prohibit arable farming (MNL OL DF 278835): '*...easdem terras nunquam arare, sed semper usui pecudum boum vestrorum, quam praefatorum civium* *nostrorum supplicantium permisimus... [we allow that these fields should never be ploughed, but they should remain for the use of your stock, as well as of our aforesaid burghers who asked for it].'* The name of the village appears later on in late 15th c. tax records, but not in 16th c. Turkish tax collections (defterler) (Engel, 2001), this suggests that it became depopulated by the mid-16th c. Apart from this single example, no other substantive evidence has yet been found to support a trend similar to the English one, where 'sheep devoured men' (More, 1516).

In general, written sources do not provide sufficient information about the potential factors of desertion. Despite the fact that there is a relatively large a host of court cases recorded in medieval charters, they do not report systematically on natural disasters or anything else that would explain changes in the settlement pattern on such a large scale. Although these sources fail to explain possible causes, they paint a detailed picture about the outcome of this late medieval landscape transformation. We see that market towns tended to gain control over both the uninhabited and the deserted zones, developing their economic activities by focusing on extensive animal husbandry, while becoming the targets of migration from deserted zones. Evidence on urban monasteries also reveal that their economic activities in the 15th century were connected to animal husbandry in the region. An illustrative example is the unusual alms received by the Franciscans in Debrecen (the only town in the northern part of the GHP, where there was a monastic community): the order received half of the tongues of the oxen butchered in the town's shambles (Archive of the Franciscan Friary in Bratislava, Lad. XXXI).

The above cited studies on different regions of Europe and North America suggest that the early phase of the LIA brought positive precipitation anomalies and increasing water cycle extremities causing settlement desertion in certain vulnerable areas – including the border zones of aquatic habitats. The present zonal method can be considered as a step in developing explanatory models for identifying socio-natural causative factors of the transformation of social structures situated in low-lying areas. Thematic comparisons of land-use and settlement systems of great plains together with their cultural and environmental context may provide a broad perspective for archaeological and historical narratives. This makes exploring wider correlations of human-nature interactions possible. Future investigations have yet to clarify this issue, but not solely out of historical curiosity. As researchers have realized the necessity of better understanding and mapping anthropogenic effects, e.g. settlement and population density or land use, the reconstruction of historic land cover recently gained importance in climate modelling (Kaplan et al., 2010; Pongratz et al., 2010; Goldewijk et al., 2011). This direction of research is particularly relevant in the case of open lands (Gaillard et al., 2010). Our analysis revealed that the size of temporarily or constantly water covered areas as well as grazing lands increased considerably (by ca. 50%), while arable lands became more concentrated, typically in highly suitable zones in the first phase of the LIA. The increase of water covered areas raised the albedo and transformed the pattern of evaporation, which may have induced a perceptible transformation in the microclimate and also in the regional climate system. Taking into account that aquatic habitats are distinguished places with a huge potential to store carbon, nitrogen and phosphorus influencing biochemical fluxes at a wider scale, the assessment of anthropogenic impacts – i.e. changes in the land use system and the settlement pattern – are particularly important in the context of getting more accurate readings and interpretations of climate and environmental changes in the studied landscape type.

6.1. Final remarks

Medieval evolution of the UNESCO World Heritage Hortobágy landscape, a home to one of the most extensive protected natural grasslands in Europe, culminated in almost total settlement abandonment. Agents shaping the process have been widely discussed in Hungarian landscape historiography, though relying only on scanty direct written or archaeological sources. Given that this transformation of the settlement pattern has determined the actual character of the landscape to date and the ecological values of the area have been recognized and their restoration has been initiated (Török et al., 2012), the present investigation has a particular relevance not only from climatic or historical, but also from a landscape ecological point of view (Swetnam et al., 1999).

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8. References

Aarnes, I., Kühl, N., Birks, H.H., 2012. Quantitative climate reconstruction from late-glacial and early Holocene plant macrofossils in western Norway using the probability density function approach. Rev. Palaeobot. Palynol. 170, 27–39. doi:10.1016/j.revpalbo.2011.11.001

Abel, W., 1980. Agricultural Fluctuations in Europe: From the Thirteenth to the Twentieth. Methuen and St Martin Press, London – New York.

Antal, E., Járó, Z., Somogyi, S., Várallyay, Gy., 2000. A XIX. századi folyószabályozások és ármentesítések földrajzi és ökológiai hatásai Magyarországon (Geographical and Ecological Impacts of River Channelization and Flood Control Measures]. Geographical Research Institute, HAS, Budapest.

Balogh, I., 1953. Adatok az Alföld középkori régészetéhez [Data of the archaeology in the Great Hungarian Plain]. Arch. Ért. 2, 141–150.

Beresford, M.W., Hurst, J.G., 1990. Wharram Percy: Deserted Medieval Village. B.T. Batsford – English Heritage, London.

Birks, H.H., 2013. Plant Macrofossil Introduction. in: Elias, S.A. (Ed.), Encyclopedia of Quaternary Science. Elsevier, Vol. 4, pp. 593–612.

Blanchard, I., 1986. The Continental European Cattle Trades, 1400-1600. The Economic History Review 39, 427–460.

Bockheim, J.G., Gennadiyev, A.N., Hammer, R.D., Tandarich, J.P., 2005. Historical development of key concepts in pedology. Geoderma 124, 23–36. doi:10.1016/j.geoderma.2004.03.004

Borhidi, A., 1995. Social behaviour types, the naturalness and relative ecological indicator values of the higher plants in the Hungarian Flora. Acta Bot. Hung. 39, 97–181.

Braudel, F., 1949. La Méditerranée et le Monde Méditerranéen a l'époque de Philippe 1–3. [The Mediterranean and the Mediterranean World in the Age of Philip II]. Armand Colin, Paris.

Brázdil, R., Kotyza, O. 1995. History of Weather and Climate in the Czech Lands I (Period 1000-1500). Zür. Geogr. Schr. 62. Geographisches Institute, Zürich.

Campbell, B.M.S., 2010. Nature as historical protagonist: environment and society in pre-industrial England. Econ. Hist. Rev. 63, 281–314. DOI: 10.1111/j.1468-0289.2009.00492.x

Campbell, B.M.S., 2011. ‘Panzootics, pandemics and climatic anomalies in the fourteenth century’, 177–215. in: Herrmann, B. (Ed.), Beiträge zum Göttinger Umwelthistorischen Kolloquium 2010-2011. Universitätsverlag Göttingen, Göttingen, pp. 177–215.

Centeri, C., Belényesi, M., Halász, T., Kristóf, D., Magyari, J., Neidert, D., Pataki, R., Podmaniczky, L., Schneller, K., 2006. Magyarország ökotípusos földhasználati vizsgálata: Agráralkalmassági-környezetérzékenységi elemzés Magyarország területére [Ecotype-Based Land Use Analysis of Hungary: Agro-Suitability and Enviro-Vulnerability]. Környezet- és Tájgazdálkodási Tervező Iroda, Gödöllő.

Clark, J., Darlington, J., Fairclough, G., 2002. Using Historic Landscape Characterisation. English Heritage – Lancashire County Council, Lancashire.

Cook, E.R., Woodhouse, C.A., Eakin, M.C., Meko, D.M., Stahle, D.W., 2004. Long-Term Aridity Changes in the Western United States. Science 306, 1015–1018. DOI: 10.1126/science.1102586

Cook, E.R., Seager, R., Kushnir, Y., Briffa, K.R., Büntgen, U., Frank, D., Krusic, P.J., Tegel, W., Schrier, G., Andreu-Hayles, L., Baillie, M., Baittinger, C., Bleicher, N., Bonde, N., Brown, D., Carrer, M., Cooper, R., Čufar, K., Dittmar, C., Esper, J., Griggs, C., Gunnarson, B., Günther, B., Gutierrez, E., Haneca, K., Helama, S., Herzig, F., Heussner. K.U., Hofmann, J., Janda, P., Kontic, R., Köse, N., Kyncl, T., Levanič, T., Linderholm, H., Manning, S., Melvin, T.M., Miles. D., Neuwirth, B., Nicolussi, K., Nola, P., Panayotov, M., Popa, I., Rothe. A., Seftigen, K., Seim, A., Svarva, H., Svoboda, M., Thun, T., Timonen, M., Touchan, R., Trotsiuk, V., Trouet, V, Walder, F., Ważny, F., Wilson, R., Zang, C., 2015. Old World megadroughts and pluvials during the Common Era. Sci. Ad. 1, e1500561 DOI: 10.1126/sciadv.1500561

Curtis, D.R., 2013. The Emergence of Concentrated Settlements in Medieval Western Europe: Explanatory Frameworks in the Historiography. Can. J. Hist. 48, 223–251.

Davis, B.A.S., Collins, P.M., Kaplan, J.O., 2014. The age and post-glacial development of the modern European vegetation: a plant functional approach based on pollen data. Veg. Hist. Archaeobot. 24, 303–317. doi:10.1007/s00334-014-0476-9

Deák, B., Valkó, O., Kelemen, A., Török, P., Miglécz, T., Ölvedi, T., Lengyel, S., Tóthmérész, B., 2011. Litter and graminoid biomass accumulation suppresses weedy forbs in grassland restoration. Plant Biosyst. 145, 730–737.

Dobrovolný, P., Rybnícek, M., Kolár, T., Brázdil, R., Trnka, M., Büntgen, U., 2015. A tree-ring perspective on temporal changes in the frequency and intensity of hydroclimatic extremes in the territory of the Czech Republic since 761 AD. Clim. Past 11, 1453–1466. doi:10.5194/cp-11-1453-2015

Dövényi, Z., 2010. Magyarország kistájainak katasztere [Cadastre of the Geographical Microregions in Hungary]. Geographical Institute of the Hungarian Academy of Sciences, Budapest.

Dyer, C., 1982. Deserted Medieval Villages in the West Midlands. Ec. Hist. Rev. 35, 19–34. DOI: 10.1111/j.1468-0289.1982.tb01184.x

Dyer, C., 2010. Villages in crisis: social dislocation and desertion, 1370–1520. in: Dyer, C., Jones, R. (Eds.), Deserted Villages Revisited. University of Hertfordshire Press, Hertfordshire, pp. 28–45.

Ecsedy, I., Kovács, L., Maráz, B., Torma, I., 1982. Magyarország Régészeti Topográfiája 6. Békés megye, Szeghalmi járás [Hungarian Archaeological Topography 6. Békés County, Szeghalom Discrit]. Akadémiai Kiadó, Budapest.

Ellenberg, H., 1974. Zeigerwerte der Gefässpflanzen Mitteleuropas Scripta Geobotanica 9. [Indicator Values of Central European Vascular Plants] Goltze Verlag, Göttingen.

Engel, P., 2001. Magyarország a középkor végén. Digitális térkép és adatbázis a középkori Magyar Királyság településeiről [Hungary at the end of the Middle Ages. Digital map and database of the settlements of the medieval Kingdom of Hungary]. Magyar Tudományos Akadémia Történettudományi Intézete – Térinfo Bt, Budapest.

Farr, T.G., Rosen, P.A., Caro, E., Crippen, R., Duren, R., Hensley, S., Kobrick, M., Paller, M., Rodriguez, E., Roth, L., Seal, D., Shaffer, S., Shimada, J., Umland, J., Werner, M., Oskin, M., Burbank, D., Alsdorf. D., 2007. The Shuttle Radar Topography Mission. Rev. Geophys. 45, RG2004. doi:10.1029/2005RG000183

Fox, J., 2005. The R Commander: A Basic-Statistics Graphical User Interface to R. J. Stat. Softw. 14, 1–42. DOI:10.18637/jss.v014.i09

F. Romhányi, B., 2000. Kolostorok és társaskáptalanok a középkori Magyarországon [Monasteries and Collegiate Chapters in Medieval Hungary]. Pytheas, Budapest.

F. Romhányi, B., 2017. Changes of the 11th–13th century Settlement System in the Hungarian Plain: The Testimony of the Monastic Network. in: Szabó, Á., Takács, M. (Eds.), Festschrift for Andrea Vaday. Budapest. (in print)

Fyfe, R., Roberts, N., Woodbridge, J., 2012. A pollen-based pseudobiomisation approach to anthropogenic land-cover change. Holocene 20, 1165–1171. doi:10.1177/0959683610369509

Gábris, Gy., Horváth, E., Novothny, A., Ruszkiczay-Rudiger, Z., 2012. Fluvial and Aeolian landscape evolution in Hungary – results of the last 20 years research. Neth. J. Geo. 91, 111–128. DOI: http://dx.doi.org/10.1017/S0016774600001530

Gábris, Gy., Nádor, A., 2007. Long-term fluvial archives in Hungary: response of the Danube and Tisza rivers to tectonic movements and climatic changes during the Quaternary: a review and new synthesis. Quat. Sci. Rev. 26, 2758–2782. doi:10.1016/j.quascirev.2007.06.030

Gábris, Gy., Túri, Z., 2008. Homokmozgás a történelmi időkben a Tiszazug területén [Sand moving periods in historic times near Tisza River]. Földr. Közl. 132, 241–250.

Gaillard, M-J., 2013. Archaeological Applications. in: Elias, S. (Ed.), Encyclopedia of Quaternary Science. Elsevier, Vol. 4, pp. 880–903.

Gaillard, M-J., Sugita, S., Mazier, F., Trondman, A.K., Brostrom, A., et al., 2010. Holocene land-cover reconstructions for studies on land cover-climate feedbacks. Clim. Past 6, 483–499. doi:10.5194/cp-6-483-2010

Galloway, J.A., Potts J.S., 2007. Marine flooding in the Thames estuary and tidal river c. 1250–1450: Impact and response. Area 3, 370–379. DOI:10.1111/j.1475-4762.2007.00753.x

Glowacki, D.M. 2015. Living and Leaving. A Social History of Regional Depopulation in Thirteenth-Century Mesa Verde. University of Arizona Press, Tucson.

Gojda, M., 2005. Features, Sites and Settlement Areas in the View of Air Survey (Bohemia, 1992–2003). A Century of Information. Bourgeois, J., Meganck, M. (Eds.), Academia Press, Ghent, pp. 101–112.

Goldewijk, K.K., Beusen,A., van Drecht, G., de Vos, M., 2011. The HYDE 3.1 spatially explicit database of human-induced global land-use change over the past 12,000 years. Glob. Ecol. Biogeogr. 20, 73–86, DOI: 10.1111/j.1466-8238.2010.00587.x

Griffin, J.B., 1961. Some correlations of climatic and cultural change in eastern north American prehistory. Ann .N.Y. Acad, Sci 95, 710–717. DOI: 10.1111/j.1749-6632.1961.tb50071.x

Grove, J.M., 2004. ‘Little Ice Ages’– Ancient and Modern. Routledge, London – New York.

Gumerman, G.J., Swedlund, A.C., Dean, J.S., Epstein, J.P., 2003. The evolution of social behavior in the prehistoric American southwest. Art. Life 9, 435–444.

Györffy, Gy., 1963. Az Árpád-kori Magyarország történeti földrajza I. [Historical Geography of Árpád-Era Hungary I]. Akadémiai Kiadó, Budapest.

Györffy, Gy., 1987. Az Árpád-kori Magyarország történeti földrajza. III. Budapest, Akadémiai Kiadó, Budapest.

Gyulai, F., 2010. Archaeobotany in Hungary: Seed, Fruit and Beverage Remains in the Carpathian Basin from the Neolithic to the Late Middle Ages. Archaeolingua, Budapest.

Holzhauser, H., Magny, M., Zumbühl, H.J., 2005. Glacier and lake-level variations in west-central Europe over the last 3500 years. Holocene 15, 789–801. doi: 10.1191/0959683605hl853ra

Hoffmann, T., Schlummer, M., Notebaert, B., Verstraeten, G., Korup, O., 2013. Carbon burial in soil sediments from Holocene agricultural erosion, Central Europe. Glob. Biogeochem. Cycles 27, 828–835. DOI: 10.1002/gbc.20071

Horváth, B., 1970. Előzetes jelentés az 1965-68. évi tiszaörvényi feltárásokról [Report from the excavation of Tiszaörvény, 1965-68]. Arch. Ért. 97, 126–133.

Hosszú, Cs., 2011. A Nagyberek változó arca a települési struktúra tükrében [Changing face of Nagyberek in the mirror of settlement structure]. in: Kázmér, M. (Ed.), Környezeti események a honfoglalástól napjainkig történeti és természettudományos források tükrében [Environmental History 2: Environmental Events since the Hungarian Conquest until Now]. Hantken, Budapest, p. 37.

Hui, W., Gel, Y.R., Gastwirth, J.L., 2008. lawstat: An R Package for Law, Public Policy and Biostatistics. J. Stat. Softw. 28, 1–26. DOI: 10.18637/jss.v028.i03

Jacomet, S., Brombacher, C., Dick, M., 1989. Archäobotanik am Zürichsee. Ackerbau, Sammelwirtschaft und Umwelt von neolitischen und bronzezeitlichen Seeufersiedlungen im

Raum Zürich [Archaeobotanics at Zürichsee. Agriculture, Gathering Economy and Environment of Neolithic and Bronze Age Lakeside Settlements in the Zurich Area]. Verlag Orell Füssli, Zürich.

Jankovich, B.D., Makkay, J., Szőke, B.M., 1989. Magyarország Régészeti Topográfiája 8. Békés megye Szarvas járás [Hungarian Archaeological Topography vol. 8. Békés County, Szarvas Discrit]. Akadémiai Kiadó, Budapest.

Kaplan, J.O., Krumhardt, K.M, Ellis, E.C., Ruddiman, W.F., Lemmen, C., Goldewijk, K.K., 2010. Holocene carbon emissions as a result of anthropogenic land cover change. Holocene 21, 775–791. doi: 10.1177/0959683610386983

Kern, Z., Németh, A., Gulyás, H.M., Popa, I., Levanič, T., Hatvani, I.G., 2016. Natural proxy records of temperature- and hydroclimate variability with annual resolution from the Northern Balkan-Carpathian region for the past millennium - 2 review & recalibration. Quat. Int. 415, 109–125. http://dx.doi.org/10.1016/j.quaint.2016.01.012

Kidder, T.R., Adelsberger, K.A., Arco, L.J., Schilling, T.M., 2008. Basin-scale reconstruction of the geological context of human settlement: an example from the lower Mississippi Valley, USA. Quat. Sci. Rev. 27, 1255–1270. doi:10.1016/j.quascirev.2008.02.012

Kiss, A., Laszlovszky, J., 2013. 14th-16th-century Danube floods and long-term water-level changes reflected in archaeological-sedimentary evidence - in comparison with documentary evidence. J. Env. Geo. 6, 1–11. DOI: 10.2478/jengeo-2013-0001

Kaniewski, D., Van Campoa, E., Weiss, H., 2012. Drought is a recurring challenge in the Middle East. PNAS 109, 3862– 3867. doi:10.1073/pnas.1116304109

Lamb, H.H., 1965. The early medieval warm epoch and its sequel. Palaeogeogr. Palaeoclimatol. Palaeoecol. 1, 13–37. doi:10.1016/0031-0182(65)90004-0

Laszlovszky, J., 1991. Árpád-kori és későközépkori objektumok. [Objects in Árpád-Era and late Middle Ages]. in: Tálas, L., Madaras, L. (Eds.), Régészeti ásatások Tiszafüred–

Morotvaparton [Archaeological Excavations in Tiszafüred–Morotvapart]. Szolnok Megyei Múzeumi Adattár [Database of the Museums of Szolnok County], Szolnok, pp. 317–384

Lechner, Gy., 1867. Előadás a tisza-körösi hajózási és öntöző csatorna ügyében II [The second presentation in the case of irrigation and navigation canal of Tisza-Körös]. Magyar Mérnök és Építész Egylet Közlönye 3, 181–194.

Leopold, L.B., Wolman, M.G., Miller, J.P., 1995. Fluvial Processes in Geomorphology. Dover Publications, New York.

Le Roy Ladurie, E., Pesez, J.M., 1965. Les villages désertés en France: vue d'ensemble. Annales 2, 257–290. doi: 10.3406/ahess.1965.421786

Le Roy Ladurie E., 1971. Times of Feast, Times of Famine: A History of Climate since the 1000 Year. Allen & Unwin, London.

Lucas, H.S., 1930. 'The Great European Famine of 1315, 1316 and 1317'. Speculum 5, 343–77.

Luterbacher, J., Pfister, C., 2015. The year without a summer. Nature Geosci. 8, 246–248. doi:10.1038/ngeo2404

Magyari, E.K., Chapman, J.C., Passmore, D.G., Allen, J.R.M., Huntley, J.P., Huntley, B., 2010. Holocene persistence of wooded steppe in the northern Great Hungarian Plain. J. Biogeogr. 37, 915–935.

Makkai, L., 1990. Transformation into a western type state, 1196–1301. in: Sugár, A., Hanák, P., Frank, T. (Eds.), A History Hungary. Indiana University Press, Bloomington, pp. 15–22.

Matthews, J.A., Briffa, K.R., 2005. The ’Little Ice Age: re-evalution of an evolving concept. Geo. Ann. 87, 17–36. DOI: 10.1111/j.0435-3676.2005.00242.x

McCormick, M., Dutton, P.E., Mayewski, P.A., 2007. Volcanoes and the Climate Forcing of Carolingian Europe, A.D. 750–950. Speculum 82, 865–895. DOI:10.1017/S0038713400011325

McCormick, M., Büntgen, U., Cane, M.A., Cook, E.R., Harper, K., Huybers, P., Litt, T., Manning, S.W., Mayewski, P.A., More, A.F.M., Nicolussi, K., Tegel, W., 2012. Climate change during and after the Roman Empire: Reconstructing the past from scientific and historical evidence. Journal of Interdisciplinary History 43, 169–220. doi:10.1162/JINH_a_00379

McHarg, I.L., 1992. Design with Nature. John Wiley & Sons, New York.

Méri, I., 1952. Beszámoló a Tiszalök-Rázom pusztai és Túrkeve-mórici ásatások eredményeiről [Report on excavations in Tiszalök-Rázom puszta and Túrkeve-Móric]. Arch. Ért. 1, 49–67.

Mesterházy, K., 1969. Szerep – Csonkatorony. Rég. Füz. 22, 91.

Mesterházy, K., 1970. Szerep. Rég. Füz. 23, 72.

Módy, G., 1972. Hajdú-Bihar megye településtörténeti vázlata a tatárjárástól a hódoltság megszűnéséig [Settlement history of Hajdú-Bihar county from the Mongol invasion to the end of the Turkish occupation]. in: Komoróczy, G. (Ed.), Hajdú-Bihari kéziratos térképek [Historical Maps of Hajdú-Bihar County]. Déri Múzeum, Debrecen, pp. 171–190.

More, T., 1516. Utopia. (Ed.), Morley, H., Cassell & Company, London. http://www.gutenberg.org/files/2130/2130-h/2130-h.htm#startoftext; 01.11.2015

Molnár, C., Molnár, Z., Barina, Z., Bauer, N., Biró, M., Bodonczi, L., Csathó, A.I., Csiky, J., Deák, J.Á., Fekete, G., Harmos, K., Horváth, A., Isépy, I., Juhász, M., Szerényi, K.J., Király, G., Magos, G., Máté, A., Mesterházy, A., Molnár, A., Nagy, J., Óvári, M., Purger, D., Schmidt, D., Sramkó, G., Szénási, V., Szmorad, F., Szollát, Gy., Tóth, T., Vidra, T., Virók, V., (2008) Vegetation-based landscape-regions of Hungary. Acta Bot. Hun. 50, 47–58. DOI: 10.1556/ABot.50.2008.Suppl.4

Monastersky, R., 2015. The greatest vanishing act in prehistoric America. Nature 527, 26–29. doi:10.1038/527026a

Murray-Wallace, C.V., 2013. Eustatic Sea-Level Changes – Glacial–Interglacial Cycles. in: Elias, S. (Ed.), Encyclopedia of Quaternary Science. Elsevier, Vol. 4, pp. 427-438.

Németh, P., 1997. A középkori Szabolcs megye települései [Settlements of the Medieval Szabolcs County]. Ethnica, Nyíregyháza.

Nicholas, D., 1992. Medieval Flanders. Longman, London – New York.

Pálóczi Horváth, A., 1993. A környezeti régészet szerepe Magyarországon a középkor kutatásában [The role of environmental archaeology in Hungarian medieval studies]. in: Kósa, L., Várkonyi, R.Á. (Eds.), Európa híres kertje. Történeti ökológiai tanulmányok Magyarországról [Famous Garden of Europe. Historio-Ecological Studies on Hungary]. Budapest, pp. 44–66.

Panin, A.V., Nefedov, V.S., 2010. Analysis of Variations in the Regime of Analysis of variations in the regime of rivers and lakes in the Upper Volga and Upper Zapadnaya Dvina based on archaeological-geomorphological data. Water Res. 37, 16–32. doi:10.1134/S0097807810010021

Pécsi, M., Sárfalvi, B., 1964. The Geography of Hungary. Corvina Press, Budapest.

Pfister, C., 1998. Winter air temperature variations in western Europe during the Early and High Middle Ages (AD 750–1300). Holocene 8, 535–552. doi:10.1191/095968398675289943

Pinke, Zs., Pósa, P., Mravcsik, Z., Gyulai, F., 2015. Archaeobotanical Database in Hungary from the Neolithic to the Modern Age. Poster. Launching workshop of PAGES' working group LandCover6k, Paris, 18–20. February 2015.

Pinke, Zs., Ferenczi, L., Gábris, Gy., Nagy B., 2016. Settlement patterns as indicators of water level rising? Case study on the wetlands of the Great Hungarian Plain. Quat. Int. DOI:10.1016/j.quaint.2015.11.032 (In print)

Pongratz, J., Reick, C.H., Raddatz, T., Claussen, M., 2010. Biogeophysical versus biogeochemical climate response to historical anthropogenic land cover change. Geophys. Res. Lett. 37, L08702. DOI: 10.1029/2010GL043010

Popa, I., Kern, Z., 2009. Long-term summer temperature reconstruction inferred from tree-ring records from the Eastern Carpathians. Clim. Dyn. 32, 1107–1117. DOI:10.1007/s00382-008-0439-x

Putnam, A.E., Putnam, D.E., Andreu-Hayles, L., Cook, E.R, Palmer, J.G., Clark, E.H., Wang, C., Chen, F., Denton, G.H., Boyle, D.P., Bassett, S.C., Birkel, S.D. , Martin-Fernandez, J., Hajdas, I., Southon, J., Garner, C.B., Cheng, H., Broecker, W.S., 2016. Little Ice Age wetting of interior Asian deserts and the rise of the Mongol Empire. Quat. Sci. Rev. 131, 33–50. doi:10.1016/j.quascirev.2015.10.033

Roberts, B.K., Wrathmell, S., 2000. An Atlas of Rural Settlements in England. English Heritage, London.

Sugita, S., 2007. Theory of quantitative reconstruction of vegetation I: Pollen from large lakes REVEALS regional vegetation composition. Holocene 17, 229–241. doi: 10.1177/0959683607075837

Sümegi, P., Jakab, G., Majkut, P., Törőcsik, T., Zatykó, Cs., 2009. Middle Age paleoecological and paleoclimatological reconstruction in the Carpathian Basin. Időjárás [Quarterly Journal of the Hungarian Meteorological Service] 113, 265-298.

Swetnam, T.W., Allen, C.D., Betancourt, J.L., 1999. Applied Historical Ecology: Using the Past to Manage for the Future. Ecol. Appl. 9, 1189–1206. doi:org/10.1890/1051-0761(1999)009[1189:AHEUTP]2.0.CO;2

Szabó, P., 2005. Woodland and Forests in Medieval Hungary. Archaeopress, Basingstoke Press, Oxford.

Timár, G., 2003. Geológiai folyamatok hatása a Tisza alföldi szakaszának medermorfológiájára [The effects of geological processes on the channel planform of the Tisza River, the Great Hungarian Plain]. Doctoral (Ph.D) thesis. ELTE, Budapest.

Timár, G., Gábris Gy., 2008. Estimation of water conductivity of the natural flood channels on the Tisza flood-plain, the Great Hungarian Plain. Geomorphology 98, 250–261. doi:10.1016/j.geomorph.2006.12.031

Török, P., Miglécz, T., Valkó, O., Kelemen, A., Tóth, K., Lengyel, S., Tóthmérész, B., 2012. Fast restoration of grassland vegetation by a combination of seed mixture sowing and low-diversity hay transfer. Ecol. Eng. 44, 133–138. doi:10.1016/j.ecoleng.2012.03.010

Turner, N.J., Davidson-Hunt, I.J., O'Flaherty, M., 2003. Living on the Edge: Ecological and Cultural Edges as Sources of Diversity for Social–Ecological Resilience. Hum. Ecol. 3, 439-461. DOI:10.1023/A:1025023906459

Utterstrom, G., 1954. Some population problems in preindustrial Sweden. Scan. Econ. Hist. Rev. 2, 103–165. DOI:10.1080/03585522.1954.10407619

Vadas, A., 2010. Weather Anomalies and Climatic Change in Late Medieval Hungary: Weather events in the 1310s in the Hungarian Kingdom. VDM Verlag Dr. Müller, Saarbrücken.

Vadas, A., 2011. Late Medieval Environmental Changes of the Southern Great Hungarian Plain – A Case Study, Ann. Med. Stud. CEU 17, 41–60.

Xoplaki, E., Fleitmann, D., Luterbacher, J., Wagner, S., Haldon, J.F., Zorita, E., Telelis, I., Toreti, A., Izdebski, A., 2015. The Medieval Climate Anomaly and Byzantium: A review of the evidence on climatic fluctuations, economic performance and societal change. Quat. Sci. Rev. 136, 229–252. doi:10.1016/j.quascirev.2015.10.004

Zoltai, L., 1925. Települések, egyházas és egyháztalan falvak Debrecen város mai határában [Settlements and villages in the area of Debrecen town]. A Debreceni Tisza István Tudományos Társaság Honismertető Bizottságának Kiadványai, Debrecen.

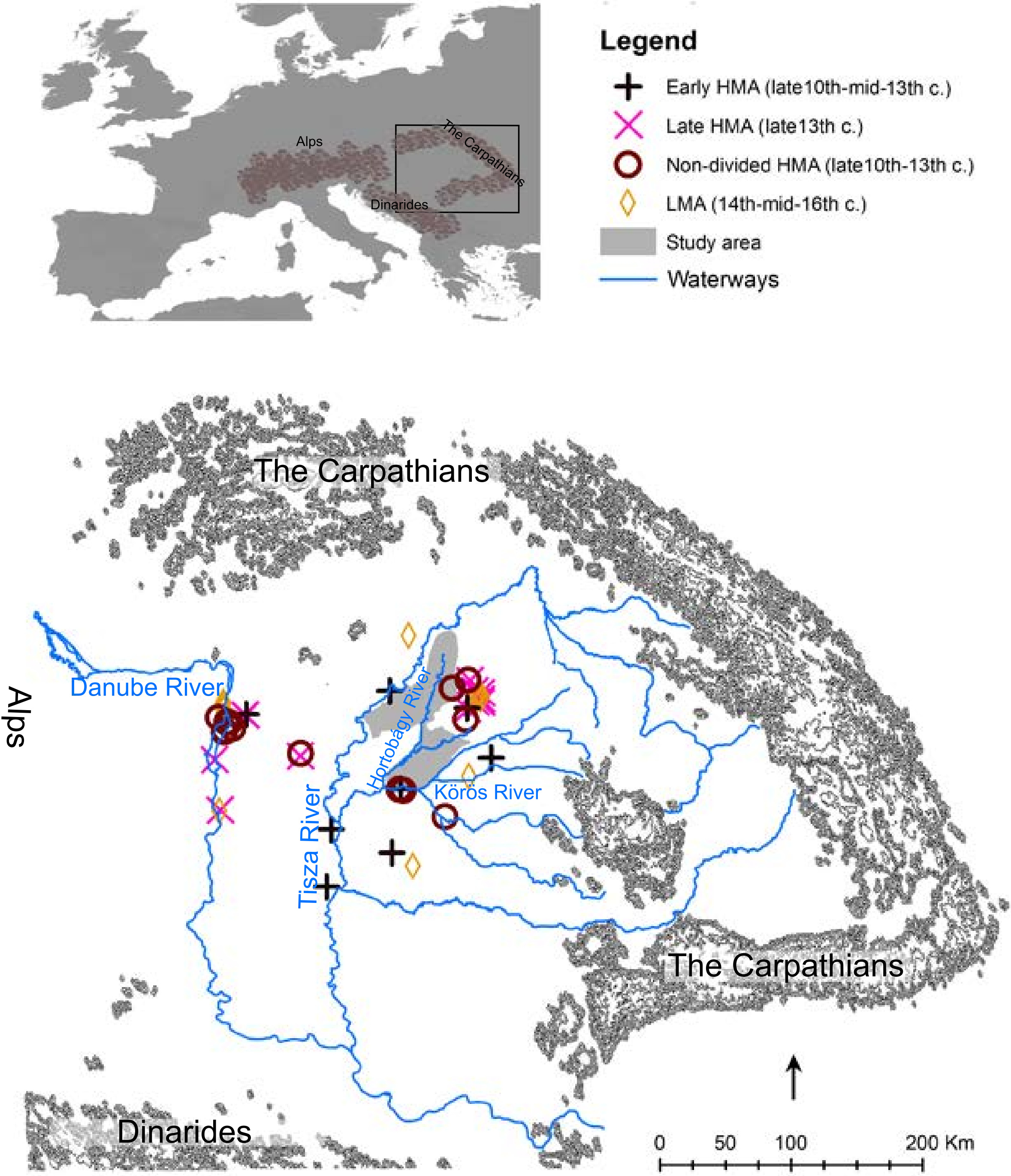
8.1. Internet databases

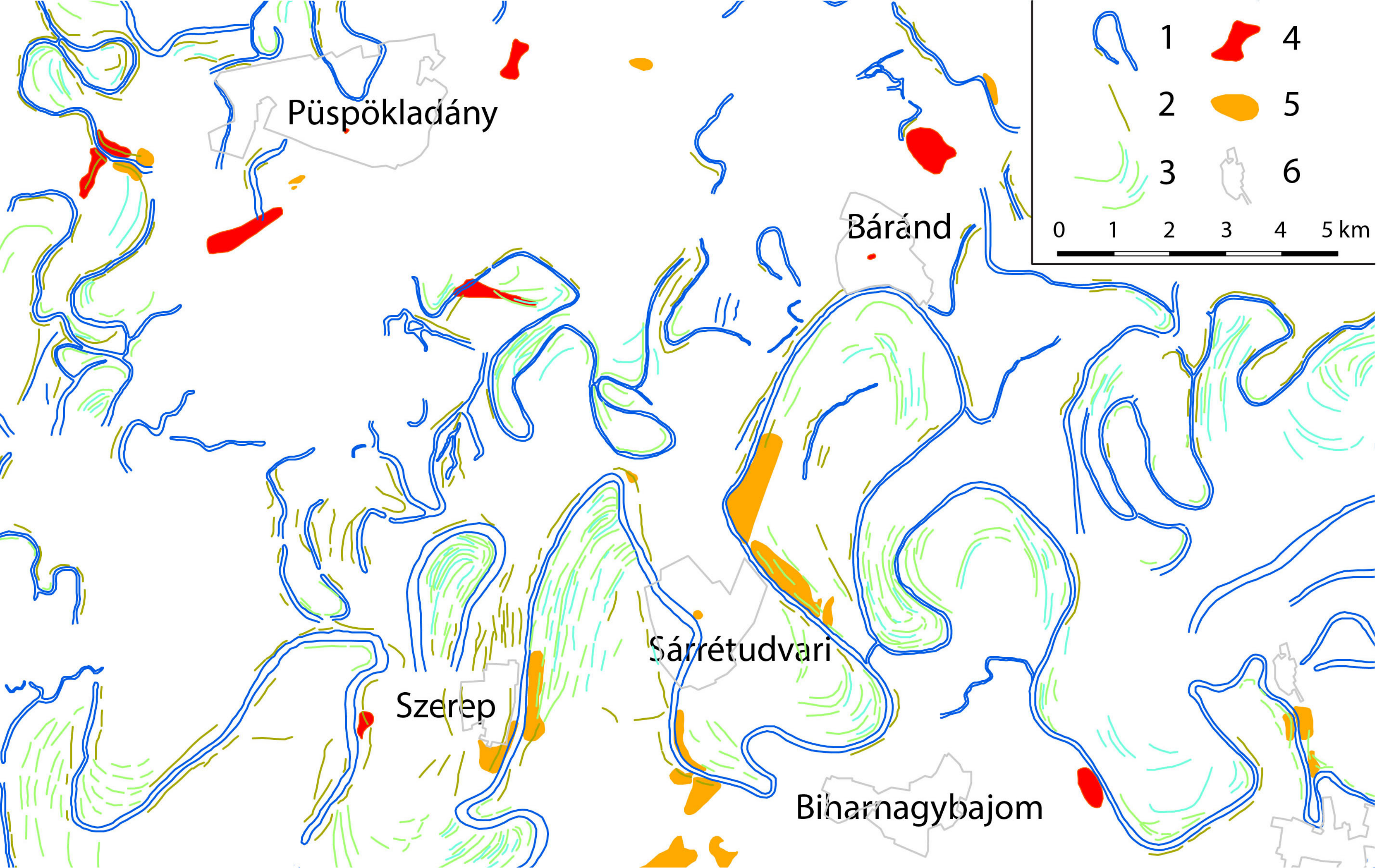
nasa.gov – http://www2.jpl.nasa.gov/srtm/; 2011.02.11.

8.2. Archival data

Archive of the Franciscan Friary in Bratislava Lad. XXXVI

Magyar Országos Levéltár [Hungarian National Archive] MNL OL DF 278835


Alps
The Carpathians
Dinarides
Legend
Early HMA (late10th-mid-13th c.)
Late HMA (late13th c.)
Non-divided HMA (late10th-13th c.)
LMA (14th-mid-16th c.)
Study area
Waterways
The Carpathians
Danube River
Alps
Hortobágy River
Körös River
Tisza River
The Carpathians
Dinarides
0
50
100
200 Km


Püspökladány
Báránd
Sárrétudvari
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1
2
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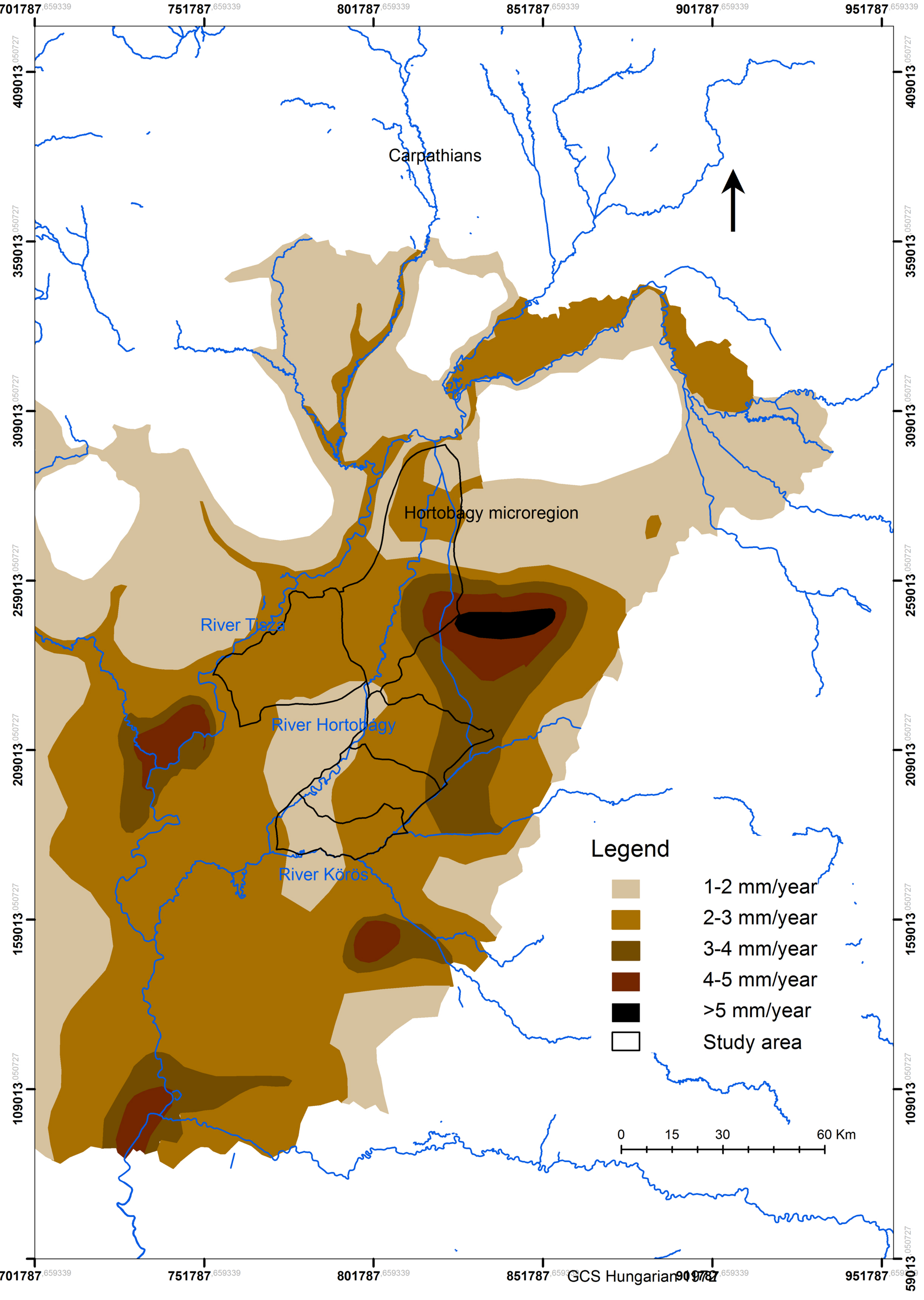
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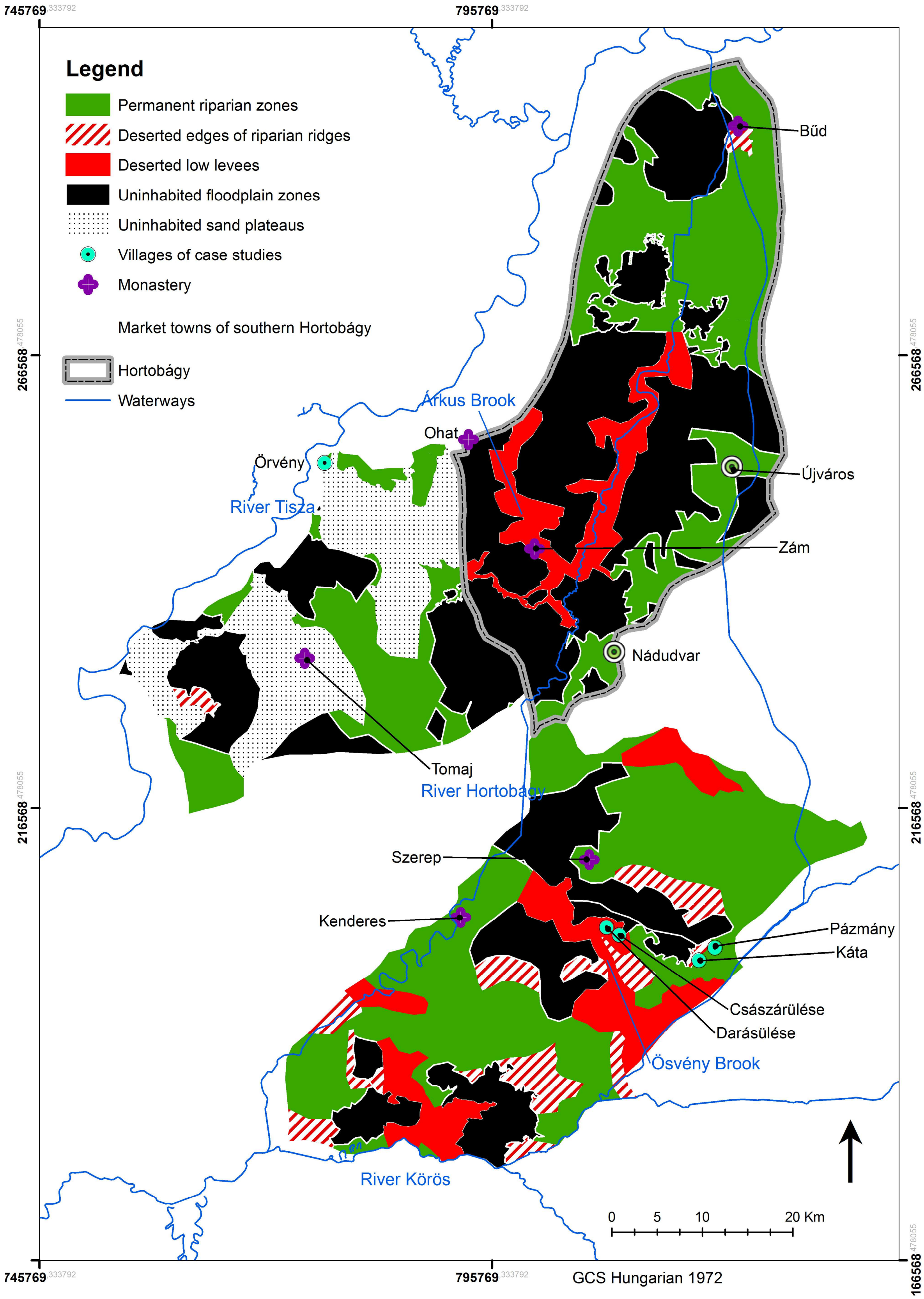
Carpathians
Hortobágy microregion
River Tisza
River Hortobágy
River Körös
Legend
1-2 mm/year
2-3 mm/year
3-4 mm/year
4-5 mm/year
>5 mm/year
Study area
0
15
30
60 Km
GCS Hungarian 1972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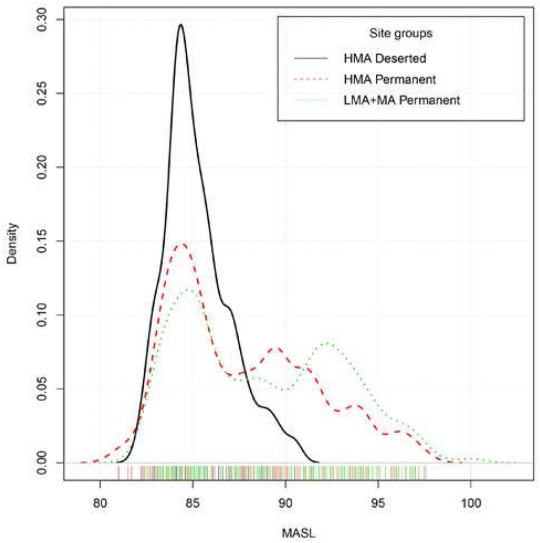
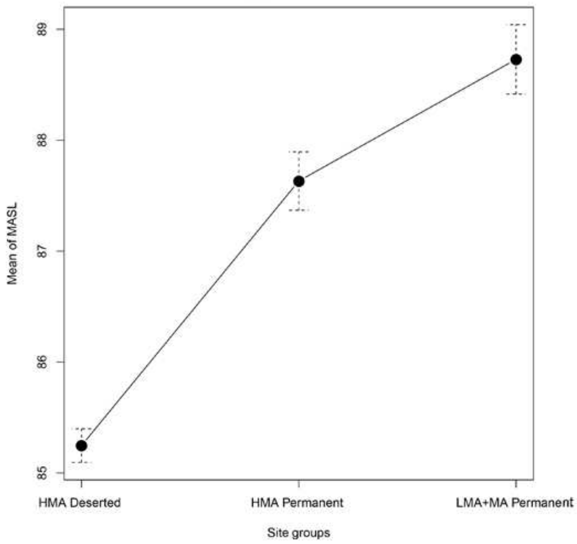
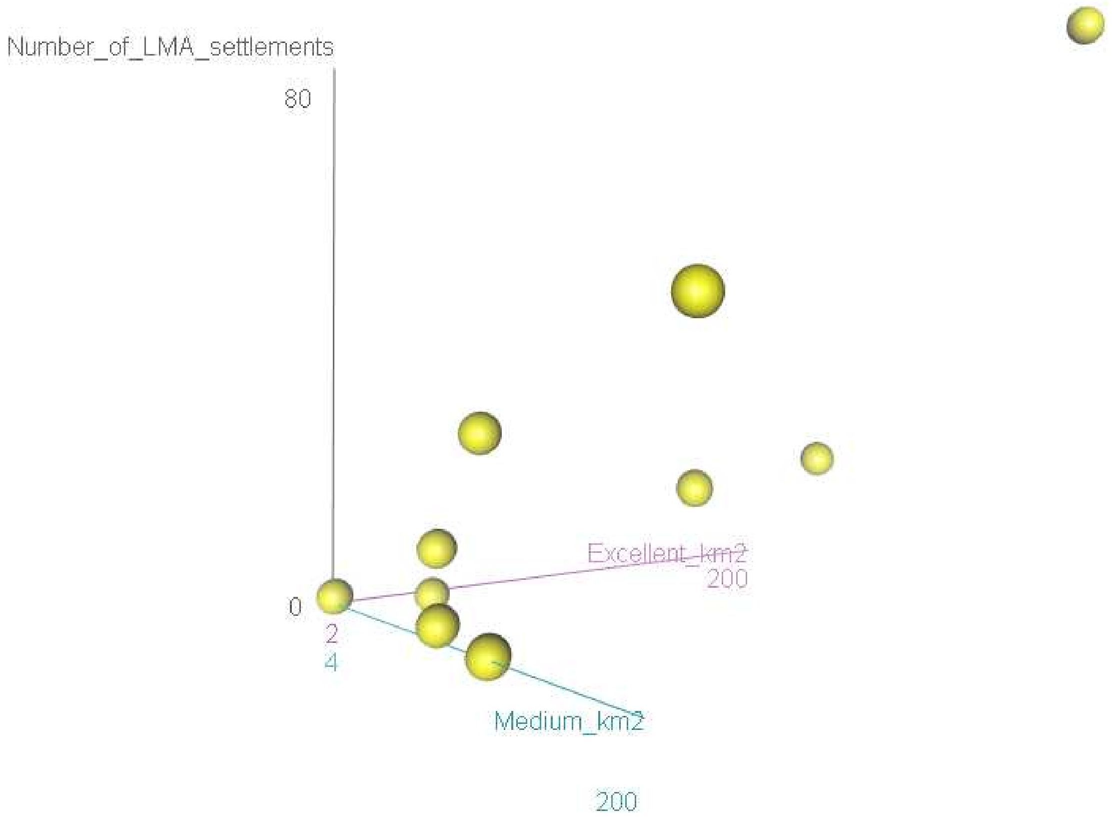
Legend
Permanent riparian zones
Deserted edges of riparian ridges
Deserted low levees
Uninhabited floodplain zones
Uninhabited sand plateaus
Villages of case studies
Monastery
Market towns of southern Hortobágy
Hortobágy
Waterways
Bűd
Árkus Brook
Ohat
Örvény
Újváros
River Tisza
Zám
Nádudvar
Tomaj
River Hortobágy
Szerep
Kenderes
Pázmány
Káta
Császárülése
Darásülése
Ösvény Brook
River Körös
0
5
10
20 Km
GCS Hungarian 1972





		ΔMASL	df	p
1	HMA – LMA	1.93	343.03	>0.01
2	HMApermanent – HMAdeserted	2.41	329.72	>0.01
3	LMA+MApemanent – HMApermanent	1.10	374.33	>0.01
4	LMA+MApermanent – HMAdeserted	3.48	257.86	>0.01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80
0
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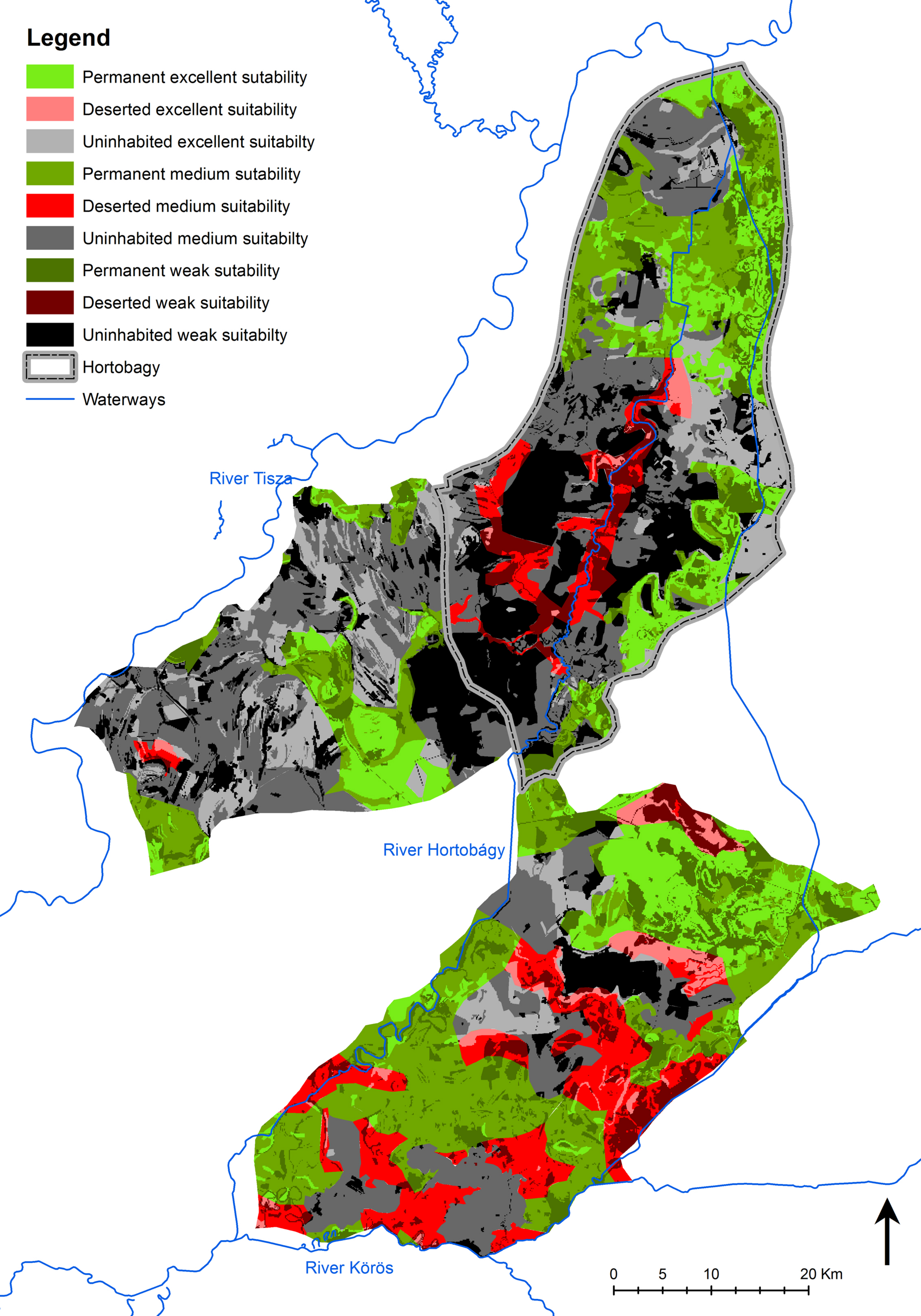
200
2
4
Medium_km2
200


Legend
Permanent excellent sutability
Deserted excellent suitability
Uninhabited excellent suitabilty
Permanent medium sutability
Deserted medium suitability
Uninhabited medium suitabilty
Permanent weak sutability
Deserted weak suitability
Uninhabited weak suitabilty
Hortobagy
Waterways
River Tisza
River Hortobágy
River Körös
0
5
10
20 Km

Highlights

- transformation of lowland settlement patterns as a response to hydrological challenge
- hydroclimatic driven settlement abandonment in the 13th century Great Hungarian Plain
- wetlands significantly rose and croplands narrowed in the overture of Little Ice Age
- causal link between agro-ecological conditions and stability of settlement pattern
- broad synchronism between changing vegetation and settlement structure in early LIA