Author's version
Molnár, Zs., Biró, M., Bartha, S. and Fekete, G. (2012): Past Trends, Present State and Future Prospects of Hungarian Forest-Steppes. In: Werger, MJA, van Staalduinen, MA (eds.): Eurasian Steppes. Ecological Problems and Livelihoods in a Changing World. Springer, Dordrecht, Heidelberg, New York, London, pp. 209-252.

Chapter 7

Past Trends, Present State and Future Prospects of Hungarian Forest-Steppes

Zs. Molnár, M. Biró, S. Bartha, and G. Fekete
Department of Functional Ecology, Centre for Ecology, Hungarian Academy of Sciences, Vácrátót, Hungary, e-mail: molnar.zsolt@okologia.mta.hu; biro.marianna@okologia.mta.hu; bartha.sandor@okologia.mta.hu; h6868fek@helka.iif.hu

Abstract

In Hungary a countrywide vegetation mapping project carried out between 2003 and 2006 provided immense, detailed data on the current status of the forest-steppe vegetation (MÉTA database). In addition, two fundamentally important historical sources from the late eighteenth century have been analyzed recently. Using these sources we reconstruct and evaluate the past history and current status, and forecast the expected future of the vegetation types within the forest-steppe zone.

We show that by the end of the eighteenth century most forest-steppe habitats had undergone considerable change. While steppe woodlands had largely disappeared, large areas of sand steppes and closed steppes on chernozem remained and were used for grazing, some having been degraded into dune areas with windblown sand.

As a result of man's activities, including mechanized land-use, the forest-steppe vegetation underwent great changes during the past 200 years. We review these changes. In the past decades cessation of mowing and grazing is problematic. Presently, approximately 251,000 ha (6.8%) of the total of 3,700,000 ha of forest-steppe vegetation have survived in Hungary, of which only 5.5% of the stands may be considered natural, 38% semi-natural, 46% moderately degraded, and 10% strongly degraded.

We predict future trends in the forest-steppe vegetation by evaluating (1) past trends, (2) current threats and regeneration potential, and (3) expected climate change. Important threats are (1) spread of invasive species; (2) abandonment of traditional land-use; (3) drop of the groundwater table due to regulation and draining, (4) plowing; (5) overgrazing; (6) excessive wild game populations; (7) afforestation; and (8) forest management practices. They will lead to further decline and fragmentation of most dry vegetation types, and we predict that steppe woodlands on loess and sand will almost fully disappear in the coming decades, though lack of grazing may lead to the extension of Juniperus-Populus scrub in sand dune areas.

7.1 . Introduction

Information on past changes of the vegetation in any studied landscape may greatly help to interpret the current situation and predict future changes (Rackham 1980; Pickett 1989). This is particularly true in the case of the forest-steppe vegetation in Hungary. Compared to deciduous forests and grassland habitats in the mountain ranges, this vegetation has been transformed by humans to such a great extent that its current pattern and dynamics may be hardly understood by direct contemporary studies (Biró 2006; Molnár 2007).

The forest-steppe is a distinct vegetation zone in the transitional belt between the climatic zones supporting closed forests and steppes. It incorporates a large number of different vegetation types, including those that are much more broadly distributed than the zone itself, and are thus not exclusively linked to this vegetation zone (for edaphic factors, for example). Characteristics of the zone are determined by specific vegetation types that are primarily restricted to this zone (climatically zonal and intra-zonal communities) (Berg 1958).

The characteristics of the East-European forest-steppe, including physiognomy, structure, biogeographical and ecological patterns, vegetation dynamics and post- glacial history, have already been described in detail (Aliokhin 1950; Artushenko 1970; Berg 1958; Lavrenko 1956, 1981; Lavrenko et al. 1991; Lavrenko and Karamysheva 1993; Tarasov et al. 1998, 2000). However, botanical knowledge on the past changes, current status and expected changes of this forest-steppe vegetation is much less, and has not yet been reviewed. For Hungary, until recently such a review was not even possible, because of lack of quantitative data, and available data on past changes concerned only few locations. However, the past 10–15 years have brought great progress in this field.

A country-wide vegetation mapping project carried out between 2003 and 2006 provided data on the current status of the forest-steppe vegetation, which were degrees of magnitude more detailed than ever before (the MÉTA-program, see Molnár et al. 2007b; Horváth et al. 2008). The overall goal of the project was to collect a great variety of information on the natural vegetation as part of the natural heritage of Hungary. 199 persons completed the project in about 7,000 field days.

Recent studies on vegetation history have also yielded new results. New locations (e.g., the drier, interior part of the Hungarian forest-steppe zone) have been researched and dating methods became more refined. In addition, two fundamentally important historical sources from the eighteenth century have been botanically analyzed (the outstandingly detailed diary of the botanist Pál Kitaibel with data from thousands of locations in Hungary, and the 1:28,800 scale maps and supplementary country description of the First Military Survey with a detailed legend and full coverage of the territory of Hungary) (Biró 2006; Molnár 2007). These sources are particularly important, because they allow the reconstruction of the environment from before the beginning of major landscape transformations (river regulation, evelopment of dispersed farmsteads, plowing up the steppe, adoption of intensive agricultural technologies).

The new methods and data gave us the unique opportunity within the Eurasian forest-steppe zone to reconstruct and evaluate the past history, describe the current status, and forecast the expected future of each vegetation type in detail. Here we outline the Holocene history of the 13(15) most significant vegetation types of the forest-steppe zone in Hungary, and describe their status at the end of the eighteenth century with the changes since then (Table 7.1). We also provide information on their current extent and condition along with their regeneration potential and threat- ening factors.

The following vegetation types are discussed (codes of the Hungarian Habitat Classification System are in parentheses, Bölöni et al. 2007): Closed steppe on chernozem soil (H5a) , *Artemisia* steppe on loess and clay cliffs (I2), Steppe woodland of *Quercus* on loess (M2), Continental deciduous steppe thicket (M6), Open sand steppe (G1), Closed sand steppe (H5b), *Juniperus*, *Populus* steppe woodland and scrub (M5), Steppe woodland of *Quercus* on sand (M4), *Artemisia* steppe on solonetz soil (F1a), *Achillea* steppe on meadow solonetz (F1b), Saline meadow (F2), Tall herb meadow steppe on solonetz soil (F3), Annual vegetation of salt lakes and mud-flats, and vegetation of saline flats (F5), *Puccinellia* meadow (F4), and Steppe woodland of *Quercus* on saline soil (M3).

Forest-steppe and forest-steppe-like vegetation also occur on the foothills and even at higher regions in the mountain ranges. These are, however, either extra- zonal communities, such as relic stands of *Spiraea* shrubberies, now found only locally in the mountains, or are secondary or edaphic in origin as the *Brachypodium pinnatum*-dominated vegetation developing after forest clearing, and grasslands on calcareous and siliceous bedrock, respectively. These are not treated here (as salt marshes are also left out of the analysis). Because of their small area, we do not discuss the isolated stands of closed *Acer* and *Tilia* forests, which represent the cool continental forest-steppe vegetation (Fekete 1965), and the forest-steppe-like *Pinus sylvestris* forests (Pócs 1966). Because the literature on the forest-steppe vegetation in Hungary has been published mostly in Hungarian, our paper also serves as an introduction to this literature for the international scientific community.

7.2. The Hungarian Forest-Steppe – Biogeographical Background

By far the largest part of the Great Hungarian Plain has been considered by most Hungarian botanists as part of the forest-steppe biome (Soó 1926, 1929, 1931, 1960; Borhidi 1961; Zólyomi 1957, 1989; Varga 1989; Zólyomi and Fekete 1994). There, the annual precipitation ranges from 450 to 600 mm (250–350 in the vegetation period and 200–250 from November to April), and the mean annual temperature is 10–11°C (17–18 in the vegetation period and 3–4 from November to April) (HMS 2000). The forests are composed typically of oaks (mostly *Quercus robur*), while the steppes are dominated by *Festuca* and *Stipa* species. It is still debated, however, whether the driest innermost parts of the plain still meet the criteria of the forest-steppe biome, or should be regarded as representatives of the steppe zone. Although the severity of summer droughts in this area does not reach the aridity level experienced in the zone of typical *Stipa* steppes, the length of the arid period is longer and water deficit well exceeds that observed in the area of the East European forest-steppe zone. About 40% of the years are so-called steppe years with weather characteristics typical of the steppe zone (Borhidi 1961; Kun 2001).

Table 7.1 Historical change of some attributes of the main forest-steppe habitats in Hungary in the last 200 years based mainly on Biró (2006) and Molnár (2007)

Code	Short name	(1) likelihood of historical continuity	(2) main period(s) of extensive change (century)	(3) change in naturalness in the past 200 years	(4) change in intensity of grazing	(5) degree of degradation due to afforestation	(6) degree of degradation due to amelioration	(7) current proportion with neglected management	(8) change in the groundwater table	(9) leaching (-) salinization (+)	(10) change in the extent of bare ground	(11) change in patch size	(12) change in total area	(13) amount of invasive species
H5a	Closed steppe on chernozem soil	●●●	18, 19	- - -	-	●	●	●●				- - -	- - -	+
I2	Vegetation of loess/clay cliffs	●●●	20	- -	-	●●●		●			-	-	-	+++
M2, M6	Steppe thicket and woodland on loess	●●●	<18	- -	- -	●		●●				- -	- -	+
G1	Open sand steppe	●●●	19, 20	+	- -	●●●		●			- -	- -	- -	++
H5b	Closed sand steppe	●	19, 20	- - -	- -	●●	●	●			-	- - -	- - -	++
M5	Juniperus-Populus scrub	●	19, 20	++	- -	●●●		●●	- -		-	++	+++	++
M4	Steppe woodland on sand	●●●	<18, 19, 20	- - -	- - -	●		●	- - -			- -	- - -	+++
F1a	Artemisia steppe on solonetz soil	●●●	20	-	- -		●●	●●	-	-		-	-	0
F1b	Achillea steppe on asolonetz soil	●	19-20	N/A	- -	●	●●●	●●	-	-		++	+++	0
F2	Saline meadow	●●	20/2	- - (-)	- - -		●●	●●	- (- -)	- (- -)	-	- (- -)	- -	0
F3	Saline meadow steppe	●●●	19, 20	- - -	+	●●	●●	●	- -	+		- -	- - -	+
F4, F5	*Puccinellia* meadow and vegetation of saline - and mud-flats	●●●	20/2	- (- -)	- -		●	●	- (- -)	- (- -)	- -	- -	- -	0
M3	Steppe woodland on saline soil	●●●	<18, 19, 20	- -	- -	●		●●	- -			-	- -	+

The forest-steppe vegetation in Hungary is the westernmost representative of the Eurasian forest-steppe (Soó 1926, 1960; Zólyomi 1989; Niklfeld 1973–1974) with some small outposts in Austria and the Czech Republic. The largest continuous steppe of Central Europe, the Hortobágy, also is found in Hungary (most of it is preserved now in a national park).

There are two types of forest-steppe distinguished within the European forest- steppe with broad-leaved forests. These are the continental and the sub-Mediterranean forest-steppes (Borhidi 1961; Niklfeld 1973–1974). The continental forest-steppe is characterized by closed and rather mesic *Quercus* forests and adjacent lush, forb-rich meadow steppes. This continental forest-steppe extends from the east as far as Podolia, and also occurs in isolated patches in the eastern part of the Carpathian Basin (Transylvania), and in the Gödöllő Hills in north-central Hungary (Fekete 1965; Niklfeld 1973–1974). The sub-Mediterranean forest-steppe is spread out in a long strip to the south and southwest of the continental forest-steppe and appears in several disjunct patches at the foothills of Cis Caucasia, the Crimean Peninsula, in Bessarabia and southern Moldova, and along the lower Danube in Romania and Bulgaria (Lavrenko 1970; Niklfeld 1973–1974). Most of the forest-steppe in the Carpathian Basin also belongs to this type especially in the western and central parts of Hungary. The main and typical communities of this forest-steppe type are dry and open woodlands and parklands of *Quercus* spp. developed under the partial influence of the submediterranean climate, and with a variable number of submediterranean floristic elements (one of the commonest is *Quercus pubescens*). Forest and steppe plants exhibit similar distributional pattern: species numbers of the two groups show decreasing gradients towards the driest and warmest central part of the plain (Fekete et al. 2010). The lack of chorological symmetry may presumably indicate the lack of the true steppe biome in the Carpathian Basin.

Characteristic of the Hungarian forest-steppe is its mosaic structure. The zonal arrangement of climate, soil types and vegetation so typical of Eastern Europe is disrupted here, and replaced by a mosaic landscape (Kádár 1975; Varga 1992). Owing partly to relief and pedological features, the forest-steppe zone is discontinuous: loess tables and plateaus and sand dune areas are fringed by river valleys with saline vegetation at the margins and in depressions. Zonal forest-steppe vegetation has developed on loess and humus-rich sand, whereas the vegetation on saline soils and wind-blown sand is intra-zonal. Extra-zonal forest-steppe vegetation occurs on the southern slopes and rocky outcrops in the surrounding hills and mountains (Zólyomi 1958, 1989; Jakucs 1961; Soó 1964; Borhidi 2003; Illyés and Bölöni 2007).

The Hungarian forest-steppe exhibits the characteristics of the more eastern forest-steppe, and also displays some unique features, which are generally attributed to submediterranean climatic influences and their isolated geographical situation (being surrounded by the high mountains of the Carpathians). For these reasons, it is regarded a distinct biogeographical unit, the Pannonian Biogeographical Region, first mapped out by Soó (1933), and recently by Varga (Varga 2003; European Environmental Agency 2006). The Pannonian Region is the western neighbour of the Pontic Region.

Presently we consider that most of the Great Plain (with exception of its marginal areas) was part of the forest-steppe zone throughout the entire Holocene (Magyari et al. 2009). It is likely that most of the floodplains and parts of the sand dunes and fens were covered with forests, whereas the loess tables and plateaus were probably wooded only to a small extent. The saline areas, however, may have been almost completely devoid of woody vegetation. Plowing up the forest-steppe habitats started as early as the Neolithic Age. The plowed areas became truely extensive probably by the Bronze Age. By the eleventh century, most of the area suitable for agriculture had been plowed. The process of forest loss, however, is not known in detail, but it seems that the decreasing trend has been continuing over millennia. The forest cover reached its minimum by the end of the eighteenth century (Zólyomi 1936, 1952; Járai-Komlódi 1966, 1987; Fairbairn 1992, 1993; Sümegi 1998; Gyulai 2001; Sümegi et al. 2000, 2006; Jakab et al. 2004; Magyari et al. 2009; Molnár 2009)

7.3. The Databases

In this paper, we use the units of the Hungarian Habitat Classification System (Bölöni et al. 2007), which is the most frequently used and thoroughly tested system of vegetation classification in Hungary. In this system, a unit includes all plant communities that occur in similar habitats, and have similar species com- position and physiognomy (Bölöni et al. 2011). For a detailed phytosociological description of forest-steppe plant communities see Borhidi (2003, 2012). Species names follow Király (2009).

Our reconstruction of the Holocene history of the vegetation is based on available relevant literature data. Since we were primarily interested in the development of the current vegetation, we mostly reviewed the data since the Boreal Period (and sometimes the Late Glacial Period). Unfortunately, for several reasons significantly less information is available on the Holocene history of the Hungarian forest-steppe than needed. First, only a few sites have remained that are suitable for paleobotanical research (few bogs, swamps and mires, extensive saline areas, and dry habitats). Second, the location of the pollen source (whether moor or the adjacent steppe habitat) is uncertain in the case of several taxa (i.e. Quercus spp., Poaceae). Finally, the pollen of several characteristic species or species groups are indistinguishable from that of other species or even sometimes other genera. As a consequence, it is not possible to determine, e.g., the proportion of Quercus robur versus Q. pubescens in steppe woodlands, or the exact habitat (whether dry steppe on chernozem soil or saline soil, or even arable land) of Artemisia and Chenopodiaceae species, and not even to identify the major grasses of the steppes to at least the generic level (*Stipa*, *Festuca*, *Bromus*, etc.). Nevertheless, the more recent research (e.g. Sümegi 1998, 2004, 2005a, d; Sümegi et al. 2006; Jakab et al. 2004; Magyari 2002, Magyari et al. 2009) has modified the results of earlier works (e.g. Rapaics 1918; Zólyomi 1936, 1952; Járai-Komlódi 1966, 1987; Győrffy and Zólyomi 1994; Medzihradszky and Járainé Komlódi 1995) in many details.

For the reconstruction of the vegetation at the end of the eighteenth century (Biró 2006; Molnár 2007) two main sources were used: (1) the field notes of Pál Kitaibel (Gombocz 1945; Lőkös 2001), and (2) maps of the First Military Survey of Hungary (1783–1785) and the supplementary written description. Kitaibel was a traveling field botanist being way ahead of his time in many respects. As a botanist, he described many plant species new to science, and at the same time he had a very broad interest in other fields (balneology, geology, ethnography, etc.). His diary, which was continually written during his journeys, is very detailed. Of the more than 1,500 pages of the diary, about 500 pages touch on areas of forest-steppe vegetation. While traveling on a wagon, Kitaibel usually took only short notes at any given locale. Nonetheless, his several thousand data outline many features of the vegetation of the Great Plain in his days. By reading his diary, we were able to follow his path on the sheets of the First Military Survey. We identified old scientific plant names mostly with the help of the work of Sándor Jávorka (1926–1945). The data were sorted by habitat types.

Features of the landscape are shown on the maps of the First Military Survey (1:28,800, 1783–1785) in such great detail that the characteristics of the plains at the end of the eighteenth century may be much better determined than from any other maps of that time. The so-called Country Description, a supplement to the maps, contains short notes on the quality of the roads, the condition of the forests, the quality of meadows and grazing fields, and topographical features for each map sheet and each settlement (Borbély and Nagy 1932). These data were also sorted by habitat types.

We were able to recover such a large amount of data for saline habitats from the field notes of Kitaibel that we could analyze them by the COCKTAIL algorithm (Bruelheide 2000) and the JUICE software (Tichy 2002). The JUICE software groups individual species that more frequently co-occur than expected by chance. Accidental species only infrequently occurring in saline habitats and/or species typical of other habitats were grouped into "pseudo-species" to simplify analysis (such as species of dry steppe on chernozem soils, meadow species, arable weeds). We listed all significant species groups and individual species, and also provided the first few non-significant species or species groups in parentheses, because the program was designed for analyzing phytosociological samples, whereas we worked with fragmentary species lists.

Most of the information on the present state of forest-steppe habitats was derived from the MÉTA database (Molnár et al. 2007b; Horváth et al. 2008). Data were collected from a survey using the so-called MÉTA method (Molnár et al. 2007b). This is a vegetation mapping method, supported by satellite images, which applies a grid of hexagonal cells in which vegetation is mapped directly in the field.

The survey was based on cells with an area of 35 ha each (267,813 cells cover the entire territory of Hungary). Habitat types were listed per hexagon, then the area, habitat condition based on naturalness values, spatial pattern, connectedness, and threatening factors were estimated and recorded for each habitat type. For standard- ization of mapping, three different pre-printed data sheets and two detailed guides (Mapping Guide and Habitat Guide) were prepared, and field trainings were organized (Molnár et al. 2007b; Bölöni et al. 2007).

One hundred contiguous hexagons formed a MÉTA quadrat (35 km^2), the basal unit of distribution maps. The total number of quadrats was 2,813. For the preparation of distribution maps, SQL queries (Horváth and Polgár 2008) were carried out per habitat and per MÉTA quadrat. The so-obtained data were quality-checked, which included the deletion of apparently erroneous data and the estimation of missing values (ca. 6% of the total).

We used a naturalness-based attribute in the MÉTA-database (Table 7.2) to characterize overall quality of vegetation stands in the field. This attribute quantifies habitat quality according to the following scale: 1: completely degraded, 2: heavily degraded, 3: moderately degraded, 4: semi-natural, 5: natural (see details in Németh and Seregélyes 1989; Molnár et al. 2007b). Naturalness values integrate variables related to structural properties and species richness into a single number. Though the estimation of naturalness values includes subjective elements, we took great care to standardize the method during the MÉTA project (Molnár et al. 2007b; Bölöni et al. 2007).

Table 7.2 Percentage of stand area of each habitat type per degree of naturalness based on the MÉTA database (2: heavily degraded, 3: moderately degraded, 4: semi-natural, 5: natural (for details see Bölöni et al. 2008a, b)

Code	**Short name**	**Naturalness value**				**Total area (ha)**
		2	**3**	**4**	**5**	
H5a	Closed steppe on chernozem soil	25	62	12	0	25,000
I2	Vegetation of loess/clay cliffs	59	18	23	0	95
M6	Steppe thickets	0	38	30	32	3
M2	Steppe woodland on loess	8	62	30	0	100
G1	Open sand steppe	22	44	31	3	10,700
H5b	Closed sand steppe	20	55	23	1	28,000
M5	Juniperus-Populus woodland and scrub	6	33	48	12	3000
M4	Steppe woodland on sand	10	41	42	7	290
F1a	Artemisia steppe on solonetz soil	2	34	54	10	33,800
F1b	Achillea steppe on solonetzi soil	12	58	29	1	46,000
F2	Saline meadow	5	41	48	6	93,000
F3	Saline meadow steppe	28	41	29	3	1,120
F4	*Puccinellia* meadow	1	13	52	34	7,000
F5	Vegetation of saline - and mud-flats	1	19	43	37	2,500
M3	Steppe woodland on saline soil	21	57	22	0	130
	All habitats together	10.3	45.9	38.2	5.5	250738

For the assessment of endangerment, we listed a number of potential threatening factors and evaluated their effect on each habitat unit. Then we estimated the cumulative area of the affected habitat unit for each factor (Table 7.3). The effective threatening factors (the ones that are most likely to affect the survivorship of the habitat type in a MÉTA hexagon in the next 10–15 years, Molnár et al. 2007b, Molnár et al. 2008c) were selected from a list of 28 factors. Severity of threat was not recorded. We developed 12 synthetic indicators from the threatening factors by thematic grouping, which we then used for the evaluation of general endangerment of each habitat unit (interpretation of the 12 indicators is explained in detail in Molnár et al. 2008c). We ordered the indicator values across habitats and within factors according to their rank, and then averaged these ranks across factors (Molnár et al. 2008c).

Regeneration potential of a focal vegetation unit was assessed at the spatial scale of the MÉTA quadrats (i.e. with regard to all other units detected in the quadrat, Table 7.4). We evaluated three regeneration scenarios (for more details see Seregélyes et al. 2008): (1) regeneration success of an existing stand following moderate disturbance or degradation; (2) successful development in a different habitat type following environmental change (e.g. development of steppe vegetation in a dried- out meadow); (3) successful development in vegetation-free areas, i.e. the ability to colonize abandoned old-fields. Although the evaluation of regeneration potential is necessarily subjective, we standardized the evaluation method as much as possible. In the Habitat Guide we (1) specified the factors that determine regeneration potential of a certain habitat type, and (2) for each vegetation type we provided a detailed list of examples for each regeneration scenario (we described about 720 examples altogether, Bölöni et al. 2003, 2007; Molnár et al. 2007b).

Table 7.3 Factors threatening forest-steppe habitats (% of the total habitat area threatened) in Hungary, based on the MÉTA habitat database (Values below 2% are not shown (for details see Molnár et al. 2008c)

Code	Habitat name	draining	undergrazing	overgrazing	lack of grazing	lack of mowing	amelioration	shrub encroachment	burning	improper management of forests	premature clearing	tree plantation	wild game	invasive species	plowing	construction	mining
H5a	Closed steppe on chernozem soil		2	11	10	12	2	**39**	2			6	3	**31**	**22**	11	2
I2	Vegetation of loess/clay cliffs			6	6			14						**59**	10	12	
M6	Steppe thickets							**23**	4				**16**	13	7	5	4
M2	Steppe woodland on loess				4	11		**26**		10	**35**	12	**27**	**42**			
G1	Open sand steppe			13	2			**48**				7		**69**	3	7	
H5b	Closed sand steppe		2	**15**	5	7	3	**32**				11		**47**	**34**	12	5
M5	Juniperus-Populus woodland and scrub							2		**19**	5	**24**		**49**			
M4	Steppe woodland on sand		4		2	2		9		**20**	**20**	**26**	**18**	**74**			
F1a	Artemisia steppe on solonetz soil	**25**	5	14	8	6								4	13	4	
F1b	Achillea steppe on solonetz soil	**35**	11	10	10	10	3							12	15	6	
F2	Saline meadow	**41**	5	9	10	12	2	5						**16**	**24**	6	3
F3	Saline meadow steppe	**24**			3	11	3	11				4		**20**	**27**	14	
F4	*Puccinellia* meadow	**35**		8		6									9	6	7
F5	Vegetation of saline - and mud-flats	**21**	4	9	7										4	4	
M3	Steppe woodland on saline soil	8			14	**18**		**19**	5	12	**16**	8	12	**45**	9		

Table 7.4 Percentage of stand area of each habitat type with at least medium regeneration potential, based on the MÉTA database (For details see Seregélyes et al. 2008 Three types of regeneration potential were assessed: *1*: on site following disturbance, *2*: in other adjacent habitat units, and *3*: on old-fields separately. Note that the habitat types totals can add up to more than 100%)

Code	Short name	(1)	(2)	(3)
H5a	Closed steppe on chernozem soil	67	37	27
I2	Vegetation of loess/clay cliffs	63	19	18
M6	Steppe thickets	69	59	7
M2	Steppe woodland on loess	53	30	2
G1	Open sand steppe	76	45	34
H5b	Closed sand steppe	84	30	20
M5	Juniperus-Populus woodland and scrub	96	90	65
M4	Steppe woodland on sand	23	13	0
F1a	Artemisia steppe on solonetz soil	99	78	64
F1b	Achillea steppe on solonetz soil	100	93	78
F2	Saline meadow	99	78	62
F3	Saline meadow steppe	76	59	44
F4	*Puccinellia* meadow	100	75	32
F5	Vegetation of saline - and mud -flats	95	58	12
M3	Steppe woodland on saline soil	46	44	0

7.4. The Vegetation of the Hungarian Forest-Steppe

7.4.1.Closed Steppe on Chernozem Soil (Habitat Code: H5a)

These are closed steppes on humus-rich chernozem soils typically developed over loess, and dominated usually by *Festuca rupicola*. Most of the surviving stands occur on slopes in the lowland or on foothills (Virágh and Fekete 1984; Zólyomi and Fekete 1994; Horváth 2002; Illyés and Bölöni 2007; Bartha 2007a).

Characteristic, dominant and constant species are: *Bothriochloa ischaemum*, *Brachypodium pinnatum*, *Bromus inermis*, *Carex humilis*, *Chrysopogon gryllus*, *Elymus hispidus*, *Festuca rupicola*, *Koeleria cristata*, *Poa angustifolia*, *Stipa capillata*, *Stipa joannis* (*S. pennata*), *S. pulcherrima*, *Adonis vernalis*, *Ajuga laxmannii*, *Allium paniculatum*, *A. rotundum*, *Astragalus austriacus*, *A. dasyanthus*, *A. onobrychis*,*Chamaecytisus austriacus agg.*, *Crambe tataria*, *Dorycnium* spp., *Euphorbia pannonica* (*E. glareosa*), *Fragaria viridis*, *Galium glaucum*, *Hypericum elegans*, *Inula germanica*, *Linaria biebersteinii*, *Nepeta parviflora*, *Phlomis tuberosa*, *Plantago media*, *Ranunculus polyanthemos*, *Rapistrum perenne*, *Salvia austriaca*, *S. nemorosa*, *S. nutans*, *Taraxacum serotinum*, *Teucrium chamaedrys*, *Thalictrum minus*, *Viola ambigua.*

The cold-continental steppes (including meadow steppes and semi-desert-like vegetation) of most of the Great Hungarian Plain were transformed into warm continental steppes during the early Holocene (Nyilas and Sümegi 1991; Sümegi et al. 2000; Sümegi 2005b). These steppes persisted essentially uninterrupted till their transformation into arable lands, since forest development was prevented by climatic conditions, grazing, fires and human influences (see Medzihradszky et al. 2000; Magyari et al. 2009). The late glacial steppes were dominated by grasses, *Artemisia* and Chenopodiaceae species, although other species, such as *Helianthemum*, *Scabiosa*, *Knautia arvensis*, *Trifolium*, *Sedum*, *Achillea*, *Leontodon*, *Taraxacum*, *Centaurea scabiosa* agg. were also recorded

(Járai-Komlódi 1966; Sümegi 2005b; Sümegi et al. 1999, 2006; Magyari 2002). These genera reveal very little about the actual species composition and degree of dominance in the steppe vegetation (perhaps they suggest the presence of a kind of meadow steppe). It is not known what species of grasses formed the matrix of these steppes, how many and what kind of forbs were intermixed, and to what degree the vegetation was closed.

The Holocene steppe vegetation of present-day Hungary is also little known. It is often assumed that the loess tablelands were covered with forest-steppe with scattered *Quercus* woodlands, although certain parts of the plains may have been continuously treeless (Zólyomi 1936, 1952; Járai-Komlódi 1966; Sümegi et al. 1999; Magyari 2002; Magyari et al. 2009; Sümegi 2005a, b). Plowing up the steppes started in the Neolithic age, and continued with only small interruptions (Fairbairn 1992, 1993; Sümegi 1998; Gyulai 2001). The first major period of destruction of steppes on chernozem soil may have been the eleventh to fourteenth centuries, when the country was characterized by a large number of small settlements and intensive land use (see Győrffy 1966; Blazovich 1985). Changes in the settlement structure, such as desertion of small villages and development of rural towns, a process starting in the second half of the thirteenth century and increasing in intensity throughout the fourteenth century (Blazovich 1985), may have resulted in at least the partial regeneration of the steppe vegetation over large areas.

Referring to this vegetation type, Kitaibel wrote: the grassland stands are "*essentially oldfields.*" He documented rather species-rich stands only at a few places, which suggests that along the roads he traveled such steppes did not occur. Many of the specialist, characteristic steppe species were found on the unplowed strips between arable lands and on earthworks marking the boundary between settlements. Kitaibel reported the occurrence of *Crambe tataria* at several locations. This species was probably quite widespread and occurred adjacent to and even on arable land. At times he also observed *Salvia nutans* in unbelievable amounts ("*everywhere across the grazing field from right to left*, *as if it had been sown*"). It is apparent from the comparison of maps of the First Military Survey and current soil maps that a substantial part of the loess tables east of the Tisza river was covered with arable land in addition to extensive steppes.

Steppes of the Great Plain were almost completely transformed to arable land by the end of the twentieth century. Sizeable steppe areas have survived in gullies west of the Danube, on the foothills of mountain ranges, and on elevated terrain embedded in saline steppes. Part of the stands situated on slopes is in good condition and appears stable over time (Virágh and Fekete 1984; Horváth 2002; Bartha 2007a). The stands on level ground, however, are degraded almost without exception (Tóth 1988; Molnár 2007). Steppe remnants on kurgans, earthen fortifications and on unplowed sections among arable fields are sometimes the only survivors of this vegetation type (Zólyomi 1969a; Csathó 2010). Invasive species, though spreading, are not yet abundant. The formerly grazed and currently abandoned stands, parti- cularly on foothills, at places have been invaded by shrubs, and typically show an accumulation of dead organic matter (Bartha 2007a). Mainly stands next to arable land are threatened by plowing (Csathó 2010). Their capacity for regeneration is limited. Good regeneration on oldfields has been observed only on foothills (in abandoned vineyards). This type of steppe vegetation covers about 25,000 ha (of which ca. 6,000 ha are on foothills and slopes). Hardly 10% of the stands are in good condition (naturalness 4 and 5). All stands next to arable lands and those in good conditions are greatly threatened (Fig. 7.1).

7.4.2. Artemisia Steppe on Loess and Clay Cliffs (Habitat Code: I2)

This is the characteristic open vegetation of loess/clay cliffs and steep slopes with *Kochia prostrata* and *Agropyron pectiniforme* as dominant species. It also occurs on kurgans. Too steep loess cliffs are not suitable for the development of this vegetation just like cliffs invaded by *Robinia pseudacacia* or *Lycium barbarum*. The southern slopes of kurgans host usually species-poor stands. Fragmented stands can survive even on the most disturbed kurgans.

Characteristic, dominant and constant species are: *Agropyron pectiniforme* (*A. pectinatum*), *Bothriochloa ischaemum*, *Bromus hordeaceus*, ***B.*** *tectorum*, *Poa bul- bosa*, *Stipa capillata*, *Allium sphaerocephalon*, *A. flavum*, *Anthemis tinctoria*, *Artemisia austriaca*, *A. campestris*, *A. pontica*, *Bassia sedoides*, *Brassica elongata*, *Ephedra distachya*, *Iris pumila*, *Kochia prostrata*, *Lappula patula*, *Linaria genisti- folia*, *Linum austriacum*, *Sedum* (*Hylotelephium*) *maximum*, *Xeranthemum* *annuum.*

The lower parts of loess cliffs often turn into vertical walls, where the microclimate is rather extreme with strong insolation and only 100–200 mm annual precipitation. As a consequence, these habitats are inhabited by cryptogamous communities, mainly mosses. They are extra-zonal desert communities exhibiting floristic similarities to the vegetation of gypsum deserts in southern Spain and the cryptogamous desert vegetation of the climatic loess deserts in the Dead Sea area. Based on the current distribution and ecological characteristics of many of the moss species in this vegetation it is presumed that these communities are very old. Several species may have been part of the xeric flora of the late Tertiary, and survived through the glacial period when they had large areas of distribution (Pócs 1999). The cold-continental dry steppes in the Carpathian Basin were transformed into warm-continental steppes during the Holocene. Characteristic species of the former (i.e. *Krascheninnikovia ceratoides*, *Bassia prostrata*) found refuge in extreme habitats, such as loess cliffs (Zólyomi 1936, 1952; Járai-Komlódi 1966; Zólyomi and Fekete 1994). There is hardly any palynological evidence of the presence of this vegetation type during the Holocene (but see Jakab et al. 2004). Since the Neolithic Age, and even more since the Bronze Age, it may have developed also in secondary habitats on the southern slopes of abandoned earthworks and kurgans.

Kitaibel observed this habitat type (*Bassia prostrata*) at several places. He also recorded repeatedly *Agropyron pectiniforme*, but mainly in closed steppes (the species also is listed among plants growing on kurgans).

The present-day stands of this vegetation type seem to be stable, although invasive species are spreading (*Robinia pseudacacia*, *Lycium barbarum*, *Prunus institia*, *Ailanthus altissima*). Certain habitat patches are afforested with *Robinia pseudacacia*. The stands directly adjacent to arable fields are often plowed. The total area of this vegetation type is about 95 ha. It was found at 152 locations in Hungary. The condition of only hardly one quarter of all the stands is rather natural. They are threatened and have limited regeneration potential (Fig. 7.1).

7.4.3. Steppe Woodland of Quercus on Loess (Habitat Code: M2) and Continental Deciduous Steppe Thicket on Loess (Habitat Code: M6)

These are low or moderately tall mixed oak forests (*Quercus robur*, *Q. pubescens*) on deep, humus-rich soils developed over loess with usually a dense shrub layer and forest and steppe species in the herb layer (M2), as well as thickets of *Amygdalus nana* (*Prunus tenella*), *Cerasus* (*Prunus*) *fruticosa* and *Rosa* species (*R. gallica*, *R. pimpinellifolia*) forming small patches in grasslands and fringes of xerothermo- philous forests (M6) (Zólyomi 1957, 1958).

Characteristic, dominant and constant species are: *Acer tataricum*, *A. campestre*, *Cotinus coggygria*, *Crataegus monogyna*, *Fraxinus ornus*, *Ligustrum vulgare*, *Prunus spinosa*, *Pyrus pyraster*,*Quercus pubescens*, *Q. robur*, *Q. petraea s.l.*, *Q. cerris*, *Ulmus minor*, *Viburnum lantana*, *Adonis vernalis*, *Ajuga laxmannii*, *Buglossoides purpurocaerulea*, *Carex humilis*, *Dictamnus albus*, *Festuca rupicola*, *Nepeta pannonica* (*N. nuda*), *Peucedanum cervaria*, *P. alsaticum*, *Phlomis tuberosa*, *Polygonatum odoratum*, *Pulmonaria mollis*, *Stipa capillata*, *Tanacetum corymbosum*, *Thalictrum minus i*n woodlands, and *Amygdalus nana*, *Cerasus fruticosa*, *Colutea arborescens*, *Crataegus monogyna*, *Prunus spinosa*, *Rosa spinosissima*, *R. gallica*, *Adonis vernalis*, *Brachypodium pinnatum*, *Dictamnus albus*, *Festuca rupicola*, *Fragaria viridis*, *Geranium sanguineum*, *Inula ensifolia*, *I. hirta*, *Iris variegata*, *Peucedanum cervaria*, *Phlomis tuberosa*, *Stipa* spp., *Vinca herbacea*, in steppe thickets.

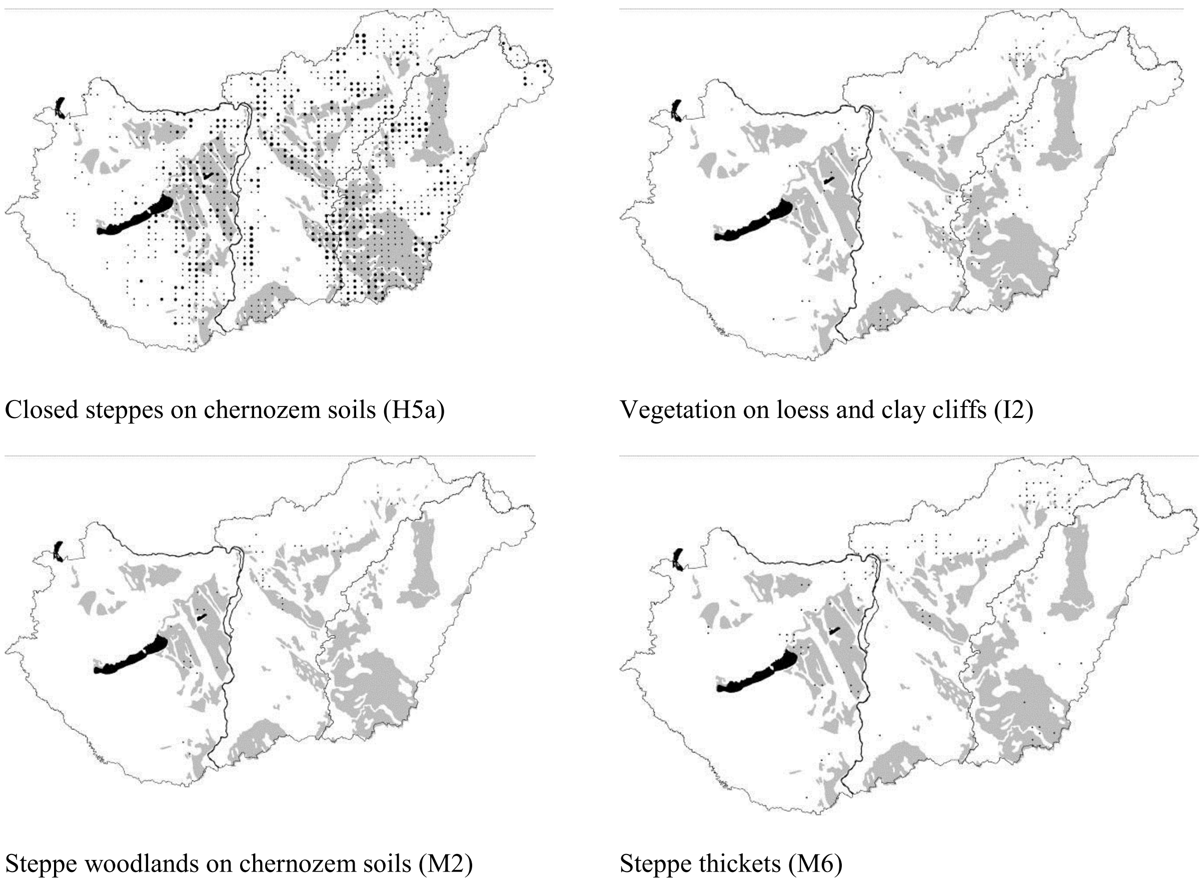


Fig. 7.1 Present distribution of forest-steppe habitats on loess in Hungary. The background *gray color* indicates potential distribution of dry vegetation on loess (Based on Zólyomi 1989)

The extent and characteristics of steppe woodlands and thickets growing on the Great Plain during the Holocene are not known. Based on the estimates of several authors (Zólyomi 1952; Járai-Komlódi 1966; Jakab et al. 2004; Sümegi 2005a, c; Sümegi et al. 2006), large areas were treeless on the loess tables and plateaus (at most 10–20 [−30]% woodland cover). This is directly or indirectly supported by the richness of the steppe flora, the occurrence of steppe animals, the behavior of nomadic peoples, and the occurrence of chernozem soils without signs of forest presence (see Medzihradszky et al. 2000). The regeneration potential of steppe woodlands on level loess tables with a dry climate and often very homogeneous habitats without refugia, and where the effect of human land use is more intense, is likely to be lower than on the topographically more diverse foothills and sand dune areas with a variety of habitats.

Kitaibel observed steppe woodlands on loess only on few occasions, most of them at the margins of the plains. According to his field notes, there were nearly no trees, except for some *Salix* and in most areas even shrubberies were rare. At one location, however, the now extinct *Spiraea crenata* was abundant. On the sheets of the First Military Survey, the lack of forests on the dry loess tables is particularly noticeable.

Today, rather natural steppe woodlands are found only at the margins of the plains and on loess-covered slopes west of the Danube. Its total area is less than 100 ha (for their current conditions see Lendvai and Kevey 2008). Only about a dozen stands of steppe thickets have remained on the Great Plain. They are small, usually degraded, and thus greatly endangered (Fig. 7.1).

7.4.4. Open Sand Steppe (Habitat Code: G1)

These are drought-tolerant shortgrass steppes with at most 75% vegetation cover, occupying loose, humus-poor sand in the Great Plain and more infrequently in hilly regions and foothills. The dominant species are drought-tolerant tussock grasses (*Festuca vaginata*, *Stipa borysthenica*). Formerly, their stands formed mosaics partly with steppe woodlands of *Quercus* or *Juniperus* and *Populus* scrub, as well as with *Molinia* meadows located in depressions. It is an endemic community.

Characteristic, dominant and constant species are: *Bothriochloa ischaemum*, *Bromus tectorum*, *B. squarrosus*, *Carex liparicarpos*, *Festuca vaginata*, *F. wagneri*, *Koeleria glauca*, *Poa bulbosa*, *Secale sylvestre*, *Stipa capillata*, *S. borysthenica*, *Achillea ochroleuca*, *Alkanna tinctoria*, *Alyssum tortuosum*, *A. montanum* subsp. *gmelini*, *Arenaria serpyllifolia*, *Artemisia campestris*, *Centaurea arenaria*, *Colchicum arenarium*, *Corispermum nitidum*, *C. canescens*, *Dianthus serotinus*, *D. diutinus*, *Ephedra distachya*, *Euphorbia seguierana*, *Fumana procumbens*, *Gypsophila fastigiata* subsp. *arenaria*, *Iris humilis*, *Kochia laniflora*, *Linum hirsutum* subsp. *glabrescens*, *Medicago minima*, *Onosma arenaria*, *Polygonum arenarium*, *Potentilla arenaria*, *Salsola kali*, *Silene borysthenica*, *S. conica*, *Syrenia cana* (*Erysimum canum*), *Teucrium chamaedrys.*

The sand dune areas of the Great Plain were formed during the ice age, and were naturally mobilized several times until recently (Lóki et al. 1995; Jakab et al. 2004; Sipos and Kiss 2006). Areas of shifting sand were also generated by overgrazing. The vegetation of shifting sand is one of the most dynamic communities of Hungary (regarding changes in forest cover and in the dominance-structure of species) (Fekete 1992; Biró and Molnár 1998; Bartha 2007b; Biró et al. 2007, 2008; Bartha et al. 2008a, b, c). There are no direct data on the forest cover of the dunes, but it is likely that they were not forested completely at any time throughout the Holocene (Jakab et al. 2004; Sümegi et al. 2005). Thus, at least parts of the grassland vegetation are likely to be continuous from the late glacial and the early postglacial (Boreal) periods. Also, it is not known since when *Festuca* and *Stipa* species have been the dominant grasses of these open steppes.

In the description of Kitaibel, the current flora of shifting sand may be recognized, but in a much more open and treeless landscape. The maps of the First Military Survey show extensive treeless sand dune areas with very few arable lands, tree plantations, orchards and vineyards (Biró and Molnár 1998). At that time, the open sand steppes formed an extensive, partly contiguous system of habitat patches in the sandhill area between the Danube and Tisza Rivers (Biró 2003). The primary species stabilizing sand dunes in the nineteenth century was *Festuca vaginata* (Fekete 1992; Biró and Molnár 1998).

With the diminishing effect of wind and declining frequency of overgrazing since the nineteenth century, natural closure of the vegetation has been taking place and shrubs have been spreading. Today, *Juniperus communis*, *Populus alba*, *P. nigra*, *P. canescens*, and *Crataegus monogyna* are common, sometimes abundant, in most sand dune areas. Shifting sand dunes disappeared, and vegetation cover increased strongest in communities dominated by *Festuca wagneri* (Fekete et al. 2002). Afforestation of shifting sand and the simultaneous establishment of orchards and vineyards with the development of a network of distant farms commenced in the nineteenth and were completed in the twentieth century. As a result, the total area of open sand steppes was reduced to 6–8% of their original size (Biró 2008).

Invasive species (*Asclepias syriaca*, *Robinia pseudacacia*, *Ailanthus altissima*, for example) have been spreading rapidly, although mainly in the secondary or more degraded stands, and in oldfields and plantations adjacent to them (Botta- Dukát 2008; Czúcz et al. 2011). Today, these steppes are rarely plowed, but their afforestation is still in progress. Their total area is 10,700 ha, of which only one third is rather natural. It is because many tracts of arable land have been abandoned recently in sandy habitats, which undergo relatively rapid regeneration (Csecserits and Rédei 2001; Bartha 2007c; Bartha et al. 2008b, c), and thus are classified in this habitat category. The vegetation type is a bit endangered (Fig. 7.2).

7.4.5. Closed Sand Steppe (Habitat Code: H5b)

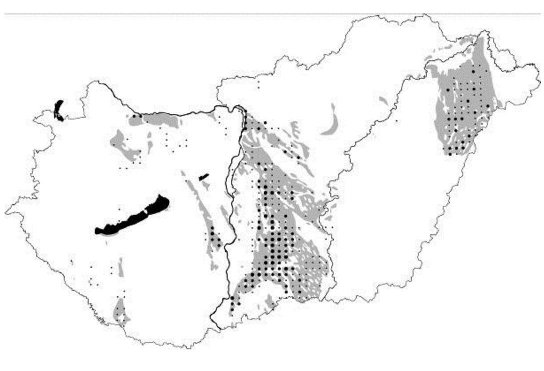
Closed dry and semi-dry steppes on humus rich sandy soils. The minimum cover of the herb layer is 50%. They occur in almost every sandy region of the country.

Characteristic, dominant and constant species are: *Bothriochloa ischaemum*, *Carex humilis*, *Chrysopogon gryllus*, *Festuca wagneri*, *F. rupicola*, *Holoschoenus romanus* (*Scirpoides holoschoenus*), *Koeleria cristata*, *Phleum phleoides*, *Poa angustifolia*, *Stipa capillata*, *S. borysthenica*, *Achillea ochroleuca*, *Adonis vernalis*, *Anemone sylvestris*, *Anthericum liliago*, *A. ramosum*, *Asperula cynanchica*, *Aster linosyris*, *Astragalus austriacus*, *A. dasyanthus*, *A. exscapus*, *A. asper*, *Chamaecytisus* *ratisbonensis*, *Colchicum arenarium*, *Dianthus giganteiformis* subsp. *pontederae*, *Filipendula vulgaris*, *Geranium sanguineum*, *Inula salicina*, *Iris aphylla* subsp. *hungarica*, *Iris humilis*, *I. variegata*, *Peucedanum arenarium*, *Plantago media*, *Potentilla arenaria*, *Pulsatilla pratensis* subsp. *hungarica*, *P. patens*, *Salix repens* subsp. *rosmarinifolia*, *Salvia pratensis*, *Scabiosa canescens*, *Senecio* (*Tephroseris*) *integrifolius*, *Silene borysthenica*, *Teucrium chamaedrys*, *Trifolium alpestre*, *Veronica pallens* (*Pseudolysimachion incanum*), *V. spicata* (*Pseudolysimachion spicatum*).

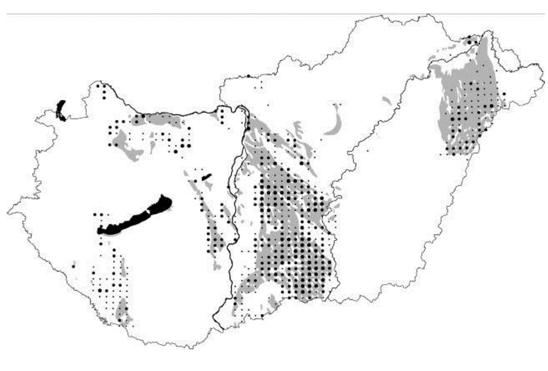
The habitat of closed sand steppes is completely suitable for forests (Magyar 1961). Despite this, the available, but not yet decisive historical data suggest that it was only partially forested during the last 10,000 years (Jakab et al. 2004; Sümegi et al. 2005). In the first half of the Holocene, there might have been more extensive steppe woodlands in sandy habitats, the disappearance of which probably took place during the past 5–6,000 years (see Sümegi et al. 2005). From the late Neolithic Age to the eighteenth century, most of the closed steppe stands may have been plowed up (many of them even several times), or were at least grazed for several thousand years. It is unknown how many sand steppe species had disappeared by the eighteenth century. The decline in the number of steppe species from the mountain ranges to the center of the sandhill area is very evident today (Fekete et al. 1999, 2010). Our field experience and earlier floristic data suggest that similarly to salt steppe woodlands, the steppe flora is richer in the vicinity of sand steppe woodlands than at sites having been treeless for long. This phenomenon may be explained by less intense land use, a great diversity of microclimatic sites, a small-scale variation in habitat conditions, and, as a conse- quence of all these, by a great variety of microrefugia (Molnár 1998; Molnár et al. 2008d).

Judged from his species lists, Kitaibel probably observed mostly disturbed and species-poor, weed-infested, supposedly secondary stands (many of them may have been oldfields). Floristic data, mainly from the nineteenth century, indicate an altogether rich steppe flora (see Molnár et al. 2008d). According to the sheets of the First Military Survey, the plowing of closed sand steppes already began at the end of the eighteenth century, although most of the sandy habitats with humus-rich soil were still covered with almost completely treeless sand steppe.

During the nineteenth century, almost 100% of the closed sand steppes were plowed up. Apart from some military grounds, this vegetation survived only in refugia (fringes and glades of sand steppe woodlands, rather humus-rich depressions among sand dunes, dune tops in marshy and saline environments). Owing to draining of wetlands in the second half of the twentieth century, many secondary and species- poor, atypical stands have developed from former calcareous fens and *Molinia* meadows (Molnár et al. 2008d). Certain stands are invaded by shrubs, others by invasive species (e.g., *Robinia pseudacacia*). Litter accumulation is pronounced in stands recently freed from grazing. It undergoes slow regeneration, often in small areas, because oldfields in this habitat occur mostly at the edges of sand dunes and as enclosures in wetlands. Sand steppes developed from drained meadows are often plowed up. The total area of closed sand steppes is 28,000 ha, of which only a few percent is found in their original habitat. Only one quarter of the stands are considered natural (naturalness 4 and 5). The more species-rich stands are greatly endangered (Fig. 7.2).



Open sand steppes (G1)



Closed sand steppes (H5b)

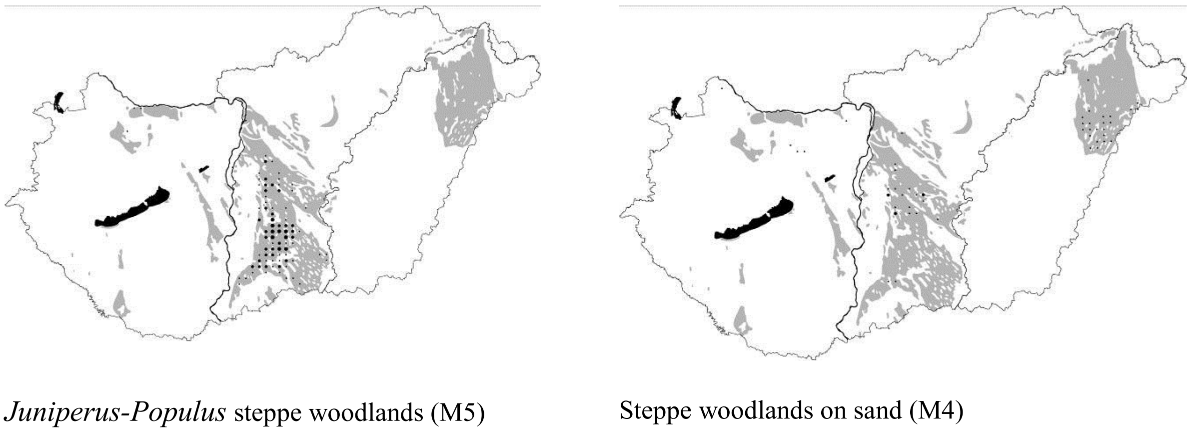


Fig. 7.2 Present distribution of forest-steppe habitats on sand in Hungary. The background *gray color* indicates the potential distribution of sand vegetation (Based on Zólyomi 1989)

7.4.6. Juniperus-Populus Steppe Woodland and Scrub (Habitat Code: M5)

These are open woodlands or scrub dominated by *Juniperus communis* and/or *Populus alba* and *P. canescens* on sandy soils with low to moderate humus content. This species poor, open vegetation type is typically poor in forest species, and forms a mosaic with open sand steppes (G1). It is most widespread on the Great Plain, in the sandy region between the Danube and Tisza rivers.

Characteristic, dominant and constant species are: *Berberis vulgaris*, *Crataegus monogyna*, *Juniperus communis*, *Ligustrum vulgare*, *Populus alba*, *P. canescens*, *P. nigra*, *Rhamnus catharticus*, *Brachypodium sylvaticum*, *Convallaria majalis*, *Geum urbanum*, *Hieracium umbellatum*, *Lithospermum officinale*, *Polygonatum odoratum*, *P. latifolium*, *Vincetoxicum hirundinaria*, *Viola hirta*, *V. odorata.*

Although *Juniperus communis* is a widespread species on the sand dunes today, very few data on its occurrence are available from the past 10,000 years (Járainé Komlódi 1985). It may have appeared in the landscape 2,000 years ago simultaneously with the decline of *Quercus* followed by *Carpinus* and *Fagus*.

According to the hypothesis of Gábor Fekete (Fekete 1992), the surfaces of sand dunes well above the groundwater table are settled, in the absence of habitat specific woody species, by the generalist *Juniperus communis* and/or *Populus alba* and *P. canescens* 'borrowed' from floodplain forests. Thus, this scrub is the edaphic climax community in the successional series of sand dunes. With regard to the origin of *Juniperus-Populus* scrub, other hypotheses have also been put forward. Soó (1960) does not exclude the possibility that *Juniperus-Populus* scrub may develop from closed *Quercus* forests via degradation, though he also accepts the view that this vegetation may be part of the natural successional series of primary succession on sand dunes. Simon (1985) argues that the direct successional vegetation development from open sand steppe via *Juniperus-Populus* scrub to *Quercus* woodlands is possible. These opposing views stem partly from the fact that stands of oak trees are still present in certain sand dune areas, whereas the forest flora is completely absent in others.

Phytosociological material documenting the species composition of Juniperus-Populus scrub is very scant. The only published phytosociological tables are from Szodfridt (1969). Based on these data, he explicitly rejects the idea that Juniperus-Populus scrub may develop from Quercus woodlands via degradation. Based on the position of this community on dunes, two types were described. The first is found on top of the dunes, in which species typical of sand steppes are still dominant, whereas in the other type, growing in depressions, already some species of open forests and closed steppes with broad ecological tolerances (mostly shrubs) appear. There are only very few exclusive forest species (while mesophilous forest plants are completely absent), even though oak woodlands and forests are not absent in the studied landscape.

In the sand dune areas of Hungary, several types of Juniperus-Populus scrub may develop depending on the geomorphology of the dunes. They primarily differ in the dominance relations of the two edifying species, which is determined by their dynamics (for instance, Populus species grow larger and form denser stands in concave, more favorable sites, from which Juniperus is gradually excluded owing to strong shading). The position of these types relative to one another and the occurrence of these types as a series is characteristic of the landscape (Babos 1955).

As of today, there are no relevant data available from the Holocene to test the two hypotheses (data from landscape analyses currently support both). The total absence of extensive Juniperus scrub in the sandhill area between the Danube and Tisza rivers during much of the Holocene cannot be excluded either. In evaluating the hypotheses, it is important to consider that there are fully grown Quercus robur and Q. pubescens trees in the dry sand dunes, and it is also possible that Quercus woodlands could not develop in certain sand dune areas during the last millennia due to continual forest clearing, fires and heavy grazing.

At the time of the First Military Survey, most sand dune areas in the Kiskunság were treeless (Biró 2003). Often, even open Populus woodlands and thickets were missing there. Even Kitaibel recorded only loose groups of Populus trees on sand dunes with typical species of the sand steppe flora in between.

During the nineteenth century, the sparse woodlands of the dunes extended in area (Biró 2008; Biró and Molnár 2009), which was partly a spontaneous process, and partly the result of afforestation to stabilize shifting sand. It is possible that Populus nigra has become a typical species of the sand dune flora this way (Molnár 2003). One reason for their depauperate forest flora may be just their secondary origin (besides their open canopy and dry habitat conditions). Their regeneration potential is very good, particularly in sand steppes, but also in oldfields. The presence of invasive species in the stands is typical (*Robinia pseudacacia*, *Ailanthus altissima*, more recently *Prunus serotina*, Juhász and Bagi 2008; Juhász et al. 2009; Botta-Dukát et al. 2008). Certain stands are under intensive forest management (Babos 1955). Grazing in this vegetation has almost stopped by now. Their total area is about 3,000 ha. Almost two thirds of the stands are rather natural (naturalness 4 and 5). It is not endangered (Fig. 7.2).

7.4.7. Steppe Woodland of Quercus on Sand (Habitat Code: M4)

These are steppe woodlands developed on humus-rich sandy soils and dominated by *Quercus robur*. They are represented both by rather small groups of trees or more extensive stands. In the landscape, they typically form a mosaic with sand steppes. Their shrub layer is generally tall and rather dense. *Festuca rupicola* and *Poa angustifolia*, together with the so-called forest-steppe species are common in the herb layer (Hargitai 1940; Soó 1943).

Characteristic, dominant and constant species are: *Berberis vulgaris*, *Betula pendula*, *Chamaecytisus ratisbonensis*, *Cornus sanguinea*, *Corylus avellana*, *Crataegus monogyna*, *Euonymus europaeus*, *Fraxinus angustifolia* subsp. *pannonica*, *Ligustrum vulgare*, *Malus sylvestris*, *Populus alba*, *P. tremula*, *Pyrus pyraster*, *Quercus robur*, *Q. pubescens*, *Rhamnus cathartica*, *Rosa elliptica*, *R. gallica*, *Salix rosmarinifolia*, *Viburnum lantana*, *Anemone sylvestris*, *Brachypodium pinnatum*, *B. sylvaticum*, *Campanula bononiensis*, *Clinopodium vulgare*, *Convallaria majalis*, *Cucubalus baccifer*, *Dictamnus albus*, *Gentiana cruciata*, *Geranium sanguineum*, *Hieracium umbellatum*, *Iris variegata*, *Jurinea mollis*, *Lithospermum officinale*, *Lychnis coronaria*, *Melampyrum cristatum*, *Origanum vulgare*, *Peucedanum cervaria*, *P. oreoselinum*, *Polygonatum odoratum*, *Silene conica*, *Tanacetum corymbosum*, *Thalictrum minus*, *Trifolium alpestre.*

It is assumed that the extent of forests in areas of dry sand was greater in the first half of the Holocene, and much smaller afterwards. Based on indirect evidence, these woodlands were perhaps composed of *Tilia* and *Ulmus* in addition to *Quercus* (see Járai-Komlódi 1966, 1985; Jakab et al. 2004; Sümegi et al. 2005). In the Middle Ages, much more extensive woodlands existed in certain areas, but they were far in between (Hargitai 1940).

It may be inferred from the *Descriptio* of the First Military Survey that most of the wooded areas were *Quercus* woodlands, most of them with a 15-year clearing cycle (Molnár 1998). Data from Kitaibel suggested the heavy use of these forests along with their protection (for example, dense *Salix* hedgerows protecting them from grazing).

The stands have shrunk to a fraction of their original size during the past 200 years. They were transformed to arable land to a lesser, and tree plantations, first *Robinia* then *Pinus*, to a large extent. The formerly short clearing cycle was gradually increased to 25, then 40 years, and grazing in the forest was abandoned. Owing to water regulation carried out in the region in the twentieth century, the groundwater table has dropped 2–3 m, and the oaks started to die (Molnár 1998). The forests have been degraded first by the invasion of *Robinia pseudacacia*, more recently by *Prunus serotina*, and at places by wild game populations (wild boar, fallow deer) well exceeding carrying capacities. Most of the stands are surrounded by *Robinia* plantations. Several of the original species went locally extinct (for example *Majanthemum bifolium*, *Dracocephalum austriacum*). Establishment of oak plantations by currently adopted forestry methods is hardly successful (Molnár 1998). The total area of this vegetation type is ca. 290 ha. This is one of the most endangered vegetation types in Hungary. Half of the stands are degraded, and their regeneration potential is the lowest among all. Despite their legal protection, stands are cleared even today by forestry companies (Fig. 7.2).

7.4.8. Artemisia Steppe on Solonetz Soil (Habitat Code: F1a)

These steppes occur in the Carpathian Basin on saline, mainly solonetz soils that are periodically (but rarely and then only slightly) moist for a short time. They are shortgrass steppes dominated by *Festuca pseudovina* and *Artemisia santonicum* as the most frequent co-dominant species. Large stands (the so-called *puszta*) are typical. This vegetation type is usually rich in halophytic species, whereas species of wet meadows and dry steppes on chernozem soils are rare. It also hosts a number of endemic taxa.

Characteristic, dominant and constant species are: *Festuca pseudovina*, *Hordeum hystrix*, *Poa bulbosa*, *Allium vineale*, *Artemisia santonicum*, *Bassia prostrata*, *Bupleurum tenuissimum*, *Cerastium dubium*, *C. pumilum*, *Erophila verna*, *Gypsophila muralis*, *Limonium gmelini*, *Lotus tenuis* (*L. glaber*), *Myosotis stricta*, *Ornithogalum tenuifolium*, *Plantago schwarzenbergiana*, *Podospermum canum*, *Ranunculus pedatus*, *Scilla autumnalis*, *Trifolium retusum*, *T. angulatum*, *T. parviflorum* (*retusum*), *Veronica arvensis*.

Sümegi et al. (2006) consider the Hortobágy steppe as an almost completely treeless saline landscape (with graminoids, *Plantago maritima*, *Artemisia santonicum*, many Chenopodiaceae, among them supposedly *Atriplex tatarica*, *Suaeda* spp.) at the end of the Glacial Period and through the Holocene. In the interior of the roughly 100,000-ha-large Hortobágy, the pollen of *Fagus*, *Carpinus*, *Fraxinus* and *Tilia* were absent throughout the entire Holocene (as opposed to the nearby floodplains). These data suggest that the current stands of *Artemisia* steppe of the Great Plain may have directly descended from former salt steppes in earlier parts of the Holocene (Somogyi 1965; Sümegi et al. 2000, 2006). It is not known, however, how much the species pool has changed since the late Glacial Period, and for how long *Festuca pseudovina* and *Artemisia santonicum* have been the dominant species.

We identified the following species group in the 92 detailed lists of salt steppe species of Kitaibel, which were recorded during his journeys through the Great Plain around the turn of the eighteenth to nineteenth century. *Artemisia santonicum*-group: *Artemisia santonicum*, *Limonium gmelini*, *Bromus hordeaceus*, *Achillea collina*, *Plantago maritima*, (*Festuca pseudovina*), (*Podospermum canum*), (*Puccinellia limosa*), (*Atriplex hastata*). This list recalls the *Artemisia* salt steppe for contemporary botanists. The written and often very apt descriptions of Kitaibel, which were based on great field experience, also indicate that he saw the saline steppes east of the Tisza River the same as we see them today. Species frequencies in the 92 species lists also correspond well to the current situation. On the sheets of the First Military Survey prepared between 1783 and 1785, the saline steppe cannot be recognized, but it is likely that the grassy fields mentioned in the description as "*moist from rain*" were not part of the floodplain, but of saline steppe. Robert Townson, a British explorer, traveling through the Hortobágy almost the same time (1799) as did Kitaibel, describes the Hortobágy unambiguously as a desolate land and depicts it as an immense barren land devoid of trees (apud Nyilas 1999).

The extension of *Artemisia* steppes has been reduced by plowing, amelioration and establishment of rice paddies during the past 200 years, although substantially less compared to other forest-steppe habitats. The degree of weed infestation is limited (*Bromus hordeaceus*, *Hordeum hystrix*), and the condition of many stands has improved in response to decreasing overgrazing in the past 30–40 years. They are almost completely free of invasive species. A long-term threat is leaching of the upper soil layer prompted by dropping groundwater levels, which results in the replacement of the halophytic species by generalist ones. On sufficiently saline soils, the *Artemisia* steppe has high regeneration potential, and can develop even in oldfields. It is one of the least endangered vegetation types in the forest-steppe zone in Hungary. Its total area currently is 33,800 ha, two thirds of which are in rather natural condition (naturalness 4 and 5) (Fig. 7.3).

7.4.9. Achillea Steppe on Solonetz Soil (Habitat Code: F1b)

This is a secondary, species-poor and usually shortgrass community growing typically on meadow solonetz soil. It is dominated generally by *Festuca pseudovina* and *Achillea setacea* and/or *A. collina*, which are associated with other pseudo- halophytic species, dry grassland species and generalist meadow species (it is usually poor in *Achillea asplenifolia* and stenohalophytic species). It occurs on drained or naturally dry former floodplains and may also develop from *Artemisia* steppes following leaching of the soil.

Characteristic, dominant and constant species are: *Carex stenophylla*, *Cynodon dactylon*, *Festuca pseudovina*, *Koeleria cristata*, *Lolium perenne*, *Poa angustifolia*, *Achillea setacea*, *A. collina*, *Bupleurum tenuissimum*, *Cardaria* (*Lepidium*) *draba*, *Euphorbia cyparissias*, *Inula britannica*, *Limonium gmelini*, *Plantago lanceolata*, *Podospermum canum*, *Ranunculus pedatus*, *Scleranthus annuus*, *Trifolium fragiferum.*

Data on its Holocene history are not available. Because of the regular relocation of riverbeds during the Holocene (Somogyi 1965; Sümegi et al. 2000), and the presumed periodical leaching of saline soils (Somogyi 1964, 1965), its occurrence may have been rather frequent in the past. There is no reference to this vegetation type in the notes of Kitaibel.

In the past 200 years, its area could have multiplied. It is the dominant habitat type in unplowed, but drained floodplains. It may develop in place of riparian forests after their clearing (Molnár and Borhidi 2003). It is often weed-infested, particularly when heavily grazed or when the soil is drained or leached, but invasive species are rare. It may develop in oldfields or from ameliorated *Artemisia* steppes and drained saline meadows. It easily regenerates, even in oldfields. Its total area is 46,000 ha, but only less than one third of the stands are in rather "natural" conditions (naturalness 4: low cover of weeds, dominance of *Festuca* and *Achillea*). It is not an endangered vegetation type (Fig. 7.3).

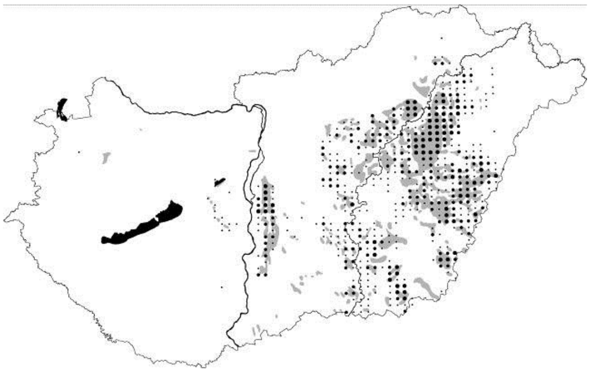
7.4.10.Saline Meadow (Habitat Code: F2)

These are seasonally inundated tallgrass meadows growing on solonetz or solonchak meadow soils. Their habitat typically is covered with water from October till May or June, and the soil remains moist throughout much of the year. They are less diverse on solonetz soils, where characteristic tussocks on small mounds of mud are formed, and this contributes to increased naturalness and species diversity.

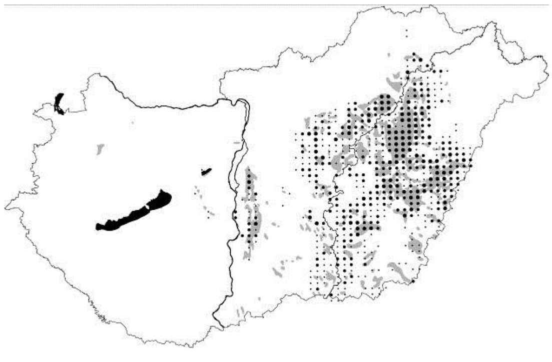
Characteristic, dominant and constant species are: on solonetz: *Alopecurus pratensis*, *Beckmannia eruciformis*, *Glyceria fluitans* subsp. *poiformis*, *Oenanthe silaifolia*, *Plantago schwarzenbergiana; Ranunculus lateriflorus*, *R. sardous*, *Rorippa sylvestris* subsp. *kerneri*, on solonchak: *Carex distans*, *Festuca arundina- cea*, *Juncus gerardii*, *Puccinellia limosa*, *Achillea asplenifolia*, *Linum perenne*, *Orchis laxiflora* subsp. *palustris* (*Anacamptis palustris*), *Rhinanthus angustifolius* subsp. *serotinus*, *Scorzonera parviflora*, *Taraxacum bessarabicum*, *Triglochin maritimum.*

It is unknown whether or not these meadows were originally forested, though the former existence of forests in these habitats is very unlikely not only for the presence of salts in the soil, but also for the widely fluctuating water regime and the heavy soil (Debreczy in Molnár and Kun 2000). Sümegi (2005b) demonstrated the presence of regularly desiccating, but not flooded meadows in the Hortobágy during the Holocene, which could have been saline meadows.

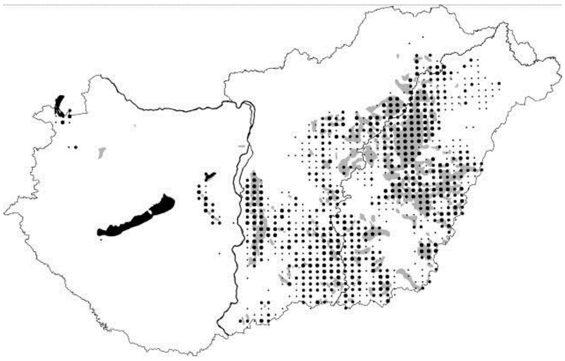
We identified three species groups in the species lists of Kitaibel: (1) *Beckmannia* group: *Lythrum virgatum*, *Beckmannia eruciformis*, *Trifolium fragiferum*, *Glyceria poiformis* subsp. *fluitans*, meadow species, (*Festuca pratensis-arundinacea*), (marsh species), (*Alopecurus geniculatus*) and (*Alopecurus pratensis*); (2) *Ranunculus lateriflorus* group: *Ranunculus lateriflorus*, *Elatine alsinastrum*, *Rorippa sylvestris* subsp. *kerneri*, *Eleocharis palustris*, *Glyceria poiformis* subsp. *fluitans*, marsh species, *Alopecurus geniculatus*, (*Plantago tenuiflora*) and (meadow species); (3) *Achillea asplenifolia-Agrostis stolonifera* group: *Festuca arundinacea- pratensis*, *Achillea asplenifolia*, *Agrostis stolonifera*, (fen species), (*Carex distans*), (*Juncus compressus*).



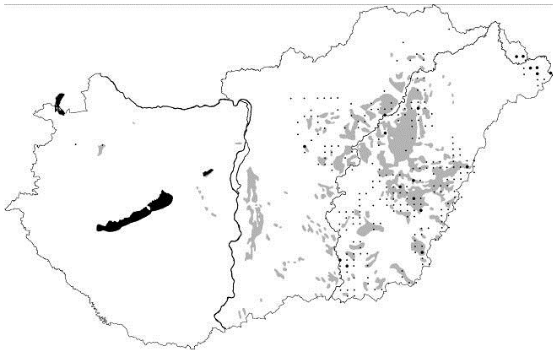
Artemisia steppe on solonetz soil (F1a)



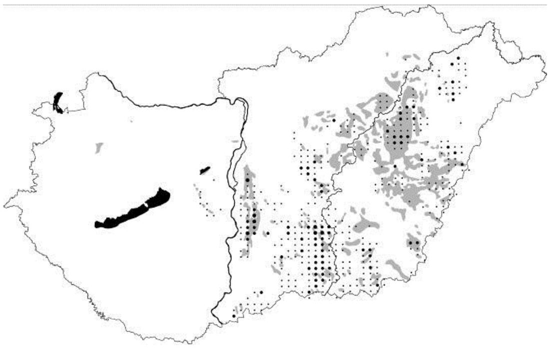
Achillea steppe on solonetz soil (F1b)



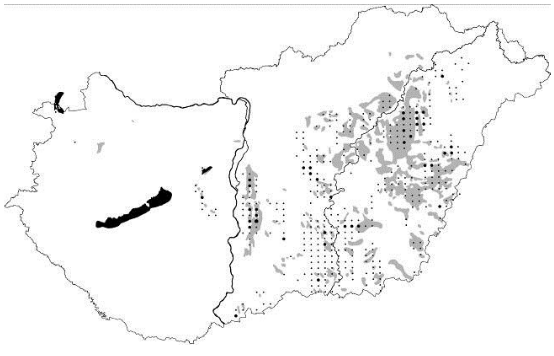
Saline meadow (F2)



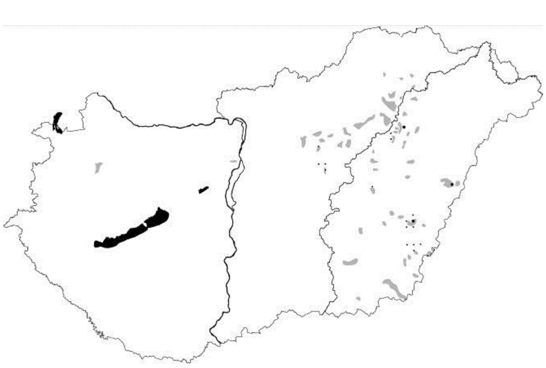
Tall herb meadow steppe on solonetz soil (F3)



Puccinellia meadow (F4)



Annual vegetation of salt lakes and mud-flats, and vegetation of saline flats (F5)



Steppe woodland of *Quercus* on saline soil (M3)

Fig. 7.3 Present distribution of forest-steppe habitats on saline soils in Hungary. The background *gray color* indicates the potential distribution of saline vegetation in general, and that of saline steppe woodlands in particular (Based on Zólyomi 1989)

The *Beckmannia* group suggests the presence of characteristic, wet saline meadows with ample supply of water, whereas the *Ranunculus* and *Achillea-Agrostis* groups indicate muddy habitats with heavily grazed (possibly by cattle) vegetation and solonchak meadows, respectively. Maps of the First Military Survey depict the non-flooded (possibly saline) meadows only irregularly, and thus the reconstruction of their original extent is not reliable. According to Kitaibel, *Alopecurus pratensis* was a common and typical species of saline meadows also at his time.

Saline meadows on solonetz soils have become substantially drier in the past 200 years, and their extension also decreased. Nevertheless, a very large number of stands have survived due to their heavy soils and the topographical features (many small local depressions that are very costly to drain) of their habitats. The extension of saline meadows on solonchak soils, however, has been drastically reduced. The groundwater table has dropped, sometimes as much as 2–3 m (Pálfai 1994), and the soil has been leached. Invasive species are rare. Plowing threatens mainly the stands on sand. They regenerate well, even in oldfields and after ame- lioration of the habitat. When left unmanaged, leaf litter accumulates rapidly, and diversity drops. Its total area is 93,000 ha, making it the most common habitat type in Hungary. More than half of its stands are in conditions close to natural (naturalness 4 and 5). It is rather threatened on solonchak soils, but not on solo- netz (Fig. 7.3).

7.4.11. Saline Tall Herb Meadow Steppe (Habitat Code: F3)

These saline meadow steppes are dominated by meadow steppe and dry steppe spe- cies as well as halophytes; primarily Apiaceae and other tall herbs determine their structure. They occur mainly in the eastern part of Hungary on solonetz soils. Their habitat is typically wet in the spring and dry in the summer. The most frequent char- acteristic species are *Aster punctatus*, *Artemisia pontica* and *Peucedanum officinale*. The more mesic variant resembles tallgrass meadows and is rich in characteristic species and species of meadow steppes, whereas the drier variant is rather short and represents a transitional stage towards *Achillea* steppes. The species-richest stands are linked to steppe woodland of oaks on saline soils or hardwood (*Fraxinus*, *Ulmus*, *Quercus*) gallery forests, but most of the stands occur now in non-wooded environ- ments. Similar habitats occur as far to the East as Mongolia (Varga 1989).

Characteristic, dominant and constant species are: *Alopecurus pratensis*, *Festuca pratensis*, *F. rupicola*, *F. pseudovina*, *Phragmites australis*, *Artemisia pontica*, *Aster linosyris*, *A. punctatus*, *Clematis integrifolia*, *Dianthus pontederae* (*D. gigan- teiformis* subsp.), *Filipendula vulgaris*, *Fragaria viridis*, *Iris spuria*, *Limonium gmelini*, *Lotus angustissimus*, *Lychnis flos-cuculi*, *Peucedanum officinale*, *Plantago schwarzenbergiana*, *Rumex pseudonatronatus*, *Serratula tinctoria*, *Seseli varium*, *Veronica spicata* (*Pseudolysimachion spicatum*), *Viscaria vulgaris* (*Lychnis viscaria*).

These saline meadow steppes may have been continuously present in the eastern part of the Great Plain since at least the Late Glacial Period, which is suggested by fossil pollen of *Thalictrum* sp., *Peucedanum* sp., *Filipendula ulmaria*, and *Sanguisorba officinalis* found at the margin of the Tisza floodplain (Magyari 2002; Sümegi 2004). More detailed data, however, are not available.

Kitaibel described stands of *Peucedanum officinale* at several locations. The co-occurring species there were essentially the same as those today, but the number of stands linked more strongly to floodplains may have been higher. Analysis using the JUICE software resulted in the following species group: *Peucedanum officinale-Aster punctatus* group: *Peucedanum officinale*, *Aster punctatus*, *Artemisia pontica*, dry steppe species, *Clematis integrifolia*, *Eryngium planum*, *Peucedanum alsaticum*. This list completely concurs with the flora of characteristic contemporary stands. Contrary to our expectation, Kitaibel recorded *Peucedanum officinale* only infrequently suggesting that this kind of meadow steppe was uncommon on floodplains and their margins even 200 years ago. The First Military Survey does not provide information.

During the past 200 years, many of its stands have been plowed or afforested. Others dried up, which has lead to the development of vegetation of shorter stature with an atypical species composition. They are sometimes infested by weeds. Stands adjacent to forests may be invaded by shrubs. They have limited regeneration potential, although some of the typical species readily enter oldfields where they may become abundant (i.e. *Aster punctatus*). The total area of this community is barely 1,120 ha, one third of which is in good condition (naturalness 4 and 5). It is endangered (particularly the species-rich stands) (Fig. 7.3).

7.4.12. Puccinellia Meadow, Annual Halophytic Vegetation of Salt Lakes and Vegetation of Saline Flats (Habitat Code: F4 and F5)

In the most saline habitats of Hungary, three main community types are distinguished: (1) annual halophytic vegetation of salt lakes and mud-flats (F5); (2) vegetation of saline flats embedded in dry saline steppes as small patches (F5); and (3) closed *Puccinellia* meadows (F4). These communities are rich in Pannonian endemics, and exhibit pronounced continental characteristics. They develop on strongly saline soils that are under water early in the vegetation period, but then dry out completely. On solonchak soils, precipitation of crystallized salts on the ground surface is common.

Characteristic, dominant and constant species are: *Crypsis aculeata*, *C. alope- curoides*, *C. schoenoides*, *Cyperus pannonicus*, *Pholiurus pannonicus*, *Puccinellia limosa*, *P. festuciformis* subsp. *intermedia*, *Aster tripolium* subsp. *pannonicus*, *Atriplex littoralis*, *Bassia sedoides*, *Camphorosma annua*, *Chenopodium chenopo- dioides*, *C. glaucum*, *Lepidium crassifolium*, *Matricaria chamomilla* var. *salina*, *Myosurus minimus*, *Plantago maritima*, *P. tenuiflora*, *Plantago schwarzenbergiana*, *Rorippa sylvestris* subsp. *kerneri*, *Salicornia prostrata*, *Salsola soda*, *Spergularia media*, *S. salina*, *Suaeda pannonica*, *S. maritima*, *S. salinaria.*

We assume that stands of considerable size may have existed continuously in Hungary since the Pleistocene. However, direct evidence is very scarce, because the survival chance of pollen grains is greatly reduced by soil salinity and soil cracking. Furthermore, it is very difficult to distinguish among Chenopodiaceae pollen (but see fossil evidence for the occurrence of *Suaeda* and *Atriplex tatarica* in the Hortobágy steppe, Sümegi et al. 2006). Before the draining of wetlands, several hundred salt lakes of variable ages occurred on the Great Plain (Molnár 1979; Boros and Biró 1999). Surprisingly, *Polygonum aviculare*, which is considered an indicator species of human disturbance (trampling by humans and livestock), has been a regular companion in the communities on saline mud-flats in the Hortobágy through- out the Glacial and Postglacial periods (Sümegi et al. 2006) suggesting that it is a natural component of these communities.

Kitaibel observed similar habitats at many places. He often recorded salt harvests by sweaping, and even the collection of soda (sodium carbonate). Once he describes the vegetation zones of a salt lake: open water in the center with *Bolboschoenus maritimus*, then *Puccinellia limosa* outward, followed by other species (*Plantago maritima*, *Podospermum canum*, *Lepidium crassifolium*, *Camphorosma annua*). This perfectly corresponds to the vegetation zones of current salt lakes with white water. We identified the following six species groups by analyzing the 92 species lists of Kitaibel with the JUICE software: (1) *Pholiurus* group: *Trifolium angula- tum*, *Ventenata dubia*, *Pholiurus pannonicus*, arable weeds, *Bromus hordeaceus* and *Myosurus minimus*; (2) *Hordeum hystrix-Lepidium ruderale* group: *Matricaria chamomilla* var. *salina*, *Polygonum aviculare*, *Hordeum hystrix*, *Lepidium ruderale*, *Bromus hordeaceus*, *Pholiurus pannonicus*, (*Artemisia santonicum*) and (*Plantago tenuiflora*); (3) *Matricaria chamomilla* group: *Bromus hordeaceus*, *Matricaria chamomilla* var. *salina*, arable weeds, *Lepidium perfoliatum*, *Festuca pseudovina*, (*Myosurus minimus*), (*Podospermum canum*) and (*Lepidium ruderale*). (4) *Suaeda maritima* group: *Suaeda maritima*, *Salicornia prostrata*, *Suaeda pannonica*, *Scorzonera parviflora*, *Aster tripolium*, *Atriplex hastata*, *Crypsis aculeata*, (*Spergularia maritima*); (5) *Lepidium crassifolium* group: *Lepidium crassifolium*, *Camphorosma annua*, (*Plantago maritima*), (*Aster tripolium*); (6) *Puccinellia limosa-Lepidium crassifolium-Camphorosma annua* group: *Camphorosma annua*, *Lepidium crassifolium*, *Puccinellia limosa*, *Limonium gmelini*, *Plantago maritima*, (*Lepidium ruderale*), (*Atriplex hastata*).

The first three groups indicate disturbed stands on solonetz soils. The cause of disturbance may be regular trampling, grazing, and partly the inclusion of secondary stands at the margin of arable fields into the species lists. The fourth and fifth group represent species characteristic of salt lakes and saline flats on solonchak soils, respectively, whereas the sixth group includes the generalist species of *Puccinellia* meadows and saline flats. In the latter cases the species lists also correspond to the current situations.

In the First Military Survey, the Austrian military officers sometimes attached some texts to salt lakes, such as "*Himmelteich*" (a lake from the sky), and "*dries up completely by summer*". These data most likely refer to temporal intermittent lakes without concentrated inflow. The tiny salt lakes and muddy surfaces in the salt steppes are not depicted on the maps, however.

In the past 200 years, these habitats dried up considerably, or their soil often became leached. Certain stands were plowed up or ameliorated. Most of the salt lakes in sandy areas have completely dried up in the last third of the twentieth century, whereas salt lakes on heavy solonetz soils suffered less from drought (there the spread of *Bolboschoenus* causes some problems). Their vegetation rapidly regenerates in suitable habitats, but regeneration ability sharply drops on leached soils. Soil leaching is followed by colonization of meadow, marsh or steppe species, and the development of a closed vegetation cover. Salt accumulation on the surface has ended at many places. Invasive species are missing. Only heavy overgrazing may cause moderate weed infestation. The total area is approximately 9,500 ha. The condition of around 80% of the stands is close to natural (as the degraded ones are often classified into other habitat types). They are not threatened on the short run (except for salt lakes, which are endangered), but on the long run leaching may result in the transformation of many stands (Fig. 7.3).

7.4.13. Steppe Woodland of Quercus on Saline Soils (Habitat Code: M3)

These are open woodlands on saline soils dominated by *Quercus robur*. The stands rarely reach a height of 15 m, and form a habitat mosaic with saline tall herb meadow steppes, halophytic communities, dry steppes and reed beds. Forest elements are mixed with steppe and halophytic species. This habitat occurs almost exclusively in the eastern part of Hungary.

Characteristic, dominant and constant species are: *Acer tataricum*, *Crataegus monogyna*, *Fraxinus angustifolia* subsp. *pannonica*, *Ligustrum vulgare*, *Malus syl- vestris*, *Prunus spinosa*, *Pyrus pyraster*, *Quercus robur*, *Ulmus minor*, *Agropyron caninum*, *Alopecurus pratensis*, *Arum orientale*, *Aster punctatus*, *Betonica officinalis*, *Brachypodium sylvaticum*, *Carduus crispus*, *Carex melanostachya*, *Corydalis cava*, *Cucubalus baccifer*, *Doronicum hungaricum*, *Lathyrus niger*, *Melampyrum cristatum*, *Melica altissima*, *Peucedanum officinale*, *Poa nemoralis*, *Polygonatum latifolium*, *Pulmonaria mollis*, *P. officinalis*, *Ranunculus ficaria*, *Scilla vindobonensis*, *Serratula tinctoria*, *Viola cyanea-odorata.*

A substantial portion of the current stands of steppe woodlands on saline soil may have developed from hardwood gallery forests by means of water loss in their habitat, which has been witnessed in the past 150 years, and as a consequence, canopy gaps developed. We propose this hypothesis on the basis of indirect historical evidence, literature data (Máthé 1933; Soó 1960; Zólyomi and Tallós 1967; Zólyomi 1969b, c; Molnár 1989), and the examination of current stands. This hypothesis was put forward first by Máthé (1933). Later it was accepted by Soó (for example Soó 1960) as opposed to Zólyomi (Zólyomi and Tallós 1967; Zólyomi 1969b, c). Another group of saline steppe woodlands may represent stands that developed before draining and water regulation. They may have occurred in floodplains where the soil had a deep saline soil horizon, and which gradually dried out as a consequence of changes in the course of rivers (see Somogyi 1965). This origin is suggested by the geographical situation of certain stands that are now bordered by ancient riverbeds and oxbows, which were naturally cut-off from the river many centuries ago. Habitat desiccation and salinization thus may have taken place before water regulation, which represented only the second step in their development.

On the Great Plain, Kitaibel observed 'forests on saline soils' at several locations, which were rather similar to those today, but exhibited more pronounced gallery forest characteristics. He also described forests growing in floodplain and/or saline environments with large amounts of *Peucedanum officinale* and *Aster punctatus.* During the First Military Survey, data making this vegetation type reliably recognizable were not collected (only the continuous existence of the present forests on saline soil may be demonstrated, but not their saline character 200 years ago).

During the past 200 years, the size of the few remaining stands further decreased, and some even disappeared. The canopy has been closing, and the glades have been invaded by shrubs owing to the cessation of grazing and cutting. The forest interior tended to become atypical (species-poor) rather than weedy. Spread of invasive species has started. Some of the stands are still intensively managed, while most of them are under legal protection. Several saline areas have been afforested with *Quercus robur*. A portion of these plantations have opened up, and the rather old stands gradually attain steppe woodland physiognomy. The regeneration ability of these steppe woodlands is generally good in glades, poor in plantations, and zero in oldfields. Their total area is barely 130 ha, although with the directly adjacent closed forest patches – that are classified in a different habitat type: closed lowland *Quercus* forests (L5) – it is twice as large. Barely one fifth of the stands are in good condition (naturalness 4 and 5). It is a strongly endangered vegetation type (Fig. 7.3).

7.5. Past Trends in the Hungarian Forest-Steppe Habitats

It was at the end of the eighteenth century that the spatial and temporal density, reliability and detail of vegetation data suddenly increased in Hungary. At that time the first detailed data on the extension, species composition and land use his- tory of almost all forest-steppe habitats were collected (Kitaibel's diary, First Military Survey, Biró 2006; Molnár 2007). Luckily, this was before river regula- tion and afforestation programs were launched in Hungary (Tóth 1997). The data indicate that most forest-steppe habitats already had undergone considerable transformation by this time. Steppe woodlands on loess had almost completely disappeared (in fact we do not even now their extent during the entire Holocene). Steppe woodlands on sand were already missing in many sand areas and those that remained became thin and patchy. The steppe woodlands on saline soils were also small in size. Large sections of the forest-steppe area were treeless and even shrubless. Roughly 20% of all the forests may have been steppe woodland (mostly on sand), 67% were wet or mesic forest on floodplains and along rivers and rarely swamps, and 13% were individual trees or groups of trees and shrubberies. Around 63% of the forests were dominated by *Quercus robur* (Biró and Molnár 2009). According to both Kitaibel and the First Military Survey, the most common woody vegetation types were gallery forests, steppe woodlands on sand and shrubberies. The forests were cleared usually in short cycles (<20 years) and/or were heavily grazed. For these reasons the species number and abundance of forest herbs were small (Molnár 1998).

According to the data of Kitaibel and the First Military Survey (Biró 2006; Molnár 2007), there were large areas covered with sand steppes and closed steppes on chernozem soil, most of which were used for grazing (although part of them had already been plowed up). The most typical farming method – besides the three-field rotation – was switching between crop cultivation and grazing in several-year cycles. Marshes, as well as saline and sand dune areas were, however, plowed up only very sporadically. The "struggle" between grazing land and arable land was apparent in the landscape. Dune areas with wind-blown sand were extensive and occupied an area larger than expected under natural conditions because of excessive grazing. They were mostly treeless (*Populus* stands were rare, *Juniperus* was almost fully absent), and many of them were shifting dunes. The grassy vegetation (dominated by *Festuca* and *Stipa* spp.) was open and heavily grazed. The area of closed steppes on chernozem soil, which were extensive during the entire Holocene, further expanded following a minimum in the Middle Ages. As the several-hundred-year- old regenerating oldfields were very widespread, species-rich stands may have been rather sporadic. Most of the characteristic steppe species even then occurred on roadsides and in the unplowed strips between arable fields.

According to the descriptions of Kitaibel, both the solonetz and solonchak areas were very similar to those of today (species composition, zonal arrangement of com- munities, land use). Their extension may have reached its maximum then (Kitaibel saw only few arable fields on saline soil). His data suggest heavy grazing. Kitaibel's data also show that the saline vegetation did not undergo significant changes during the past 200 years (see Molnár 1996b, 2003; Molnár and Borhidi 2003), and paleo-biological evidence suggests the continuity of this vegetation since the end of the Last Glacial Period (Sümegi et al. 2000, 2006). We emphasize this, because the extensive (thousands of hectares) steppes on solonetz soil were considered secondary and no more than 150 years old until recently in the Hungarian botanical and pedo- logical literature (see Szabolcs 1961; Jakucs 1976; Varga and Sipos 1993).

The forest-steppe vegetation experienced great changes during the past 200 years (Table 7.1). Former trends continued (degradation, plowing) and new processes started due to motorized technologies in agri- and sylviculture. Amelioration and plowing of saline soils along with transformation into rice paddies started (though the latter attempts have been given up). Indigenous *Quercus* forests have been replaced by *Robinia* and *Pinus* plantations (still ongoing), and sand dunes have been afforested (now slowing down). Draining of wetlands has lead to soil leaching, and colonization of non-salt-tolerant species has resulted in the development of atypical vegetation. In the second half of the twentieth century, the spread of invasive species has intensified and eventually has become a widespread and harmful process. Another threatening factor arising in the past decades is the cessation of mowing and grazing.

Based on a comparison of the latest vegetation map showing the potential natural vegetation (Zólyomi 1989) and the actual data of the MÉTA database, approxi- mately 251,000 ha (6.8%) of the total of 3,700,000 ha of forest-steppe vegetation have survived until today (Figs. 7.1, 7.2 and 7.3). Habitat types that survived most extensively and in the largest patches are those on saline soil, which are unsuited for crop and intensive hay production (184,000 ha, which is at least 27% of the original area). Fragments with sizes of several thousands or even several tens of thousands of hectares are not infrequent. Although stands of the open sand steppe with sizes of several hundreds hectares still remain, of the overall 1,300,000 ha of forest-steppe on sand, only 42,000 ha remain (3.3%). Most stands of the closed steppe, however, are secondary, developed from drained wet meadows. The greatest decline in the extent of forest-steppe vegetation occurred on loess. Of its former 1,730,000 ha, barely 1.5% are left. A substantial portion of them is fragmented and restricted only to roadsides in certain parts of the country (Zólyomi 1969a; Csathó 2010). Presently, they remain to a large extent as enclosures in saline steppes instead of on large loess tablelands, and as dry derivatives of meadows. The woody component of the Hungarian forest-steppe has almost completely disappeared from the loess tablelands and saline soils and has been drastically reduced on sand.

7.6. The Present Status of the Hungarian Forest-Steppe Habitats

The condition of only 5.5% of the stands may be considered natural, 38% semi-natu- ral, 46% moderately degraded, and 10% strongly degraded (or barely to moderately regenerated), based on the combined data of all forest-steppe habitat units in the MÉTA database. The rest of the stands (2.5%) has been degraded to such a degree that they can no longer be identified. The degree of degradation of the stands seems to greatly depend on the suitability of the habitat for crop production, soil condition, and the secondary origin of stands. The proportion of rather natural stands exceeds 80% only in the case of *Puccinellia* meadows and the annual vegetation on saline and mud- flats. This number is around 60% in *Artemisia* steppe and *Juniperus-Populus* scrub, and 12–25% in closed steppe on chernozem soil and on sand, in the vegetation of loess and clay cliffs, and in steppe woodland on saline soil and on loess tablelands.

7.7. Future Prospects of the Hungarian Forest-Steppe Habitats

We considered three approaches for predicting future trends in forest-steppe vegetation in Hungary: (1) extrapolation of past trends, (2) current threats and regeneration potential, (3) expected climate change and expected changes in land use.

According to the MÉTA database, the most influential factors threatening the forest-steppe vegetation are (1) spread of invasive species; (2) abandonment of traditional land-use (and, as a consequence, spread of shrubs and accumulation of leaf litter); (3) drop of the groundwater table due to regulation and draining, (4) plowing; (5) overgrazing; (6) excessive wild game populations; (7) afforestation of grassland habitats; (8) forest management practices (Molnár et al. 2008c) (Table 7.3).

The most successful and common invasive species are *Robinia pseudacacia*, *Asclepias syriaca*, *Ailanthus altissima*, *Elaeagnus angustifolia*, and more recently *Prunus serotina.* In view of predicted climate change and changes in land use we expect new invasive species to appear (Walther et al. 2009).

After a peak in the 1980s, the number of domestic animals kept on grazing fields has been declining in Hungary for 25 years. Today mostly sheep graze on the steppe, while only a few percent of the cattle herds graze in the field. The vegetation of abandoned or undergrazed fields gradually changes: leaf litter accumulates, certain species (for instance, *Alopeurus pratensis*, *Elymus repens*, *Bothriochloa ischaemum*) become overdominant, the abundance of short plants decreases (such as *Thymus* spp., *Potentilla arenaria*, annuals), while shrubs and invasive species start spreading.

It may seem surprising that groundwater directly influences around 55% of the forest-steppe vegetation in Hungary. These are primarily forest-steppe habitats on saline soils and steppe woodlands on sand. The explanation for the latter is that these woodlands are dominated by *Quercus robur*, a rather mesic tree of the lowlands. Under current climatic conditions, this oak can be an edifying species in the forest-steppe on sand only if its roots reach down to the groundwater. In areas covered with sand, however, the groundwater table has dropped drastically (3–5 m, Pálfai 1994; Szilágyi and Vorosmarty 1997) in the past decades, and therefore these forests can barely regenerate themselves, and even older trees die off (Molnár 1998).

The regeneration potential of different forest-steppe habitat units is greatly different (Seregélyes et al. 2008). It depends on the dispersal abilities of species making up the local vegetation, which tends to be good in species of open sand steppe and saline mud-flats (Bartha et al. 2008a, b, c; Csecserits and Rédei 2001; Czúcz et al. 2011; Biró 2006; Molnár 2007), and on the speed of regeneration, which is rather low for forests and closed steppes on chernozem soil (Bartha 2007a; Molnár and Botta-Dukát 1998; Molnár 1996a, 1998). It also depends on the spatial characteristics of the neighbouring landscape, such as the presence of suitable sources of propagules (Molnár and Botta-Dukát 1998; Czúcz et al. 2011) and availability of habitat patches for colonization. Unfortunately, steppe woodlands, which are among the rarest vegetation types of Hungary, are also the ones with the lowest regeneration potential among all Hungarian habitat units. This may be the consequence of (1) their strong fragmentation, (2) the spread of invasive species, (3) the reduced survival and reproductive success of oaks (due to the increasing frequency of arid years and a decrease in the groundwater table, Molnár 1998), and (4) the inherently slower regeneration of dry woodlands. We anticipate further decline in the regeneration potential of almost all forest-steppe habitat units because of the expected harmful changes in land use, the spread of invasive species, and the predicted increase in aridity.

We may provide only crude estimates on the effects of expected climate change on forest-steppe habitats (Czúcz et al. 2009, 2010). It is likely that increasing aridity will facilitate transformation of habitats, spread of invasive species, changes in land use, and will affect the level of under- or over-utilization (Fekete and Varga 2006). The strength of these effects, however, may greatly depend on the forecasted energy crisis (Czúcz et al. 2010). Forecasts based on statistical distribution models (SDM) are, however, not sufficiently reliable because of the many artifacts these models produce.

As we have shown, most of the forest-steppe vegetation in Hungary has been exterminated and replaced by arable land, plantations and settlements. Although ca. two-thirds of the remnants are under legal protection (Horváth et al. 2003, unpublished), the efficiency of protection measures is variable. In the past decades, conservationists have abandoned the approach of focusing exclusively on reserves, and conservation strategies have been developed for entire regions with varied landscapes (Natura 2000 network, EU agri-environmental schemes). We believe, however, that the official bodies of conservation are not yet prepared for the expected changes in land use and climate. They have to face two issues simultaneously: (1) how to maintain disappearing traditional land use, which fundamentally contributes to the survival of the natural heritage (see Molnár et al. 2008a), and (2) how to maintain the ability of natural habitats to regenerate and to adapt to the forecasted climate and land-use change (Bartha 2007a; Seregélyes et al. 2008; Czúcz et al. 2010).

Considering the past changes and current situation of natural habitats, we think that, of all forest-steppe habitat units in Hungary, steppe woodlands on loess and sand will almost fully disappear in the coming decades owing to the concerted effects of improper forest management and spread of invasive species. We further expect significant degradation and reduction in area of tall herb saline meadow steppes due to increased aridity and plowing, and of closed steppes on chernozem soil, steppe thickets and closed steppes on sand due to spread of shrubs and other invasive species, as well as plowing. Degradation of the vegetation on loess and clay cliffs and open sand steppe also is expected owing to the spread of invasive species in both, and afforestation in the latter. The area of *Puccinellia* meadows, vegetation of saline and mud-flats, saline meadows and steppe woodlands on saline soils will further decrease due to increasing aridity and leaching. The extent of the secondary *Achillea* steppe will probably increase (although it may be partly plowed up) as a consequence of leaching of the soil of saline *Artemisia* steppes and drying of saline meadows. Saline *Artemisia* steppes seem to be relatively stable, although soil leaching, and thus their slow transformation, are ongoing processes. As a long-term outcome of lack of grazing, the extension of *Juniperus-Populus* scrub in sand dune areas may increase (though this may be hindered by invasive species) despite the increasingly arid climate.

In sum, we predict further transformation, invasion of weeds, and fragmentation of the forest-steppe habitats in Hungary – although at different speeds and to different degrees depending on habitat types –

and, as a consequence, the decline of their resilience and regeneration potential.

References

Aliokhin VV (1950) Karta rastitelnosti SSSR. Masshtab 1:18,000,000. (The map of vegetation of the USSR. Scale 1: 18,000,000.) In: Aliokhin VV (ed), Geografiya rasteniy. (The plant geography.) Uchpedgiz, Moscow

Artushenko AT (1970) Rastitel'nost' lesostepi i stepi Ukrainy v chetvertichnom periode. Naukova Dumka, Kiev

Babos I (1955) A nyárfások homokbuckán előforduló megjelenési formái. (Physiognomical types of poplar groves growing on sand dunes.) Erdészeti kutatások 4:31–86

Bartha S (2007a) Kompozíció, differenciálódás és dinamika az erdőssztyep biom gyepjeiben. (Composition, differentiation and dynamics in the grassland of the forest-steppe biome.) (Slope steppes, loess steppes and forest steppe meadows in Hungary.) In: Illyés, Bölöni (eds) Lejtősztyeppek, löszgyepek és erdősztyepprétek Magyarországon. MTA ÖBKI, Budapest, pp 72–100

Bartha S (2007b) Homoki gyepek spontán dinamikai folyamatai. In: Horváth A, Szitár K (eds) Agrártájak monitorozása. A hatás-monitorozás elméleti alapjai és gyakorlati lehetőségei. (Spontaneous dínamical processes in sand grassland. In: Horváth A, Szitár K (eds) Monitoring agricultural landscapes. Theoretical foundations and practical prospects of effect monitoring.) MTA ÖBKI, Vácrátót, pp 183–188

Bartha S (2007c) Másodlagos szukcesszió felhagyott homoki szántókon. In: Horváth A, Szitár K (eds) Agrártájak monitorozása. A hatás-monitorozás elméleti alapjai és gyakorlati lehetőségei. (Secondary succession in sandy oldfields. In: Horváth A, Szitár K (eds) Monitoring agricultural landscapes. Theoretical foundations and practical prospects of effect-monitoring.) MTA ÖBKI, Vácrátót, pp 202–207

Bartha S, Campetella G, Ruprecht E, Kun A, Házi J, Horváth A, Virágh K, Molnár Zs (2008a) Will inter-annual variability in sand grassland communities increase with climate change? Commun Ecol 9(Suppl):13–21

Bartha S, Molnár Zs, Fekete G (2008b) Patch dynamics in sand grasslands: connecting primary and secondary succession. In: Kovács-Láng E, Molnár E, Kröel-Dulay Gy, Barabás S (eds) The KISKUN LTER, long-term ecological research in the Kiskunság, Hungary. Institute of Ecology and Botany, H.A.S, Vácrátót, pp 37–40

Bartha S, Molnár Zs, Horváth A, Virágh K (2008c) Időjárási szélsőségek – társulásszintű adaptív válaszok. Évelő nyílt homokpusztagyepek 12 éves monitorozásának tapasztalatai. In: Korsós Z, Gyenis Gy, Penksza K (eds) Előadások Összefoglalói. (Meteorological extremities – adaptive community responses. Results of the monitoring of open sand steppes over 12 years.) Abstract of presentations. MBT XXVII, Vándorgyűlés 2008, Szeptember 25–26, pp 1–6

Berg LS (1958) Die Geographischen Zonen der Sowjetunion I. Teubner Verlag, Leipzig

Biró M (2003) A Duna-Tisza köze vegetációja a 18. században. Rekonstruált vegetáció térkép, méretarány 1:100 000. (Vegetation of the area between the Danube and Tisza Rivers in the 18th century. Reconstructed vegetation map. Scale 1:100,000.) In: Molnár Zs (ed) A Kiskunság száraz homoki növényzete. (Dry sand vegetation of Kiskunság, Hungary.) Természet Búvár Alapítvány Kiadó, Budapest, p 30

Biró M (2006) A történeti térképekre alapuló vegetációrekonstrukció és alkalmazásai a Duna- Tisza közén. Doktori értekezés. (The method of vegetation reconstruction based on historical maps and its application to the area between the Danube and Tisza Rivers.) Ph.D. dissertation, Pécs

Biró M (2008) A Duna-Tisza köze fásszárú vegetációjának átalakulása a 18. század óta, különös tekintettel a száraz homokterületekre. (Development of woody vegetation of the Danube Tisza Interfluve since the 18th century.) In: Kröel-Dulay Gy, Kalapos T, Mojzes A (eds): Talaj-vegetáció-klíma kölcsönhatások. (Soil-vegetation-climate interactions.) MTA Ökológiai és Botanikai Kutatóintézete, Vácrátót, pp 23–38

Biró M, Molnár Zs (1998) A Duna-Tisza köze homokbuckásainak tájtípusai, azok kiterjedése, növényzete és tájtörténete a 18. századtól. (Landscape types and their extent, vegetation and history of the sand dune areas between the Danube and Tisza rivers from the 18th century.) Történeti Földrajzi Füzetek 5:1–34.

Biró M, Molnár Zs (2009) Az Alföld erdei a folyószabályozások és az alföldfásítás előtti évszázadban. (Forests of the Great Plain before river regulation and afforestation.) In: Kázmér M (ed) Környezettörténet 2006. A környezet változásai történeti és természettudományi források tükrében. Hantken Kiadó, Budapest, pp 169–206

Biró M, Révész A, Molnár Zs, Horváth F, Czúcz B (2007) Regional habitat pattern of the Duna-Tisza köze in Hungary II. – The sand, the steppe and the riverine vegetation; degraded and ruined habitats. Acta Bot Hung 50(Suppl):21–62

Biró M, Horváth F, Papp O, Molnár Zs (2008) Historical landscape changes near Fülöpháza in the Kiskunság. In: Kovács-Láng E, Molnár E, Kröel-Dulay Gy, Barabás S (eds) The KISKUN LTER: Long-term ecological research in the Kiskunság, Hungary. Institute of Ecology and Botany, Vácrátót, pp 11–12

Blazovich L (1985) A Körös-Tisza-Maros köz középkori településrendje. (Settlement structure in the area between the Körös and Maros Rivers.) Dél-alföldi Századok, Békéscsaba, Szeged

Bölöni J, Kun A, Molnár Zs (eds) (2003) Élőhely-ismereti útmutató 2.0. (Habitat guide 2.0.) Manuscript, MTA ÖBKI, Vácrátót. http://www.novenyzetiterkep.hu/eiu/index.html
Bölöni J, Molnár Zs, Illyés E, Kun A (2007) A new habitat classification and manual for standardized habitat mapping. Annali di Botanica nouva serie 7:105–126
Bölöni J, Molnár Zs, Biró M, Horváth F (2008a) Distribution of the Hungarian (semi-)natural habitats II. Woodlands and shrublands. Acta Bot Hung 50(Suppl):107–148
Bölöni J, Molnár Zs, Horváth F (2008b) Naturalness-based habitat quality of the Hungarian (semi-) natural habitats. Acta Bot Hung 50(Suppl):149–159
Bölöni J, Molnár Zs, Kun A (2011) Magyarország élőhelyei. A hazai vegetációtípusok leírása és határozója. (Habitats in Hungary. Description and identification guide of Hungarian vegetation types.) MTA ÖBKI, p 341
Borbély A, Nagy J (1932) Magyarország I. Katonai Felvétele II. József korában. (The first military survey of Hungary under Joseph the 2nd.) Térképészeti Közl 2:35–85
Borhidi A (1961) Klimadiagramme und klimazonale Karte Ungarns. Ann Univ Budapest Ser Biol 4:21–50
Borhidi A (2003) Magyaroszág növénytársulásai. (Plant associations of Hungary.) Akadémiai Kiadó, Budapest
Borhidi A (2012) Plant associations of Hungary. Akadémiai Kiadó, Budapest (in print)
Boros E, Biró Cs (1999) A Duna-Tisza közi szikes tavak ökológiai állapotváltozásai. (Changes in ecological conditions of the salt lakes in the area between the Danube and Tisza Rivers.) Acta Biol Debr Oecol Hung 9:81–105
Botta-Dukát Z (2008) Invasion of alien species to Hungarian (semi-)natural habitats. Acta Botanica Hungarica 50(Suppl):219–227
Botta-Dukát Z, Molnár E, Szitár K (2008) Invasion of alien plants in the sand vegetation of Kiskunság. In: Kovács-Láng E, Molnár E, Kröel-Dulay Gy, Barabás S (eds) The KISKUN LTER: long-term ecological research in the Kiskunság, Hungary. Vácrátót, pp 35–36
Bruelheide H (2000) A new measure of fidelity and its application to defining species groups. J Veg Sci 11:167–178
Csathó AI (2010) Fragments of steppe vegetation in roadsides and railway verges in the Great Hungarian Plain. In: Programme and book of abstracts. 2010 IENE international conference on ecology and transportation: improving connections in a changing environment, pp 85–86
Csecserits A, Rédei T (2001) Secondary succession on sandy old-fields in Hungary. Appl Veg Sci 4:63–74
Czúcz B, Torda G, Molnár Zs, Horváth F, Botta-Dukát Z, Gy K-D (2009) A spatially explicit, indicator-based methodology for quantifying the vulnerability and adaptability of natural ecosystems. In: Filho WL, Mannke F (eds) Interdisciplinary aspects of climate change. Peter Lang Scientific Publishers, Frankfurt, pp 209–227
Czúcz B, Gathman JP, McPherson GR (2010) The impending peak and decline of petroleum production: an underestimated challenge for conservation of ecological integrity. Conserv Biol 24(4):948–956
Czúcz B, Csecserits A, Botta-Dukát Z, Kröel-Dulay Gy, Szabó R, Horváth F, Molnár Zs (2011) An indicator framework for the climatic adaptive capacity of natural ecosystems. J Veg Sci 22:711–725
European Environmental Agency (2006) EEA Report No1/2002. Europe's biodiversity — biogeographical regions and seas. Biogeographical regions in Europe. The Pannonian region. http://www.eea.europa.eu/publications/report_2002_0524_154909
Fairbairn AS (1992) Archaeobotanical investigations at Csőszhalom: a Late Neolithic tell site in north-east Hungary. M.Sc. thesis, University College London, Institute of Archeology, p 67
Fairbairn AS (1993) Plant husbandry at the prehistoric Hungarian tell sites of Csőszhalom and Kenderfüöld. Final report for the British Academy Applied Sciences in Archaeology Fund
Fekete G (1965) Die Waldvegetation im Gödöllőer Hügelland. Akadémiai Kiadó, Budapest, 223 pp
Fekete G (1992) The holistic view of succession reconsidered. Coenoses 7:21–29
Fekete G, Kun A, Molnár Zs (1999) Floristic characteristics of the forest-steppe in the Duna-Tisza Interfluve. In: Kovács-Láng E (eds) Long-term ecological research in the Kiskunság, Hungary. MTA ÖBKI, Vácrátót, pp 13–14
Fekete G, Molnár Zs, Kun A, Virágh K, Botta-Dukát Z (2002) Záródó homokpusztagyep a Duna-Tisza-közén: a Festuca wagneri gyepjei. (Closed sand steppe in the area between the Danube and Tisza Rivers: stands of Festuca wagneri.) In: Salamon-Albert É (ed) Magyar botanikai kutatások az ezredfordulón. Tanulmányok Bohidi Attila 70. születésnapja tiszteletére. (Botanical Research in Hungary at the turn of the millennium. Studies in honor of the 70th birthday of Attila Borhidi.) PTE TTK, Pécs, pp 381–414
Fekete G, Varga Z (eds) (2006) Magyarország tájainak növényzete és állatvilága. (Vegetation and wildlife of Hungarian landscape.) MTA Társadalomkutató Központ, Budapest, pp 460
Fekete G, Somodi I, Molnár Zs, Fekete G, Somodi I, Molnár Zs (2010) Is chorological symmetry observable within the forest-steppe biome in Hungary? A demonstrative analysis of floristic data. Commun Ecol 11:140–147

First Military Survey (1783–1785) Scale 1:28,000. Map collection of the National Museum of Military History, Budapest

Gombocz E (ed) (1945) Diaria Itinerum Pauli Kitaibelii I-II. Verlag des Ungarischen Naturwissenschaftlichen Museums, Budapest, 1083 pp

Győrffy Gy (1966) Az Árpád-kori Magyarország történeti földrajza. (Historical geography of Hungary in the age of the Árpád dinasty.) Bp

Győrffy Gy, Zólyomi B (1994) A Kárpát-medence és Etelköz képe egy évezred előtt. (The Carpathian Basin and Etelköz a thousand years ago.) In: Kovács L (ed) A honfoglalásról sok szemmel I. Honfoglalás és régészet. (The Hungarian conquest from different aspects I. The conquest period and archaeology.) Balassi Kiadó, Budapest, pp 13–37

Gyulai F (2001) Archaeobotanika. A kultúrnövények története a Kárpát-medencében a régészeti növénytani vizsgálatok alapján. (Archeobotany. The history of cultivated plants in the Carpathian Basin on the basis of botanical research.) Jószöveg Kiadó, Bp., 221 pp

Hargitai Z (1940) Nagykőrös növényvilága. II. A homoki növényszövetkezetek. (The flora and vegetation of Nagykőrös. II. Plant associations on sand.) Bot Közlem 37:205–240

HMS (2000) Climate atlas of Hungary. Hungarian Meteorological Service, Budapest Horváth A (2002) A mezőföldi löszvegetáció términtázati szerveződése. (The spatial organization of the vegetation on the loess plateaux in the Mezőföld.) Scientia Kiadó, Budapest

Horváth F, Polgár L (2008) MÉTA SQL expert interface and access service. Acta Bot Hung 50(Suppl):35–45

Horváth F, Kovács-Láng E, Báldi A, Gergely E, Demeter A (2003) Európai jelentőségű természeti területeink felmérése és értékelése. (Survey and evaluation of natural areas with European significance.) MTA Ökológiai és Botanikai Kutatóintézete, Vácrátót

Horváth F, Molnár Zs, Bölöni J, Pataki Zs, Polgár L, Révész A, Krasser D, Illyés E (2008) Fact sheet of the MÉTA Database 1.2. Acta Bot Hung 50(Suppl):11–34

Illyés E, Bölöni J (eds) (2007) Slope steppes, loess steppes and forest-steppe meadows in Hungary. [Lejtősztyepek, löszgyepek és erdőssztyeprétek Magyarországon.] MTA ÖBKI, Budapest, pp 236

Jakab G, Sümegi P, Magyari E (2004) A new paleobotanical method for the description of Late Quaternary organic sediments (Mire-development and paleoclimatic records from S Hungary.) Acta Geol Hung 47:1–37

Jakucs P (1961) Die phytozönologischen Verhältnisse der Flaumeichen-Buschwälder Südostmitteleuropas. Akadémiai Kiadó, Budapest

Jakucs P (1976) A Hortobágy növényvilága. Flora and vegetation of the Hortobágy. In: Kovács G, Salamon F (eds) Hortobágy. A nomád pusztától a Nemzeti Parkig. (Hortobágy. From the nomadic puszta to the national park.) Natura Kiadó, Budapest, pp 38–56

Járai-Komlódi M (1966) Palinológiai vizsgálatok a Magyar Alföldön a Würm glaciális és a holocén klíma- és vegetációtörténetére vonatkozóan. Kandidátusi Értekezés. (Palinological studies on the Hungarian Plain with regard to the vegetation history and climate of the Würm and the Holocene.) Dissertation for the Degree of Candidate, ELTE, Bp., 280 pp

Járai-Komlódi M (1987) Postglacial climate and vegetation in Hungary. In: Pécsi M, Kordos L (eds) Holocene environment in Hungary. MTA Földrajzi Kutatóintézete, Budapest, pp 37–47

Járainé Komlódi M (1985) Pollenanalitikai vizsgálatok a Kolon-tónál. (Palinological studies at the Lake Kolon.) In: Tóth K (ed) Tudományos kutatások a Kiskunsági Nemzeti Parkban (Scientific research in the Kiskunság National Park 1975–1984) Hungexpo, Budapest, pp 152–155

Jávorka S (1926, 1929, 1934, 1935, 1936, 1945) Kitaibel herbáriuma I-V. és Pteridophyta. (Herbaria and pteridophytes of Kitaibel.) Ann Musei Nat Hung 24:428–585; 26:97–210; 28:147–196; 29:55–102; 30:7–118; 38:85–97

Juhász K, Bagi I (2008) A Prunus serotina EHRH. élőhely preferenciái az invázió diszperziós szakaszában homoki területeken. (Habitat preference of Prunus serotina EHRH. in the dispersal stage of invasion on sand.) Bot Közlem 94(1–2):1–16

Juhász M, Bagi I, Csintalan Zs (2009) The critical effect of drought stress on the invading features of bird cherry (Prunus serotina Ehrh.) during dispersion stage on a sand dune area in Hungary. Cereal Res Commun 37:553–556

Kádár Z (1975) Landscapes, zones and their regional energy. Acta Geogr Debr 13:35–80

Király G (ed) (2009) Új magyar füvészkönyv. Magyarország hajtásos növényei. Határozókulcsok. New Hungarian herbal. Vascular plants of Hungary. Identification keys. Aggteleki Nemzeti Park Igazgatóság, Jósvafő

Kun A (2001) Analysis of precipitation year-types and their regional frequency distributions in the Danube-Tisza Mid region, Hungary. Acta Bot Hung 43:175–187

Lavrenko EM (1956) Stepi i sel'skohoziastvennye zemli na meste stepei. (Steppes and agricultural areas in the places of former steppes) In: Lavrenko EM, Sochava VB (eds) Rastitel'nyi pokrov SSSR, V kn. (The

vegetation cover of the USSR, vol. V.) Akademii Nauk SSSR, Moscow
Lavrenko EM (1970) The provincial Division of the Central Asian Steppe Subregion of Eurasia. Botanicheski Zhournal 55:1734–1747
Lavrenko EM (1981) Vegetation of Pleistocene periglacial steppes of the USSR. Bot Zhurn 66:313–327
Lavrenko EM, Karamysheva ZV, Nikulina RI (1991) Stepi Evrazii (Steppes of Eurasia), Leningrad, Nauka
Lavrenko EM, Karamysheva Z (1993) The steppes of the former Soviet Union and Mongolia. In: Coupland RT (ed) Ecosystems of the world, vol 8b. Elsevier, Amsterdam
Lendvai G, Kevey B (2008) Aceri tatarico – Quercetum roboris. In: Kevey B (ed) Magyarország erdőtársulásai. (Forest Associations of Hungary.) Tilia 14:415–417
Lóki J, Sümegi P, Félegyházi E, Hertelendi E (1995) A Kolon-tó fenékszintjébe mélyített fúrás rétegsorának szedimentológiai, pollenanalitikai és malakológiai elemzése. (Sedimentological, palinological and malakological analysis of the core from the bed of Kolon Lake.) Acta Geogr Debr 33:93–115
Lőkös L (ed) (2001) Diaria Itinerum Pauli Kitaibelii III., Természettudományi Múzeum, Bp., 459 pp
Magyar P (1961) Alföldfásítás I-II. (Afforestation in the Great Plain I-II.) Akadémiai Kiadó, Bp., 466 + 512 pp
Magyari E (2002) Climatic versus human modification of the Late Quaternary vegetation in Eastern Hungary. Unpublished Ph.D. Thesis, University of Debrecen, Hungary, 150 pp
Magyari EK, Chapman JC, Passmore DG, Allen JRM, Huntley JP, Huntley B (2009) Holocene persistence of wooded steppe in the northern Great Hungarian Plain. J Biogeogr 37:915–935
Máthé I (1933) A hortobágyi Ohat-erdő vegetációja. (Vegetation of the hat Forest in the Hortobágy). Bot Közlem 28:163–184
Medzihradszky Zs, Járainé Komlódi M (1995) Az ember természetformáló tevékenysége a holocén folyamán a Kárpát-medencében. Emlékkötet Andreánszky Gábor születésének 100. évfordulójára. (Human impact on the environment in the Carpathian Basin during the Holocene.) Magyar Természettudományi Múzeum, Budapest
Medzihradszky Zs, Bölöni J, Molnár Zs, Kertész M, Varga Z, Debreczy Zs, Molnár A (2000) Mit tudunk a múltról? (What do we know about the past?) In: Molnár Zs, Kun A (eds) Alföldi erdőssztyeppmaradványok Magyarországon. (Forest-steppe remnants in Hungary.) WWF Füzetek 15, Budapest, pp 20–25
Molnár B (1979) A Duna-Tisza köze kialakulása és földtani felépitése. (Geology and development of the area between the Danube and Tisza rivers.) In: Tóth K (ed) Nemzeti Park a Kiskunságban. (National Park in the Kiskunság.) Natura Kiadó, Budapest, pp 64–73
Molnár A (1989) A bélmegyeri Fás-puszta növényzete. (Vegetation of the Fás puszta at Bélmegyer.) Bot Közlem 76:65–82
Molnár Zs (1996a) Ártéri vegetáció Tiszadob és Kesznyéten környékén II: A keményfaligetek (Fraxino pannonicae – Ulmetum) története és mai állapota. (Vegetation of the floodplain near Tiszadob and Kesznyéteny. II. The history and current status of hardwood gallery forests (Fraxino pannonicae – Ulmetum).) Bot Közlem 83:51–79
Molnár Zs (1996b) A Pitvarosi-puszták és környékük vegetáció- és tájtörténete a Középkortól napjainkig. (Vegetation and landscape history of Pitvaros puszta from the Middle Ages.) Natura Bekesiensis 2:65–97
Molnár Zs (1998) Interpreting present vegetation features by landscape historical data: an example from a woodland-grassland mosaic landscape (Nagykőrös-wood, Kiskunság, Hungary). In: Kirby KS, Watkins C (eds) The ecological history of European forests. CAB International, Wallingford, pp 241–263
Molnár Zs (ed) (2003) A Kiskunság száraz homoki növényzete. (Dry sand vegetation of Kiskunság, Hungary.) TermészetBÚVÁR Alapítvány Kiadó, 159 pp
Molnár Zs (2007) Történeti tájökológiai kutatások az Alföldön. Doktori értekezés, Pécsi Egyetem. Studies in historical landscape ecology in the Great Plain. Ph.D. dissertation, University of Pécs, Pécs
Molnár Zs (2008a) A Duna-Tisza köze és a Tiszántúl növényzete a 18–19. század fordulóján I. módszertan, erdők, árterek és lápok. (Vegetation of the Great Plain east of the Danube River at the turn of the 18th and 19th centuries. I. Methodology, forests, floodplains and fens.) Bot Közlem 95:11–38
Molnár Zs (2008b) A Duna-Tisza köze és a Tiszántúl növényzete a 18–19. század fordulóján II. szikesek, lösz- és homokvidékek, legelők, sáncok, szántók és parlagok. (Vegetation of the Great Plain east of the Danube River at the turn of the 18th and 19th centuries. II. saline areas, loess tables, sand areas, grazing fields, ancient earthworks, arable land and oldfields.) Bot Közlem 95:39–63
Molnár Zs (2009) A Duna-Tisza köze és a Tiszántúl fontosabb vegetációtípusainak holocén kori története: irodalmi értékelés egy vegetációkutató szemszögéből. (Holocene history of the common vegetation types in the areas east of the Danube River, and between the Danube and Tisza Rivers: literature review from the standpoint of a vegetation scientist.) Kanitzia 16:93–118
Molnár Zs, Borhidi A (2003) Continental alkali vegetation in Hungary: syntaxonomy, landscape history, vegetation dynamics, and conservation. Phytocoenologia 21:235–245
Molnár Zs, Botta-Dukát Z (1998) Improved space-for-time substitution for hypothesis generation: secondary grasslands with documented site history in SE-Hungary. Phytocoenologia 28:1–29
Molnár Zs, Kun A (eds) (2000) Alföldi erdőssztyeppmaradványok Magyarországon. (Lowland forest-steppe

remnants in Hungary.) WWF Füzetek 15., Budapest, 56 pp
Molnár Zs, Bartha S et al (2007b) A grid-based, satellite-image supported, multi-attributed vegetation mapping method (MÉTA). Folia Geobot 42:225–247
Molnár Zs, Bartha S, Babai D (2008a) Traditional ecological knowledge as a concept and data source for historical ecology, vegetation science and conservation biology: A Hungarian perspective. In: Szabó P, Hedl R (eds) Human nature. Studies in historical ecology andenvironmental history. Institute of Botany of the ASCR, Brno, pp 14–27
Molnár Zs, Bölöni J, Biró M, Horváth F (2008b) Distribution of the Hungarian (semi-)natural habitats I. Marshes and grasslands. Acta Bot Hung 50(Suppl):59–105
Molnár Zs, Bölöni J, Horváth F (2008c) Threatening factors encountered: Actual endangerment of the Hungarian (semi-)natural habitats. Acta Bot Hung 50(Suppl):199–217
Molnár Zs, Fekete G, Biró M, Kun A (2008d) A Duna-Tisza közi homoki sztyepprétek történeti tájökológiai jellemzése. In: Talaj-vegetáció-klíma kölcsönhatások (eds Kröel-Dulay Gy, Kapalos T, Mojzes A) (Characterization of closed sand steppes between the Danube and Tisza Rivers on the basis of their history and landscape ecology. In: Kröel-Dulay Gy, Kapalos T, Mojzes A (eds) Soil, climate, vegetation interrelations.) MTA ÖBKI, Vácrátót, pp 39–55
Natura (2000) Network, European Comission. http://ec.europa.eu/environment/nature/natura2000/ index_en.htm
Németh F, Seregélyes T (1989) Természetvédelmi információs rendszer: Adatlap kitöltési útmutató. (Information system of nature conservation: Guide for completing the data sheets.) Manuscript, Környezetgazdálkodási Intézet (Institute of Environmental Management), Budapest.
Niklfeld H (1974) Natürliche Vegetation Karte, 1:200 000. In: Niklfeld H (ed) Atlas der Donauländer. Deuticke Vlg. Wien, Karte, 171
Nyilas I (1999) Az angol Robert Townson leírása a Hortobágyról. (Description of the Hortobágy by the British Robert Townson, 1793.) In: Rózsa P (ed) Robert Townson magyarországi utazásai. (The travels of Robert Townson in Hungary.) Kossuth Egyetemi Kiadó, Debrecen, pp 143–146
Nyilas I, Sümegi P (1991) The mollusc fauna of Hortobágy at the end of the Pleistocene (Würm 3) and in the Holocene. In: Proceedings of tenth international malacological congress (Tübingen 1989), pp 481–486
Pálfai I (1994) Összefoglaló tanulmány a Duna-Tisza közi talajvízszint-süllyedés okairól és a vízhiányos helyzet javításának lehetőségeiről. In: Pálfai I (eds.): A Duna-Tisza közi Hátság vízgazdálkodási problémái. A synthetic study on the causes of decreasing groundwater table between the Danube and Tisza Rivers, and the options for improving the current situation. In: Pálfai I (ed) Problems in water management between the Danube and Tisza Rivers. Nagyalföld Alapítvány, Budapest, pp 111–123
Pickett STA (1989) Space-for-time substitution as an alternative to long-term studies. In: Likens GE (ed) Long-term studies in ecology: Approaches and alternatives. Springer, Berlin, pp 110–135
Pócs T (1966) A magyarországi tűlevelű erdők cönológiai és ökológiai viszonyai. Kandidátusi értekezés tézisei. (Phytosociological and ecological characteristics of coniferous forests in Hungary.) Theses for the dissertation for the candidate degree, Budapest
Pócs T (1999) A löszfalak virágtalan növényzete I. Orografikus sivatag a Kárpát-medencében. (Non-flowering vegetation of loess cliffs I. Orographic desert in the Carpathian Basin.) Kitaibelia 4:143–156
Rackham O (1980) Ancient woodland. Arnold, London
Rapaics R (1918) Az Alföld növényföldrajzi jelleme. (The pytogeographical characteristic of the Great Plain.) Erdészeti Kísérletek 21:1–164
Seregélyes T, Molnár Zs, Csomós Á, Bölöni J (2008) Regeneration potential of the Hungarian (semi-)natural habitats. I. Concepts and basic data of the MÉTA database. Acta Botanica Hungarica 50(Suppl):229–248
Simon T (1985) Az ELTE Növényrendszertani és Ökológiai Tanszéke komplex ökológiai kutatásai. (Complex ecological research of the Department of Ecology and Plant Systematics of the ELTE.) In: Tóth K (ed) Tudományos kutatások a Kiskunsági Nemzeti Parkban. (Scientific research in the Kiskunság National Park.) KNP, Kecskemét, pp 140–173
Sipos Gy, Kiss T (2006) OSL mérés lehetőségei: hagyományos módszerekkel nem datálható, kvarctartalmú üledékek korának meghatározása. (OSL measurements: a method for dating quartz-containing sediments that cannot be dated by traditional methods.) In: Kázmér M (ed) A Környezettörténet 2006 konferencia előadásainak összefoglalói. (Abstracts of the conference entitled History of the Environment 2006.) Hantken Kiadó, Budapest, pp 43–45
Somogyi S (1964) A szikes talajok képződésének földrajzi tényezői Magyarországon. (Geographical factors in the development of saline soils in Hungary.) Földr Közlem 3:219–244
Somogyi S (1965) A szikesek elterjedésének időbeli változásai Magyarországon. (Temporal changes in the extent of saline soils in Hungary.) Földr Közlem 4:41–55
Soó R (1926) Die Entstehung der ungarischen Puszta. Ungarische Jahrbücher 6:258–276
Soó R (1929) Die Vegetation und die Entstehung der ungarischen Puszta. J Ecol 17:329–350
Soó R (1931) A magyar puszta fejlődéstörténetének problémája. (Problems in the developmental history of the

Hungarian puszta.) Földr Közlem 59:1–17
Soó R (1933) Floren- und Vegetationskarte des historischen Ungarns. A Tisza István Társaság Honismertető Bizottság Kiadványai 30:1–35
Soó R (1943) A nyírségi erdők a növényszövetkezetek rendszerében. (The forests of the Nyírség in the phytosociological system of classification.) Acta Geobot Hung 5:315–352
Soó R (1960) Az Alföld erdői. (Forests of the Great Plain.) In: Magyar P (ed) Alföldfásítás I. (Afforestation on the Great Plain I.) Akadémiai Kiadó. Budapest, pp 419–478
Soó R (1964) Magyarország növénytársulásainak részletes (kritikai) áttekintése. (Critical review of plant associations of Hungary.) In: Soó R (ed) A magyar flóra és vegetáció rendszertani- növényföldrajzi kézikönyve I. (Phytosociological and phytogeographical handbook of the flora and vegetation of Hungary I.) Akadémiai Kiadó, Budapest, pp 130–289
Sümegi P (1998) Az utolsó 15000 év környezeti változásai és hatásuk az emberi kultúrákra Magyarországon. (Environmental changes and their effect on human cultures in Hungary over the past 15,000 years.) In: Ilon G (ed) A régésztechnikusok kézikönyve. (Handbook for archeology technicians.) Savaria Kiadványa, Szombathely
Sümegi P, Magyari E, Daniel P, Hertelendi E, Rudner E (1999) Reconstruction of the Quaternary evolution of the Fehér-lake at Karoskút (Hungary). Földtani Közlöny 129:479–519
Sümegi P (2004) Findings of geoarcheological and environmental historical investigations at the Körös site of Tiszapüspöki-Karancspart Háromága. Anthaeus 27:307–342
Sümegi P (2005a) A comparative geoarcheological report and environmental history of the Bronze Age tell of Polgár, Kenderföld. In: Poroszlai I et al (eds) Bronze Age in Hungary: Koszider Periode. Százhalombatta Archaeological Expedition sorozat, III. kötet, Matrica Múzeum, Százhalombatta, pp 185–234
Sümegi P (2005b) Loess and upper paleolithic environment in Hungary. An introduction to the environmental history of Hungary. AUREA, Nagykovácsi, p 312
Sümegi P (2005c) The environmental history of the Jászság. In: Gál E, Juhász I, Sümegi P (eds) Environmental archaeology in north-eastern Hungary. Varia Archaeologica Hungarica sorozat, XIX. kötet, MTA Régészeti Intézet, Bp., pp 103–110
Sümegi P, Molnár A, Szilágyi G (2000) Szikesedés a Hortobágyon. (Salinization in the Hortobágy.) Természet Világa 131:213–216
Sümegi P, Mucsi M, Fényes J, Gulyás S (2005) First radiocarbon dates from the freshwater carbonates of the Danube-Tisza interfluve. In: Hum L, Gulyás S, Sümegi P (eds) Environmental historical studies from the late tertiary and quaternary of Hungary. University of Szeged, Szeged, pp 103–118
Sümegi P, Bodor E, Törőcsik T (2006) A hortobágyi szikesedés eredete. (The origin of salt affected soils in the Hortobágy.) In: Kiss A, Mezősi G, Sümeghy Z (eds) Táj, környezet és társadalom. Ünnepi tanulmányok Keveiné Bárány Ilona professzor asszony tiszteletére. (Landscape, envi- ronment, society. Studies dedicated to the honor of Prof. Keveiné Bárány Ilona.) SZTE Kiadványa, Szeged, pp 633–641
Szabolcs I (1961) A vízrendezések és öntözések hatása a tiszántúli talajképződési folyamatokra. (The effect of water regulation and irrigation on soil formation processes east of the Tisza.) Akadémiai Kiadó, Budapest, 355 pp
Szilágyi J, Vorosmarty Ch (1997) Modelling unconfined aquifer level reductions in the area between the Danube and Tisza rivers in Hungary. J Hydrol Hydromech 45:328–347
Szodfridt I (1969) Borókás nyárasok Bugac környékén. (Juniper-poplar scrub near Bugac). Bot Közlem 56:159–166
Tarasov PE, Webb T et al (1998) Present-day and mid-Holocene biomes reconstructed from pollen and plant macrofossil data from the former Soviet Union and Mongolia. J Biogeogr 25:1029–1053
Tarasov PE, Volkova VS et al (2000) Last glacial maximum biomes reconstructed from pollen and plant macrofossil data from northern Eurasia. J Biogeogr 27:609–620
Tichy L (2002) JUICE, software for vegetation classification. J Veg Sci 13:451–453
Tóth A (1988) Degradálódó hortobágyi löszgyepek reliktum foltjainak synökológiai viszonyai. (Synecological relations in remnant stands of degraded steppe on loess in the Hortobágy.) In: Tóth A (ed) Tudományos kutatások a Hortobágyi Nemzeti Parkban. (Scientific research in the Hortobágy National Park.) Budapest, pp 11–83
Tóth A (1997) A közép-tiszavidéki táj gyökeres megváltozása a folyószabályozási munkálatok nyomán. (Changes in the Middle Tisza Region as a result of river regulation.) In: Füleky Gy (ed) A táj változásai a honfoglalás óta Kárpát-medencében. (Changes of the landscape in the Carpathian Basin since the time of the Conquest.) GATE MSZKI, Gödöllő, pp 347–353
Varga Z (1989) Die Waldsteppen des pannonischen Raumes aus biogeographischer Sicht. - Düsseldorf. geobot. Koll 6:36–50
Varga Z (1992) Biogeographical and ecological background with special reference to lowland habitats. In: Fésüs I et al (eds) Interaction between agriculture and environment in Hungary. IUCN, Budapest, pp 20–52

Varga Z (2003) A Kárpát-medence állatföldrajza. A Kárpát-medence állatföldrajzi helyzete. (Zoogeography of the Carpathian Basin. Place of the Carpathian Basin in the phytogero- graphical system.) In: Láng I, Bedő Z, Csete L (eds) Növény, állat, élőhely. (Plant, animal, habitat.) MTA Társadalomkutató Központ – Kossuth Kiadó, Budapest, pp 89–128

Varga Z, Sipos J (1993) Hortobágyi Krónika (Hortobágy Chronicle). Alföldi Nyomda Debrecen, 96 pp

Virágh K, Fekete G (1984) Degradation stages in a xeroseries: composition, similarity, grouping, coordination. Acta Bot Hung 30:427–459

Walther G-R, Roques A et al (2009) Alien species in a warmer world: risks and opportunities. Trends Ecol Evol 24:686–693

Zólyomi B (1936) Tízezer év története virágporszemekben. (The history of ten thousand years in pollen grains.) Term Tud Közlöny 68:504–516

Zólyomi B (1952) Magyarország növénytakarójának fejlődéstörténete az utolsó jégkorszaktól. (History of the vegetation in Hungary since the last glacial period.) MTA Biol Oszt Közlem 1:491–530

Zólyomi B (1957) Der Tatarenahorn-Eichen Lösswald der zonalen Waldsteppe. Acta Bot Hung 3:401–424

Zólyomi B (1958) Budapest és környékének természetes növénytakarója. (The natural vegetation of Budapest and its neighborhood.) In: Pécsi M (ed) Budapest természeti képe. (Natural heri- tage of Budapest.) Akadémiai Kiadó, Budapest, pp 511–642

Zólyomi B (1969a) Földvárak, sáncok, határmezsgyék és a természetvédelem. (Earthworks, earthen fortifications, unplowed land strips and nature conservation.) Természet Világa 100:550–553

Zólyomi B (1969b) Közép-Tiszavidék: Természetes növényzet. (Middle Tisza region: natural vegetation) In: Pécsi M (ed) Magyarország Tájföldrajza. II. A tiszai Alföld. (Regional geo- graphy of Hungary. II. The Great Plain along the Tisza.) Akadémiai Kiadó, Budapest, pp 124–131

Zólyomi B (1969c) Körös-Maros közi síkság: Természetes növényzet. (Körös-Maros plain: natural vegetation.) In: Pécsi M (ed) Magyarország Tájföldrajza. II. A tiszai Alföld. (Regional geography of Hungary. II. The great plain along the Tisza.) Akadémiai Kiadó, Budapest, pp 317–319

Zólyomi B (1989) Magyarország természetes növénytakarója. (Map of the natural vegetation of Hungary.) In: Pécsi M (ed) Nemzeti Atlasz. (National Atlas.) Kartográfia Vállalat, Budapest, p 89

Zólyomi B, Fekete G (1994) The Pannonian loess steppe: differentiation in space and time. Abst Bot 18:29–41

Zólyomi B, Tallós P (1967) Galatello-Quercetum roboris. In: Zólyomi B (ed) Guide der Excursionen des Internationalen Geobotanischen Symposiums. Ungarn, Eger-Vácrátót, pp 55–61