This manuscript is contextually identical with the following published paper: Biró, M., Bölöni, J. and Molnár, Zs. (2018): Use of long-term data to evaluate loss and endangerment status of Natura 2000 habitats and effects of protected areas. Conservation Biology. 32(3):660-671. The original published pdf is available in this website:
https://onlinelibrary.wiley.com/doi/full/10.1111/cobi.13038

Use of long-term data to evaluate loss and endangerment status of Natura 2000 habitats and effects of protected areas

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Keywords: Convention on Biological Diversity, forest-cover change, grassland loss, historical change, Natura 2000 habitats, retrospective, wetland loss, yearly rate of change

Article Impact Statement: Long-term habitat trends provide more realistic estimates of endangerment, and protected areas exert measurable impacts on habitat loss.

Abstract

Habitat loss is a key driver of biodiversity loss. However, hardly any long-term time series analyses of habitat loss are available above the local scale for finer-level habitat categories. We analysed, from a long-term perspective, the habitat specificity of habitat-area loss, the change in trends in habitat loss since 1989 (dissolution of the communist state), and the impact of protected areas on habitat loss in Hungary. We studied 20 seminatural habitat types in 5000 randomly selected localities over 7 periods from 1783 to 2013 based on historical maps, archival and recent aerial photos and satellite imagery, botanical descriptions, and field data. We developed a method for estimating habitat types based on information transfer between historical sources (i.e., information from a source was used to interpret or enrich information from another source). Trends in habitat loss over time were habitat specific. We identified 7 types of habitat loss over time regarding functional form: linear, exponential, linear and exponential, delayed, minimum, maximum, and disappearance. Most habitats had continuous loss from period to period. After 1986 the average annual rates of habitat loss increased, but the trend reversed after 2002. Nature conservation measures significantly affected habitat loss; net loss was halted, albeit only inside protected areas. When calculating the degree of endangerment based on short-term data (52 years), we classified only 1 habitat as critically endangered, but based on long-term data (230 years), this increased to 7 (including habitat that no longer existed). Hungary will probably reach the global Convention on Biological Diversity Target 5 but will probably not achieve the EU Biodiversity Strategy target of halting habitat loss by 2020. Long-term trend data were highly useful when we examined recent habitat-loss data in a wider context. Our method could be applied effectively in other countries to augment shorter-term data sets on trends in habitat area.

Introduction

There is an increasing amount of published data on biodiversity loss, its acceleration over recent decades, and its impacts on human well-being (e.g., MA 2005; Keil et al. 2015). In 1992 the Convention on Biological Diversity set ambitious targets to reduce the rate of biodiversity loss (CBD 1992). In 2010 the EU agreed on a target of halting the loss of biodiversity in the EU by 2020 (EC 2011). Aichi Target 5 also aims to reduce the loss of natural ecosystems (CBD 2011).

Protected areas may decrease biodiversity loss (Coad et al. 2015; Ferraro & Pressey 2015; Kallimanis et al. 2015), although more evidence is needed on the effect such areas have on habitat loss in various regions (Watson et al. 2016). Hardly any published data are available for most temperate regions (see Geldmann et al. 2013).

Habitat loss is a key element of biodiversity loss (Hanski 2011; Newbold et al. 2015). In many cases, habitat loss rates are presented in aggregate (Brooks et al. 2002; Keil et al. 2015), whereas other researchers confine themselves to reporting levels of biome and land-cover type losses, rather than losses at a finer habitat level (Keith et al. 2009). The findings of habitat-loss studies are alarming, although precise data are scarce. Thirty-five percent of mangroves have been lost (Valiela et al. 2001). Coral reefs have decreased by 20% (MA 2005). An estimated 64–71% of global wetlands may have been lost since 1900 (Davidson 2014). Native cover of temperate grasslands had fallen nearly 70% by 1950 (MA 2005).

Biodiversity loss necessitates a broader assessment of and greater focus on risks to habitats, analogous to assessing risks to species. Furthermore, habitat-specific data could help increase effectiveness of conservation efforts (Keith et al. 2009). The extent and rate of the change in habitat area should be central criteria for such assessments (Keith et al. 2009; Bland et al. 2016). Habitat-level analyzis of long-term habitat loss, however, is difficult. One major limitation is the scarcity of historical data; most habitat-loss data sets span only decades (Keith et al. 2009; Hooftman & Bullock 2012). Historical maps and written sources before the 1950s are usually of limited reliability when it comes to habitat type and characterisitics (Keith et al. 2009; Gimmi et al. 2011; Kaim et al. 2016); thus, long-term studies of habitat loss are scarce (but see Batek et al. 1999; Hall et al. 2002; Wulf & Rujner 2011; Bradshaw 2012; Hooftman & Bullock 2012).

An increasing number of studies document longer-term land-cover changes (Gillanders et al. 2008). In many cases land-cover categories can be regarded as broad-scale habitat categories. Forest and grassland area changes have been studied most commonly, although it is usually limited to such broad habitat categories as ancient versus recent habitats (Johansson et al. 2008; De Keersmaeker et al. 2015; Loran et al. 2016) or coniferous and mixed forests (Munteanu et al. 2015). Hardly any long-term, multiple, time-series analyses are available for finer-level habitat types (but see Poschlod et al. 2005; De Keersmaeker et al. 2015). Among other information, data on habitat loss over the past 200 years were collected in an assessment of European habitat types (Janssen et al. 2016). However, for most habitat types and countries, the available data were insufficient to attempt even a rough estimate of long-term habitat loss (Janssen et al. 2016).

McClenachan et al. (2012) warn that omitting historical data can result in overly optimistic assessments of conservation status. Some may argue that the more distant past should be disregarded because historical reconstructions are often limited, but we believe the past should never be entirely left out of the ecological reckoning of the present and future (Rackham 1994). Long-term historical data sets can, for example, help overcome the problem of a shifting baseline (McClenachan et al. 2012). To make reliable and detailed long-term reconstructions of habitat loss for finer-level habitat types, we developed a point-based, iterative method. This method involves information transfer between data sources (information from one data base is transferred to another database) carried out on the basis of expert knowledge to overcome problems caused by data limitations, topographical incompatibilities among historical sources, and the abiotic heterogeneity of patches (e.g., Hohensinner et al. 2013; Munteanu et al. 2015; Kaim et al. 2016).

We sought to determine whether trends in change in habitat area (habitat loss) are habitat specific over the long term (between 1783 and 2013) in Hungary; habitat loss has accelerated since the fall of communism and Hungary's accession to the European Union; protected areas have exerted a measurable impact on habitat loss rates; and habitats are more or less endangered (according to IUCN criteria) when analysed over the short term (50 years) or the long term (>200 years). We used the term "habitat" to refer to habitat types as defined by the European Union's Habitats Directive (EC 1992).

Study area

Hungary lies in Central Europe. The climate is subcontinental and the natural vegetation consists of *Quercus petraea, Carpinus betulus* , and *Fagus sylvatica* dominated broad-leaved forests and *Quercus robur* dominated forest steppes (mean annual temperature 9.5-11 °C, annual precipitation 500-800 mm) (Mersich et al. 2002).

Human population density was relatively low after the Ottoman occupation but began to increase rapidly in the 18th century (KSH 1996). Increased demand for arable land and timber was the main driving force behind river regulation and landscape change that began in the mid-19th century (Bellon 2004). Arable land reached its maximum extent around WWII (KSH 2016). After 1949, under communist rule, agriculture was reorganised into cooperatives and wetland drainage continued, as did agricultural intensification (Borvendég & Palasik 2016). After the fall of communism in 1989, land was reprivatised, land-use became temporarily less intensive, and grazing livestock numbers fell sharply (Jepsen et al. 2015; KSH 2015; Mihók et al. 2017).

The first protected area was established in 1939 (Rakonczai 2009; FM 2017). After WWII areas never previously used intensively were converted into low-profit arable fields, tree plantations, and rice fields by socialist cooperatives (Borvendég & Palasik 2016). Society responded to the increased (and unjustifiable) habitat loss by designating protected areas. The total area covered by protected areas increased slowly until the first national parks were established in the 1970s (Rakonczai 2009). After the fall of communism in 1989, nature conservation institutions were reinvigorated, culminating in stricter legislation in 1996 (Rakonczai 2009; Mihók et al. 2017).

In 2002 areas known as protected natural areas covered 9.2% of the country (FM 2017). This category provides the highest level of protection, and other designations (e.g., ecological network) are significantly less effective. Natura 2000 areas, which cover 21.39% of the country, were designated mostly in 2004 (FM 2017).

Methods

We studied habitat changes throughout Hungary. We analyzed twenty seminatural forest, grassland, and wetland habitat types in 5000 randomly selected sample localities (Supporting Information) over 7 periods from 1783 to 2013.

Of the 46 Natura 2000 habitat types that occur in Hungary (FM 2017; Haraszthy 2014), we analyzed 18 that are not rare and can be recognised from the historical and recent data sources we used (Supporting Information). Two additional, formerly widespread habitat types were studied: reed beds and floating moors. We did not analyze data regarding the rare seminatural habitat types constituted only 11% of all data on seminatural areas.

Sample localities were randomly selected from 287,613 grid centroids in the MÉTA Habitat Mapping Database (Molnár et al. 2007). A sample locality was a circular area that was roughly the minimum area of a habitat type. We determined habitat types for 7 periods (T1-T7) (Table 1) within each of the localities. Periods were chosen to represent major landscape-transformation periods. The first period was aligned with the first detailed map of the country. Data-set management and analyzes were performed using ArcGIS version 10.1 (ESRI 2012) and QGIS version 2.0.1software(QGIS Development Team).

Main and Additional Information Sources

We selected one main source (MS1-MS7) for each period (Table 1). The main sources were military maps, satellite images, and aerial photos. All were available in a georeferenced format or were rectified during the work. If necessary, the accuracy of digitised historical military maps was augmented by further ground-control points defined based on castles, medieval churches (KÖH 2012), constant roads, bridges, and stabile sections of watercourses. Georeferencing tools were used in ArcGIS version 10.1 (ESRI 2012) (spline-interpolation) and in Global Mapper version.14.0.3(Blue Marble Geographics 2012) (shift-function).

Central dates (CD) were calculated as an average of the dates of the maps or images (calculation of CD for T4, T6, and T7 were corrected with other sources used [Table 1]). We also used additional sources (AS1-AS13) (e.g., historical written and map sources, botanical and forestry data, soil maps) to improve the information gained from the main sources (Table 1, Supporting Information). Some of these additional sources were of particular significance to certain of the main sources, such as the travel diary of Kitaibel (AS1), which provided botanically detailed and spatially well-localised data for T1. Travel routes with the exact location of over 2400 species lists were reconstructed during research based on this diary and on the first and second military surveys. In addition to the Corona satellites (T4) and Landsat-

TM (T5), archive aerial photographs and topographic maps were used (AS9, AS7, AS13). For T6 a large amount of actual field data was incorporated (AS2/a,b,c). New, targeted field-vegetation surveys were conducted for T7 (AS2/d).

Land-Cover Interpretation and Habitat Estimation

We carried out the habitat-estimation process by working on only one locality at a time. The land-cover type was interpreted in the locality for all periods. Prior to this, the exact spatial position of the sample locality was determined for all main sources. Because of the spatial inaccuracy of MS1 and MS2, in several cases we reinterpreted point positions retrospectively with microtopographical positions (e.g., small valley, waterbody), roads, railways, and canals visible in more precise recent sources (called the backdating approach by Kaim et al. [2016]). Following the land-cover interpretation we initiated a habitat estimation procedure where seminatural habitat occurred in any period or periods.

In the first phase selection of the potential habitat types was carried out based on land cover and abiotic features (Supporting Information), such as geomorphological position (aspect, slope, microrelief, etc.), water supply, main soil type, bedrock, and soil extremities (e.g., too dry, too wet, salty, rocky). We selected the potential habitat types iteratively (by gradual approximation), progressing through the abiotic features (Supporting Information) on a step-by-step basis. In each step, all main and additional sources relevant to the investigated feature were used for backward and upward information transfer between different sources, which efficiently increased the information content available for habitat selection (Supporting Information). Selection of the habitat types for the different periods was always carried out in parallel during one step.

In phase 2, we continued selection and reduced the list of potential habitat types based on biogeographical, landscape, and vegetation features such as biogeographical position (e.g., local species pool, possible forest-forming tree species, presence of non-native species), landscape context, land use, age of vegetation stand (ancient or secondary), vegetation dynamics, and locally possible habitat transformations between periods (e.g., effects of hydrological changes). In sample localities where seminatural habitat types were still present in T6 or T7 or both, we used the method described above to determine probable habitat types retrospectively, starting from the recent field data and taking into consideration the reconstructed changes of abiotic and biotic features over the 230-year period . The final result of phase 2 enabled us to select the most probable habitat type (or maximum 2 habitats) for every period. Their probabilities were given as a percentage at the end of the process.

In phase 3, we rechecked all sources and decisions made during the habitat estimation in the locality. In all sample localities, further checks were conducted for certain habitat types and a number of transformation types (e.g., all arable, old-field, grassland habitat transformations and all from forest to plantation transformations). All localities were checked 2-5 times on average.

Data Analyses

Python scripts were developed to summarize data and export graphs. We defined the required habitats in input Microsoft Excel sheets for each query. Calculations done with the scripts were run on the GIS database with ArcGIS version 10.1 (ESRI 2012). A configuration file was used to set up the required habitats. Output Excel sheets contained the summarised frequency data weighted by the estimation probability, graphs of frequency and relative frequency (frequency in 1783=100%), and summarized estimated minimum-maximum values for each queried habitat.

Uncertainty in the habitat-classification procedure was indicated with estimated minimum and maximum values based on summarized minimum and maximum values of each point locality. Maximum values were 2 times the estimated probability of the period for the point locality (but maximum 100). Minimum values were the estimated probability of the period for the point locality divided by 2 (but not divided when estimated probability was 100%). Habitat-loss data were calculated for the entire 230 years and for 1 subperiod (T3-T5: communist era). Average annual habitat change rates were calculated for the more recent subperiods from linear loss rates of 19 habitats (total of the rates divided by 19). To determine trend types, linear and exponential trend lines were fitted to the graphs and R^2 values were calculated for habitats showing consistently decreasing trends. No fitting was possible for the other habitat types because drivers of habitat loss changed considerably through time. Localities in protected natural areas and in Natura 2000 areas were selected (429 and 1023 localities, respectively) based on NCIS (2016). The year of designation of all localities was determined from NCIS (2016), online databases (FM 2017) and from Rakonczai (2009). If uncertain, we consulted local authorities. Sample localities designated at least 6 years before the periods of the analyzis were used for calculations (i.e. by the end of 1980 and 1996, respectively). Data summaries were made for all seminatural forests and seminatural grasslands (including wetlands) because the habitat-level analyzis was limited by the small sample size for many habitat types.

International Union for Conservation of Nature Red List criteria and threshold values were used to estimate the degree of endangerment of habitat types (Bland et al. 2016). Values of the criterion ”reduction in geographic distribution” were calculated for all habitat types ”over the past 50 years” and ”since approximately 1750”.

Table 1. List and references of the main sources (MS) and additional sources (AS) used to determine habitat types;

Code	Source (reference)[a]	Source period [b]	Central year (code) [c]	Type of sources [d]	Main feature (reference)[a]
MS1	first military survey (1782-1785) (1)	1780s	1783 (T1)	C	Last decades of feudalism, land consolidation
MS2	second military survey (1840-1866) (2)	1840s–1860s	1858 (T2)	C	River regulations, start of capitalistic agriculture
MS3	WWII Military Survey (1940-1944) (3)	1940s	1942 (T3)	C	Last years of private land ownership
MS4	Corona satellite images (1961-1969) (4)	1950s-1960s*	1961 (T4)	C	First decades of the communist period
MS5	Landsat 4-5 TM (1984-1987) (5)	1980s	1986 (T5)	C	Last decade of intensive communist land-use
MS6	digital orthophoto series (2000) (6)	2000–2005**	2002 (T6)	C	End of transformational period after communism
MS7	satellite images (2010-2013) (7)	2010–2015 ***	2013 (T7)	C	EU membership
AS1	Kitaibel's travel diary	1796–1817	(T1)	B	Botanical data of the diary in (8) and (9)
AS2	recent botanical and forestry data	1980s–2015	(T5-7)	B	AS2/a:MÉTA Habitat Database (Molnár et al. 2007); AS2/b:DT-Map Database (2006) (10) ; AS2/c:National Forest Inventories (1980-2015) (11); AS2/d:actual field data (2013-15)
AS3	archive botanical and forestry data, botanical literature	19th-20th century	(T2-4)	B	Papers, book chapters of botany and forestry, maps, diaries up to 1980s, See references in Supporting Information
AS4	expert knowledge on vegetation and vegetation dynamics	18th-20th century	(T1-7)	B	Authors' and experts' knowledge on vegetation and probable vegetation transformations during T1-T7 due to landscape trasformations
AS5	country description (1782-1785) (12)	1780s	(T1)	G	Descriptions of ecological features mapped during the First Military Survey
AS6	archive geographical and ethnographical data	18th-20th century	(T1-4)	G	Urbaria, toponym databases, ethnographical descriptions, land-use history and oral history data on habitat use, etc. See references in Supporting Information
AS7	new military survey (1953-1959) (13)	1950s	(T4)	C	
AS8	soil maps, soil data	20th century	(T3-6)	C	Agrotopo Database (1996) (14) and data from Kreybig Soil Maps (15)
AS9	aerial photos	1950s-2005	(T4-6)	C	Archival aerial photos (1950-1990) (16); digital ortophotos (2005) (17)
AS10	third military survey (1872-1884) (18)	1870s-1880s	(T2-3)	C	
AS11	manuscript and cadastral maps	18th-19th century	(T1-2)	C	Available on: www.hungaricana.hu and www.mapire.eu (accessed January 2017, Arcanum Adatbázis Kft)
AS12	digital elevation data	2009	(T1-7)	C	ASTER-DEM USGS 2009; SRTM USGS (available from Global Mapper); DDM30 (2013) (19)
AS13	topographic maps 1984-1987.	1980s	(T5)	C	Topographic Maps (1976-1998) (20); Topographic Military Maps (1983-1991) (21)

[a]References: 1, HM HIM 1782–1785; 2, HM HIM 1840–1866; 3, HM HIM 1940–1944; 4, U.S. Geological Survey 1961–1969; 5, U.S. Geological Survey 1984–1987; 6, BFKH 2000; 7, ESRI 2010–2013; 8, Gombocz 1945; 9, Lőkös 2001; 10, Biró et al. 2006; 11, NÉBIH 1980–2015; 12, HM HIM Country Description 1782–1785; 13, MH GEOSZ 1953–1959; 14, Várallyay et al. 1994; 15, Laborczi et al. 2013; 16, BFKH 1950–1990; 17, BFKH 2005; 18, HM HIM. 1872–1884; 19, BFKH 2013; 20, BFKH 1976–1998; 21, MH GEOSZ 1983–1991.

[b] Dates of sources defined by the MS or AS. Asterisks show the MS when one of the AS was also used to define the source period: (*****:AS7; **:AS2/a; ***: AS2/d. For example for Digital Orthophotos 2000 (∗∗), we used AS2a (field survey conducted 2003–2005), which is why the period represented is not simply 2000 but 2000–2005.

[c] Calculated as an average of the dates of the map sheets or images.

[d] Abbreviations: C, cartographic or remote sensing; B, botanical; G, geographical or ethnographical.

Results

Long-Term Habitat Loss Trends

All habitat types decreased in areal extent over the 230-year period (Fig. 1), with one exception (91N0, Pannonic inland sand dune thickets). Habitat loss was habitat specific. Seven functional form types were found: exponential loss (R^2 values were higher for exponential than for linear fitting) (4 habitats), linear loss (4 habitats), linear and exponential loss (R^2 values were high but almost the same for both linear and exponential fitting) (3 habitats), delayed loss (habitat loss started only in the 19-20th century) (5 habitats), trend with a minimum value in T3-T5 periods (2 habitats), trend with a maximum value in T2 period (1 habitat), and total disappearance (1 habitat) (details in Supporting Information). Between T1 (1783) and T2 (1858) most habitat types decreased. Between T2 and T3 (1942) almost all habitat types lost a significant portion of their area; extremely saline sites lost the least. During this period, no habitat increased in area. Previously vast floating moors disappeared completely. Some forest types decreased sharply during and after WWII (T3 [1942] to T4 [1961]). Just before and during the communist period (between T4 and T5: [1986]) loss of several habitats increased**.**

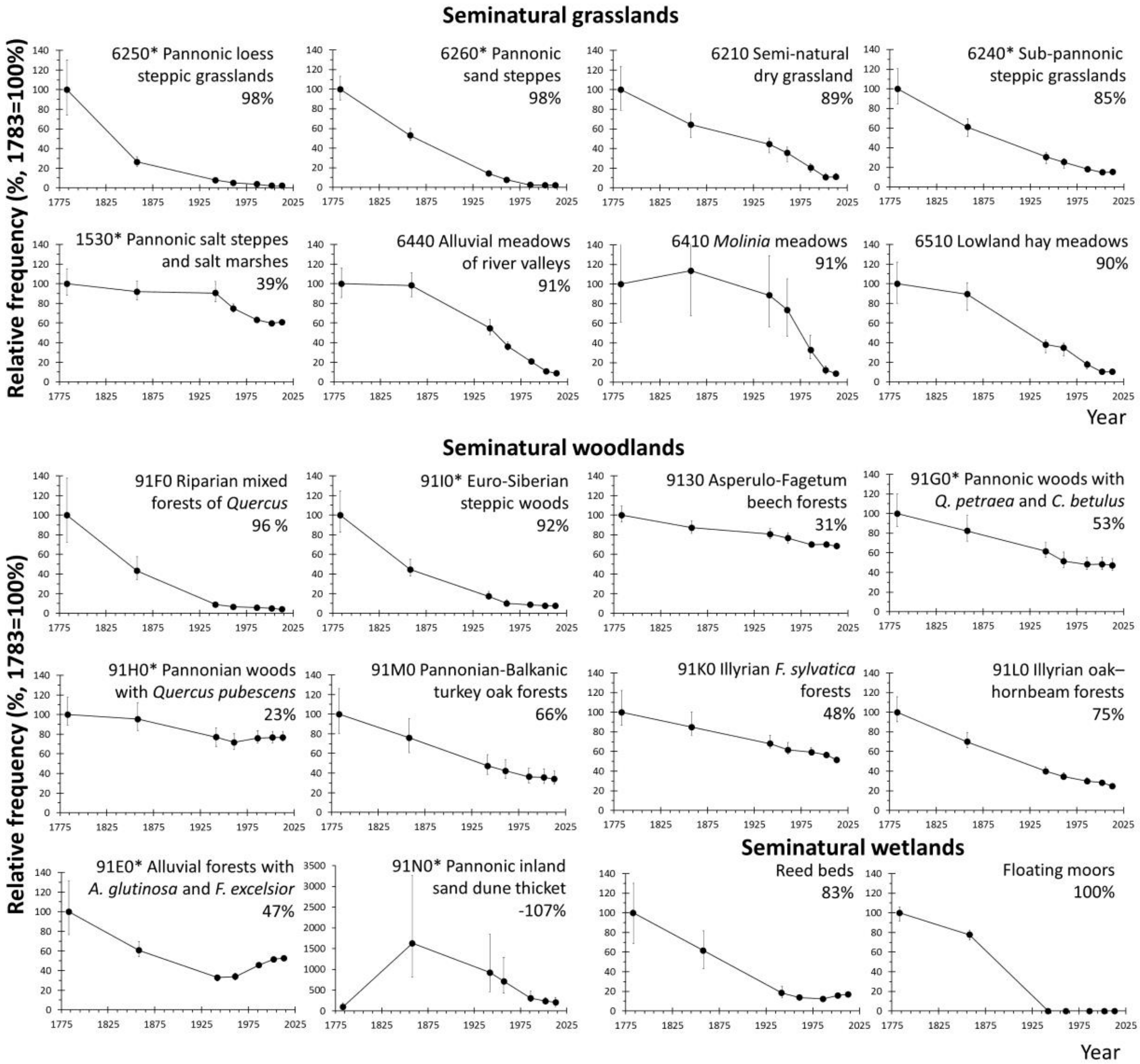

Figure 1. Changes in area of seminatural habitat types from 1783 to 2013 in Hungary based on 5000 randomly selected sample localities. Total loss values (percent area loss since 1783) and estimated minimum and maximum values (see bars) are also shown. Numbers next to names of habitat types are the Natura 2000 codes (asterisks, priority habitat types).

Changes in Loss Rates around and after the Fall of Communism

The average annual loss rate of habitats from 1961 to 1986 was 0.89%. During the next period, communism collapsed (between T5 and T6), and the average annual loss rate increased slightly (to 0.95%), but after 2002 it decreased considerably (to 0.46%). From 1986 to 2002, loss rates of 6 habitat types increased and loss rates of 5 decreased relative to the previous period. For 4 habitat types, the differences between the rates were <0.2%, for 3 types the trend reversed from loss to gain, and 1 type had a slower gain in area relative to the previous period. In the last period (2002–2013), loss rate of 4 habitat types increased and 10 decreased relative to the previous period. For 3 habitat types, the area increase continued but at a decelerated pace, and for 2 habitats the trend reversed from gain to loss (Supporting Information). Overall, average annual habitat loss rates increased in the period around and after the fall of communism and decreased after Hungary's accession to the EU.

Impact of protected areas on habitat loss

In protected areas designated in or before 1996, both forests and seminatural grasslands (including wetlands) decreased less rapidly from 1783 to 1942 than forests and seminatural grasslands that were not protected later (protected, 20% grassland loss; unprotected, 64% loss) (Fig. 2). However, from 1942 to 1986, before and around the first wave of large-scale designations, nearly one-third (31%) of seminatural grasslands (large tracts of sand and salt steppes, and floodplain meadows) were lost in these (later protected) areas. Later (1986-2013), grassland loss inside protected areas was reversed to a 2.1% gain (Fig. 2). However, we found no significant difference in trends between areas designated before 1981 (mostly from 1973 to 1980) and those designated from 1981 to 1996, although the trends in areas designated prior to 1981 were slightly more positive. The trends for protected and unprotected forests were closer to each other than the trends for protected and unprotected grasslands (including wetlands).

From 2002 to 2013 habitat loss was relatively high in areas outside all designations (0.44% loss per year). In Natura 2000 areas outside national protected natural areas, loss rates were lower (0.28% loss per year). Areas that are both protected natural areas and Natura 2000 areas had gains in habitat area (0.09% gain per year).

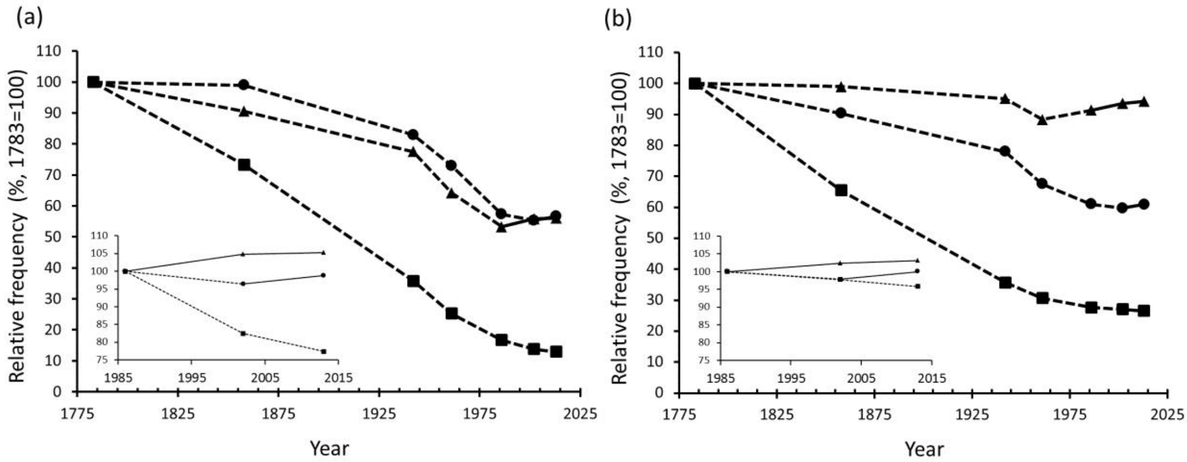

Figure 2. Changes in (a) seminatural grasslands (including wetlands) and (b) seminatural forests from 1783 to 2013 inside national protected areas (triangles, areas designated before 1981; circles, areas designated from 1981 to 1996) and outside national protected natural areas (squares) in Hungary based on 5000 randomly selected sample localities. Inset graphs show the last 2 periods (last 27 years [1986 = 100%]).

Estimating Degree of Endangerment (Red-List Status)

Seven habitat types lost >90% of their area since 1783 (the IUCN threshold for critically endangered status is loss of habitats >90% since approximately 1750) (Fig. 3, data in Fig. 1). Three of them (6250∗, 6260∗, 91I0∗) are typical Pannonian habitats. Five habitats lost >70% (threshold for endangered status). In the last 50 years, 1 habitat type lost >80% (this level of loss in the past 50 years is the threshold for critically endangered status) and 6 habitats were classified as endangered (i.e., lost >50% of their area). Five of these 6 were grasslands, mostly dry grasslands.

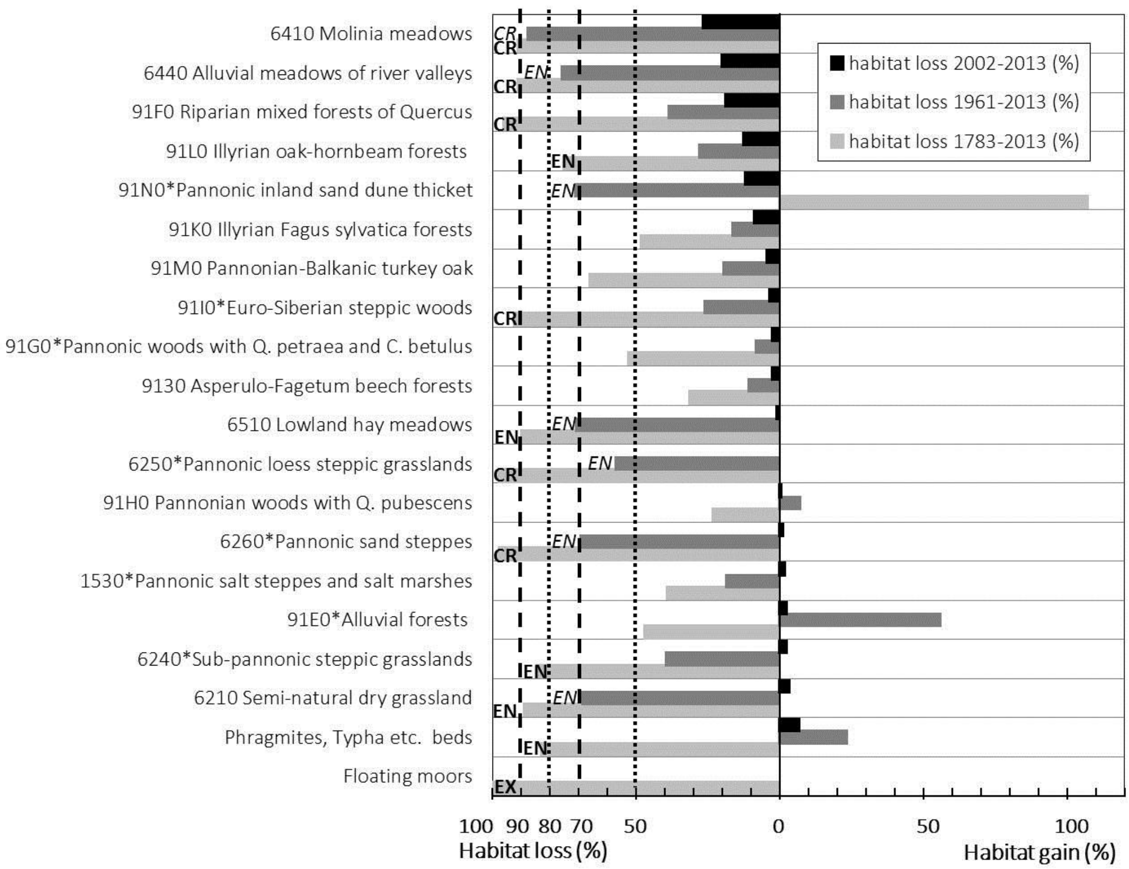

Figure 3. Habitat change of the studied seminatural habitat types in the last 230, 52, and 11 years and the degree of endangerment of habitat types based on the criterion of International Union for Conservation of Nature (IUCN) Red List (Bland et al. 2016). Reduction in

geographic distribution is for the past 50 years (dotted lines, italics) and since approximately 1750 (dashed lines, bold) (CR, critically endangered; EN, endangered; EX, extinct CR), and IUCN Red List threshold values (CR 250 years: 90% loss; EN 250 years: 70% loss; CR 50 years: 80% loss; EN 50 years: 50% loss) are shown. Numbers next to the names of habitat types are the Natura 2000 codes (asterisks, priority habitat types).

Discussion

Habitat-specific types of loss trends

The general trend was loss, and area changes were habitat specific. We identified 7 different types of habitat loss trends. With exponential trends, habitat loss rates were high in the 19th century but fell considerably in the last 40-70 years (Fig. 1). Former extensive stands of these habitats have disappeared almost completely (with the exeption of sub-pannonic steppic grasslands), and mostly marginal stands in areas less suitable for agriculture and forestry survived. Nature conservation may have played a crucial role in slowing loss by providing increased protection to the remnant stands.

With linear trends, habitat loss was continuous and slower during the 19th century (Fig. 1). These habitat types were mostly woodland habitats, where edaphic factors (e.g., steepness, humid climate) and later strict Hungarian forestry laws, as well as nature conservation, may have played an important role in preventing conversion.

Delayed trends were typical for wet habitats. Wet alluvial meadows were converted only after the country-wide program of river regulation, and Pannonic salt habitats were converted after WWII. *Molinia* meadows were drained even later because they occurred in smaller, closed depressions that were harder to drain (Biró et al. 2013). Considering the high uncertainty of estimation, we categorized this habitat as having a delayed trend.

Only three habitat types exhibited clearly nonmonotonic loss trends over time (with a definite minimum or maximum in areal extent and with temporarily upward trends). These were reed beds and two pioneer woody habitats, whose regeneration and spread depended on the actual land-use system. It was the change from cattle to sheep grazing in the case of juniper-poplar forest steppe thickets on sand during the 19th century (Biró et al. 2013); the abandonment of agriculture in flood ways in the case of soft-wood alluvial forests (De Keersmaeker et al. 2015), and the decrease of livestock density on pastures in the case of reed beds.

Only one habitat type disappeared completely from Hungary during the last 230 years: floating moors. These moors occurred in large lowland depressions, and were mostly fed by slow rivers flowing under the organic tissue of floating vegetation. From the mid-19th century onward, rivers were diverted, depressions were channelized, and moors dried up.

Increase and Decrease of Loss rates after the Fall of Communism

The decrease in habitat loss rates since Hungary's accession to the European Union may be the result of the decreasing amount of seminatural habitat area available for loss (for land conversion), marginal agricultural areas being abandoned (gain), and the increasing impact of environmental movements and nature conservation (Mihók et al. 2017). However, the area of 11 habitat types is still declining. The actual loss trends may be more negative than we found because we may have omitted slow and partial degradation caused by the loss of sensitive specialist species (homogenisation) or the spread of invasive species.

Halted Net Habitat Loss in Protected Areas

Nature conservation had a significant effect on habitat loss: trends were reversed, net habitat loss ceased, albeit only in the roughly 9% of the country with national protection (see also Mihók et al. 2017). One of the main pillars of European action to halt biodiversity loss is the Natura 2000 network (EC 1992). The effectiveness of the network is under discussion (Jack

2006; Pullin et al. 2009). Our data support the conclusions of Kallimanis et al. (2015) that the network has a measurable impact on land conversion and on decreasing habitat loss.

Ferraro and Pressey (2015) suggest scientists adopt more sophisticated research designs for evaluating the impact of protected areas. Controlling for landscape characteristics (e.g., for marginal regions, slope steepness, extreme soils [Joppa & Pfaff 2011]) would certainly reduce the estimated impact of Hungarian protected areas on habitat loss by a considerable degree. There is an ongoing debate (Joppa & Pfaff 2011; Geldmann et al. 2013) about whether the observed trends in habitat loss inside versus outside protected areas are the result of conservation policy or reserve site selection (i.e., protected areas are located in areas unsuitable for agriculture and thus there is less human demand for intensification and land conversion). Our long-term data support the first argument (decreased loss is the result of conservation policy, see the changing trends of presently protected areas before and after designation).

In Hungary nature protection is well organised: all state protected areas have a conservation ranger responsible for the management of natural assets protected by law, large areas are well-managed for biodiversity, harmful land conversion (e.g., ploughing of grasslands, new afforestations, urbanisation) is limited by law, abandonment of arable land is incentivised, drainage is partly controlled, and many drainage ditches are being removed (Rakonczai 2009; Mihók et al. 2017).

Impact of Longer-Term Data on Degree of Endangerment

More habitats (7, including the 1 habitat disappeared) were classified as critically endangered when calculated with long-term data (230y) compared with short-term data (1 habitat) (52 years) (Fig. 3). Two of these habitats (hardwood forests, forest-steppe forests) were not even classified as endangered if calculated with 52 years of data. Moreover, of the 7 habitats that had increasing area trends in the last 11 years, 1 was critically endangered and 3 were endangered based on long-term data. After having lost 83-98% of their area since 1783, these habitats slowly increased in agricultural areas where intensity of land use decreased or management was abandoned after the fall of communism. We argue that if longer-term data sets were used, the list of critically endangered and endangered habitats in Europe would be much longer (cf. Janssen et al. 2016).

Method Advantages and Limitations The reconstruction of past habitat changes faces methodological challenges, data limitations, and uncertainties (e.g., Grossinger et. al. 2007; Biró et al. 2013; Kaim et al. 2016). However, if one uses a variety of historical sources (military and cadaster maps, travel diaries, botanical descriptions, archival aerial, and satellite imagery), long-term changes can be reconstructed in detail (Gimmi et al. 2011; Hohensinner et al. 2013). With our point-based methods (and use of iterative habitat type estimation and information transfer between historical sources), long-term (> 100-200 years) field-based data sets could be generated for most common or relatively common habitat types over large areas. However, we found that the method is less suitable for rare habitat types and for habitats that are difficult to recognise from available sources.

We believe our method can be used effectively in many countries where historical spatial data are available (e.g., Fuchs et al. 2015; Munteanu et al. 2015; Kaim et al. 2016). We argue that longer-term historical reconstructions could effectively increase the applicability of recent habitat trend data (e.g., EC 2013 and the Natura 2000 habitat-area-change data reported every 6 years by all member states) and could contribute to the development of more habitat-specific nature conservation measures.

We conclude that protected areas have exerted a measurable impact on habitat loss. Net habitat loss has ceased inside protected areas but not outside. To achieve the EU target of halting habitat loss (EC 2011) by 2020 in Hungary, levels of nature protection need to be extended, especially outside protected areas. However, protection measures will probably achieve the global Convention on Biological Diversity (2011) Target 5 in Hungary.

We found that longer-term data sets helped recent changes in habitat loss to be better understood and interpreted. We argue that long-term habitat-trend data are crucial for a more realistic estimation of habitat endangerment status. Our results could also improve the way extent of habitat loss is communicated to the public. Saying that one-third of seminatural habitats are critically endangered may prove a stronger message than saying that seminatural habitats are decreasing at an alarming rate of 0.46%/year on average.

Acknowledgments

This research was supported by the project Sustainable Conservation on Hungarian Natura 2000 Sites (SH/4/8) within the framework of the Swiss Contribution Program and by the National Research, Development and Innovation Office (GINOP-2.3.2-15-2016-00019 project). We thank We thank F. Horváth, L. Lellei, V. Besnyői, Cs. Vadász, Z. Botta-Dukát, I. Pánya, A. Lengyel and B. Czúcz for their advice and help on data analysis, B. Palotás for her assistance in data processing, and S. Kane for English-language editing.

Supporting Information

A map of the 5000 sample localities (Appendix S1), a list of studied habitats (Appendix S2), a figure of habitat estimation (Appendix S3), a set of examples for habitat estimation (Appendix S4), a table on information transfer between sources (Appendix S5), a table of R^2 values and fitted trend lines (Appendix S6), data on habitat loss and yearly rates (Appendix S7), and references of written data sources (Appendix S8) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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