

GIS-based decision support tool for evidence-based policy making for biodiversity protection

Milan Husar^{1*}, Jakub Hajduk¹ and Vladimír Ondrejčka¹

¹Spectra Centre of Excellence of the EU, Slovak University of Technology in Bratislava, Vazovova 5, 812 43 Bratislava, Slovakia

Abstract. Geographic Information Systems (GIS) based decision support systems can play a crucial role in protecting biodiversity in spatial planning. These systems use spatial data and analytical tools to help decision-makers identify areas of high biodiversity value and prioritize conservation efforts. By integrating data on species distribution, habitat suitability, and land use, GIS decision support systems can also identify potential threats to biodiversity and assess the impact of different management scenarios. Additionally, GIS decision support systems can be used to monitor the effectiveness of conservation efforts and identify areas where additional action is needed. GIS decision support systems provide a powerful tool for integrating biodiversity considerations into spatial planning and can help to ensure that conservation efforts are targeted to where they will be most effective. In the area of biodiversity protection, we are also faced with two phenomena: (1) overflow of data and information from various countries and areas, supported by open data policies and technical solutions (e.g. GIS) for producing and storing copious amounts of data; and (2) challenge to navigate in the data and incompatibility of data due to various methodologies, scales etc. For policy makers it is increasingly difficult to produce evidence-based policies as it is relatively easy to find arguments to support multiple attitudes and measures. The aim of this paper is to present a tool produced by Interreg DTP SaveGREEN and ConnectGREEN Projects aimed at fostering evidence-based policy making in the field of biodiversity protection. The Decision Support Tool, an interactive GIS-based support tool prepared as a help mainly in the pre-planning phase of the decision-making process about new investments in the territory. Objective of this tool is to help nature conservationists and spatial planners to provide evidence for policy makers in the policy making preparation processes aimed at protecting the biodiversity of Carpathians.

1 Introduction

Geographic Information Systems (GIS) are tools that have become essential in the field of spatial planning and environmental planning. GIS provides a platform for spatial data management, analysis, and visualization. It has revolutionized the decision-making process by providing a powerful tool for decision-makers to analyze spatial data and information.

* Corresponding author: milan.husar@stuba.sk

GIS technology has a wide range of applications in urban and environmental planning. The purpose of this article is to provide an overview of the importance of GIS in decision-making processes in urban and environmental planning.

The paper firstly introduces the GIS and their role in spatial planning and biodiversity protection and then moves on to the decision support systems and their use in practice. We review some existing tools and the main part of the paper is focusing on the Decision Support System developed as a part of the ConnectGREEN Project for the purposes of fostering the biodiversity protection.

2 Use of GIS in spatial planning and decision-making

Geospatial data is essential when making decisions about urban and environmental development. The data may be utilized to provide an immense advantage of providing insights about the physical and natural surroundings. This geographical data may be integrated, analyzed, and visualized using GIS, which makes it simpler for decision-makers to comprehend the intricate linkages between various spatial elements.

Using GIS in decision-making processes has several important advantages, one of which is the capacity to recognize spatial correlations and patterns. By analysing geographic data, decision-makers can find patterns and connections that would not be apparent from non-spatial data. Planning for cities and the environment, where decisions are usually based on spatial information, both greatly benefit from this ability to identify spatial patterns and correlations. With the aid of GIS, decision-makers can view information in an understandable way. Decision-makers need data visualization because it provides an intelligible representation of the data, which is essential for decision-making. A few examples of the different ways that GIS can visualize data include maps, graphs, and charts [1].

Scenario planning is another important benefit of utilizing GIS in decision-making processes. The act of designing and analysing several scenarios to find the best answer to a certain problem is known as scenario planning. Decision-makers can swiftly construct and assess various scenarios thanks to GIS.

The public's and decision-makers' access to geospatial data is essential for the development of cities and the environment. The public's access to geospatial data has significantly increased during the past several years. The arrival of new technologies and the accessibility of open-source software are what have caused this growth in availability.

Accessing and analysing geographic data has become simpler for decision-makers because to open-source applications like QGIS. Decision-makers may more easily comprehend complicated interactions between various geographical variables thanks to QGIS' platform for the integration, analysis, and visualization of geospatial data.

Another significant development in recent years is the development of online mapping platforms, such as Google Maps and OpenStreetMap. These platforms provide the public with access to a wealth of geospatial data, making it easier for the public to understand the spatial relationships between different features.

3 Literature review on decision support systems

A decision support system provides the decision-makers the data and additional information required to make informed decisions. Decision-makers have various platforms for integrating, analysing, and visualizing geographic data thanks to decision support tools in GIS.

One of the most common decision support tools in GIS is the spatial decision support system (SDSS). An SDSS is a system that provides decision-makers with the ability to analyze and visualize geospatial data to support decision-making processes. SDSS provides

decision-makers with the ability to conduct scenario planning, evaluate alternatives, and visualize data in a meaningful way [2]. The land-use decision support system (LUDSS) is yet another typical decision-support tool in GIS. A LUDSS is a tool that enables decision-makers to compare several land-use scenarios and determine which one has the highest chance of solving a given issue. Decision-makers may use LUDSS to assess the environmental effects of various land-use scenarios and to spot possible conflicts.

Living in the age of information it is crucial for urban planning to use gathered data to tackle upcoming challenges, especially spatial data, but also merge it with technical and legal information. Due to the complexity and plentifulness of available information, access and management of it can be confusing and troublesome. As data is gathered and processed, in case of spatial data with help of GIS software, it is possible to create models that are limited (because of limitation of accessible data) and simplified answers to urban planning challenges. A GIS software is used to integrate, store, edit, analyse and share spatial or geographic information, which is later used to design decision support systems based on this data analysis. There are human cognitive deficiencies in memory and analysis abilities, and in order to address complex spatial problems or issues, support systems are often necessary and useful. The basic task of spatial decision support tools is to provide the decisions makers with their required spatial information and to enhance their ability to select or generate alternative solutions and to represent and simulate their spatial situations and consequences [3]. As an abundance of information must be taken into account and different stakeholders are involved in the process, the system has to be participative and interactive.

The spatial approach in regard of decision support systems is unique as its usefulness is regulated by not only the technology but also by available spatial data from outside the organization and outside the discipline of the spatial data support systems user. The availability of spatial data has greatly improved over the past 30 years, thanks in part to the lowering of data acquisition costs and also due to national and transnational geospatial data initiative [4]. What contributed to better accessibility of data is an open science movement, which includes open access to data and publications, open evaluation and policies as well as developing its own tools. As a result, it is changing the way of involving citizen by opening up research throughout the process, from idea generation and planning to conducting the research and disseminating outputs [5]. Generally speaking, participatory approach in spatial decision-making process is now applicable even on the level of data collection, as OpenStreetMap project is a good example of the way in which data can be crowdsourced.

Apart from data availability, decision support systems are also based on the set of rules that are dependent on the specificity of a problem to solve and what kind of outcome is expected. The good understanding of what it means to make a spatial decision in practice must be applied to DSS, as the cognitive aspects of decision-making in spatial planning is crucial. Obviously, the quality of data and appropriateness of the decision-making models (where these apply) will affect the value of the decision taken [6].

When it comes to literature dealing with the subject of decision support tools some tendencies are to be found. For example, there is a wide range of papers referring to this issue in general. 'Spatial Decision Support Systems: Three decades on' by Keenan and Jankowski is providing good understanding on how the field is growing and changing over the last thirty years and explaining the relation between Spatial Decision Support Systems and Decision Support System and how both fields were expanding quite independently from each other. While SDSS started with a solid base in the earlier seminal DSS literature, the rapidly expanding literature since then has had limited links to the DSS literature and new areas of SDSS application often have limited links to either the DSS or GIS literature [4].

The other category of articles is the ones that are presenting specific concepts of decision support systems addressing certain concerns. In this kind of elaboration on DSS, firstly authors introduce the reader to an actual, universal planning challenge and to the

characteristics of the site, after that the range of the methods is presented. In the next parts the explanation of the mechanics of a DSS is to be expected, and then the description of how it works applied to the site, surely followed up by conclusions. The ‘Integrating ecosystem services into spatial planning—A spatial decision support tool’ by Adrienne Grêt-Regamey, Jürg Altwegg, Elina A. Sirén, Maarten J. van Strien, Bettina Weibel [7] and ‘The Use of a Decision Support System for Sustainable Urbanization and Thermal Comfort in Adaptation to Climate Change Actions—The Case of the Wrocław Larger Urban Zone (Poland)’ by Jan K. Kazak [8] are good examples of this category.

4 Examples of DST

In the next part of an article we describe a few examples of well-developed decision support systems that served as inspiration during the preparation of the decision support system described later in the article.

4.1 Linkage Mapper

Linkage Mapper supports regional wildlife habitat connectivity analyzes. It is based on tools that automate the mapping and prioritization of wildlife habitat corridors. It consists of open source Python scripts provided in the ArcGIS toolbox. These decision support system links core areas to create maps of least-cost corridors between the areas. This system is created from six separate tools.

Linkage Pathways Tool is a base tool of Linkage Mapper. It uses ArcGIS and Python scripts to identify adjacent (adjacent) major areas and maps the cheapest corridors between them. It then creates a mosaic of individual corridors to create one complex corridor map.

Climate Linkage Mapper fine tunes the routes of mapped linkages between core areas such that they minimize the range of micro-climates (e.g. temperatures, or climatic water difference) that are encountered along the linkage.

Pinchpoint Mapper marks bottlenecks and points of constriction in corridors created by Linkage Mapper.

Barrier Mapper determines critical points of connections, such as spatial barriers, for example, transport infrastructure.

Centrality Mapper helps prioritize and choose the best way for connections. It is used to designate the core centrality of a corridor

Linkage Priority Tool is used to quantify the priority. It is made to compare the selected priorities of connections. It is based on the analysis of weighted combinations of many factors.

Synthesis of Tool Outputs combines data from Barrier Mapper, with output from Linkage Priority, Pinchpoint Mapper and Linkage Pathways to map the priorities of all analyzes and compare them with each other.

4.2 UHI-DS

UHI-DS (urban heat island-decision system) is a tool that helps reduce urban heat. It informs urban policy, development assessment and planning practices related to potential building and urban interventions, used to cool streetscapes and cities, decrease energy consumption, protect the population’s vulnerable health-wise, and improve conditions of comfort.

This decision support system was made to integrate scientific models with a range of mitigation techniques to perform urban heat island mitigation analysis across both building and urban scales, such as building coatings and roofs, urban form and density, greenery and infrastructure.

This program contains many important information that can be used during the planning process. It is based on integration of building information models (BIM) and precinct information models (PIM) with GIS. It shows 3D visualization of urban structure, for example different urban forms, densities and roof and paving materials. It is also used to monitor and characterise the microclimate. UHI-DS shows the strategies and possible cooling interventions for varying urban form and building materials. One of the most important tools is what-if scenarios of UHI mitigation performance under standard climate conditions. As a conclusion program shows optimal UHI mitigation solutions or strategies to meet multi-objective performance targets.

4.3 Scenario 360

It is GIS-based decision support software for regional and local planners. It is an ArcGIS extension that adds interactive analysis tools and a decision-making framework to the ArcGIS platform. This tool is used for comprehensive planning of buildings and the entire infrastructure, land-use, estimating construction costs, analysing the impact on the environment and landscape, determining the possibilities of building development and assessing natural hazards. It makes the planning process more visual, more collaborative and more effective. This DSS includes few tools that in the whole create complex planning software.

The 360 Indicators Wizard tool provides a comprehensive, well rounded set of standard planning measurements in the fields of land use, demographics, transportation, recreation, environment, housing, and employment.

TimeScope tool it is possible to observe the evaluation of investment and its impact year by year simply by moving a slider bar. All data is systematically updated

Land-Use Designer is used for "painting" land-use types on a map and instantly see associated socioeconomic and environmental impacts. It creates different scenarios for certain land-use.

Build-Out Wizard tool calculates the development capacity of exact land. It shows the "capacity" of your land based on all the commercial or residential buildings allowed by current land-use regulations.

Allocator Wizard tool provides economical information about terrain. It helps determine where growth is most likely to occur over time. It uses the classic supply-and-demand approach. It is an extra paid option.

Suitability Wizard tool changes the weighting of each factor that the user takes under consideration. This option makes it very easy to find a perfect land that suits someone's expectation.

Common Impacts Wizard automatically creates GIS-based impact analyses commonly associated with growth and development. It presents the most commonly used indicators of economic, environmental, and social outcomes associated with alternative growth scenarios.

Custom Impacts Wizard sets up analysis models for impacts that are important to you but that are not covered in the Common Impacts Wizard or elsewhere.

5 Innovative decision support system for biodiversity protection

The innovative Decision Support Tool (DST) is putting together and facilitating the analysis of the most relevant spatial data. It was created by spatial planners in cooperation with partners from fields of ecology and environment protection. Its objective is to ensure that the most appropriate solutions are taken in order to safeguard the ecological corridors and to resolve various conflicts between nature conservation and the intended or existing economic development projects (based on [9]).

The target groups of the future users of this DST include local public authorities, national public authorities, sectoral agencies, infrastructure and public service providers, interest groups including NGOs and universities and training institutions.

The DST engages spatial planners, environmentalists, authorities and other stakeholders by involving them in relevant meetings and workshops where the tool will be developed and demonstrated in practice.

The DST strives to demonstrate that informed decisions can be made much easier and faster by having together and overlapping all major categories of spatial data (e.g., ecological corridors, land-use categories and ownership, road and railways, settlements, etc.). In this way, the decisions can be easily accepted and shared by the majority of the stakeholders. Additionally, the system shall be transferable and replicable to other areas providing existence and availability of spatial data.

The DST is not intended to replace the planning process nor the Environmental Impact Assessment procedure, it is meant to be the first step whether to go into the project and to be user-friendly and easy to use. It is designed to be comprehensive and easy to use so that anyone (planner, environmentalist, investor, municipality) can utilize it.

The DST is to a GIS-based support tool in the pre-planning phase of the decision-making process about a new investment in the territory. Its aim is to help looking for a better alternative or a better location of a planned infrastructure according to the ecological value of the area.

It is intended for municipalities or investors as a helping hand to foster the information base before the planning process is launched and it helps to answer the question if the investment is eco-friendly and suitable for the area from the point of view of ecological connectivity. For instance, in case a municipality is planning a new road, the DST helps to point out if the tracing of the road is cutting across a protected area or an important component of the ecological network or in case of several tracing alternatives, it helps to evaluate the alternatives according to their position in relation to the protected areas or components of the ecological network.

5.1 DST Functioning

The system is calculating the area covered by the proposed investment and evaluates to what extend it occupies protected areas and/or components of the ecological networks. This way, the user can have an information about the risk of the proposed investment. The output of the DST is an information about possible conflicts, after identification of possible data, information and indicators which could be relevant with structural and functional connectivity and covered by GIS under three topics:

- Biodiversity;
- Spatial planning (land-use planning);
- The harmonisation of interests among Development and Biodiversity.

There are two types of ecological connectivity – structural and functional. Structural connectivity indicates the part of the landscape that is actually connected through e.g. corridors. In contrast, functional connectivity includes species-specific aspects and their interaction with landscape structures. Thus, functional connectivity is actual connectivity from a species' perspective [10] indicating the ability to move and migrate on a concrete habitat or corridor.

The user in the web application draws a tracing of the planned investment and the system informs him/her about the impacts of the planned investment. The user can enter various tracings and then compare the risks of the alternatives to help him/her evaluate which

alternatives have the least impact on the territory from the point of view of ecological connectivity.

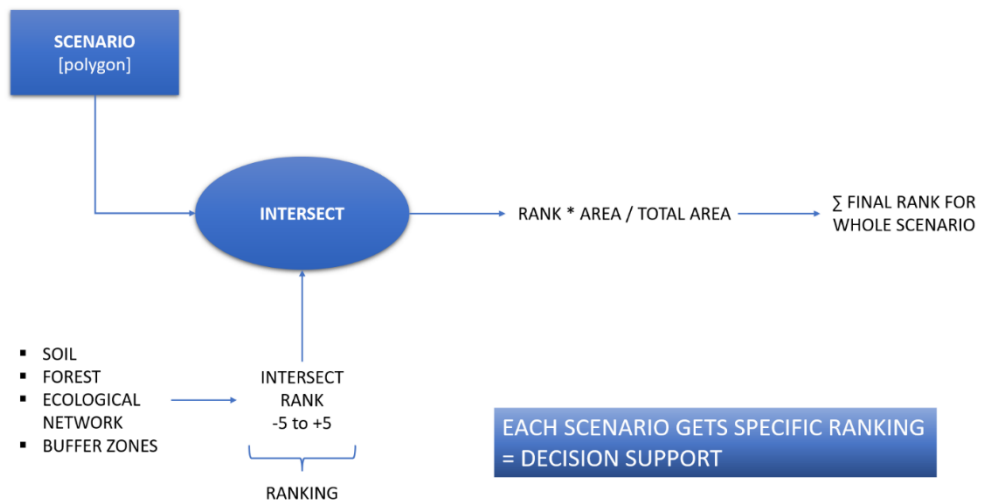


Fig. 1. How the DST works

After inserting the tracing of the planned investment, the DST calculates the ranking and risk of the proposed investment according to the area which intersects across valuable territories (protected areas, components of the ecological network (Fig. 1).

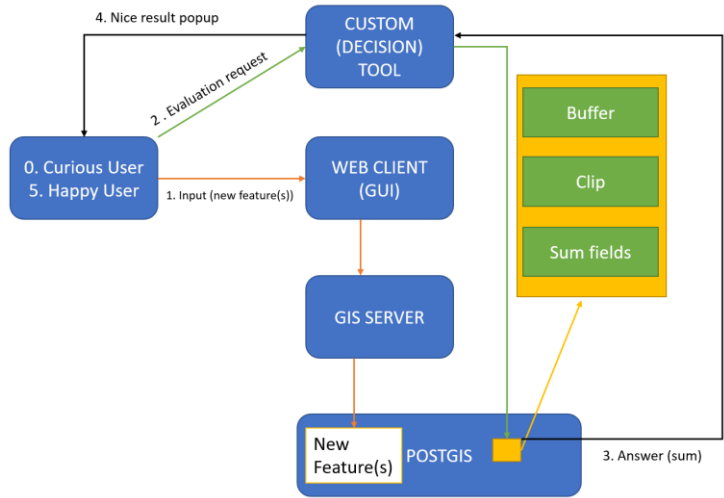


Fig. 2. Technical description of the DST operation

The technical details of the DST operation are described in Fig. 2. The curious user wants to know how his/her proposed investment impacts the territory. He/she inserts a tracing of linear investment through the GIS Web Client GUI (Graphical User Interface). Then, the request is sent to the GIS Server which is using simple geoprocessing tools (buffer, clip and sumfields). The output of this process of an answer to the user – a sum of areas in various risk zones. It calculates how much area in a given territory is planned to be taken and the risk is calculated.

The risk for the purposes of the DST is calculated according to the attributes of the polygons. The lowest risk value is 3 – good areas for biodiversity. The risk value 2 are the polygons covering important areas for biodiversity – ecological corridors. The highest risk value 1 are the key areas for biodiversity - critical zones, which must be protected and any investments here should be avoided.

5.2 Risk calculation

The user can trace his/her selected infrastructure in the system. The system is looking for overlaps with the elements of the eco-network and compares the suitability of building the infrastructure in the territory. If the tracing is crossing over an area with the risk value of 3 (=low risk), the colour of the overlapping segment turns into green – as a good area for biodiversity where mitigation measures are needed in form of tunnels or overpasses (Fig. 3). If the tracing is crossing over an area with the risk value of 2 (=medium risk), the colour of the overlapping segment turns into orange – as an important area of biodiversity and avoidance or strong mitigation or compensation measures are needed, for instance large tunnels, creating a new patch of forest etc. If the tracing is crossing over an area with the risk value of 1 (=highest risk), the colour of the overlapping segment turns into red – as a key area for biodiversity and avoidance and avoidance measures are required.

	Risk 1	Highest risk	Key are for biodiversity	Avoidance is necessary
	Risk 2	Medium risk	Important area for biodiversity	Avoidance or strong mitigation or compensation needed (e.g., big tunnels, viaducts, ecoducts, create a new patch of forest or a new wetland)
	Risk 3	Low risk	Good area for biodiversity	mitigation needed (e.g., tunnels, viaducts, underpasses, overpasses)

Fig. 3. Risk categories

To evaluate various possibilities of tracing the investment, the user can download the result from the system and compare the length of segments crossing various risk areas. This way, the user can see the length of segments in risk zone 1, 2 or 3 and made an informed decision.

5.3 User interface

After opening the DST, the GIS Web Application Graphical User Interface allows the user to see the legend, find the broader area of interest using the zoom in/zoom out options or by using the search button or to select the layers to be displayed (Fig. 4).



Fig. 4. The DST user interface

To use the DST, the user clicks on the button on the left where he/she can insert the value for the ‘influenced zone’ and draw the proposed investment. When the drawing is done, the user clicks on ‘Run’ which send the request to the GIS Server and the geoprocessing tools calculate the risk. The result can be seen in various ways. It can be exported in various geodata formats (CSV file, JSON file, GeoJSON file) where the sum of areas in various risk zones are calculated. According to these values, the user can evaluate the alternatives. It can be also displayed in the attribute table on screen.

The graphic user interface displays the result on screen for the user, too, in accordance with the colors in Fig. 3. Fig. 5 shows an example of attribute table displayed on user’s screen as an output from the DST.

OBJECT_ID	OBJECT	ID	AREA	CAT_CODE	SUBC_CODE	CAT_NAME	SUBC_NAME	HIGHWAY	PRIM_ROAD	OTHER_ROAD	RAILWAY	SETTLEMENT	WATER_AREA	NONFOREST	Shape_Leng	RISK	people	buffer
1	05	05	300.36	1	11	Recreative and suitable habitat	continuous Recreative area	0	0	0	0	0	0	0	279 320.14	1		
2	05	05	300.36	1	11	Recreative and suitable habitat	continuous Recreative area	0	0	0	0	0	0	0	279 320.14	1		
5	75	75	28.36	1	12	Recreative and suitable habitat	other suitable area	0	0	0	0	0	0	0	48 050.48	1		
6	75	75	28.36	1	12	Recreative and suitable habitat	other suitable area	0	0	0	0	0	0	0	48 050.48	1		

Fig. 5. Example of the attribute table of the DST output

5.4 Other considerations

As mentioned earlier, rather than substituting any of the planning processes, this Decision Support Tool serves as a tool for users to evaluate their proposed investments according to their impact on the components of ecological network. In the next phases of the process, expert advice and assessment of professional planners and nature conservationists is required.

The DST is support tool, so it does not evaluate it outputs but provides objective description of eligible risks. Using the export table, the user can prepare graphs and comparative tables for evaluation.

Another issue to consider is the economic point of view of the project and potentially required mitigation solutions. It is important to calculate and consider the costs of the mitigation measures versus the costs of different tracing of the proposed investment which avoids the conflicts with the components of ecological network. This gives the user the information if the benefits of the investment are higher that the costs of the investment and if the investment is remunerative.

Lastly, what needs to be considered is the scale, i.e. the local vs global impact of the investment. This means that a small part of the investment which is evaluated using the DST might be problematic, however the investment as a whole can be of higher benefit.

6 Conclusion

This paper was focusing on the use of GIS and the GIS-based decision-making support systems as instruments helping the spatial planners, nature conservationists and decision makers in their pursuit to protect the nature and improve the ecological connectivity protection of the Carpathians. It can be used as an awareness raising tool as well as a part of the process for approving new investments and their evaluation by designated bodies. It cannot replace the full and proper environmental assessment procedures, but can be of a help for initial decision by decision-makers and evaluators and also by all stakeholders who are in a need of help with their work.

Acknowledgments

This contribution is the result of the project SaveGREEN and ConnectGREEN supported by Danube Transnational Programme co-financed from European Regional Development Fund. We also would like to thank Izabela Wróblewska and Martyna Tuptyńska from the University of Technology in Gdańsk who assisted in preparation of this article as a part of their research internship at the Slovak University of Technology in Bratislava.

References

1. M. Sztubecka, M. Skiba, M. Mrówczyńska, A. Bazan-Krzywoszańska, An Innovative Decision Support System to Improve the Energy Efficiency of Buildings in Urban Areas. *Remote Sensing* **12**(2), 259 (2020). <https://doi.org/10.3390/rs12020259>
2. M. Crossland, *Spatial Decision Support System*. (Boston: Encyclopedia of GIS, 2008)
3. J. Chen, M. Gold, *Research Directions for Spatial Decision Support*. (1992). https://www.researchgate.net/profile/Jun_Chen141/publication/266455823_Research_Directions_for_Spatial_Decision_Support/links/56b614fd08ae5ad360598d36/Research-Directions-for-Spatial-Decision-Support.pdf
4. P.B. Keenan, P. Jankowski, *Spatial Decision Support Systems: Three decades on*. *Decision Support Systems* **116**, 64-76 (2019). <https://doi.org/10.1016/j.dss.2018.10.010>
5. R. Shrestha, J. Flacke, *Leveraging citizen science to advance interactive spatial decision support technology: A swot analysis*. Dhulikhel, Nepal: *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences: International Workshop on “Capacity Building and Education Outreach in Advanced Geospatial Technologies and Land Management*. 5/W3 edn, vol. **42**, 99-105 (2019). <https://doi.org/10.5194/isprs-archives-XLII-5-W3-99-2019>
6. V. Maliene, V. Grigonis, V. Palevičius, S. Griffiths, *Geographic information system: Old principles with new capabilities*. *Urban Des. Int.* **16**, 1-6 (2011). <https://doi.org/10.1057/udi.2010.25>
7. A. Grêt-Regamey, J. Altwegg, E.A. Sirén, M.J. van Strien, B. Weibel, *Integrating ecosystem services into spatial planning—A spatial decision support tool*. *Landscape and Urban Planning* **165**, 206-219 (2017). <https://doi.org/10.1016/j.landurbplan.2016.05.003>
8. J. Kazak, *The Use of a Decision Support System for Sustainable Urbanization and Thermal Comfort in Adaptation to Climate Change Actions—The Case of the Wrocław Larger Urban Zone (Poland)*. *Sustainability* **10**(4), 1083 (2018). <http://dx.doi.org/10.3390/su10041083>
9. M. Husár, M. Baloga, M. Finka, V. Ondrejčka, *Innovative Decision Support Tool*. Danube Transnational Programme ConnectGREEN Project “Restoring and managing ecological corridors in mountains as the green infrastructure in the Danube basin”. 24 pp. (2021)
10. R. Grillmayer, Ch. Plutzar, K. Sedy, *Deliverable D.T1.1.3 Draft Guidelines for standardised monitoring of functional connectivity Including Deliverable D.T1.1.1 „Survey of existing monitoring methodologies with respect to cost-efficient methodologies of target species”*, (2021)