Modelling the impact of climate change on natural habitats in Hungary

Theses of PhD Dissertation

Bálint Czúcz

Corvinus University of Budapest
Faculty of Horticultural Sciences
2010

Name:	Doctoral School of Horticultural Sciences
Field:	Crop Sciences and Horticulture
Head of Ph.D. School:	Prof. Dr. Magdolna Tóth Doctor of the Hungarian Academy of Sciences Head of Department of Fruit Sciences Corvinus University of Budapest Faculty of Horticultural Sciences
Supervisors:	Dr. László Tőkei Head of Department of Soil Sciences and Water Management Corvinus University of Budapest Faculty of Horticultural Sciences
	Dr. György Kröel-Dulay Senior Research Fellow Hungarian Academy of Sciences Institute of Ecology and Botany Department of Plant Ecology

The applicant met the requirement of the PhD regulations of the Corvinus University of Budapest and the thesis is accepted for the defence process.

....	....	....
Head of Ph.D. School	Supervisor	Supervisor

„We will not be able to mitigate climate change or adapt to it
if we do not protect our ecosystems and biodiversity.
And we will not manage to halt the loss of biodiversity
if we do not mitigate climate change.”

Connie Hedegaard

1. Introduction

Global climate change will impose serious impacts on species and ecosystems worldwide during the 21st century. The inevitable decline in global biodiversity may result in a collapse of ecosystem services (e.g. pollination, pest control, erosion control, or the sustenance of biodiversity). As human well-being directly depends on the continual supply of these vital services, the protection of the integrity of ecosystems is a major task for the society. The erosion of local and global biodiversity prognosticates an increased likelihood of “ecological surprises” with potentially detrimental consequences on human society.

Climate impact modelling is a dynamically developing interdisciplinary research field. To analyze the potential ecological impacts of climate change several modelling approaches have been developed during the last few decades. *Correlative* and *mechanistic* ecological impact models, thoroughly reviewed in this dissertation, may quantify the primary consequences of the climatic drivers, whereas the *vulnerability assessment* framework, promoted i.a. by the Intergovernmental Panel on Climate Change (IPCC), is a robust tool to estimate the societal impacts of such changes (Fig. 1). Mainstream correlative and mechanistic ecological impact models, however, work best either for very specific (e.g. the local appearance/disappearance of certain species) or for very general and broad-scale (e.g. the continental scale shift of biomes) contexts. For intermediate scales and complexity (i.e. for country-level assessments or at the organizational level of communities) most existing approaches have serious limitations.

The main purpose of this study was to give a complete assessment of the climatic vulnerability of Hungarian natural and semi-natural ecosystems, using the best available methodology. Given the unusual quantity and quality of vegetation data (a spatially and thematically detailed vegetation cover database for the entire country) which is available in Hungary, this goal could only be accomplished with considerable methodological developments. These can be enumerated as the following methodological goals:

- To show that correlative distribution models predominantly used for species-level climatic *impact assessments* can be straightforwardly extended to simple *vulnerability assessments* which can effectively characterize larger areas and communities (Fig. 1).

- To produce a detailed climatic vulnerability assessment for selected communities as a case study
    - to demonstrate and test the applicability and usefulness of the constructed methodology, and
    - to provide a comprehensive and realistic overview of the climatic vulnerability of the selected communities.
- To lay the foundations of a comprehensive vulnerability assessment for terrestrial ecosystems in human-modified environments, which can serve as a ready-to-use module for interdisciplinary vulnerability and/or adaptation policy assessments.

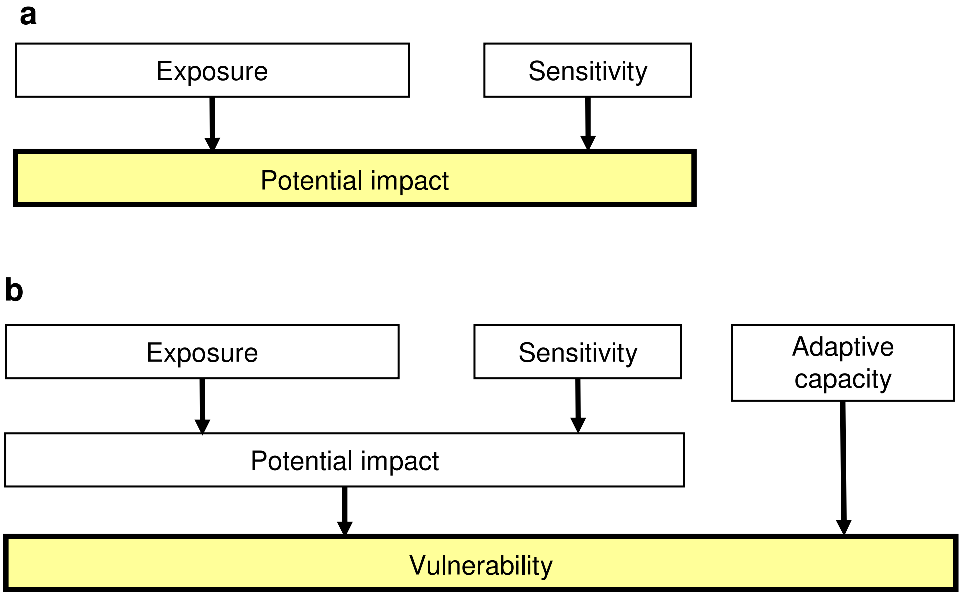

Figure 1. The conceptual design of a (a) climate *impact assessment* and a (b) *vulnerability assessment*.

2. Materials and Methods

According to the IPCC definitions, climatic *vulnerability* is “the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.” This definition offers an inherently systemic and interdisciplinary analytical framework, according to which vulnerability can be operatively assessed as the combination of few individual components (*exposure*, *sensitivity* and *adaptive capacity*; Fig. 1.). This widely used approach has, however, rarely been applied directly on ecological systems. In this study, I develop meaningful ecological constructs which directly represent the individual components of climatic vulnerability assessments. The different components can only be approached in different disciplinary contexts demanding markedly different practical approaches. Therefore I provide separate brief overviews for each component of the study as follows.

2.1. Exposure

In climatic vulnerability assessments, "exposure" generally means the future climatic environment to which the studied system is exposed. Spatially and thematically detailed information on the nature and degree of exposure is indispensable for the subsequent impact modelling. To this end, I performed simple linear downscaling of the available climatic data.

Aims: to produce high resolution projections of monthly temperature and precipitation data, as well as a few selected bioclimatic variables for three future time horizons (2025, 2050 and 2085), with the use of several global climate models (GCM) and emission scenarios (SRES).

Data sources:

- monthly temperature and precipitation outputs for six combinations of four different GCMs and three different SRES scenarios for the 21st century (HadCM3–A1b, –A2, –B1, CNCM3–A2, CSMK3–A2, GFCM21–A2; source: IPCC Data Distribution Centre);
- monthly temperature and precipitation outputs in climatic reconstructions for the 20th century from the same GCM-SRES combinations (source: IPCC Data Distribution Centre); and
- high resolution climatic surfaces (monthly temperature and precipitation) for the 1960–1990 baseline period (source: Hungarian Meteorological Service, OMSZ; and the WORLDCLIM internet database).

Methods: Simple linear downscaling (*R* statistical environment).

2.2. Sensitivity

The climatic sensitivity of a studied object can be characterized with the multivariate statistical relationship between its geographic distribution and the climatic variables. In this study the objects are plant communities (also referred to as vegetation types or "habitat" types).

Aims: to model the multivariate relationship between environmental variables and the distribution of the most important Hungarian vegetation types

Data sources:

- vegetation cover data for the Hungarian vegetation types (Landscape Ecological Vegetation Database & Map of Hungary, MÉTA);
- downscaled baseline values and projections for the bioclimatic variables; and
- detailed GIS databases of further environmental variables (soil and water availability).

Methods: correlative statistical modelling (unbiased regression trees, *R* statistical environment, *party* add-on package).

2.3. Potential Impact

In the terminology of climatic vulnerability assessments, potential impacts comprise all impacts that may occur without considering adaptation (e.g. assuming "no dispersal" for species or communities).

Aims: to estimate the potential impacts of climate change on present-day communities. In addition to the relatively easily modellable direct impacts of the changes in the climatic variables, I also tried to evaluate indirect climatic threats imposed by changes in the disturbance regimes.

Data sources:

- distribution of the selected vegetation types (MÉTA);
- climatic projections; and
- an expert panel consisting of 8 field botanists from 4 different research centres, with national overview of the distribution, functional properties and the threats to the different vegetation types.

Methods:

- direct impacts were estimated as an ensemble of model predictions for the future climatic conditions (for a few selected vegetation types; *R* statistical environment, *party* add-on package);
- indirect climatic threats were evaluated with the help of the expert panel using multi-criteria assessment (MCA) techniques.

2.4. Adaptive capacity

Ecosystems react to external changes with spontaneous adjustments. This process, called autonomous adaptation, can mitigate the "harms" (e.g. species extinctions) caused by external changes. Widely used ecological impact models do not consider any adaptive processes, or only allow for them in an unrealistically simplistic way. To overcome this general shortcoming, I propose a novel methodology which uses indicators to quantify adaptive capacity based on landscape context.

Aims:

- to develop a comprehensive set of indicators relying on a detailed conceptual model of the autonomous adaptation of ecosystems;
- to test and optimize the proposed indicator set based on independent field data;

- to quantify the proposed indicators as a spatially explicit characterization of ecological adaptive capacity (for two vegetation types: oak-hornbeam woodlands – K2, and mesotrophic meadows – D34).

Data sources: To test the indicators it is necessary to find and measure an ecological process that is fundamentally similar to the processes driving autonomous adaptation. The regeneration of abandoned agricultural fields (oldfield regeneration) is a promising candidate for this purpose, since this process is also based on species moving through the landscape. Accordingly, I used the following data:

- vegetation cover data (MÉTA);
- phytosociological relevés from 169 old-fields in the Kiskunság region of Hungary (used only for the testing; source: Kiskun LTSER).

Methods:

- GIS calculations (to quantify the different versions of the proposed indicators; *ArcGIS*);
- negative binomial generalized linear models (GLM) (to assess indicator performance; *R* statistical environment, *MASS* add-on package);
- sensitivity assessment (to optimize the indicators; *R* statistical environment).

2.5. Vulnerability

Vulnerability means the adverse impacts which are probably unavoidable even considering adaptation. I discussed two simple indicators to characterize two aspects of climatic vulnerability for two selected vegetation types (oak-hornbeam woodlands and mesotrophic meadows).

Aims: to highlight *high vulnerability areas* with high exposure and universally low adaptive capacity, and *high adaptivity areas* with still high exposure and either generally high or varying adaptive capacity.

Data sources: the previously quantified values (maps) for potential impacts and adaptive capacity indicators for the two selected vegetation types.

Methods: defining and applying threshold values based on simple "model landscapes" (*R*, *ArcGIS*).

3. Results

According to the character of my work and the novel approaches applied, I have several relevant methodological results in addition to practical ones. The most important novel approaches include a conceptual model, indicators and a testing framework for ecological adaptive capacity, which may potentially become important tools in the field of ecological climate change impact adaptation and vulnerability assessments. Furthermore, this is the first study performing an ecological climate change vulnerability assessment in Hungary, and thus the results may yield important information on the potential future and optimal management of different ecosystems in Hungary.

The most important methodological and practical results are the following:

3.1. A brief summary of the new scientific results

- Downscaled climatic maps for Hungary for the 21st century, according to six combinations of four GCMs and three SRES scenarios.
    - In accordance with several other regional climatic projections for 2050, the downscaled scenarios predict a yearly average warming of 1.7–2.6 °C, which is accompanied with a ~10 % (0–14 %) decline in summer precipitation, whereas in winter the precipitation might slightly increase (individual scenarios range from 3 % decline to 9 % increase).
    - The decrease of summer precipitation might be as high as 8 % even by 2025.
    - By the end of the 21st century (2085) annual warming might reach 5–6 °C, and the decline in summer precipitation might be 25–30 %.
- A simple methodology to quantify different aspects of climatic sensitivity using correlative habitat distribution models.
    - The 12 most climate sensitive vegetation types in Hungary are salt marshes (B6); *Arrhenatherum* hay meadows (E1); *Festuca rubra* hay meadows (E2); *Cynosurion* grasslands and *Nardus* swards (E34); *Achillea* salt steppes on meadow solonetz (F1b); *Bromus erectus–Brachypodium pinnatum* xero-mesophilous grasslands, dry tall herb communities and forest steppe meadows (H4); open vegetation of shadowed rocks (I4); lowland oak-hornbeam woodlands (K1a); oak-hornbeam woodlands (K2); beech woodlands (K5); turkey oak–sessile oak woodlands (L2a); and acidophilous coniferous woodlands (N13).
- Coarse resolution (~5 km) potential impact maps for the 12 most climate sensitive vegetation types for the entire country of Hungary and for all studied time horizons (2025, 2050 and 2085).
    - The results have explicitly confirmed the general assumption that zonal forest communities in Europe are particularly threatened by climate change. Potential impacts are highest for stands at lower elevations. The most endangered regions are South Transdanubia (Mecsek, Zselic) in the case of beech (K5) and oak-hornbeam (K2) forests, and North Hungary (Cserhát) in the case of turkey oak–sessile oak woodlands. Lowland oak-hornbeam forests (dominated by pedunculate oak, K1a) are

    negatively affected over their entire range in Hungary with the largest potential impact in South Transdanubia.
    - In the case of *Festuca rubra* hay meadows (E2), most endangered areas are in the Transdanubia region, whereas for *Arrhenatherum* hay meadows (E1) North Hungary and the Mezőföld region seem to be most endangered.
    - For several vegetation types with significant climate-dependence, global warming initially might mean favourable changes. One example is the species poor secondary vegetation type of *Achillea* salt steppes on meadow solonetz (F1b).
- Fine resolution (~500 m) potential impact maps for the oak-hornbeam forests (K2) in a South Transdanubian study area for the time horizon of 2025.
    - This analysis also confirmed the potential vulnerability of K2 forests in South Transdanubia, and particularly the Zselic region. In the case of Bakony and the adjacent mountain ranges in Central Transdanubia, the potential impacts are much smaller.
- Appraisal of "average climatic endangerment" (potential impacts at a national level) for each natural and semi-natural vegetation type of Hungary, based on a multicriteria assessment (MCA) combining the modelled (direct) potential impacts and expert knowledge on potential indirect impacts.
    - Four vegetation types were found to be extremely endangered on the national level: transition mires and raised bogs (C23), *Calluna* heaths (E5), acidophilous beech woodlands (K7a), and acidophilous coniferous woodlands (N13).
    - Thirteen further vegetation types (A4, C1, D1, E2, F2, J1b, J2, K1a, L5, M2, M3, M4, LY3) can be considered as strongly endangered at the national level.
    - 80 % of the Hungarian vegetation types (60 out of 75) is threatened by at least one mechanisms according to the consensus of experts and the model results.
    - Experts think that much more vegetation types will be potentially affected by climate change than correlative impact modelling was able to show (models identified 18 whereas the expert-based MCA identified 60 affected vegetation types). The MCA approach used here can be seen as a potential implementation of the recurring recommendation of integrating qualitative and quantitative information in climatic impact adaptation and vulnerability assessments.
- Construction of a novel and operative conceptual model on the autonomous adaptation of ecosystems to climate change, and proposing three indicators (indices of vegetation condition, landscape diversity and landscape connectivity) to estimate the local/landscape

level capacity for each of the three adaptive mechanisms identified in the conceptual model (local resilience, persistence in refuges, and species migration).

- Testing and optimizing the proposed adaptive capacity indicators based on field data.
    - There is a strong and highly significant correlation between regeneration success, and the diversity and connectivity index values characterizing the landscape context in the case of the Kiskunság oldfields. Since oldfield regeration is driven by the same underlying mechanisms (re-establishment from refuges or migration), this result can be considered as a strong indirect evidence that these indicators can effectively be used to characterize the climatic adaptive capacity of the (semi-)natural ecosystems in the local landscape context.
    - The proposed connectivity and diversity indicators are shown still to be meaningfully applicable for data sets of considerably lower spatial and thematic resolution than the MÉTA database (e.g. both indicators are readily applicable at the resolution of the Hungarian national CLC-50 Corine land cover database, and connectivity still remains meaningful for the pan-European Corine CLC-100).
    - The effective dispersal distance of the characteristic native species of the Kiskunság sand steppe is ~2-5 km per decade.
- Test calculations to quantify climatic adaptive capacity for two vegetation types of significant conservation value (oak-hornbeam woodlands – K2 and mesotrophic meadows – D34).
    - There is considerable variation in the adaptive capacity indicator values for the different regions. Both prevalence and landscape pattern seem to influence the regional adaptive capacity of the different communities.
    - In the case of the more frequent and more aggregated oak-hornbeam woodlands (K2) 13 % of the stands can be characterized with good adaptive capacity with respect to all three indicators. In the case of the less prevalent and more homogeneously distributed mesotrophic meadows (D34) this figure is only 1.6 %. By contrast, 3.6 % of the oak forests and 35 % of the meadows exhibit a poor adaptive capacity for all three indicators in the South Transdanubia region of Hungary.
    - Oak forests (K2) with low adaptive capacity were concentrated in the Balaton Highlands and the Zselic, while in the case of meadows (D34) landscapes with high and low adaptive capacity were more evenly distributed.
- The evaluation of vulnerability for oak-hornbeam woodlands (K2) in the South Transdanubia study area.

- I have compiled two simple indicators to identify particularly “hopeful” and “hopeless” situations in terms of climatic vulnerability. These indicators can be of direct use in spatial planning and adaptive management activities.
- *High adaptivity areas* (high potential impact + high adaptive capacity) are concentrated in the core of the Zselic region, whereas *high vulnerability areas* (high potential impact + low adaptive capacity) can mostly be found at the periphery of the same region – in the case of oak-hornbeam forests (K2).
- High adaptivity oak forests are typically within, while high vulnerability areas are typically outside of the Natura 2000 network, which indicates, that the current Natura 2000 network is relatively well-designed from the perspective of the climatic adaptation of oak-hornbeam forests (K2).

4. Conclusions and recommendations

As natural ecosystems are fundamentally resilient and self-organizing systems, the best way of avoiding harmful climatic impacts is to enhance the inherent capacity of ecosystems for autonomous adaptation. According to the conceptual model for ecological adaptation presented in this study, this can be implemented at three different levels:

- enhancing the ecological state (compositional, structural and functional diversity) of the communities by reducing non-climatic human pressures (e.g. draining, pollution);
- preserving and restoring landscape heterogeneity and habitat diversity;
- improving the connectivity of the landscape for the species of the natural habitats.

Under stable environmental conditions most species can be preserved by maintaining suitably large reserves. By contrast, in a changing climate, when species need to track the changing external conditions, the ability of species to survive in the landscape will largely be determined by the ecological state of the broader landscape context. To keep our ecosystems climate resilient it will be indispensable to mainstream ecological aspects into sectoral land management policies (e.g. agriculture, forestry, water management). This involves several important tasks, for example,

- to promote less intensive *agricultural* practices, and to increase heterogeneity and diversity of agricultural landscapes;
- to emphasize natural *forest* management techniques providing continual forest cover;
- to develop retention-oriented *water management* policies; or

- to incorporate ecological corridors and crossings (e.g. green bridges) into *transportation* planning.

Fortunately, this process has already started, and the several aspects of ecological resilience can already be observed in forward-looking sectoral policies (e.g. Agro-environmental schemes, Pro Silva forest management, EU Water Framework Directive, etc.), but further advancements are still required. Successful adaptation needs to rely on well-founded and detailed climate change strategies and action plans, which should not neglect any major elements or feedback loop of the complex socio-economic-ecological system. Effective actions need to be supported by thorough interdisciplinary assessments. Hopefully, the work presented in this thesis will contribute to the development of these important assessments, and thus help us to avoid detrimental impacts from the twin crises of climate change and biodiversity loss.

5. Relevant publications related to the subject of the thesis

Czúcz, B. – Gálhidy, L. – Mátyás, Cs.: Present and forecasted xeric climatic limits of beech and sessile oak distribution at low altitudes in Central Europe. *Annals of Forest Science* (in press).

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. *Journal of Vegetation Science*, doi:10.1111/j.1654-1103.2011.01251.x (in press).

Walther, G.R. – Roques, A. – Hulme, P.E. – Sykes, M.T. – Pyšek, P. – Kühn, I. – Zobel, M. – Bacher, S. – Botta-Dukát, Z. – Bugmann, H. – **Czúcz, B.** – Dauber, J. – Hickler, T. – Jarošík, V. – Kenis, M. – Klotz, S. – Minchin, D. – Moora, M. , Nentwig, W. – Ott, J. – Panov, V. E. – Reineking, B. – Robinet, C. – Semenchenko, V. – Solarz, W. – Thuiller, W. – Vilà, M. – Vohland, K. – Settele, J. (2009): Alien species in a warmer world: risks and opportunities. *Trends in Ecology & Evolution* 24(12): 686-693.

Czúcz, B. – Torda, G. – Molnár, Zs. – Horváth, F. – Botta-Dukát, Z. – Kröel-Dulay, Gy. (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. – Kröel-Dulay, Gy. – Torda, G. – Molnár, Zs. – Tőkei, L. (2009): Regional scale habitat-based vulnerability assessment of the natural ecosystems. IOP Conference Series: Earth and Environmental Science, 6(44), 442006.

Czúcz, B. – Horváth, F. – Botta-Dukát, Z. – Molnár, Zs. (2009): Modelling changes in ecosystem service supply based on vegetation projections. IOP Conference Series: Earth and Environmental Science, 6(30), 302011.

Molnár Zs. – Bartha S. – Horváth F. – Bölöni J. – Botta-Dukát Z. – **Czúcz B.** – Török K. (2009): Növényzeti örökségünk állapota és várható jövője az MTA ÖBKI MÉTA-adatbázisa alapján [The state and the future of Hungary's vegetation heritage, according to the MÉTA database]. *Magyar Tudomány* 170: 54-57.

Molnár Cs. – **Czúcz B.** (2009): A virágos kőris (Fraxinus ornus L.) terjedése és mai termőhelyei az Északi-középhegységben [Habitats and dispersal of manna ash (Fraxinus ornus L.) in the North-Hungarian Mountains]. *Botanikai Közlemények* 96(1-2): 71-81.

Csecserits A. – Szabó R. – **Czúcz B.** (2009): Növényi tulajdonságok, tulajdonság-adatbázisok és ezek felhasználása az ökológiai kutatásokban [Plant characteristics, plant trait databases, and their application in ecological research]. *Botanikai Közlemények* 96(1-2): 31-47.

Kovács-Láng E. – Kröel-Dulay Gy. – **Czúcz B.** (2008): Az éghajlatváltozás hatásai a természetes élővilágra és teendőink a megőrzés és kutatás területén [The impact of climate change on natural ecosystems and the response options for nature conservation]. *Természetvédelmi Közlemények* 14: 5-39.

Czúcz, B. – Molnár, Z. – Horváth, F. – Botta-Dukát, Z. (2008): The natural capital index of Hungary. *Acta Botanica Hungarica*, 50(Suppl. 1): 161-177.

Biró, M. – Révész, A. – Molnár, Zs. – Horváth, F. – **Czúcz, B.** (2008): Regional habitat pattern of the Duna-Tisza köze in Hungary II. The sand, the steppe and the riverine vegetation; degraded and ruined habitats. *Acta Botanica Hungarica* 50(1-2):19-60.

Gálhidy, L. – Mátyás, Cs. – **Czúcz, B.** – Torre, F. (2006): Zonal forest types, climatic variables and effect of changes for Hungary, *Lesnícky Časopis – Forestry Journal*, 52: 99-105.

Biró M. – Papp O. – Horváth F. – Bagi I. – **Czúcz B.** – Molnár Zs. (2006): Élőhelyváltozások az idő folyamán. In: Török K. – Fodor L. (szerk): *Élőhelyek, mohák és gombák. A Nemzeti*

Biodiverzitás-monitorozó Rendszer eredményei I., ISBN 963 86950 0 5, KvVM TvH, Budapest, pp: 51-66.

Czúcz, B. – Révész, A. – Horváth, F. – Biró, M. (2005): Loss of semi-natural grasslands in the Hungarian forest-steppe zone in the last fifteen years: causes and fragmentation patterns. In: D. McCollin and J.I. Jackson (eds): Planning, People and Practice: The landscape ecology of sustainable landscapes – Proceedings of the 13th Annual IALE(UK) Conference, held at the University of Northampton, 12–16 Sep. 2005., p. 73–80.