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Title page

Drivers of grassland loss in Hungary during the post-socialist transformation (1987-1999)

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Abstract

The increase in the speed of land-cover change experienced worldwide is becoming a growing concern. Major socio-economic transitions, such as the breakdown of socialism in Europe, may lead to particularly high rates of landscape transformations. In this paper we examined the loss of semi-natural grasslands in Hungary between 1987 and 1999. We studied the relationship between 9 potential driving forces and the fate of grasslands using logistic GLMs.

Grassland loss was found to be very high (1.31 % per year), which is far higher than either before or after this period. The most influential predictors of grassland loss were environmental and landscape characteristics (soil type, area of remnant grassland patches), and the socio-economic context (distance to paved road, and nearest settlement, human population density). Several processes and relationships can only be understood from a historical perspective (e.g. large extent of afforestation, strong decrease of soil water table). Grassland loss during the study period emerged as a consequence of survival strategies of individual farmers seeking adaptation to the changing environmental and socio-economic conditions, and not urbanization and agricultural intensification which are the main underlying drivers for the ongoing landscape transformations in most parts of the developed world.

Though globalization increasingly influences local land use decisions , reconstructing and modelling recent landscape changes cannot be done without a proper understanding of local history and culture. Our analysis shows the importance of large-area yet high resolution landscape change research, which may reveal unexpected patterns of land cover change, undetected at coarser scales.

Keywords: East-Central Europe, land-cover change, logistic GLMs, proximate and underlying driving forces

Introduction

Landscapes are constantly changing due to environmental and anthropogenic factors, but the increase in the speed of land-cover change experienced worldwide and its global consequences are becoming a growing concern (Vitousek et al 1997; Foley et al 2005). Most important changes are urbanization, agricultural intensification and parallel extensification and abandonment, deforestation mostly in developing countries and afforestation mostly in developed ones (Lambin et al 2001; Lepers et al 2005; Feranec et al 2010). Land use change can occur gradually and suddenly. Most of the studies of land-use change have been focusing on gradual change so far. However, in some parts of the world land-cover changes are extremely rapid, e.g. in areas with rapid economic development and increasing human population (Lepers et al 2005). Not surprisingly, after larger political and/or economic tranformations often increased land-cover changes are experienced.

The recent land-use changes caused by political and economic transitions after the breakdown of the socialist regimes in Eastern and East-Central Europe are good examples of sudden land-use changes. The effects of the socialist-capitalist transformations are widely studied, documenting major changes in landscape properties (Feranec 2000, 2010), particularly in rural landscapes (Palang et al 2006; Łowicki 2008). Feranec et al (2010) detected an average of 2.7 % land cover change in the Eastern- and East-Central European countries, Baumann et al (2011) found that in Ukraine 30 % of farmed land was abandoned after the breakdown of socialism.

Landscape changes are highly complex processes induced by many different drivers working at different spatial and temporal scales. The concept of driving forces and its use in landscape change research can help to move emphasis from patterns to processes, extrapolate results in space and time, link data of different quality, and consider socio-cultural aspects of landscape change (Bürgi et al 2004). Hersperger and Bürgi (2009) distinguish five different groups of driving forces: political (e.g. policies), economic (e.g. financial strenght of municipalities, property markets), cultural (e.g. way of life, demography), technological (e.g. land management, telecommunication), and natural and spatial driving forces (e.g. climate change, soil conditions). An important distinction should be made between proximate and underlying drivers of land-use change (cf. Lambin et al. 2001, Geist et al. 2006). Proximate causes (called also 'direct drivers') involve a physical action (e.g. ploughing, afforestation, construction) on land and land-use, while 'indirect' underlying drivers operate more diffusely and are formed by a complex of social, political, economic, demographic, technological, cultural and biophysical variables. Complex analysis of land cover changes based on driving forces may help reveal key forces (and their temporal change) and avoid oversimplification of land cover change explanations (Lambin et al 2001).

During the socialist-capitalist transition in Eastern and East-Central Europe, land property structure became highly fragmented and intensity of agricultural use decreased in many regions (Süli-Zakar 1999; Burger 2001). Most landscape change studies in this region focus on changes in forestry practices, forest cover and pattern changes and were mainly performed in the Carpathians, where deforestation, forest and bush encroachment, and changing tree composition were found to be the most common changes (Kuemmerle et al 2007; Main-Knorn 2009). On the other hand, farmland abandonment is also of major concern in many areas (Bičík et al. 2001; Lakes et al 2009; Baumann et al 2011; Hatna and Bakker 2011). These studies show that in several East-Central European countries, including Poland, Czech Republik, Slovakia, Hungary, Romania and Bulgaria, the most important land cover changes during the period of socialist-capitalist transformation were similar (abandonment of farmland, overexploitation of forests and afforestation), but the intensity and also, partly, the direction of the changes varied significantly across regions. Moreover, the magnitude and the underlying drivers of the changes in Eastern and East-Central Europe often differ fundamentally from the changes experienced in Western Europe (Baumann et al 2011), with the processes of urbanization and cropland expansion playing less significant roles in Eastern and East-Central Europe (Feranec et al 2010).

While changes in forests and croplands following the breakdown of socialism, as well as their underlying driving forces, are relatively well-documented, surprisingly little is known on transformation rates, spatial patterns, and driving forces of changes in the case of the loss of (semi-)natural grasslands. In contrast to Western Europe, many grasslands of this region are not of woodland origin, but they are the remnants of primary steppes or forest-steppes. In addition, grassland management was generally less intensive in these countries during the last couple of decades (Molnár 2003, Molnár et al 2012). Accordingly, grasslands in these regions have, in general, a much higher biodiversity than in Western Europe, constituting a significant portion of the natural heritage of these countries. The apparent lack of interest in the fate of high diversity grasslands in this region might be explained by two conjectural reasons: (1) grasslands are less valued by the society than forests, consequently less data is being collected on their state and changes, official statistical data is far less adequate for the analysis of grassland changes, (2) remote sensing techniques are much less reliable in mapping grasslands than forests, their thematic and spatial resolution is still not enough to reveal finer changes in grassland quantity and quality (e.g. change in species composition, habitat quality, subtle changes in management) (Feranec 2007; Kuemmerle et al 2008). In regions, which primarily consist of a mosaic of several types of grasslands, wetlands, old-fields, fallows, and arable fields (just like the Danube-Tisza Interfluve region, the study region of this paper in Hungary, see later) accurate mapping of grasslands based on remote sensing is very challenging (Ferenc Csillag pers. comm.)

Since any form of land cover change, even sudden changes have deep roots in the past of the landscape, a thorough understanding of the proximate causes and the underlying drivers in a historical context is expected to enhance our capability to understand present and predict future landscape changes (Marcucci 2000; Antrop 2005). Socio-economic, cultural and historical legacies may also significantly influence the process of habitat transformation. For example, Baumann et al (2011) detected fundamentally different abandonment patterns in Ukraine than in Western Europe:

farmland abandonment rates were higher in fertile lowlands and lower in marginal areas. They explained this unexpected pattern with the late-socialist socio-economic circumstances in Ukraine.

In this paper, we studied the fate of natural and semi-natural grasslands between 1987 and 1999 during the political and economic regime shift in Hungary, in the central part of the Great Hungarian Plain (the Danube-Tisza Interfluve region, ca. 14,000 km^2). This region is a mosaic of relatively small urbanized areas with high, medium and low intensity agricultural land and grasslands. In this region altogether 400.74 km^2 of (semi-)natural grasslands were destroyed during the studied 13 years, which is 14.7 % of the grasslands that existed in 1987 before the breakdown of socialism. The main proximate causes of grassland disappearance were ploughing (235 km^2), construction (including urbanization and infrastructural development, 74 km^2), and afforestation (mainly with alien species, 35 km^2) (Czúcz et al 2005; Biró et al 2008). 60 % of the destroyed grasslands were former wet *Molinia*-dominated meadows and wetlands (12 % of their area in 1987), which became accessible to agriculture due to a significant decrease in soil water table during the 1970s and the 1980s (Kovács Székely and Szalai 2009). A further 25 % of the lost grasslands were wet or dry salt steppes (10 % of their original extent), 18 % dry open sand steppe (5 % of original extent), and 1 % dry loess and closed sand steppe (4 % of original) (Biró et al 2008). The development of new grasslands after the abandonment of arable areas could theoretically compensate for the losses. However, we did not incorporate grassland expansion into our model for two reasons: (1) these grasslands are generally of very low natural value, (2) reliable data on their pattern in an appropriate spatial resolution were missing.

Our main objectives are (1) to analyse the effect of the underlying environmental and socio-economic driving forces which could influence the studied process; and (2) to provide a comprehensive discussion on the social, cultural, environmental and historical context which explains the experienced patterns during this period of rapid systemic transition.

Materials and methods

Study area

Our study was performed in the Danube-Tisza Interfluve region (excluding the river floodplains - 11,876 km^2), a lowland region with highly diverse environmental conditions embraced by the two main rivers of the Carpathian Basin (Fig. 1., 47º 46' – 45º 56' N; 18º 56' – 20º 06' E, Molnár 2003, Kovács-Láng et al 2008). This lowland landscape (80-120 m a.s.l.) was mostly formed during the Pleistocene and Holocene periods and is covered with coarse or fine sand, and loess. Low-humus and chernozem-like sand soils are typical, in many places heavily affected by ground-water and salt (Biró et al 2008). The entire region is relatively homogeneous climatically, with a yearly precipitation of 500-600 mm and a mean annual temperature of 10-11 °C. The original Holocene forest-steppes were rid of most of their forests by the Medieval times. Overgrazing resulted in the mobilization of sand, which was followed by widespread afforestations and the development of a small-farm system during the 19-20th centuries. Intensive drainage of the wetlands started relatively late, mostly in the 1940s (Molnár 2003). Drainage, together with irrigation and drinking water extraction resulted in a serious decrease in ground-water levels between 1968-72 and 1993-97 (0.92 m in average with a maximum of 5-6 m, Kovács Székely and Szalai 2009). This resulted in a universal desiccation and degradation of wet habitats. According to the Corine land cover database (2000) the present landscape is dominated by agricultural areas (arable fields, vineyards, orchards, 57 %), semi-natural grasslands (19 %), forests (19 %), mostly plantations of non-native species, and settlements (6 %). The widespread small-farm system has been disintegrating since the 1970s, and arable areas started to become abandoned during the 1980s (Csatári and Farkas 2008). Nature protected areas cover 5.8 %. Agricultural production was most intensive during the 1980s. In 1980 120 860 tones of fertilizers were used (in 1970 78,500, in 1990 63,300 and in 2000 only 15,700 - KSH database, see Csatári and Farkas 2008 for other details).

GDP per person of the region (NUTS 2) is low, only ca. 43 % of the EU27 average, and 67 % of the Hungarian value (KSH Database).

Figure 1. approximately here#

Grassland loss (response variables)

Data on habitat loss was generated using the Actual Habitat Map of the area (Biró 2000, Biró et al 2006). This habitat map, focusing on grasslands, was primarily derived from a series of 1:25 000 scale Hungarian topographical military maps (MHM TÉHI). These maps are the most reliable maps about Hungary. Topographic mapping was based on field surveys (1987-1988) which were facilitated with recent aerial photos. The resulting maps were intended for military use, thus land cover type, a main determinant of several relevant operational characteristics (e.g. transparency, passableness, etc) was distinguished with relatively great care. Closed and open forests, shrublands, grasslands, wetlands (wet meadows and marshes), water bodies, and arable areas were mapped as separate land cover categories. On the other hand, recent abandonments of arable areas were mapped inconsistently.

To create a land cover database we digitized all patches indicated as ‘grasslands’, ‘wetlands’, and ‘open forests’ on these maps that were larger than 0.01 km^2. This resulted in a database of 12 224 habitat patches, which were represented with 46 930 sampling data points, (each point would stand for an area of ~ 0.06-0.1 km^2 of the patch). The points were classified into 57 categories (including 13 categories of lost (5) and partially lost (8) grasslands) based on the interpretation of SPOT 4 images from 1998-1999 (Eurimage, FÖMI, Hungary). This point database was validated with field data collected from local experts on ~33 % of the mapped territory. For further analysis, a map of ‘grassland loss’ was prepared based on the database (see Fig. 2. for a section of the map).

Based on the overlay of military maps and satellite data several ‘loss types’ could be identified which represent the most important proximate causes leading to grassland destruction. Loss due to *ploughing* was defined as any grassland present on the military maps which disappeared by 1998-1999 to give place for arable fields, orchards or vineyards. Another important process leading to the destruction of grasslands was *construction*, which includes any kind of soil sealing, the construction of residential, industrial and commercial buildings, and other kinds of earthwork. *Afforestation* and spontaneous tree encroachment went on mostly with alien tree species (e.g. Robinia pseudacacia, Pinus nigra). In addition to the three main routes of grassland destruction discussed above, there were grasslands which were destroyed in some other way which does not fit into the main 'loss types' mentioned above (e.g. flooding/fisheries, mining activities, etc), or where the cause of the loss was not identifiable. These cases were classified as *miscellaneous*.

Based on these data we constructed four binary response variables (*ploughing, construction, afforestation and total destruction*) according to the loss types defined above (Fig. 3). These variables were coded as 1 for each point lost with the respective loss type during the studied period, and as 0 otherwise. The general loss type *total destruction* includes all grasslands lost (including the three major types and the miscellaneous category).

#Figure 2 and Figure 3 approximately here#

Predictor variables

There are several major ecological, environmental and socio-economic factors (KSH ÁMÖ 2000) and processes which can potentially have an impact on grassland loss. We studied nine major driving forces which were identified as regionally influential based on previous studies (Molnár 2003; Csatári and Farkas 2008; Kovács-Láng et al 2008; Kertész et al 2011). In order to facilitate discussion these drivers are grouped into three main groups of (1) *ecological and environmental* *context*, (2) *socio-economic prosperity* and (3) *land use activities*. The first two groups constitute the environmental and the social part of the underlying drivers behind the grassland loss process, whereas the third group consists of land use activities which are not directly involved in the destruction of grassland patches, yet exerting indirect influence thereon (e.g. through market processes). This roughly corresponds to the classification of indirect drivers given by Hersperger and Bürgi (2009), with "natural and spatial driving forces" corresponding to our group (1), and all other categories (political, economic, cultural and technological) to our group (2). Our third group consists of a direct land use activity (grazing) which is not considered by Hersperger and Bürgi (2009), as well as activities / regulations with direct local land use impacts (the presence of tourism, the delineation of nature protection areas). These drivers are directly connected to benefits (ecosystem services) that society obtains from grasslands (fodder production, aesthetic beauty and biodiversity conservation).

In order to analyze the background factors and identify the most influential drivers, we have to define predictor variables based on available data sets which can be either direct measurement of the underlying drivers or, more commonly, proxy variables serving as indicators for the typically elusive drivers. Following this approach we defined 16 directly measured or proxy variables available from public data sources, which can be used as predictors for the studied drivers (Table 1).

#Table 1. approximately here#

These variables do not render a complete representation for all aspects of the driving forces, they are just indicators which are supposed to be in more or less strong, direct or indirect relationship with the underlying real drivers (driving processes). This framework exhibits inherent endogeneity, which may further be exacerbated by additional unrecognized and/or unmeasured drivers. To minimize the negative effects from missing predictors we tried to include a broad and comprehensive set of plausible background factors from the available data based on hypotheses about their relationships to drivers and loss types (proximate causes) of grassland loss (Table 1). The two classic landscape metrics (AREA, PROX) describing patch configuration were derived from our grassland loss map, whereas all the other indicators were acquired from public datasets available in Hungary (Table 1).

Data exploration

To ensure that our data is suitable for analysis and to chose an appropriate modelling tool, we performed an extensive exploratory analysis on our data sets following the advice of Zuur et al (2010). All calculations were performed in R version 2.13.2 (R Development Core Team, 2011). Dropping sampling data points from a few (14) highly outlier settlements in the socioeconomic variables reduced our dataset to 43,279 points (all of these outliers were suburbs in the Budapest metropolitan area). As our data seemed to be suitable (no signs of heteroskedasticity, zero inflation or overdispersion) for binomial generalized linear models (GLM), we selected this modelling approach. Collinearity among the predictors was tested with generalized variance inflation factors ($GVIF^{1/(2df)}$ R package 'car' ver 2.0-11, Fox and Monette 1992), neither of which exceeded 2.5 which is generally considered as acceptable level of collinearity (Haan 2002). In order to reduce the high level of spatial autocorrelation, the complete map was only used for the determination of the predictors describing the landscape/patch configuration (AREA, PROX), but the statistical analysis was performed on a spatially stratified subsample from the complete dataset. To carry out this spatial stratification we laid a grid of 1×1 km over the entire study region, and from each grid cell we randomly selected a single point. This resulted in a greatly reduced data set (8783 data points), but without significant spatial autocorrelation, which was tested with a series of permutation tests over Moran correlograms (R package 'ncf' ver 1-1.3, O. N. Bjornstad).

Data analysis

We used logistic GLMs to explore the relationship between the predictor variables and the fate of the grasslands. We fitted two series of models for each binary response variable (loss types):

(1) We fitted univariate logistic GLMs for each of the 16 studied predictors using single term additions to a constant null model. Significance of the relationships were estimated with Bonferroni-corrected chi-square tests (α=.05).

(2) We searched for the best first-order model using a stepwise forward and backward algorithm minimizing AIC values.

These two series characterize the ability of the variables to predict grassland loss from two different perspectives: (1) characterizes the 'total information' a predictor holds about the binary response, whereas (2) focuses at the 'independent information content' of a predictor in the presence of all other informative predictors. Coinciding results from the 'univariate' and the 'best model' tests can indicate particularly strong and unambiguous relationships, the direction and significance of which is not affected by the presence of the other predictors.

Results

The analysis showed that there were significant statistical relationships between the predictors (representing complex underlying drivers) and the response variables (equalling the proximate causes for loss - see Table 2 and the online supplementary material). Results from the 'univariate' and the 'best model' tests agreed in most of the cases (61%), indicating generally strong and unambiguous relationships. All predictors showed significant relationships in some contexts. Of the 34 a priori hypotheses formulated 20 were unequivocally supported by the results (59%), and 4 hypotheses (12%) remained entirely unsupported or even refuted (Table 2). Some of the predictors showed coherent relationships with all loss types (e.g. AREA), whereas others seemed to vary for the different proximate causes. The most influential predictors of the fate of the grasslands were

SOILTYPE, AREA and DISTROAD, exhibiting coherent univariate and best-model relationships for each of the studied loss types. Further influential predictors were POPDEN, DISTSETT and NATPROT. On the other hand four predictors (POPDEN.PP, INCOME, SHEEPDEN, TOURISM) did not exert in the two series of tests (univariate, bestmodel) a consistent and significant impact for any of the loss types. But even these predictors proved to be significant or entered the best first order models in the case of at least one response variable.

Table 2 approximately here

Overall grassland loss was positively correlated with human population density, increasing trends in population density and annual net income. Negative correlations were found with grassland patch area, proximity, distance to nearest paved road, settlement and major city, as well as sheep density. Grasslands in sandy soils were more endangered, whereas grasslands on salty or wet soils and in nature protection areas had a lower chance to be destroyed.

Grassland loss to agricultural activities (ploughing) was positively correlated with human population density. Negative correlations were found with grassland patch area, proximity to other grasslands, distance to roads and major cities. Grasslands on salty or wet soils and in nature protection areas had a lower chance to be destroyed.

Grassland loss to construction was positively correlated with human population density, increasing trends in human population density, periphery population and annual net income. Negative correlations were found with grassland patch area, proximity, groundwater table decrease, distance to nearest paved road, settlement and major city, as well as sheep density. Grasslands on sandy soils were more endangered, whereas salty and wet regions had a lower chance to be destroyed.

Grassland loss to afforestation was positively correlated with distance to nearest paved road, settlement, increasing trends in human population density, annual net income, sandy and wet soils, especially in areas with larger groundwater decrease. Negative correlations were found with salty soils, grassland patch area, proximity, human population density, periphery population, sheep density, tourist nights and nature protection areas.

Discussion

Increased destruction of semi-natural grasslands during the socialist-capitalist transformation

Grassland loss between 1987 and 1999 was found to be 1.3 % per year (Czúcz et al 2005; Biró et al 2008). This high rate of loss stands in strong contrast with the relatively static conditions of the preceding decade. According to the data from the Hungarian Statistical Office, between 1970 and 1985 the total area of grasslands remained unchanged (with a minimal growth of yearly 0.12 %, KSH). These data support the view that in this period the loss of (semi)natural grasslands was lower than afterwards (Molnár 2003). Disintegration of the small farm system and the effects of nature protection resulted in the acceleration of conversion of arable land to grassland. However, abandonment during the last decade of socialism was confined to small areas on less fertile, dry sand areas close to natural sand steppes (Molnár 2003), as all suitable land was used for agricultural production.

Estimations based on recent monitoring data show that the study period was followed again with a period of significantly lower rate of grassland loss. Between 1999 and 2008 the rate of grassland loss was reduced to ~0.35 % per year (Biró et al 2011). Even though the exact reason for this deceleration is not known, it might be explained by a saturation effect as suggested by Schneeberger et al (2007b) for landscape changes in the Swiss Alps.

The experienced loss rate of 1.3 % in the study period is high even in international comparison. Feranec et al (2010) compared total land cover change of 24 European countries between 1990 and 2000. Hungary was on the 6th place with its value of 3.9 % change (European average: 2.5 %), and 3rd among the 11 investigated Eastern and East-Central European countries. In the investigated period, the highest rate of grassland loss in Europe was documented in the lowlands of the Italian Alps, where in a 80 km^2 area in the period 1980-2000, 18.5 %, of meadows were converted to human settlements, agricultural use, shrubland and uncultivated land (1% annual loss rate, Monteiro et al 2011). In Southern Romania cropland expansion was 10.9 % between 1995 and 2005 (1 % per year), while abandonment was 17 %, resulting in net increase of total grassland area (Lakes et al 2009). Since many studies only measure net grassland change, the real decrease of (semi-)natural grasslands is generally underestimated.

The development of new grasslands after the abandonment of arable areas could theoretically compensate for the losses. However, we did not incorporate grassland expansion into our model for two reasons. New grasslands are generally species poor and weed dominated, which cannot completely compensate for the loss of species rich semi-natural old grasslands (Molnár 2003, Cramer et al. 2008). Furthermore, no reliable data on farmland abandonment with an appropriate spatial resolution was available for the study period. Emerging grasslands are typical in the driest sand regions (Molnár 2003), where they might decrease the isolation of the remaining sand grasslands (Biró 2011). Theoretically, permanent (or at least very long term) abandonment can contribute to the connectivity of the landscape from the perspective of the species of the regenerating habitats. Landscape connectivity can become a crucial factor determining the rate of biodiversity erosion in an era of substantial climate change (Czúcz et al. 2011). Nevertheless, any signs of consciousness and long-term planning are still entirely missing from the land abandonment process, and current regulations often favour return to an intensive management system. Even nature conservation authorities lack tools to adequately influence abandonment inside protected areas.

Underlying drivers of grassland loss in the transition period

Based on the proxy variables applied (Table 1) we can draw consequences on the importance of the underlying driving forces in the process of grassland transformation. In agreement with our a priori hypotheses (Table 1), all of the studied underlying drivers (see Table 1) seemed to affect grasslands, though not to an equal degree.

The studied ecological and environmental predictors all exerted strong significant impacts on one or more of the loss types, which were however not always consistent with our a priory expectations.

One major driver generally assumed to be very important for the study region is the decrease of groundwater table experienced since the early 1980s. This resulted in a significant reduction in agricultural profitability. An answer to the worsening soil quality on dry sand was to move cropland „downwards" into previously wet depressions. Our results were in agreement with this process: areas with high ground-water level decrease were more prone to ploughing and afforestation. However, WATTAB seemed to be redundant with some of the other variables in the case of ploughing, as this variable appears with the opposite sign in the best first order model. The seemingly surprising negative correlation between WATTAB and construction can be explained by the extensive groundwater domes that had built up below larger settlements due to deficiencies in sewage handling.

Soil type which determines the usefulness of land for different kinds of human uses was expected and found to be one of the most influential predictors for grassland loss in the case of all loss types. Salty soils were less affected, while sandy and previously wet soils were mostly used for afforestations. Surprisingly, according to our analysis, grasslands in dry sand areas were often ploughed for agriculture, while previous analyses showed that only 5 % of dry sand grasslands were destroyed (Biró et al 2008). Explanation lies in the resolution of the soil map. Small interdune wet depressions are not depicted, though from local studies we know, these were the main targets for conversion to cropland (Biró et al 2008).

Indicators for landscape structure, the area and isolation of the remaining contiguous grassland patches were also highly significant factors in the case of most loss types. In our landscape large grassland patches had only survived on extreme soils unsuitable for cultivation. Many of these grasslands are protected by nature conservation. All these factors contributed to a decreased chance of loss for large, non-isolated grassland patches.

We studied three demographic variables describing different aspects of human population density, most of which seemed to be significantly positively correlated with grassland loss if studied individually. However, in the best first order models it was generally only one or two of these variables which remained “significant”. Effect of demography is completely in agreement with the common sense hypothesis that a high level and an increasing trend in human population density leads to more intensive landscape changes.

Economic development and prosperity induces an increase in human activities, which entails higher risks for grassland loss (Lambin et al 2001; Lepers et al 2005; Feranec et al 2010). According to our a-priori hypothesis we expected it among the most important drivers in our study as well. However, we found that though INCOME had significant individual effects on two loss types, but neither of these relationships were preserved in the joint analysis. This suggests that the effect for income was weak and redundant with other predictors (presumably demographic ones).

Our results did not convincingly support the major role of economic development in determining the fate of grasslands in this region. This can be due to several facts. Firstly, the available proxy variable for economic development was problematic: it was based on statistical data collected in an era of great societal, economic and institutional changes, and its relationship to the studied driver was not unambiguous, either. Secondly, even the meaning of economic ‘development’ or ‘prosperity’ is challenging to interpret in an era of systemic transition, when the main goal of individuals and organizations is survival. In contrast to several studies in Western Europe and other parts of the world (e.g. Lambin et al 2001; Foley et al 2005; Lepers et al 2005; Hersperger and Bürgi 2009; Feranec et al 2010), ‘economic prosperity’ in this period and region does not mean urbanization and related processes, but a boom in private enterprises, many of which were merely survival-oriented (Csatári 2005). Agricultural reorganization, in particular, created a high number of private activities unexperienced in the previous 40 years.

As we hypothesised, the vicinity of human settlements and transportation infrastructure significantly influenced grassland loss (Révész et al 2004). All three indicators of accessibility were found to be strong predictors of several loss types. Accessibility on paved roads increased the risk of ploughing, construction and total loss, and decreased the risk of afforestation. This relationship, along with the strong positive effect of distance to settlements suggests that afforestation in this period was mostly performed in remote areas. All other relationships agree with our preliminary hypotheses and are thus easily explainable by the concentration of human activities in the more easily accessible areas.

In the last decades animal grazing in this region has been dominated by sheep. Nevertheless, contrary to our hypothesis we found surprisingly little correlation between sheep grazing and grassland loss, which may be due to the poor quality of the available data and the very low level of sheepherding in the region (particularly compared to the previous times). Most of the relationships found between sheep density and grassland loss are, however, coherent with common sense and our expectations, showing that an increased demand for grazing land reduces the risk that the grasslands get transformed.

One potential benefit of the natural grasslands in the study region is that they attract tourists through their landscape beauty. Based on this relationship, we hypothesised that tourism could act as an incentive for preserving grasslands. However, we found that tourism was no major determinant of grassland loss.

In a well functioning society nature protection may reduce many unwanted transformations of natural habitats in protected areas. We expected and found that protected and unprotected areas exhibited different rates of grassland loss. However, protection could only succeed in slowing down the process of grassland loss. We found that earlier protection is more effective than later protection, which is still better than being unprotected. The differences between the loss types were also well interpretable. For example, afforestation, which is a highly regulated activity initiated mostly by official forestry directorates, was easier to control on protected land than small-scale construction activities.

Historical legacy and local adaptation as explanations for unexpected land cover change

Dominant land cover changes in Eastern and East-Central Europe in the 1985-2000 period were farmland abandonment, afforestation, forest overutilisation and in some areas cropland expansion (Bičík et al. 2001; Palang 2006; Kuemmerle et al 2007, 2008; Łowicki 2008; Lakes et al 2009; Main-Knorn et al 2009; Feranec et al 2010; Hatna and Bakker 2011; Baumann et al 2011), while in Western Europe urbanization, afforestation and in many areas farmland abandonment (Hietel et al 2005; Falcucci et al 2007; Feranec et al 2007, 2010; Schneeberger et al 2007a,b; Hersperger et al 2009; Gimmi et al 2011; Monteiro et al 2011). We argue, that any unusual processes (e.g. the ploughing of previously uncultivated grasslands in our region) can only be understood from a historical perspective.

While most of the deforestations worldwide tend to take place in the developing countries, afforestation activities are concentrated in the developed ones. The main driver behind afforestation is the industrialization of the society, accompanied by farmland abandonment (Rudel 1998; Hietel et al 2005; Falcucci et al 2007). „Surplus” land is turned into forests. In our study region, the timing and background of afforestations were totally different. First attempts at planting trees for sand stabilization and fuel date back to the 18th-19th centuries, and got a significant surge as early as after the 1st World War, when Hungary lost 88 % of its previous forest area. As a response policy, large scale afforestations had started that continued during socialism: forest cover was increased from 4.7 % to 17.6 % between 1783 and 2000 in the region (Molnár 2003; Corine LC 2000).

Drainage of wetlands in the study region was started in the socialist era, but widespread drying of marshes and wet meadows has only accelerated from the late 1970s onwards, with the start of the large-scale decline in groundwater table. This resulted in a rapid and widespread change of previously wet habitats, but the conversion of these grasslands to agricultural fields at a large scale has only started in the late 1980s and continued in the 1990s. Main-Knorn et al (2009) also prove the role of environmental legacies from socialist times (in their case forest management and pollution legacies) when explaining recent land cover change patterns.

The decrease in livestock experienced during and particularly after the era of socialism, resulted in a drastic reduction in the perceived use value of grasslands. This low regard for grasslands persisted up to very recently, when European subsidies for grasslands seem to revert this tendency. Nevertheless, intensive grassland management (sown and fertilized grasslands) has been, and is still virtually absent from the study region.

Due to the heterogeneous and often poor soil quality and the fear of restarting sand movements, large scale socialist cooperatives were less powerful in this region, consequently parts of the small farms' system could persist (Csatári and Farkas 2008). This could also contribute to the relatively high number of small grassland patches that survived the period of collectivization.

Due to the environmental and historical legacies present between 1987 and 1999, grassland loss in this region was not caused by the intensification of agriculture or increased urbanization, as would be expected in most European landscapes. It was caused partly as an adaptation to the changing physical conditions of the landscape (e.g. decrease in water table) and the changing socio-economic context. Political and economic instability fostered the diversification of survival strategies (Süli-Zakar 1999). Rapidly increasing unemployment and the reprivatization of land created new opportunities for the reorganization of local land-use (Burger 2001; Palang et al 2006; Lakes et al 2009). These strategies, born of necessity, may be regarded as deviations from the norms of well established capitalism, but this makes them effective in restructuring available resources (Csatári 2005), in our case grasslands. We argue, that instead of top-down processes, there were primarily unorganized local decisions (cf. Lambin et al 2001) behind the loss of the grassland fragments. Accordingly, local cultural and historical legacies have played an important role in shaping transformation patterns in transitional Eastern and East-Central Europe, explaining why these patterns differ so much from most of the developed world.

Conclusions

Though globalization increasingly influences local land use decisions, modelling recent landscape change cannot be done without fine-scale thematically rich maps and a proper understanding of local history and culture (Nassauer 1995; Antrop 2005; Schneeberger et al 2007b). We argue, that lack of knowledge on historical legacies and local specificities might be important reasons why European scale maps e.g. for agricultural intensity and land cover changes (Feranec et al. 2010, Temme and Verburg 2011, Hatna and Bakker 2011) are often incorrect in Eastern and East-Central Europe. However, data in adequate spatial resolutions, and time shots of many driving factors are missing for large areas in these regions, which strongly limits precise modelling of recent and future land-cover and land-use changes. This is not surprising, as land use change is generally driven by complex socio-economic and environmental processes, which are hard to characterize with solid quantitative indicators. There may be many important drivers which are very hard to access, and thus get excluded from models, or will be represented by weakly correlated indicators, which can lead to endogeneity. In our case relevant missing predictors included e.g. data on the exact use of grassland patches before their loss, forage/hay quality, suitability for arable cultivation, ownership (state, cooperative or private), and income circumstances of the owners.

Our analysis of Hungarian landscape changes showed the importance of large-area yet high resolution landscape change research, which may reveal unexpected patterns of land cover change, undetected at coarser scales. Changes found differed from other experiences in Western Europe, but also from those of Central and Eastern Europe. Our study showed that understanding different rules and driving forces behind regional differences are crucial in understanding not only post-socialist landscape transformations but also for further improvement of continental scale landscape change predictions.

Acknowledgments

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Table 1. The underlying driving forces and their indicators used as predictor variables in this study

	Driving forces	Proxy / indicator applied	Abbreviation	Unit	Spat resol	Source	A priori hypothesis***
Ecological and environmental context							
	Groundwater table changes	Level of water table decrease (1960-1993)	WATTAB	m	~1-2 km (interpolated)	VITUKI	larger decline → desiccation of wetlands → more grassland los (ploughing, construction)
	Soil properties, soil fertility	Soil type	SOILTYPE	(categorical) *	150 m	Kreybig Soil Map	1) soils suitable for cultivation → more ploughing 2) drier soils → less intensive use 3) wetter soils → less construction 4) more alkaline soils → less ploughing, less afforestation
	Landscape structure	Area of grassland patches in 1999	AREA	km^2	~100 m	D-TMap	more fragmented and isolated patches → more loss
		Proximity to neighbouring patches (1999)	PROX	(dimensionless)	~100 m	D-Tmap	more fragmented and isolated patches → more loss
Socio-economic prosperity							
	Demography	Population density of the municipality (1990)	POPDEN	person/ km^2	municipalities	KSH	more people → more loss
		Periphery population (2001)	POPDEN.PP	person/ km^2	municipalities	KSH	more people → more loss
		Trends in population density (1980-2001)	POPDEN.TR	person/ km^2	municipalities		increasing trend → more loss (esp. construction)
	Economic status	Average annual income (1992)	INCOME	HUF	municipalities	KSH	1) more prosperity → more construction 2) more prosperity → local livelihoods less dependant on agriculture → less ploughing
	Transportation and accessibility	Distance to paved roads	DISTROAD	km	~10 m	DTA50	more accessible → more threatened (esp. construction)
		Distance to nearest settlement	DISTSETT	km	~10 m	DTA50	more accessible → more threatened (esp. construction)
		Distance to nearest major city	DISTCITY	km	~10 m	DTA50	more accessible → more threatened (esp. construction)
Land use activities							
	Direct use of grasslands (grazing)	Sheep density in the municipality (2000)	SHEEPDEN	sheep/km^2	municipalities	KSH	higher sheep density → more need for pastures→ less loss
	Tourism	Tourist nights divided by the no. of inhabitants (mean of 1990 and 2001)	TOURISM	tnight / capita	municipalities	KSH	more tourism → more reason to conserve landscape → less loss
	Nature protection	Maps of the protected areas (1985, 1992)	NATPROT	(categorical) **	~10 m	TIR Database	protection → less loss

*: SOILTYPE is defined as a nominal variable with the following levels: humus rich soils with good water retention (hum), sand soils with moderate water retention (rsan), sand soils with poor water retention (psan), salt-affected soils (alk), temporary and permanent water bodies (wet), and miscellaneous or no data. The category 'humus rich soils' (hum) was used as a reference level for the statistical analysis.

**: NATPROT is defined as an ordinal variable with the following three levels: 'unprotected' < 'p90' (areas protected in 1992 but not in 1985) < 'p80' (areas protected in both 1992 and 1985).

***: a concise summary of our a priori expectations on the predictor ~ response relationships is included into Table 2.

Table 2. The impact of each predictor on the response variables. **a**: a priori expectations on the direction of the relationships based on the hypotheses in Table 2; **b**: coefficient sign of the univariate logistic GLM (only for significant predictors at α=.05 with Bonferroni-correction; **c**: coefficient sign for each term in the best first order model for the given response (see text). Empty values indicate lacking a priori hypothesis (**a**), non-significant predictors (**b**) or predictors missing from the best model (**c**). The significance of the categorical variables was determined with an omnibus test, but the corresponding coefficients are shown in detail (using treatment contrasts relative to type 'hum' for SOILTYPE and orthogonal polynomial contrasts for NATPROT).

<table>
<tr><th></th><th colspan="7">Ecological and environmental context</th><th colspan="7">Socio-economic prosperity</th><th colspan="4">Land use activities</th></tr>
<tr><th></th><th>WATTAB</th><th colspan="4">SOILTYPE</th><th>AREA</th><th>PROX</th><th>POPDEN</th><th>POPDEN.PP</th><th>POPDEN.TR</th><th>INCOME</th><th>DISTROAD</th><th>DISTSETT</th><th>DISTCITY</th><th>SHEEPDEN</th><th>TOURISM</th><th colspan="2">NATPROT</th></tr>
<tr><th></th><th></th><th>rsan</th><th>psan</th><th>alk</th><th>wet</th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th>lin</th><th>qu</th></tr>
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<tr><td>total loss</td><td>| -</td><td>|++</td><td>|++</td><td>|--</td><td>|--</td><td>-|--</td><td>-|--</td><td>+|++</td><td>+|+</td><td>+|+</td><td>|+</td><td>-|--</td><td>-|--</td><td>-|--</td><td>-|-</td><td>-|</td><td>-|--</td><td>|+-</td></tr>
<tr><td>ploughing</td><td>+|+-</td><td>+|+-</td><td>-|+-</td><td>-|--</td><td>+|--</td><td>-|--</td><td>-|--</td><td>|++</td><td>|+</td><td>| -</td><td>-|</td><td>|--</td><td>|</td><td>|--</td><td>| +</td><td>| +</td><td>-|--</td><td>|++</td></tr>
<tr><td>construction</td><td>+|--</td><td>|++</td><td>|-+</td><td>|--</td><td>-|--</td><td>-|--</td><td>-|-</td><td>|++</td><td>|+</td><td>+|++</td><td>+|+</td><td>-|--</td><td>-|--</td><td>-|-</td><td>|-</td><td>|</td><td>-|-</td><td>|+</td></tr>
<tr><td>afforestation</td><td>|++</td><td>|++</td><td>|++</td><td>-|--</td><td>|++</td><td>-|--</td><td>-|-</td><td>| -</td><td>| -</td><td>|++</td><td>| +</td><td>|++</td><td>|++</td><td>| +</td><td>| -</td><td>| -</td><td>-|--</td><td>|--</td></tr>
</table>

Electronic appendix:
ANOVA tables containing AIC, Chi^2 and p-values for single term additions and single term deletions, as well as the coefficients for each term in the best model for each type of grassland loss.

Figure captions

Figure 1. Geographic location of the study area

Figure 2. Grassland loss between 1987 and 1999 in the central part of the study area (in black) and the remnant semi-natural habitats (in grey) (based on Biró 2000)

Figure 3. Different kinds of grassland loss in the study area between 1987 and 1999 (based on Biró 2000)

Figure 1.

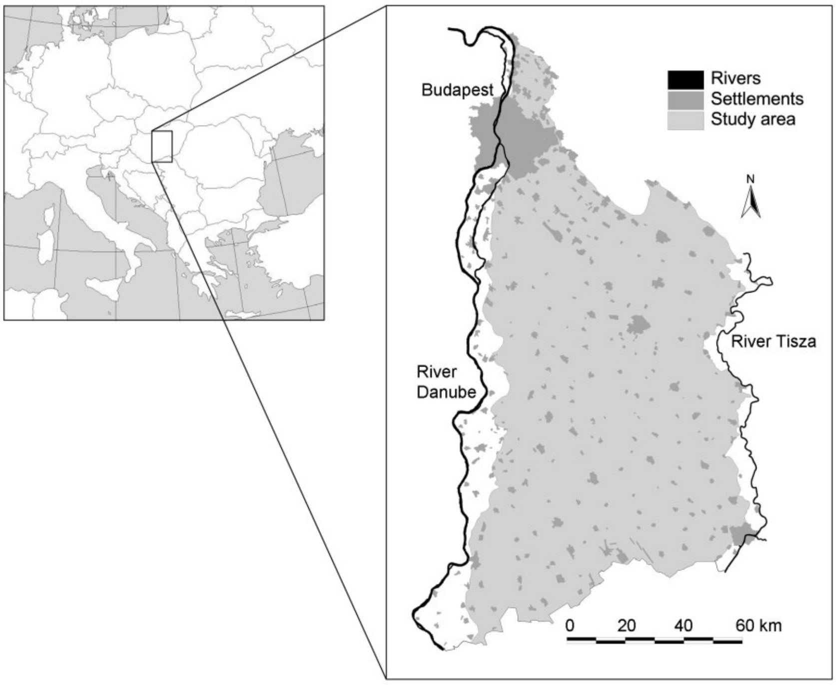
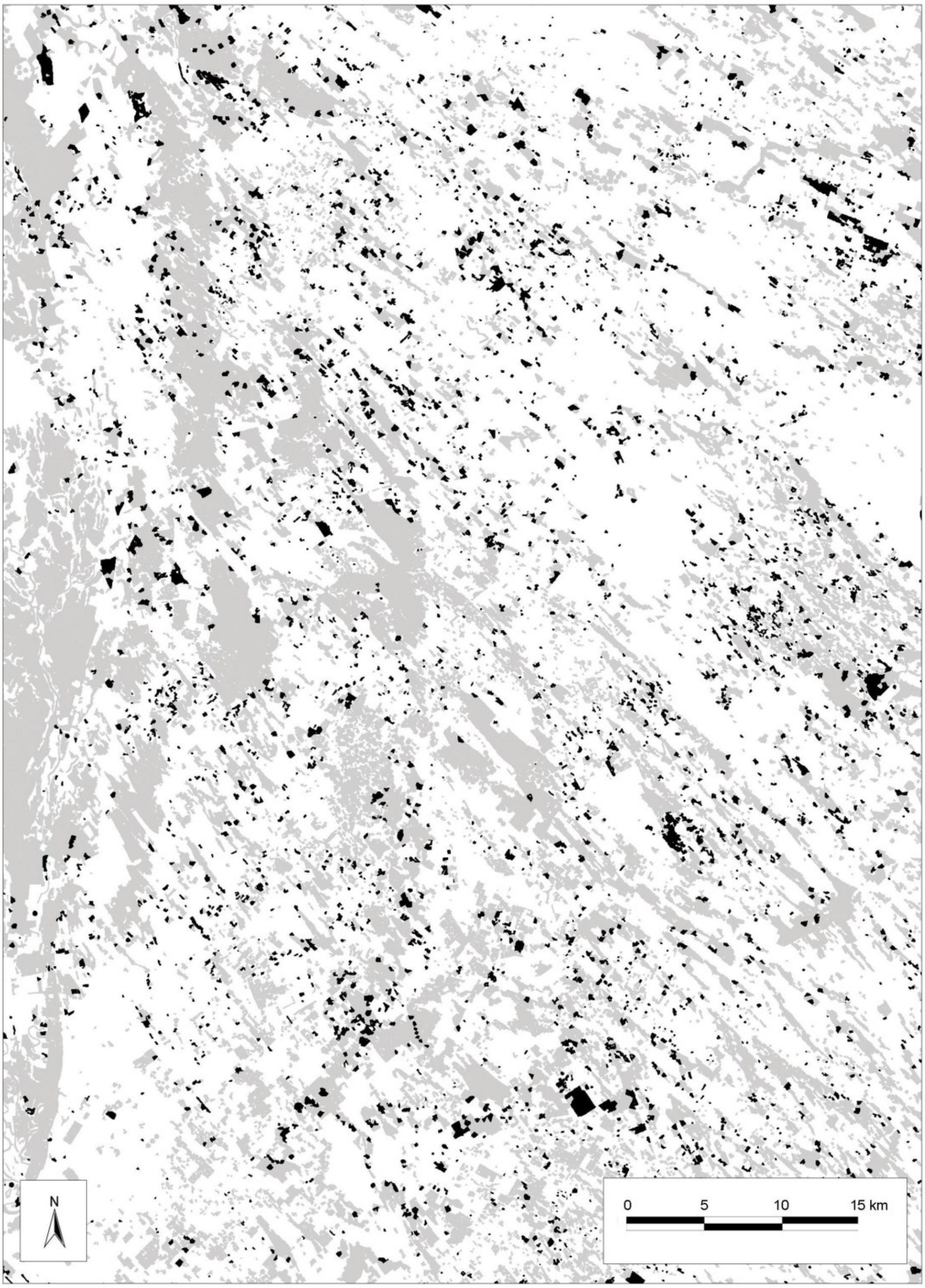
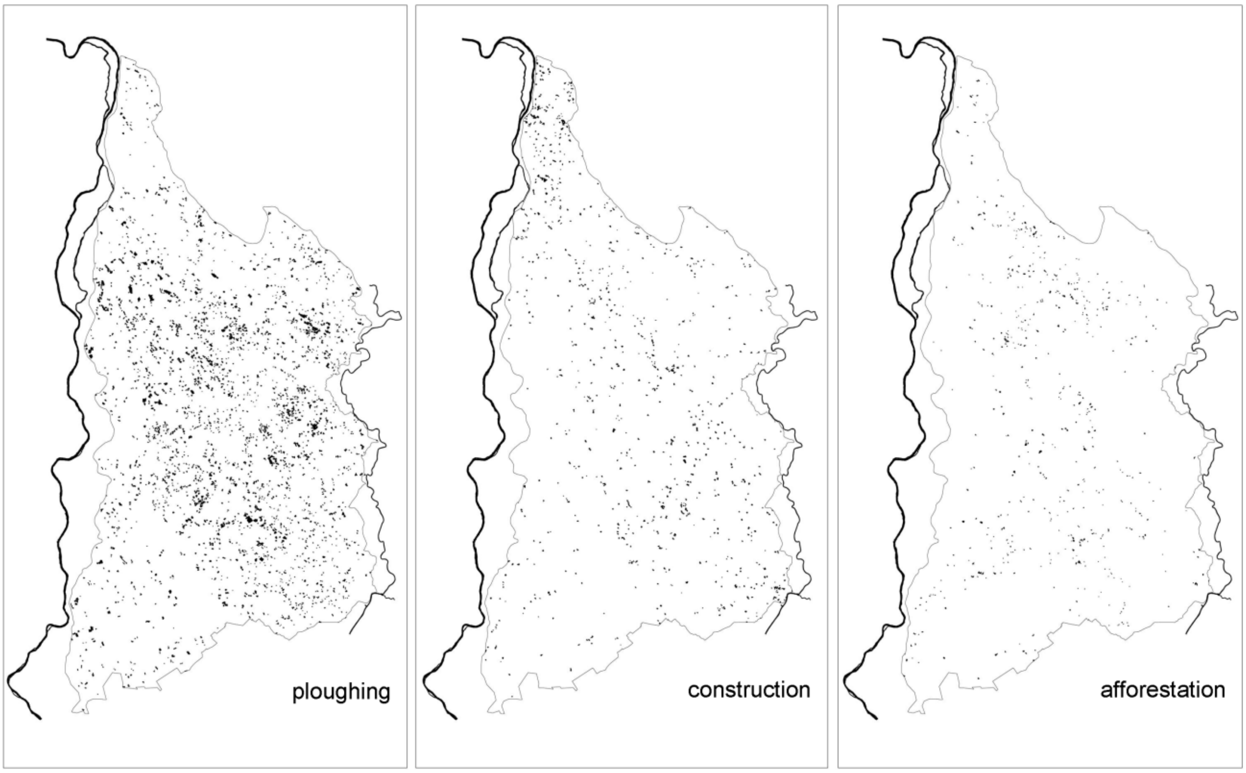

Budapest
Rivers
Settlements
Study area
N
River Tisza
River Danube
0 20 40 60 km

Figure 2.



5

Figure 3.



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