UNIVERSITY OF SZEGED
Faculty of Science and Informatics
Doctoral School of Earth Sciences
Department of Climatology and Landscape Ecology

MODEL-BASED EVALUATION OF ECOSYSTEM SERVICES

Summary of PhD thesis

MÁRTON DÁNIEL KISS

Supervisor:

Dr. Ilona Bárány-Kevei

professor emerita

Szeged

2019

I. INTRODUCTION, AIMS

The assessment of ecosystem services has been playing an increasingly important role in environmental science research and applications today. The evaluation requires a combined methodology of several disciplines, thus, a number of research results have been produced about the ecological basis of the provision of services, their monetary value or the role of services in environmental conflicts recently. The approach is suitable for expressing the social usefulness of natural values in a form that can be easily understood by decision-makers and the general public alike. Its usefulness has also contributed to the growing importance of the evaluation of ecosystem services in more and more policy areas, besides academic disciplines, and has become a basis in a number of special political decisions. The assessment of ecosystem services requires the application of geoecological and, in general, geographical methods and approaches. One of the most important elements of geographical methodology is model-based evaluation, which serves as the main methodological approach of my work.

Based on the above mentioned facts, the main hypothesis of my work was that landscape ecological conditions and geographic complexity are necessary in the evaluation process of ecosystem services (from research planning to the evaluation of the results).

The aims of my dissertation are as follows:

- Presenting the research history and main conceptual questions of the evaluation of ecosystem services (focusing on modelling, mapping and evaluations for decision support).
- Examining some national landscape and urban ecological as well as land use problems in the methodological framework of ecosystem service assessment, applying and developing a model and territorial-based assessment method based on the topic and geographical area.
- Testing the simplest method of mapping services, i.e. testing the possibilities of land cover-based assessment in a sample site along the Tisza River.
- Assessing the role of land use intensity, which significantly influences the amount of services, in the development of land use conflict, in addition to the nature and type of land cover and land use. By employing the results of a series of field measurements, I investigated the effects of nature conservation grassland and

water habitat reconstructions, and thus, some features of the greenhouse gas exchange of habitats which were treated in different ways.

- Analysing the impact of different tree species and that of forests with different management types on ecosystem services, by employing a model-based assessment of carbon sequestration, which is one of the most important services of forests, in two study areas: a karst (Aggtelek Karst) and a floodplain (along the Maros river).
- Comparing the assessments of the impact of different tree stands (located in the downtown of Szeged) on ecosystem services. The purpose of the study was to evaluate the impact of tree species differences and the intensity of use as well as to explore the possibilities of the national adaptation of the relevant model.
- Based on two examples, investigating the modelling possibilities of ecosystem services with the help of artificial intelligence tools in order to assist decision making: a genetic algorithm for spatial land use decision support (in a study area in the Sand Ridge) and Bayesian networks (for the eutrophication modelling of karst lakes).
- As the aims and results of the dissertation are partly of methodological significance, my aim is not only to address the landscape ecological problems of the different study areas, but also to test the tools available for modelling ecosystem services under national conditions and to develop new modelling methods.

2. METHODS AND STUDY AREAS

2.1. Land cover-based evaluation of ecosystem services

The need for developing a land cover-based evaluation system is supported by the fact that different types of ecosystem services (even those belonging to various primary groups) can be managed in a common framework system. Monetary evaluation is the fundamental methodological approach to cell value determination and, in general, to the whole case study. The analysed landscape type is the floodplain of the Tisza, where the monetary evaluation of services being of key importance concerning landscape ecology and regional development can be realised.

The assessment of agricultural profitability was made possible by the annual cost and revenue analyses based on a representative national sample database for the majority of the economic sectors. The profitability of the arable land and horticultural sectors as well as that of grassland management was calculated as the difference between the sectoral result and the direct state subsidies. As the aim was to determine consolidated profitability (based on land cover type), I determined the most characteristic results of the individual sectors by calculating the weighted means of national acreage or those of livestock number. I calculated the three-year (2008-2010) averages of these results by using the present value calculation based on the Agricultural Producer Price Indices (the results are relevant for 2012).

The monetary assessment of the timber-producing capacity of forests was carried out by the so-called forestry economic models (the proportions of tree species distribution and tree productivity capacity in the district forestry plan for the smaller study area were taken into account). I calculated the value of flood risk reduction with the help of the results of existing flood simulation models and the working material of the reservoir to be developed as part of the New Vásárhelyi Plan in the smaller study area. I assessed the inland excess water resistance service through the revenue loss of those utilization forms that are susceptible to inland excess water. It was based on the Pálfai's Inland Excess Water Risk Database, which I used to determine the inland excess water risk (revenue loss due to inland excess water) of each land cover category by means of a GIS cross-tabulation procedure. The smaller study area of the research was the Nagykörű floodplain of the Middle Tisza District.

2.2. Assessment of the impact of land use intensity on the example of climate-related ecosystem services

The issue relating to the intensity of use is one of the main factors of land use conflicts in almost all types of Hungarian landscapes. Therefore, it is important to analyse how different types of land use intensity affect ecosystem services within a particular type of utilization.

2.2.1. Carbon sequestration processes of forest reserves and forests with different management intensity

In the first part of my work which focuses on the impact of land use intensity, I evaluated one of the most important regulating services forests provide, carbon sequestration, by studying forests undergoing various management intensities. The model-based assessment of the carbon sequestration capacity of forests is made possible by the fact that the process of biomass formation can be described relatively well by means of long-established growth functions and equations used in forestry practice. The CO2Fix3.2. model I used is also based on this practice.

This chapter of my work can be divided into two separate parts, the first of which was to characterise near-natural forest stands that are not part of any forestry management, in terms of carbon stocks and fluxes. Its study area was the Haragistya-Lófej Forest Reserve on the Aggtelek Karst. The primary data I used was a detailed, individual-based tree survey collected at sample points. Due to the varied terrain of the karstic area and the lack of artificial tree species selection, the area is rich in tree species and associations, and it is also varied concerning age composition. For the 70-year-long simulation modelling, I categorised the forests into 9 cohorts: beech stands, which can be considered as homogeneous in terms of growth, mesophilous hornbeam-oak stands and dry oak stands, all of which represented three different age groups each (60-80 years, 80-100 years old and 100-120 years old). For the calculation of the biomass growth, I used the available tree yield tables by species, from which the values of the cohorts were generated with the help of the mixture ratio. The study area of the second part of the work was the forest of the Maros floodplain; in this case, besides characterising the forest reserve located in the area, my aim was to compare forests with different management intensity. Age and management intensity were the bases for the isolation of the 8 cohorts examined. They were indigenous and non-native softwood stands, and stands composed of common oaks (*Quercus robur*) and invasive hardwood species. In addition to the forest reserve field survey, the management plan data of the examined forest parts served as an important baseline data in the Maros floodplain. The length of the simulation was 120 years in this case.

2.2.2. Ecosystem services of urban tree stands and their management intensity-related patterns

The analysis of the ecosystem services of tree stands located in settlements is justified by the fact that there have not been any national assessments of this kind that would have evaluated these important processes, which are also easily perceived by the inhabitants. On the other hand, there are problems in relation to the intensity of use in this case, which can also provide information on practical issues related to tree stands management. In the presented evaluation, I studied the carbon sequestration and air pollution removal of the downtown tree stands of Szeged, using the data of a complete tree inventory.

I used the i-Tree Eco model for the assessment. This part of my analysis is also divided into two main parts, both of which are based on a complete tree inventory including the public areas of downtown Szeged, which consisted of nearly 3,000 individual trees at the time of the analysis. The first part of the study aimed at providing a general description of the total tree stand of the inventory. Its main purpose was to compare the services provided by different tree species in relation to tree condition. In the second part of the study, my aim was to compare the tree stands of 2-2 similar avenues and streets. One of each is under local protection and is characterised by different management intensity. The protected tree stands are alleys of József Attila Avenue and Hajnóczi Street, the not protected ones are the alleys of Petőfi Sándor Avenue and Gutenberg Street.

2.2.3. The impact of habitat reconstructions on some features of the carbon sequestration of habitats

Habitat reconstructions will be important conservation objectives in bigger and bigger areas, in accordance with European restoration ecological objectives. Therefore, it is important to know how the amount of different ecosystem services develops during secondary succession.

In the measurement series I carried out in the vegetation period of 2011, the most important measured data were the carbon and nitrogen contents of the soil (from two layers), water and vegetation. The study area was the Egyek-Pusztakócs habitat complex in the Hortobágy National Park, which was the largest grassland reconstruction area in Europe at the time of the research, and, in addition, the area witnessed various water habitat reconstruction programmes in the previous years. The designated sample points were grasslands reconstructed at different times (so being of different ages), a reference grassland area, extensively and intensively used arable land plots sampled for the purpose of characterising the previous condition, and 3 different wetland habitats selected from the coastal zone of a rehabilitated swamp.

2.3. Modelling options for ecosystem services using artificial intelligence methods

Artificial intelligence is used in environmental science more and more frequently. It is facilitated by the increasing number of available measurement and modelling data. The diversity of the methods makes it possible to find more reliable solutions for forecasting and optimisation tasks. I aimed at developing proper methods of development and testing which can provide information on the applicability of the individual methods and help set the direction of further developments.

2.3.1. Modelling the eutrophication processes of karst lakes using Bayesian networks

Bayesian networks belong to the graphic models of artificial intelligence methods. Their main characteristic is that the relationships between the variables are given with conditional probabilities, so that the information or expert decisions of different professional fields can be effectively integrated into the model. If sufficient data is available for the central variable, Bayesian networks may also be able to assess the probability of causes based on their effects (diagnosis). The ecological process I studied in the framework of my doctoral research was the eutrophication of karst lakes. The complexity of this process, and the numerous external factors affecting the system, make Bayesian networks suitable for performing analyses. The lakes I studied in my research are located on the Gömör-Torna Karst, which has experienced a rapid and spectacular recharge process in recent decades. The model included the data of one-year-long field measurements (monthly measurements) in these lakes: pH, water temperature, orthophosphate content, nitrate content, ammonia content, alkalinity and a-chlorophyll were measured. The aim of the work was to investigate the changes of the ammonia content and the factors influencing this change by employing Bayesian networks for diagnostic purposes. Ammonia has a strong influence on the health of the fish stock, and its amount is associated with the eutrophication process.

2.3.2. Spatial optimization of ecosystem services

Optimising land use is one of the traditional tasks of landscape ecology. The mapping of ecosystem services or the exploration of land use conflicts help to explore and understand land use interests. At the same time, the need may arise for determining the spatial pattern of optimal land use by taking into account a wide range of aspects. Artificial intelligence methods can significantly help to solve these types of problems. These methods include evolutionary algorithms that use a certain range of selection mechanisms characterising evolutionary processes as a model for solving the optimisation task. The framework for ecosystem services provides a good opportunity for this type of work. In my doctoral research, I aimed at developing and presenting an experimental application, which makes use of the so-called Boundary-based Fast Genetic Algorithm. A particular feature of the algorithm is that we can also weigh the optimisation aspects displayed by ecosystem service indicators with the weights we provide.

I chose one representative of the four major groups of ecosystem services as optimisation aspects. Agricultural and forestry profitability (provisioning services) and carbon sequestration (regulating service) were assessed using simple evaluation matrices. In order to characterise nature conservation value (supporting service) and aesthetic value (cultural service), I chose indicators based on landscape pattern: the indicator of the conservation value was the average patch size index, and that of the aesthetic value was the Shannon Diversity Index. The study area of this part of the research was 3*3 km area on the western border of the South Tisza Valley (bordered with the Sand Ridge), which was represented with a 100*100 grid in the process. The model was implemented using Java programming language running 4 different weighting scenarios.

3. RESULTS

3.1. Land cover-based evaluation of ecosystem services

The filling of the land cover-based evaluation matrix, which was one of the aims of the case study, was preceded by a detailed assessment of each service. Determining the value of agricultural profitability is significantly more difficult due to the annual variability of production values and costs characterising the individual sectors. At the same time, their means reflect the market position of the given sectors relatively well in the given years. The profitability of timber production was approximately 31,000 HUF/ha. Of the regulatory services, **flood risk reduction is about one order of magnitude higher than the value of provisioning services**. According to the results, the values of flood risk reduction varied between 50,000-135,000 HUF/ha in relation to the study area, and its order of magnitude being 100,000 HUF/ha was confirmed by other works of similar purpose. **Inland excess water risk can reduce agricultural profitability approximately by 10% in floodplain areas.**

Concerning the overall methodological approach and based on the experience with the results, I consider **the development of an evaluation matrix which is based on economic valuation as well as land cover types to be an applicable method for evaluating ecosystem services**, and to assist various spatial analysis tasks. However, due to the annual variability of the value of a part of the services and the study-area-specificity of the data, the results provided by the evaluation system are not suitable for an application that involves direct mapping and land use change studies. On the other hand, **they can provide important information by defining and comparing the values of the services on the basis of their order of magnitude and unit area in order to assist large-scale land use planning, indicate land use preferences**, and, as a methodological result, develop of similar evaluation systems.

3.2. Assessment of the impact of land use intensity on the example of climate-related ecosystem services

3.2.1. Carbon sequestration processes of forest reserves and forests with different management intensity

The carbon content characteristics of the above-ground biomass in **near-natural populations, which have been undisturbed** in recent years, **show the impact of habitat differences due to the variability of karstic terrain. Beech stands are characterised by the highest carbon sequestration potential**, with a maximum value of 215 t C/ha. **Mesophilous oak stands have an average amount of biomass and associated carbon content**, which is approximately 200 t C/ha in the case of older forests. **Dry oak stands have the lowest carbon sequestration values** (about 165 t C/ha at maximum), which is due to the fact that these stands are composed mainly of downy oaks (*Qercus pubescens*) growing in the shallow soil of mountain sides. **Each stand is characterised by the gradual increase in their carbon content.** It confirms international results according to which old forests with a diverse age structure can be considered as carbon sinks.

With regard to forests of different management intensity, the time-related changes of their carbon content vary from stand to stand, and **they provide** significant **information on the amount and changes of carbon stored in soil and timber products**. The maximum amount of carbon stored in the whole stand of hybrid poplars was approximately 115 t/ha, the amount stored in biomass was approximately 70 t/ha. Strong growth at a young age is followed by logging in a short period of time (about 20 years), and the short rotation cycle is accompanied by the processing of short-lived timber products.

In the case of domestic poplar species, the rotation cycle is somewhat longer, and the continuous growth of biomass amount (similarly to noble poplars) is broken by thinning. **The total amount of carbon stored in the system is somewhat smaller than that of hybrid poplar stands** (the maximum of the total system is about 105 t/ha, that of the biomass is about 55 t/ha). **Oak stands can be characterised by the highest amount of carbon stored when compared to all the forest types analysed in the study area, which is due to their long rotation cycle, and the long life of timber products** (mainly furniture). In the case of the total stored carbon content, it means about 235 t/ha with 120 years of modelling, and approximately 180 t/ha regarding biomass. Oak stands are also cut with clear-felling (usually carried out by micro-clearcuts), and the proportion of firewood in the products is relatively high, especially in relation to thinning.

3.2.2. Ecosystem services of urban tree stands and their management intensity-related patterns

The results concerning the whole **downtown tree stand of Szeged show that structural characteristics and the amount of services are primarily determined by the size distribution of the individual species and the specific species** itself. At the same time, **health condition is an important influencing factor, which can indicate the urban tolerance of the given populations or the different effects of green space management.** Analysing structural features, one of the most important information influencing the other factors is that the examined stand is characterised by a very large variety of species (the total number of species is 100). The trunk diameter distribution indicates that a dominant size range can be recognised in most species, indicating that different species have been favoured in different areas during public afforestation. **The distribution of the leaf area between species reflects the effects of the health condition the most.** For example, the share of the total leaf area of the whole downtown stand in the case of the Japanese pagoda tree (*Sophora japonica*) or the small- and large-leaved lindens (*Tilia cordata* and *Tilia platyphyllos*) is smaller than the number of their individuals would suggest, while, for example, the individuals of the *Platanus hybrida* population have really high leaf area values, which is due to their good condition and large size. **Ecosystem services provided by the individuals of different tree species follow the patterns of structural features.** The populations having the largest individual trees are characterised by the largest individual annual carbon sequestration values. In these cases, the average sequestration value per individual is over 15 kg/year, and in the case of *Platanus hybrida* it exceeds 60 kg/year. For each species, the air pollutant removal per individual is between 200-400 g for most species when all pollutants are considered. **Analysing the removal of the individual pollutants**, it can be said that **the largest amount of captured air pollutants are those which cause the greatest air pollution of the city, so in the case of Szeged it is mainly ozone and dust.**

By analysing the structural characteristics of the stands selected for comparison according to the intensity of use, it can be concluded that **management characteristics result in recognisable differences. In non-protected stands, constructions and various infrastructure development activities resulted in the removal of a significant portion of the crowns or even led to the dieback of the crowns, both of which significantly reduced leaf area** (Petőfi Sándor Avenue). The small proportion of crown missing and dieback characterised a newly planted tree line in a street (Gutenberg Street), which indicates the good condition of the newly plantation. The comparison of the provided ecosystem services has to be done by analysing trunk diameter categories. **The results** show that **the difference between the values of carbon sequestration and air pollutant removal could be detected in each and every trunk categories suitable for evaluation: the smaller proportion of crown removal and dieback resulted in higher service values in the protected tree line** (József Attila Avenue).

3.2.2. The impact of habitat reconstructions on some features of the carbon sequestration of habitats

Since I presented the results of a one-year long measurement series, **no clear trend for carbon stocks and fluxes can be detected with regard to restored grasslands in the past few years of their reconstruction**. The obtained results show that the values of the C and N contents in the soils of reconstructed grassland (2005) significantly exceed those of the later restored grassland (2008). (At the same time, in addition to gradual regeneration, grazing and the low C/N ratio of leaf mould may also contribute to this result.) **Based on the results of grasslands,** it is likely that these **near-natural, well-structured grasslands play a prominent role in the carbon sequestration of soils.** Arable land areas with intensive management and wetland habitats with *Eleocharis* populations exhibited higher C and N contents in their soil and water. The values of the biomass element content do not only indicate the signs of ecosystem regeneration, but also the characteristics of the species having settled in the areas in different periods, as well as the weather conditions of each year.

3.3. Modelling options for ecosystem services using artificial intelligence methods

3.3.1. Modelling the eutrophication processes of karst lakes using Bayesian networks

The graphical model illustrates the various factors that affect the primary process, i.e. the changes in the amount of ammonia. **The formation of ammonia is directly affected by the variables of ammonium, pH and water temperature, while these variables are influenced by the SPI drought index, alkalinity, a-chlorophyll and air temperature.** Since all the variables in my work were available, including the values of the output variable, I could use the Bayesian network for diagnostic purposes. It means that the sensitivity test of the programme could determine how the individual variables influenced the factor that was set as the end result variable in the complex system that had been created. **The results of the sensitivity analysis concerning the "Impact on fish" variable show that** the health status of **fish is the most sensitive to pH and water temperature.** It is also possible to conclude that, **from the initial independent variables, climate parameters (primarily air temperature) are more important than factors associated with bedrock (according to the sensitivity study, the health status of the fish population is the least sensitive to alkalinity, nitrate content and phosphate content).**

3.3.2. Spatial optimisation of ecosystem services

The results of the Bound-based Fast Genetic Algorithm, which was run as an experimental application, are different optimum patterns based on weight distributions I had defined. Their tendencies usually correspond to the landscape ecological aspects of the study area and the possible land use suggestions. For example, **in each scenario**, it would be **desirable to increase the area of forests and to reduce the area of arable lands to a certain extent**. The high proportion of orchards in the optimum patterns can be explained by the fact that the model, in the version presented here, took into account profitability in the first place, and by incorporating some other agro-ecological aspects (which also affect it), this picture may change. Another feature of the optimum land use patterns is the presence of small patches. It is the result of using the average patch size index, and the heterogeneity of landscape patterns is indeed a good landscape ecological goal. However, for example, in the case of arable lands, the very small patchwork pattern is not realistic in terms of land use. In relation to the optimal land use patterns resulting from the modelling, it was not my intention to provide direct land use decision support. However, **the framework is a promising tool for landscape ecology planning, and weighting the criteria makes the process particularly suitable for optimisation that is based on ecosystem services.** For services with less complex background processes or indicators, it can be suitable for practical use even at a level of complexity close to the present one.

4. CONCLUSION

According to the basic assumption of the research, the results presented here also show that **landscape ecological features determine the range and spatial pattern of ecosystem services appearing in an area. They also play an important role in the selection of applicable models and evaluation procedures. An important task for the next period is to integrate the expertise and modelling experience of the non-directly related professional fields, which** share similar topics and **objectives though, into the simpler models for evaluating ecosystem services.** It is not only important to carry out such a task, but it is also an opportunity for geography and landscape ecology as it requires an integrated approach and proper spatial aspect.

PUBLICATIONS USED DIRECTLY FOR THE THESES

Kiss, M., Tanács, E., Keveiné Bárány, I. (2011): Karsztos erdők szénmegkötésével kapcsolatos számítások egy erdőrezervátum adatai alapján. *Karsztfejlődés* 16, 157-166.

Kiss, M., Gere, Cs., Kiss, M. (2013): Basics of an integrated ecosystem service evaluation system for the Tisza River Basin. *Review on Agriculture and Rural Development* 2, 314-319.

Kiss, M., Németh, Z., Bárány-Kevei, I., Czóbel, Sz. (2014): Investigation of carbon sequestration processes of reconstructed grasslands and wetlands to aid ecosystem service-based decision making. *Acta Climatologica et Chorologica* 47-48, 63-70.

Kiss, M., Cseh, V., Tanács, E. (2015): Carbon sequestration of different types of floodplain forests in the Maros river valley (Hungary). In: M. Luc, U. Somorowska, J.B. Szmańda (szerk.): *Landscape Analysis and Planning (Springer Geographical Perspectives Series)*. Cha-Am, Thaiföld: Springer International Publishing, pp. 159-175.

Kiss, M., Takács, Á., Pogácsás, R., Gulyás, Á. (2015): The role of ecosystem services in climate and air quality in urban areas: Evaluating carbon sequestration and air pollution removal by street and park trees in Szeged (Hungary). *Moravian Geographical Reports* 23, 36-46

Kiss, M., Samu, A., Tanács, E., Bárány-Kevei, I. (2016): Modelling environmental processes with Bayesian networks based on the example of eutrophication of karstic lakes. *Acta Climatologica et Chorologica* 49-50, 41-48.

Pinke, Zs., **Kiss, M.**, Lövei, L.G. (2018): Developing an integrated land use planning system on reclaimed wetlands of the Hungarian Plain using economic valuation of ecosystem services *Ecosystem Services* 30(B), 299-308.

OTHER PUBLICATIONS IN THE TOPIC OF THE DISSERTATION

Czúcz, B., Arany, I., Potschin-Young, M., Bereczki, K., Kertész, M., **Kiss, M.**, Aszalós, R., Haines-Young, R. (2018): Where concepts meet the real world: A systematic review of ecosystem service indicators and their classification using CICES. *Ecosystem Services* 29, 145-157.

Keveiné Bárány, I., **Kiss, M.**, Tanács, E., Samu, A. (2016): Ökoszisztéma szolgáltatások és biogeomorfológiai visszacsatolások a karsztokon. *Karsztfejlődés* 21, 157-174.

Keveiné Bárány, I., **Kiss, M.** (2018): A karsztok ökoszisztéma-szolgáltatásai integrált geográfiai megközelítésben. In: Pap, N., Szalai, G. (szerk.): *Táj geográfus ecsettel.* Pécsi Tudományegyetem Természettudományi Kar (PTE TTK), Pécs, pp. 31-44.

Kiss, M., Deák, J.Á., Bárány-Kevei, I. (2009): Complex landscape ecotone analysis on the borderline region of two landscapes in the South Great Plain (Hungary). *Acta Climatologica et Chorologica* 42-43, 67-77.

Kiss, M., Tanács, E., Bárány-Kevei, I. (2011): Ecosystem services in Hungarian karst areas. *Acta Climatologica et Chorologica* 44-45, 41-49.

Takács, Á., **Kiss, M.**, Gulyás, Á. (2014): Some aspects of indicator development for mapping microclimate regulation ecosystem service of urban tree stands. *Acta Climatologica et Chorologica* 47-48, 99-108.

Takács, Á., **Kiss, M.**, Gulyás, Á., Tanács, E., Kántor, N. (2016): Solar Permeability of Different Tree Species in Szeged, Hungary. *Geographica Pannonica* 20, 32-41.

Takács, Á., **Kiss, M.**, Hof, A., Tanács, E.,, Gulyás, Á., Kántor, N. (2016): Microclimate modification by urban shade trees – an integrated approach to aid ecosystem service based decision-making. *Procedia Environmental Sciences* 32, 97-109.

Takács, Á., Kovács, A., **Kiss, M.**, Gulyás, Á., Kántor, N. (2016): Study on the transmissivity characteristics of urban trees in Szeged, Hungary. *Hungarian Geographical Bulletin* 65, 155-167.