Hungarian University of Agriculture and Life Sciences
Doctoral School of Environmental Sciences

METHODOLOGICAL OVERVIEW AND PRACTICAL APPLICATION OF THE ASSESSMENT OF HONEY PROVISIONING CAPACITY AS AN ECOSYSTEM SERVICE

Theses of Doctoral (PhD) Dissertation

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1. Background

Ecosystem services (ES) are the contributions of ecosystems to benefits obtained in economic, social, cultural and other human activity which thus underpin the maintenance and enhancement of the well-being of society and individuals. It has been one of the most dynamic concepts in the ecological and conservation community in recent decades, from scientific, policy and practical conservation perspectives. One of the conceptual models that frames the concept of ES is the so-called cascade model, which interprets the flow of services from ecosystems to society through a series of well-defined cascades. The first level of the cascade describes the structure and state of ecosystems, which is a prerequisite for their ability to provide ecosystem services. This is followed by the potential ES or also known as the ES capacity (cascade level 2), which is interpreted as the hypothetical maximum yield of the given ES, assuming sustainable use. A part of the potential services is realised, i.e. society actually uses it. This is the third level of the cascade (actual use). Level 4 of the cascade is the utilisation in the dimensions of human well-being.

There are several parallel proposals in the literature for the classification of ES, all of which distinguish between provisioning, cultural and regulatory services. Ecosystem services, by their very nature, can be approached from two disciplines: the natural sciences and the social sciences. This is why an approach that integrates both disciplines is becoming increasingly common, whereby social science indicators to measure individual and social benefits and well-being are added to classical biophysical assessment, and services are assessed partly with the involvement of local experts and stakeholders in a participatory way.

Along with wild bee species, the European honey bee (*Apis mellifera* L.) is a key mediator of many ES. One of these is pollination, which is one of the most studied ES worldwide. The honey bee is particularly essential for pollination of large-scale crops. However, the relationship between honey bees and humans is much older than the pollination provided to modern agriculture. Bees have accompanied humans throughout history, and during this time they have also been associated with the second major group of ES, the cultural services, in a number of different ways, for example as religious or cultural symbols. Today they continue to have important aesthetic, recreational and scientific values. The most direct benefits provided by bees are linked to the provisioning ES - honey and other bee products such as propolis, pollen, wax, royal jelly.

Honey is produced by bees from the sugar-rich liquid produced by the flowers or (less commonly) the vegetative organs of wild and cultivated plants – nectar – or from the sugary secretions of insects (usually aphids) – honeydew. These sources are regularly visited by worker bees, which collect the nectar in their honey stomachs and then mature it into honey in the hive. The quantity of honey that can be produced in a given landscape – in a bee pasture – is essentially determined by the quality and quantity of nectar sources present, which is, in turn, determined by the composition of the (natural or artificial) plant community. The spatial variability of nectar production is influenced by a number of geographical, climatic and ecological characteristics, while the temporal variability is mainly determined by the phenological patterns of plants, which are strongly influenced by the current weather variations and, in this context, by the success and duration of flowering of the different plant species. In the short term, honey production is maximised in bee pastures which are home to homogeneous, mass-flowering colonies of one or a few nectar-producing plants, as they allow a high honey production in a short period of time during the peak flowering period. However, in these same habitats, pollen shortages and low nectar availability are often a feature outside the nectar flow period. The more stable and balanced – in other words, the more sustainable – the supply of a bee pasture is, the less the bees are forced to use up their reserves already in the growing season. A steady and diverse flower supply is also essential for the health of bee colonies.

Hungary and Romania are major honey producers in Europe. In 2019, Romania's market share of total EU honey production was 11.07%, while that of Hungary was 10.35%. The beekeeping sector in these two countries has grown significantly in recent decades. One reason for this growth is that bee pastures have undergone significant changes over the last 50 years. Before the 1950s, the majority of beekeepers in Hungary and Romania were producing multiflower honey. Today, black locust (*Robinia pseudoacacia*) and arable crops (mainly sunflower and rapeseed), which allow for high levels of honey production, account for the bulk of honey produced in both countries. At the same time, the diversity of habitats and wild flowers, including agricultural weeds, has decreased. Often their place has been taken by newly established and spreading invasive plant species such as milkweed (*Asclepias syriaca*) and goldenrod (*Solidago canadensis*). Relatively monotonous - and consequently suboptimal - diets and increased exposure to pesticides have increased the vulnerability of bees to parasites and pathogens. Today's beekeepers are faced with a host of new diseases and environmental hazards.

There is a wealth of traditional and practical, complex knowledge about honey production and the floral resources needed to produce it, accumulated over generations of beekeepers. Nevertheless, knowledge of honey as an ES is under-represented in the ES literature, both in comparison with other provisioning services and with the other important service provided by bees, pollination.

2. Objectives

The main objectives of my research were twofold: (1) to review the models and methodological approaches used to evaluate honey provisioning capacity and to systematize existing scientific knowledge, and (2) to apply the model development process in practice. I hope that by fulfilling these objectives, I can contribute to the integration of scientific knowledge on ES with practical, empirical knowledge on beekeeping. Accordingly, the thesis has two main parts:

1. In the first part, I present the results of a systematic review, more precisely, a critical interpretive synthesis, undertaken in the topic. This includes a detailed review of the approaches and models used in the scientific literature to assess and quantify the honey provisioning capacity of ecosystems. The systematic literature review sought to answer the following questions:

- What models and methodologies are used by the authors to map or assess the honey provisioning capacity of a sample area, landscape or region?
- How are methodological decisions influenced by the availability of information (input data)?
- How do methodological decisions affect the output of the models (the resulting indicator)?
- How do different approaches identify and deal with uncertainties?

2. In the second part, I apply a specific methodology for the development of an ES model for the evaluation of honey provisioning capacity in two case studies in Hungary and Romania. I present the process and results of the assessment and mapping, and interpret and compare the results in the light of the systematic review. In my work I sought to answer the following research questions:

- How can local expert (beekeeper) knowledge be captured in the language and framework of ES science?

- What models can be used to assess the honey provisioning capacity of the two regions? What are the similarities and differences between the two models?
- How can the uncertainties identified in the critical interpretative synthesis be addressed in a regional participatory assessment?
- What are the opportunities and challenges for beekeeping in the ecosystems of the case studies and the wider region (Central and Eastern Europe)? What are the potential land use conflicts related to beekeeping?
- What are the key factors that can ensure the long-term sustainability of beekeeping in the case studies and the wider region?

3. Methods

This thesis presents the results of two empirical studies. In the first part, a specific method of systematic literature review, the so-called Critical Interpretive Synthesis, was used to analyse the assessments of honey provisioning capacity published in the scientific literature. This was done by first collecting, reviewing and analysing publications which meet the following criteria: they assess a specific case study site (local, regional or larger scale), descibe a well-documented methodological model and input data, and develop an indicator of the honey provisioning capacity. The selected studies were required to develop either an indicator specifically for the European honey bee or for a group of pollinators that includes honey bees. Studies also had to use the indicator they developed to make spatial predictions. The publications were identified from the scientific databases Scopus and Web of Science using complex search terms. According to the criteria set out above, the identified records were subjected to a two-step screening process in order to exclude the irrelevant ones. In each of the articles that met the criteria of inclusion, a single indicator was identified: the one that most closely characterizes honey provisioning capacity according to the ES methodology. These indicators, and the models on which they are based, became the subject of further analysis. The characteristics of the honey provisioning capacity indicators were aggregated in a database on the basis of specific questions (variables). The purpose of these questions was to characterise modelling approaches according to how they address different methodological issues in honey provisioning capacity assessment. The database-based review was followed by a synthesis in which I aimed to classify the methodological models they used into types. The types of models identified as a result of the synthesis can be considered as the main results of the literature review.

In the second part, I describe the process and results of assessing honey provisioning capacity in practice. The evaluation was carried out in two regional case studies: the Kiskunság Sand Hills lying in the Great Plain of Hungary, and the Niraj - Tarnava Mica region lying at the foot of the Eastern Carpathians in Romania. Both case studies took place in protected rural areas where agriculture (grazing livestock, small arable fields, vineyards and orchards) and forestry are the dominant land use types. The financial background for the Kiskunság study was provided by the OpenNESS project funded by the EU FP7 programme, while for the Niraj - Tarnava Mica study it was provided by the Niraj-MAES project, co-funded by EEA Grant and the Romanian government. In both projects, the assessment was developed jointly with the staff of the Centre for Ecological Research and implemented with the help of the project partners.

In both areas, rule-based matrix models were developed with local experts, based on a one-day expert workshop. The beekeepers involved had several decades of field experience in beekeeping in the respective areas. The ecosystem service matrix is a specific type of spatial proxy method that links ecosystem service providing units (in this case ecosystem types, ET) to ecosystem services. The spatial input to the model is the ecosystem map of the study area. The model itself is no more than a simple look-up table ('matrix') that assigns indicator values for selected ES to each spatial (ET) category. In our study, experts scored the honey provisioning capacity of each ET on a relative scale (1-10).

Rule-based matrix models are an extension of simple matrix models. By identifying additional relevant spatial input data and incorporating them into map computation operations, coarse maps derived from a matrix model can be greatly refined. To this end, I asked the experts to list these factors and to formulate how and to what extent they influence the honey provisioning capacity of different ecosystems. The next stage of the work was to process the information from the workshop in order to produce rule-based models and maps. In order to incorporate the selected additional environmental variables into the models, it was necessary to formulate the rules along which these variables modify the honey provisioning capacity of each ET. A common way of constructing rules is to define categories or (for continuous variables) ranges of values for the possible values of a given variable, and then to define algorithms for each category or range. These are simple, additive or multiplicative formulae that modify the 'matrix score'. I had great help from the geospatial data scientists of the Centre for Ecological Research and Milvus Group in finding the data sources for the calculations and in the data manipulations. The modified values obtained after applying the rules were plotted on a map and, after validation by the local experts, the final ES maps were produced.

4. Results

Systematic review

The main objective of the systematic review was to capture the diversity of models developed to quantify honey provisioning capacity. A detailed review of 16 papers resulting from the screening helped to outline the typical model schemes and to explore the diversity of approaches to input data, spatial and temporal variables. The critical interpretive synthesis identified three main types of models:

1. **Rule-based matrix models** use a GIS workflow that essentially combines two different data types. One of these is a spatial dataset that classifies geographic space into relevant ecological categories (e.g. ecosystem types or other spatially expressed variables). The other (non-spatial) input data type to the model is some measure of honey provisioning capacity. This could be an expert scoring based assessment or an estimate of nectar production in some biophysical measure. During model development, honey provisioning capacity values are assigned to spatial categories. This value can be further refined according to various defined rules with spatial data on site condition, climate, topography or land use that influence nectar production, which are then intersected with the ET map to produce the extended ET map. The output of the model is a 'supply map' of honey provisioning capacity covering the study area, showing how much resources each spatial unit ('pixel') can provide for honey bees. A special group of articles is characterised by Multicriteria Decision Analysis (MCDA) techniques. Here, maps of a number of potentially relevant spatial variables are collected in a GIS system and weighted according to the recommendations of experts (beekeepers), typically through an Analytical Hierarchy Process (AHP).
2. **Extended rule-based models** are an improved version of simple rule-based models, giving conceptually different results. In this case, the enhancement means that the models also take into account the foraging area (flight range) of the bees, by integrating the flight range as a simulation step into the GIS workflow (e.g. as a moving window

operation). This type of model therefore essentially evaluates the landscape from the perspective of a hypothetical bee colony: it quantifies the resources available to the colony at a given location. It considers each pixel as a hypothetical bee colony location, and calculates its honey provisioning capacity by aggregating the supply of the surrounding landscape into a 'hive input' metric. In a special group of articles, a number of binary criteria are first defined in the form of quantitative thresholds (e.g., minimum proportion of certain agricultural crops or grasslands). The criteria imply that these spatial conditions must be met within the area of the flight range to be suitable for beekeeping. These thresholds are then applied to all potential sites (all pixels or a narrowed down range of pixels according to other criteria). Areas that do not meet the criteria are discarded, and finally, maps of potentially suitable apiary sites are produced as a visual output of the analysis.

3. The **predictive statistical model** approach is based on establishing a statistical relationship between one or more predictor variables and the measured values of a given ES, and then projecting this relationship into the geographical space.

In the review analysis, I identified the key decision points of the evaluation process and their inherent uncertainties and possible solutions:

1. **Sustainability** in this context means that, unlike bee pastures with a massive but short nectar flow period, floral resources are available to bees throughout the growing season. If honey provisioning capacity is estimated for the whole growing season, the model schemes described above may not provide information on sustainability. This aspect can be incorporated into the models in several ways. One possibility is to carry out separate assessments for specific periods (nectar flow periods, seasons, months). An alternative is to incorporate the length of the flow periods in each habitat as a rule in the model.

2. The flowering success, nectar production and nectar sugar content of a plant species varies in space and time. Spatial variation depends primarily on **site conditions** (e.g. soil type, slope and altitude, water availability), while temporal variation depends largely on **weather conditions** (precipitation, temperature). However, nectar yield estimates based on existing measurements from literature often overestimate the yield, because they mostly refer to measured data from healthy plants grown under optimal site conditions (sometimes under targeted experimental

conditions). This over-estimation can be avoided by direct measurements on the site or by adjusting the values with rules for site and/or meteorological variables.

3. The actual utilisation of the nectar yield of habitats can only be optimally achieved by bee colonies of sufficient strength, since the population and health of a colony largely determine its carrying capacity. One of the most important ecosystem characteristics for bee health is the **availability of diverse pollen sources**. This justifies an assessment of habitat pollen capacity in addition to nectar capacity.

Case study assessment

In terms of methodology, indicator and input data, the expert models developed in the two case studies correspond to the type of rule-based matrix model that the systematic review shows to be the most common. To characterise the honey provisioning capacity of the ecosystems, an assessment score was assigned to each ET on an ordinal scale of 1 to 10, where the lowest score was assigned to the ET with lowest capacity within each study areas. The upper endpoint of the scale was common between the two case studies. This was a theoretical category defined as an ideal bee pasture in the Carpathian Basin: a lowland black locust forest with a grove structure and mixed set of tree species. Additional spatial variables identified by experts in the Homokhátság were the proportion of black locust in coniferous and deciduous forests and the proportion of agricultural crops in arable fields. In the Niraj - Tarnava Mica region, altitude, grazing intensity, soil fertility, habitat naturalness and landscape diversity were selected. In the follow-up work after the workshop, additive rules were developed for each variable to determine how and to what extent the variable changes the expert score of the ETs. Figures 1 and 2 show the final maps of honey provisioning capacities for the two case studies.

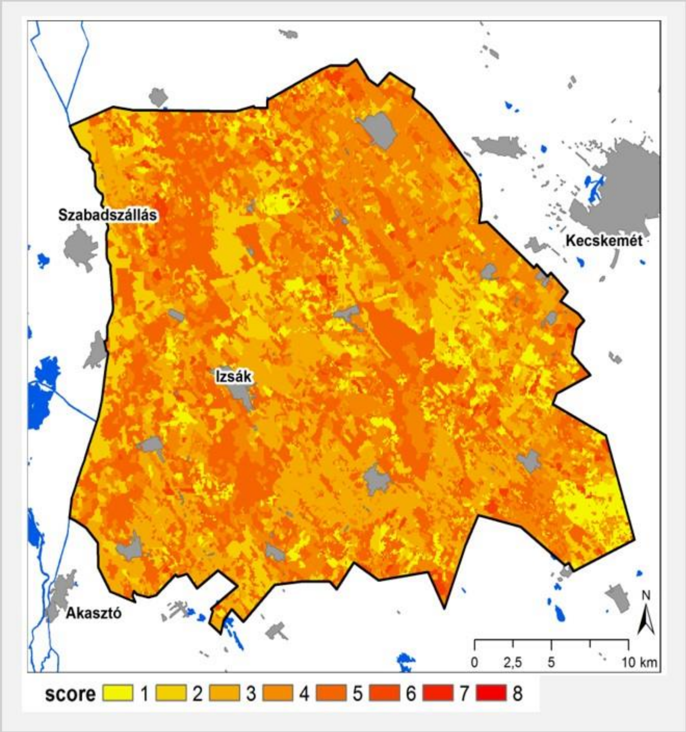

Figure 1. Final map of honey provisioning capacity in the Homokhátság region

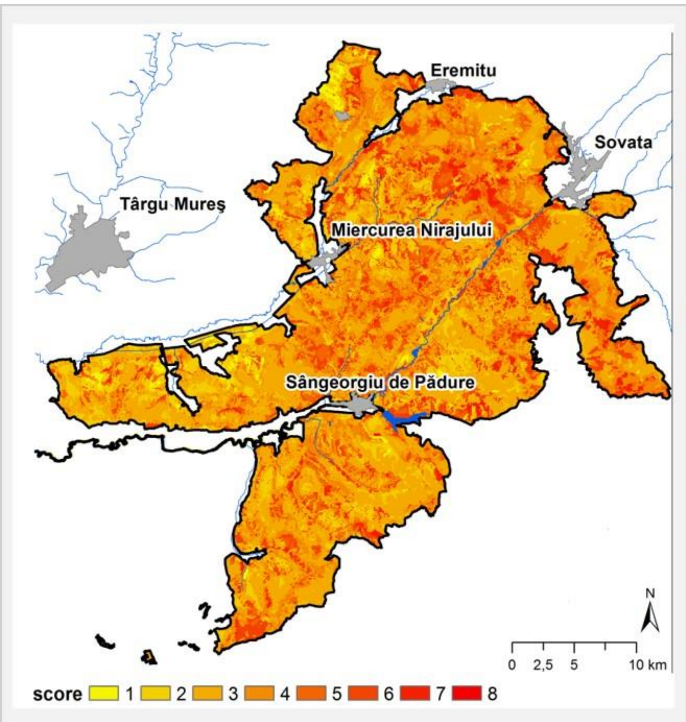

Figure 2. Final map of honey provisioning capacity in the Niraj - Tarnava Mica region

Based on the experience of the case studies, it can be concluded that in the lowland and mountain foot areas of the Carpathian Basin, the potential for beekeeping is largely determined by the extent, cultivation type and management intensity of forests and agricultural habitats, as well as the ecological condition of the habitats.

In terms of **forests**, the highest scores in both areas were given to black locust, demonstrating that this tree is an important resource for beekeeping in these countries. The ideal black locust forest in this context is considered by the experts to have a grove structure, mixed species composition and mixed age structure with mostly young trees. Such a forest has longer flowering periods and higher flowering rates than a homogeneous black locust plantation. Experts from both case studies stressed that forests rich in early flowering species are of particular importance for the development of bee colonies in spring. Generally speaking, the species richness of a forest increases its resilience to extreme events and thus allows it to maintain its functions and services, in this case the balanced production of pollen and nectar.

Agricultural crops are a crucial resource for modern beekeeping in Hungary and Romania. Despite this, intensively cultivated **arable land** has not been valuated high because of the risk of bee poisoning due to pesticides. Higher scores were given to small, extensively cultivated fields and fallows showing that the diversity of flowers, including field weeds, is important for beekeepers in agricultural areas as well. It is also important to highlight the importance of wooded habitats that enhance the heterogeneity and multifunctionality of agricultural landscapes, such as tree lines, tree groups and small forest patches.

Grasslands in general are valuable bee pastures due to their richness in flowers, which is especially true for wet and mesophilic grasslands. In addition, abandoned areas can provide a significant source of nectar due to flowering shrubs related to natural succession or, in the case of the Homokhátság, sometimes invasive alien plant species.

Lastly, it is worth mentioning the **homestead** as a traditional form of settlement in the Great Plain, with a loose distribution of gardens and agricultural land. The beekeepers of the Homokhátság valued both actively used and abandoned homesteads and their surroundings as equally valuable bee pastures.

5. Conclusions and recommendations

Applicability of the model types

The honey provisioning capacity models and the maps produced from them can have direct practical use, as they can help to select future beekeeping sites and plan possible migration by predicting the expected yield. However, for each type of model, the degree of applicability depends to a large extent on the spatial resolution and accuracy of the map (and the underlying data). In addition, the accuracy of capacity estimation is also determined by the level of detail and sophistication of the rules integrated in the models, which are able to capture the factors of ecosystem type, climate, topography or land use that underlie the large variation in nectar production. In this respect, it is worth highlighting the MCDA-based estimation, which can capture finer details than models with simple additive rules by weighting the data layers.

At coarse spatial resolution, maps are more suitable for large-scale planning (e.g. selection of regions for migration). However, when rule-based and extended rule-based models work at finer resolution, they can help in the selection of a specific site. This is particularly true for extended rule-based models, as the hive input maps provide direct information on the value of the total foraging area around potential sites. When assessed separately for each honey flow season, the time spent at each migratory sites can also be planned. This predictability is further enhanced if accessibility (distance from roads, settlements) and the availability of a natural water source for the bees are included as a rule. In the case where the model does not give the honey provisioning capacity per nectar flow periods, but aggregated over the whole growing season, it becomes particularly useful for the selection of a stationary apiary site. From applicability point of view, it is also worth highlighting the potential apiary suitability maps, in which thresholds are assigned to specific uses, allowing the model to be directly adapted to the needs. A map produced in this way can be used directly in the planning process, as opposed to, for example, relative scoring methods, which require thinking about where the relative scale of a given assessment lies on the full spectrum of real possibilities.

Methodological uncertainties

During the workshop discussions, a number of critical methodological issues emerged, which were also identified in the systematic review as uncertainties. These uncertainties are summarised in Table 1.

Table 1. Methodological options to address the uncertainties identified

Source of uncertainty	**Suggestion to manage uncertainty**
Variation of the species composition within ETs	Direct use of species distribution data Refining the species composition of ETs using species occurrence models
The nectar yield of certain plant species is unknown or uncertain	Biophysical nectar yield estimation based on field measurements in the sample area
Uncertainty of the sugar content of nectar (honey/nectar ratio)	Careful selection of the honey/nectar ratio and accurate documentation of the calculation Validation of estimated values with acual honey yields
Seasonality of nectar yield	Assume low-input stationary beekeeping when estimating honey provisioning capacity for the whole growing season, or define a reference beekeeping practice Separate assessment of each nectar flow period
Differences in nectar yield due to weather variability	Modification of biophysical nectar yield estimates with weather variables (rule-based models) Validation of estimated yields with actual honey yields
Differences in nectar yield due to site condition	Modifying the value of biophysical nectar yield estimates with site variables (rule-based models) Validation of estimated yields with actual honey yields
The uncertainty of bee preference	Analysis of the composition of honey from the sample area
Calibration with real yields of high-input beekeeping technology	A reference beekeeping practice should be defined. Referring to a low-input stationary beekeeping for valuation gives a more accurate estimate of the actual contribution of the ecosystem. When referring to high-input beekeeping, the values should be corrected by subtracting the impact of human inputs.
Harmful effects of land use on bee health	Integrating landscape structure/management practices that support and harm bee health as rule variables in the model

Land use related conflicts

A complex socio-cultural valuation is beyond the scope of my research, but I have identified, without claiming completeness, two land use conflicts that were revealed by the study. One conflict is related to nature conservation, the other to agriculture. While good ecosystem health and high biodiversity are essentially a common goal of conservation and beekeeping, the perception of some specific invasive species (black locust in both case studies and milkweed in the Homokhátság) that are harmful to nature conservation is fundamentally different, which is a potential source of conflict. The cause of conflicts in agricultural land use is rooted in crop protection practices, as highlighted by experts in both areas. In the Niraj - Tarnava Mica region, overgrazing caused by grazing livestock can also significantly reduce the honey provisioning capacities of certain habitats. To reduce conflicts, it is important to engage in a dialogue with nature conservation practitioners and agricultural land users on the management of invasive species and agricultural land and, where possible, to seek win-win solutions.

Recommendations

In order to ensure that the assessment of honey provisioning capacity as an ES indicator is consistent and that different assessments are comparable, the definitions and methodological details need to be carefully considered, and the steps and components of the indicator development methodology need to be clearly and traceably documented and communicated. The inevitable uncertainties inherent in the nature of the topic should also be consciously managed and communicated, and all assumptions should be clear and transparent. A clear distinction should be made between nectar production of plants and the potential honey yield produced by bee colonies, as the latter involves assumptions not only about the nectar supply of plants but also about the efficiency with which bees can use them. In line with this, it should always be clear whether we want to map/model the 'supply map' of floral resources or the 'input map' of the colony (the resources available to bees from a given area). As a general rule, it makes sense to choose methodologies that are less sensitive to uncertainties. If an accurate data source for biophysical assessment is not available, it is advisable to choose a more robust indicator (e.g. frequency of nectar producing plant species, expert scoring). These decisions should always be made at the research design stage, depending on the purpose and scale of the survey and the data available.

When assessing honey provisioning capacity, it is important to identify a reference beekeeping practice. While stationary beekeepers aim for the highest possible honey yield in one location, migratory beekeepers achieve that in several locations. The evaluation of honey provisioning capacity of a given site is therefore primarily applicable to stationary beekeeping. Also in line with the ES concept and the ES evaluation recommendations, it is appropriate to assume beekeeping practices that are sustainable with the minimum human input.

In all cases, participatory methods are recommended at least at some stages of the indicator development. This essentially means consulting and working with local beekeepers, who have gained knowledge about honey provisioning capacity through many years of experience in a given area. Even in the case of a fully biophysical model, it is worth validating the results by interviewing local beekeepers as experts and using data of their yields.

In order to maintain the nectar and pollen production capacity of habitats, it is important to manage them with conservation in mind. This protects both honey bees and wild bees, as advocated by several international and EU policies. In agricultural areas, careful planning and timing of potentially damaging interventions, especially pesticide applications, is necessary to minimise adverse impacts. There is also a need for collaboration between beekeepers, farmers, foresters and conservationists to optimise benefits from food, feed, timber and honey production, while ensuring favourable conservation status of habitats. The different ES maps can provide important information for such inter-sectoral discussions, help to coordinate land use and even serve as a tool for conflict resolution between sectors.

Land use has far-reaching impacts not only on honey bees, but also on wild pollinators in general and on biodiversity. Therefore, in view of the worrying situation of the latter, assessment of a complex ES such as honey can contribute to land use decisions that benefit both honey bees, their wild relatives and wild pollinator species in general.

6. New scientific findings

1. Honey provisioning capacity was interpreted in the context of the ecosystem service cascade conceptual framework.
2. I conducted a systematic literature review to identify existing scientific publications on valuation methods for honey provisioning capacity. As a result, I identified three main types of models: rule-based matrix models, extended rule-based matrix models and predictive statistical models.
3. As a result of the critical interpretive synthesis, I have identified different options for integrating several factors affecting honey provisioning capacity as decision points. These factors include the issue of sustainability, weather and site conditions, and pollen supply to support bee health.
4. I adapted the methodology of the rule-based matrix model to the regional case studies of Kiskunság and Niraj - Tarnava Mica and carried out an assessment of honey provisioning capacity in both areas with the involvement of local experts.
5. During the case study assessment, I identified the opportunities and challenges for beekeeping provided by the ecosystems of the two sample areas, as well as potential land use conflicts related to conservation and agriculture.
6. Both the systematic literature review and the case study assessment contributed to the identification of key factors that could ensure the long-term sustainability of beekeeping in the studied regions and their wider surroundings.

7. List of relevant publications

reference	Q rank	IF
Arany I., Vári Á., Aszalós R., Kelemen K., Kelemen A.M., Bone G., Lellei-Kovács E., Czúcz B. (2019): Diversity of flower-rich habitats as a persistent source of healthy diet for honey bees - *European Journal of Geography* 10 (2), 89-106.	Q2	-
Arany, I., Czúcz, B., Csonka, I., Kovács-Hostyánszki, A., & Molnár, Z. (2017): Tájváltozás, tájhasználat és az ideális méhlegelő dél-dunántúli méhészek szemével. *Természetvédelmi Közlemények* 23, 127–143.	-	-
Czúcz, B., Haines-Young, R., Kiss, M., Bereczki, K., Kertész, M., Vári, Á., Potschin-Young, M., & **Arany, I.** (2020): Ecosystem service indicators along the cascade: How do assessment and mapping studies position their indicators? *Ecological Indicators* 118, 106729.	Q1	4,2
Kuslits, B., Vári, Á., Tanács, E., Aszalós, R., Drasovean, A., Buchriegler, R., Laufer, Zs., Krsic, D., Milanovic, R., **Arany, I**. (2021): Ecosystem Services Becoming Political: How Ecological Processes Shape Local Resource-Management Networks. - *Frontiers in Ecology and Evolution* 9, 635988.	Q1	2,4
Kelemen, E., Lazányi, O., **Arany, I**., Aszalós, R., Bela, Gy., Czúcz, B., Kalóczkai, Á., Kertész, M., Megyesi, B., Pataki, Gy. (2015): Ökoszisztéma szolgáltatásokról a kiskunsági Homokhátság társadalmának szemszögéből. *Természetvédelmi Közlemények* 21, 116–129.	-	-
Czúcz, B., Kalóczkai, Á., **Arany, I**., Kelemen, K., Papp, J., Havadtői, K., Campbell, K., Kelemen, M., & Vári, Á. (2018): How to design a transdisciplinary regional ecosystem service assessment: a case study from Romania, Eastern Europe. *One Ecosystem* 3, e26363.	Q1	-

Dick J., Turkelboom F., Woods H., … **Arany I**., … Zulian G. (2018): Stakeholders' perspectives on the operationalisation of the ecosystem service concept: Results from 27 case studies. *Ecosystem Services* 29, 552-565.	Q1	6,3
Vári, Á., **Arany, I.**, Kalóczkai, Á., Kelemen, K., Papp, J., & Czúcz, B. (2020). Berries, greens, and medicinal herbs—mapping and assessing wild plants as an ecosystem service in Transylvania (Romania). *Journal of Ethnobiology and Ethnomedicine* 16(1), 13.	Q1	2,3
Czúcz, B., **Arany, I**., Potschin-Young, M., Bereczki, K., Kertész, M., Kiss, M., Aszalós, R., & Haines-Young, R. (2018b). Where concepts meet the real world: A systematic review of ecosystem service indicators and their classification using CICES. *Ecosystem Services* 29, 145–157.	Q1	6,3
Zulian, G., … **Arany, I**., … Viinikka, A. (2018): Practical application of spatial ecosystem service models to aid decision support. *Ecosystem Services* 29, 465-480.	Q1	6,3
Burkhard, B., … **Arany, I**., … Zulian, G. (2018): Mapping and assessing ecosystem services in the EU - Lessons learned from the ESMERALDA approach of integration. *One Ecosystem* 3, e29153.	Q1	-
Geneletti, D., … **Arany I**., … Broekx, S. et al. (2020): Ecosystem services mapping and assessment for policy- and decision-making: Lessons learned from a comparative analysis of European case studies. *One Ecosystem* 5, e53111	Q1	-