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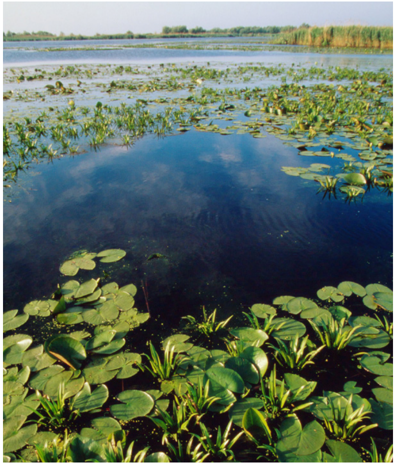

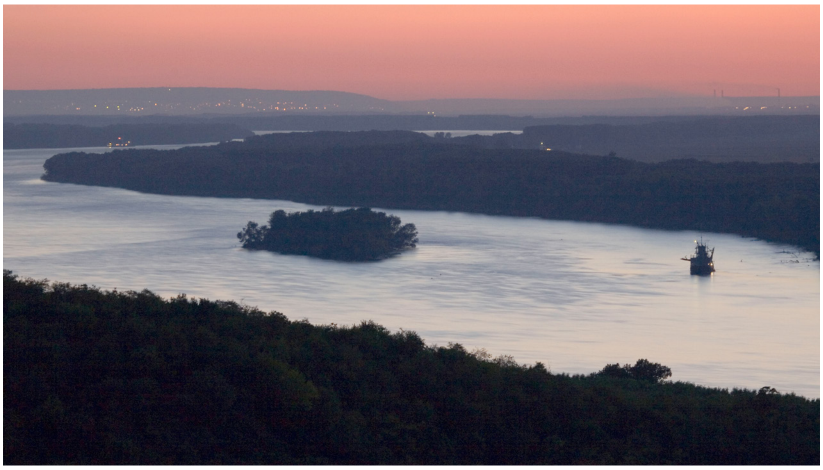

Ecosystem services in floodplains and their potential to improve water quality

- a manual for the IDES Tool -

Improving water quality in the Danube river and its tributaries by integrative floodplain management based on Ecosystem Services

Project co-funded by the European Union (ERDF, IPA)

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Ecosystem services in floodplains and their potential to improve water quality – a manual for the IDES Tool

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LIST OF ABBREVIATIONS

AFP	Active floodplain
AOI	Area of interest
BAU	Business as usual
CICES	Common International Classification of Ecosystem Services
CLC	Corine Land Cover
DPSIR	Drivers, Pressures, State, Impact, and Response
DRB	Danube River Basin
DTP	Danube Transnational Programme
EC	European Community
EEA	European Environment Agency
EEC	European Economic Community
ERDF	European Regional Development Fund
ES	Ecosystem Services
ESC	Cultural Ecosystem Services
ESP	Provisioning Ecosystem Services
ESR	Regulation & Maintenance Ecosystem Services
FCM	Fuzzy Cognitive Model
FFP	Former floodplain
GIS	Geographic Information System
GS	Grey solutions
IDES	Improving water quality in the Danube river and its tributaries by integrative floodplain management based on Ecosystem Services
IPA	Instrument for Pre-Accession Assistance
KPR	Koviljsko-petrovaradinski rit
LC/LU	Land cover/land use
MAES	Mapping and Assessment of Ecosystem and their Services
MMU	Minimum mapping unit
MMW	Minimum mapping width
N	Nitrogen
NBS	Nature-based solutions
NBS-GS	Hybrid solutions
NP	National Park
P	Phosphorus
p	p-value (statistics)
RESI	River Ecosystem Service Index
WFD	Water Framework Directive

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SUMMARY

The Danube river basin covers more than 800,000 square kilometres – 10% of continental Europe – and extends into the territories of 19 countries. Seven of these countries (Austria, Bulgaria, Germany, Hungary, Romania, Serbia, Slovenia) were partners in the 'Improving water quality in the Danube river and its tributaries by integrative floodplain management based on Ecosystem Services' (IDES) Project. The IDES Project aimed to improve water quality in the Danube River and its tributaries.

The quality of life depends on the functionality of the ecosystems through the services they provide (provisioning, maintenance and regulation, and cultural). However, pressures from agriculture (changes in land use, excessive use of fertilisers and pesticides, and soil degradation) and other sectors (energy, transport and tourism) modified and degraded those ecosystems. Consequently, human activities had direct, negative impacts on these services.

Mapping and assessing the ecosystem services in the floodplains of the Danube river basin provided an overview of the current status and offered the basis for science based/informed decision-making. Although there are multiple methods to evaluate ecosystem services, there was no specific method available to evaluate ecosystem services on floodplains. The *IDES Manual* presents a new approach for ecosystem service-based integrative floodplain management, one which considers all relevant societal interests and objectives. Twenty-six ecosystem services which are typically provided by river-floodplain systems in the Danube river basin were selected from the three main groups of services, and evaluated. Factsheets for the indicator-based evaluation of ecosystem services were created as an easy-to-use tool for decision-makers in different sectors (water management, agriculture, energy, transport and tourism). Several visualisation methods were described and applied in five pilot areas in Austria, Hungary, Romania, Serbia and Slovenia. The different pilot areas were selected to represent different territorial and practical challenges; for instance, conflicts with agriculture, forestry, flood prevention, navigation and fisheries.

The IDES approach was co-developed with local stakeholders through a series of knowledge sharing interactions that identified the most relevant ecosystem services, pressures and measures to reduce negative impacts. Fuzzy Cognitive Models, elaborated together with stakeholders, proved to be the most suitable tool to reflect the discussion among the stakeholders on how ecosystem services, pressures and measures to improve water quality are interlinked. The models were then used to draw conclusions and discuss the ideal and optimal scenarios for improving the situation. The optimal (more feasible and site-specific) scenarios rather than the ideal (where no pressure is exerted on ecosystems) scenarios were chosen to give a realistic chance of an actual implementation.

Using nature-based solutions in the floodplains to reduce the nutrient load, implement flood mitigation, address climate change adaptation, or improve water quality can be a win-win solution for a more sustainable development. Collaboration between scientists and other stakeholders fostered the integration of optimal scenarios to improve water quality in the Danube river basin into national roadmaps and the Transnational Strategy.

Multiple scientific partners and stakeholders at different levels (national, regional and local) were brought together under the Project framework. Communication between scientists and decision-makers has been strengthened. The success of IDES is best represented by the agreement among stakeholders on a common approach for the evaluation of ecosystem services in the Danube river basin, and the setting of a common goal to achieve better water quality by implementing nature-based solutions. The integration of the ecosystem services concept into all relevant policies and its operationalisation using different tools (including the IDES Tool) are necessary steps towards reaching together environmental, social and economic goals.

OVERVIEW OF THE IDES MANUAL

Julia Stäps, Andreas Gericke, Zorica Srđević, Barbara Stammel

This manual of the IDES project (Improving water quality in the Danube river and its tributaries by integrative floodplain management based on Ecosystem Services) funded by the Danube Transnational Programme of the EU (funding number DTP3-389-2.1) is intended as a methodological guide to the IDES approach to be used by key actors in water management (e.g. water agencies, planners, sectoral administrations) and other practitioners in the Danube river basin. It enables the assessment and mapping of ecosystem services along rivers and floodplains illustrated with best practice examples for the entire Danube river basin (DRB) and selected pilot areas.

Chapter 1 introduces the topic and presents the special features of rivers and floodplains and their pressures (**Chapter 1.1**), followed by the definition of ecosystem services, the latest state of research in mapping and assessing them with a special focus on the Danube river basin and the motivation on how the use of the IDES Tool can ultimately improve water quality in the DRB (**Chapter 1.2**).

Chapter 2 focuses on the method of the newly developed IDES Tool. After reviewing the links between ecosystem services and water quality (**Chapter 2.1**), the common framework of the IDES Tool as well as the calculation methods for 26 ecosystem services (9 provisioning, 11 regulating and 6 cultural ecosystem services) are described (**Chapter 2.2**). The Factsheets for the detailed indicator-based assessment of 17 water quality related ecosystem services enable the reader to assess and map the ecosystem services. Within the framework of the IDES project, the most important ecosystem services, pressures, and measures were compiled and ranked in cooperation with local and regional stakeholders for pilot areas. Also, different scenarios for reducing water quality related pressures were developed based on the causal relationship between the most important ecosystem services and pressures in each pilot area. **Chapter 2.3** briefly explains the procedure for creating these scenarios with a special focus on nature-based solutions. The synthesis and visualisation of cross-sectoral benefits in scenarios and thus in management actions are exemplified in **chapter 2.4**. Various visualisation techniques for data analyses and the communication with stakeholders are discussed.

Chapter 3 demonstrates the implementation and validation of the IDES Tool in the Danube river basin (**Chapter 3.1**) and the selected pilot areas (**Chapter 3.2**). Chapter 3.2 also gives a more detailed description of these pilot areas which represent different parts of the DRB: National park Donau-Auen (Austria), Tisza near Szolnok (Hungary), Brăila Islands (Romania), Special Nature Reserve Koviljsko-petrovaradinski rit (Serbia) and Mura River Kučnica Mura Petajnci-Gibina (Slovenia). **Chapter 3.3** describes the insights gained through the implementation of the IDES Tool in the pilot areas.

Concluding, **chapter 4** is concentrating on the added value of the IDES Tool. It shows that this added value can be expected by involving key actors and stakeholders throughout water management projects, identifying trade-offs between sectors but most of all by developing synergies between them. Such a framework can accelerate and support decisions on measures and nature-based solutions to improve water quality. Additionally, the joint approach between science and practice is important for solving current and future water management problems. Hopefully this manual together with more detailed descriptions available online at https://www.interreg-danube.eu/approved-projects/ides/outputs makes the IDES approach accessible to a wide audience. Using it, a homogenised assessment and mapping of ecosystem services can be conducted by the key actors in water management in the countries of the Danube river basin, which would help achieve a wider implementation of the ecosystem service based integrative floodplain management in the future.

CHAPTER 1

CONNECTING FLOODPLAINS, WATER QUALITY AND ECOSYSTEM SERVICES – THE IDES PROJECT

Julia Stäps, Gabriela Costea, Andreas Gericke, Barbara Stammel

1.1 Background and goal of the IDES Project

For centuries, humans have changed the shape and water quality of the Danube River, its tributaries and floodplains. These changes to the river have led to significant impacts on the ecosystem and its biological composition. Fortunately, as successful efforts to reduce pollution from point sources such as cities and industry have been achieved, and wastewater treatment plants have been newly constructed or modernised, water quality has improved during the last decades (ICPDR 2021, Kovacs and Zavadsky 2021, Mănoiu & Crăciun 2021). However, the water quality goals set by the European Water Framework Directive (WFD) require major plant nutrients loads such as nitrogen and phosphorus to be reduced even further. Although diffuse inputs of these nutrients through soil erosion and crop runoff currently clearly dominate the overall emission sources in the Danube river basin (DRB), their share significantly differs between regions (ICPDR 2021).

Besides reducing diffuse emissions from agriculture in general, active and reconnected floodplains as well as riparian buffer zones can also contribute significantly to reducing the input and concentration of nutrients in surface waters (Gericke et al. 2020, Tschikof et al. 2022). Despite progress in the implementation of floodplain management measures, headway has regrettably been rather slow so far. One of the main reasons for this slow implementation are the often strong conflicting human interests present along the river channels and in floodplain areas; for example agriculture and other land uses, shipping, hydropower and communities.

Natural floodplains represent some of the most productive and diverse ecosystems worldwide, and function as important areas of nutrient turnover (Tockner & Stanford 2002, McClain et al. 2003). Their complex habitat structures are biodiversity hotspots, and foster a multitude of aquatic and terrestrial species and ecological processes (Robinson et al. 2002). Floodplains in Europe cover only 7% of the continent's surface, but up to 30% of Europe's terrestrial Natura 2000 site areas. Moreover, floodplains provide multiple ecosystem services (Chapter 1.2), meaning benefits that society obtains from the riverine ecosystem (Christiansen et al. 2020).

Most river floodplains have been heavily affected by anthropogenic influences such as dams (Nilsson et al. 2005) or nutrient pollution (Humborg et al. 1997). The exploitive use of resources by intensive agriculture, reservoir construction, hydropower generation and navigation has significantly altered the Danube floodplain ecosystems and impaired their ability to provide ecosystem services (Funk et al. 2020, Stammel et al. 2020). Over the last 150 years, the construction of flood dykes has caused a large part of the former floodplain areas to be disconnected from the river. These former floodplains have been modified with an ongoing loss due to pressures such as land use change, river regulation, and dam construction (Hein et al. 2016). The area of floodplains in the Danube river basin has decreased by 68% in comparison to the pre-regulation period; with the highest loss in both the upper section of the Danube and the lowest in the Danube Delta (Hein et al. 2016). The disconnection of floodplains and rivers impairs the floodplain's specific biodiversity, and thus the wide array of the floodplain ecosystem services originally available (Stammel et al. 2018).

A series of EU legal frameworks (Water Framework Directive [2000/60/EC], Habitats Directive [92/43/EEC], Birds Directive [2009/147/EC] and Floods Directive [2007/60/EC]) target the protection of aquatic and terrestrial habitats while supporting the ecological development of rivers and floodplains by addressing various uses and interests. Important current EU-wide policies for the management of rivers and floodplains are the EU 2030 Biodiversity Strategy and the European Green Deal, while the European Strategy for the Danube Region (EUSDR, 2019) and the Danube river basin Management Plan (ICPDR 2021) focus specifically on the Danube river basin. The policy initiatives and legislation may deal with their own specific topics, but all aim to improve nature conservation, restore degraded habitats, create healthy and safe environment for humans, and reduce anthropogenic pressures on the environment.

Restoring degraded floodplains or reconnecting former ones can increase the provision of many ecosystem services. Such measures are called nature-based solutions (NBS) to environmental problems. While technical (grey) solutions aim to provide only a technical solution to one issue, e.g. polders for flood prevention, NBS are typically multifunctional and can contribute to simultaneously mitigating various environmental challenges. As climate change aggravates several major ecological issues such as floods, droughts and heat waves, NBS such as floodplain restoration are urgently needed.

There are 8,102 km² available for floodplain restoration along the entire Danube. Out of these, an estimated 75% show high restoration potential (Hein et al. 2016). Furthermore, the Danube Floodplain Project (https://www.interreg-danube.eu/danube-floodplain) identified 2,395 km^2 where no major restrictions for restoration (e.g. settlements) were obvious. Nevertheless, since the potential for implementation and success of floodplain restoration measures increases if local stakeholders and societal needs are already included in the planning processes (Hein et al. 2016), a variety of interests, stakeholders and their goals must be considered, combined and integrated. Although the Danube Floodplain Project was able to bring together the interests of flood protection and nature conservation, several other concerns were not addressed; including water quality improvement.

Therefore, the aim of the IDES Project (https://www.interreg-danube.eu/ides), funded by the Danube Transnational Programme (DTP), is to improve water quality along the Danube and its tributaries by developing ecosystem services-based integrative floodplain management approaches which consider all relevant societal interests and objectives. The IDES Project strengthens water quality management by demonstrating the synergies between nutrient retention and a wide range of other ecosystem services provided by the Danube and its floodplains (e.g. flood protection, recreational values and drinking water). Thus, IDES will contribute to, and accelerate the enhanced implementation of water quality management in the Danube region by identifying optimum sites for reducing the nutrient loads of rivers, and then utilising NBS, mitigating conflicts among stakeholders, and demonstrating synergies among different societal interests on floodplains. One method to realise this is the IDES Tool. The IDES Tool is an innovative approach to transnational harmonised valuation for ecosystem services. This will support the elaboration and implementation of sustainable, efficient and integrative management options along the Danube and its main tributaries.

1.2 The ecosystem service approach

1.2.1 What are ecosystem services?

Ecosystem services (ES) refer both to direct and indirect contributions of ecosystems to human well-being. Such goods and services provide direct or indirect economic, material, health, or psychological benefits to humans (TEEB 2010). For instance, the biophysical process (ecological function) of decelerating water during floods in a floodplain forest is the basis for the 'flood risk regulation' ES which is of direct benefit to people in downstream settlements. Human existence and well-being are closely linked to the provision of ES (Figure 1.2.1). Humans also directly and indirectly affect ecosystems, and the ES they provide. Hence, the ES concept links the biophysical aspects of ecosystems to human benefits; leading to an assessment of the trade-offs from ecosystem and biodiversity loss while highlighting the value of intact and healthy nature (TEEB 2010).

> *'Ecosystem services are the benefits people obtain from ecosystems'.*
>
> (MEA 2005)

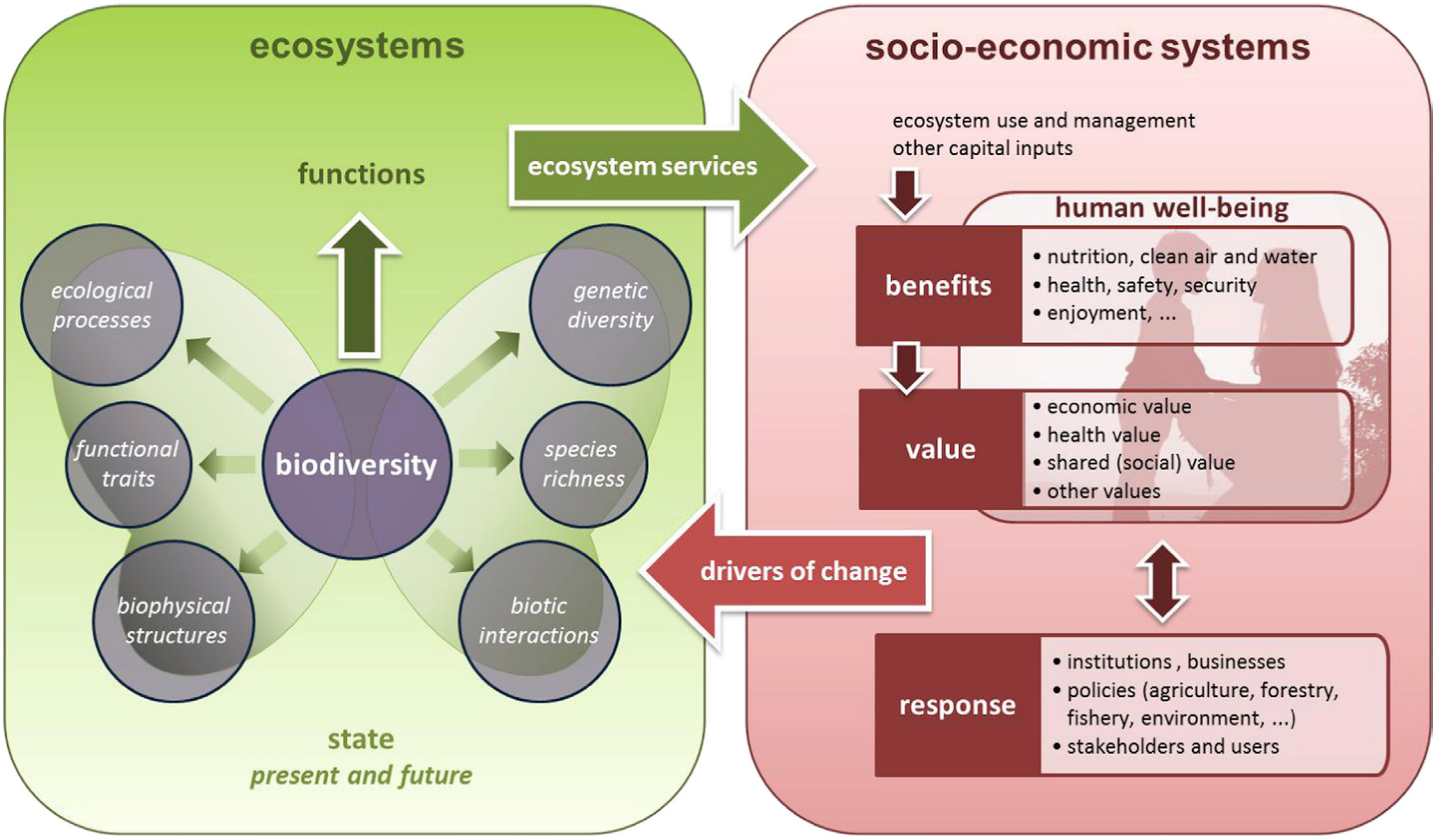

Figure 1.2.1 Relationships between ecosystems and socio-economic systems for ecosystem assessment

Currently, the Common International Classification of ES (CICES) represents the standard categorisation of the manifold ecosystem services at the European level (Haines-Young & Potschin 2018). Therefore, the IDES Project is also referring to this standard.

According to Haines-Young & Potschin (2018), ES can be divided into three main categories:

- **Provisioning ecosystem services:** the ability of ecosystems to supply various material resources (e.g. timber production, drinking water and arable crop production)
- **Regulation and Maintenance ecosystem services:** the capacity of ecosystems to affect and regulate natural processes (e.g. local climate regulation, nutrient retention, air purification, flood retention and sediment regulation)
- **Cultural ecosystem services:** the capacity of ecosystems to provide aesthetic, recreational, historical, educational or spiritual values (e.g. cultural and natural heritage, water-related activities [canoeing, swimming] and non-water related activities [birdwatching, cycling, hiking])

Ecosystems must be adequately healthy to provide these diverse ES (Maes et al. 2018), but today ecosystems and their services are increasingly under pressure (MEA 2005). It is a major challenge to reverse the degradation of ecosystems and to improve the provision of ES after they have been damaged. Use of ES in landscape management decision-making processes, as well as for developing concepts and strategies for the sustainable use of natural resources is increasing. Their implementation is particularly important at the regional level (Badura et al. 2018, Podschun et al. 2018).

1.2.2 State of the art in assessing and mapping ES

There are many different methods for assessing ES either through a monetary assessment or following a non-monetary approach (Podschun et al. 2018). Monetary assessments may have gained high awareness in the economic sciences and politics, as well as in the public, but they are restricted to a subset of ES for which a market value, or a willingness to pay, can be assumed. Notably, monetary assessments may considerably vary in geographic location and time according to socio-economic conditions (Chan et al. 2012, Perosa et al. 2021).

Non-monetary approaches can be divided into qualitative and quantitative assessments. Qualitative evaluations are descriptive, and are far from ideal to objectively combine the evaluation of different ES (Burkhard & Maes 2017). In contrast, quantitative but non-monetary assessments are easily comparable because they use absolute values (e.g. retention of a certain amount of nitrogen per hectare and year) or ordinal classes (e.g. as used in the WFD evaluation).

Nowadays, we are witnessing increased international interest in including ES in management decision-making. The practical purpose of assessing ES is to allow for the identification of the main drivers, pressures, states, impacts and responses (DPSIR). By mapping ES, it is possible to identify places where ES provision could be improved and the conservation of nature and biodiversity should be prioritised (Burkhard & Maes 2017). ES assessment and mapping is also an important means to illustrate ecosystem pressures and benchmark the current provision of ES. This approach provides the ability to highlight differences in the furnishing, use and demand for certain ES. By this, the ES approach can serve to identify areas of low ES supply and identify more sustainable management options for a specific area. The EU 2030 Biodiversity Strategy (2020) stresses the need to develop maps of ecosystem services to assess the condition of ecosystems and the associated ES, the economic value of these ES, and to promote the integration of the ecosystems' values into accounting and EU reporting systems. Thus, the European Mapping and Assessment of Ecosystem and their Services (MAES) Working Group evaluates the status of ecosystems, the pressures exerted upon them, and the services they provide at the European level (Maes et al. 2020).

In order to assess and map ES, it is necessary to understand how they are related to different processes (biological, chemical and physical) and to ecosystem functions (Figure 1.2.1), i.e. the interactions in different ecosystems (Maes et al. 2016). Ecosystem functions can be understood by employing several different methods ranging from a simplified expert-based evaluation of ES to the precise calculation and modelling of specific values and services. Indicators can also serve as proxies to evaluate values or ordinal classes.

The River Ecosystem Service Index (RESI) is a non-monetary, quantitative indicator approach used to map the services of complex ecosystems in riverine landscapes. The RESI focuses on the quantitative and spatially explicit identification and assessment of ES in order to obtain replicable and transparent results. The results of the analysis can then be directly integrated into planning processes (Podschun et al. 2018). RESI served as the basis for the IDES Tool and was adapted to the specific circumstances and challenges presented by the large transboundary DRB (Chapter 2.2).

As a first step in ES assessments, the ecosystem of interest (e.g. floodplains) and the services it provides must be selected. Secondly, the temporal and spatial scale for the analysis must be determined (Grizzetti et al. 2015). For example, should the entire watercourse or only individual sections of a watercourse be analysed during peak or mean water levels? Whereas floodplain stretches can be used for specific water management actions, the use of longer water body sections or large areas facilitates the identification of the optimum (minimum) potential ES for a region (Podschun et al. 2018). As a third step, ES can be assessed with different levels of precision depending on the available data (Podschun et al. 2018). Integrative evaluations are still a challenge for science and practices (Perosa et al 2021).

1.2.3 Ecosystem service assessment in the DRB floodplains

At approximately 2,800 km, the Danube is the second longest river in Europe and flows through ten countries on its way from its source in Germany to its mouth in the Danube Delta in Romania. The entire DRB (Figure 1.2.2) covers an area of over 800,000 km² and is home to 80 million people in 19 different countries. These inhabitants are as dependent on the Danube and its water quality as is the biodiversity (Frîncu 2021). However, about 70-80% of the original floodplains in the DRB and their ecosystem services and functions have largely been lost. The Danube floodplains have been disconnected or converted to farmland (Tschikof et al. 2022).

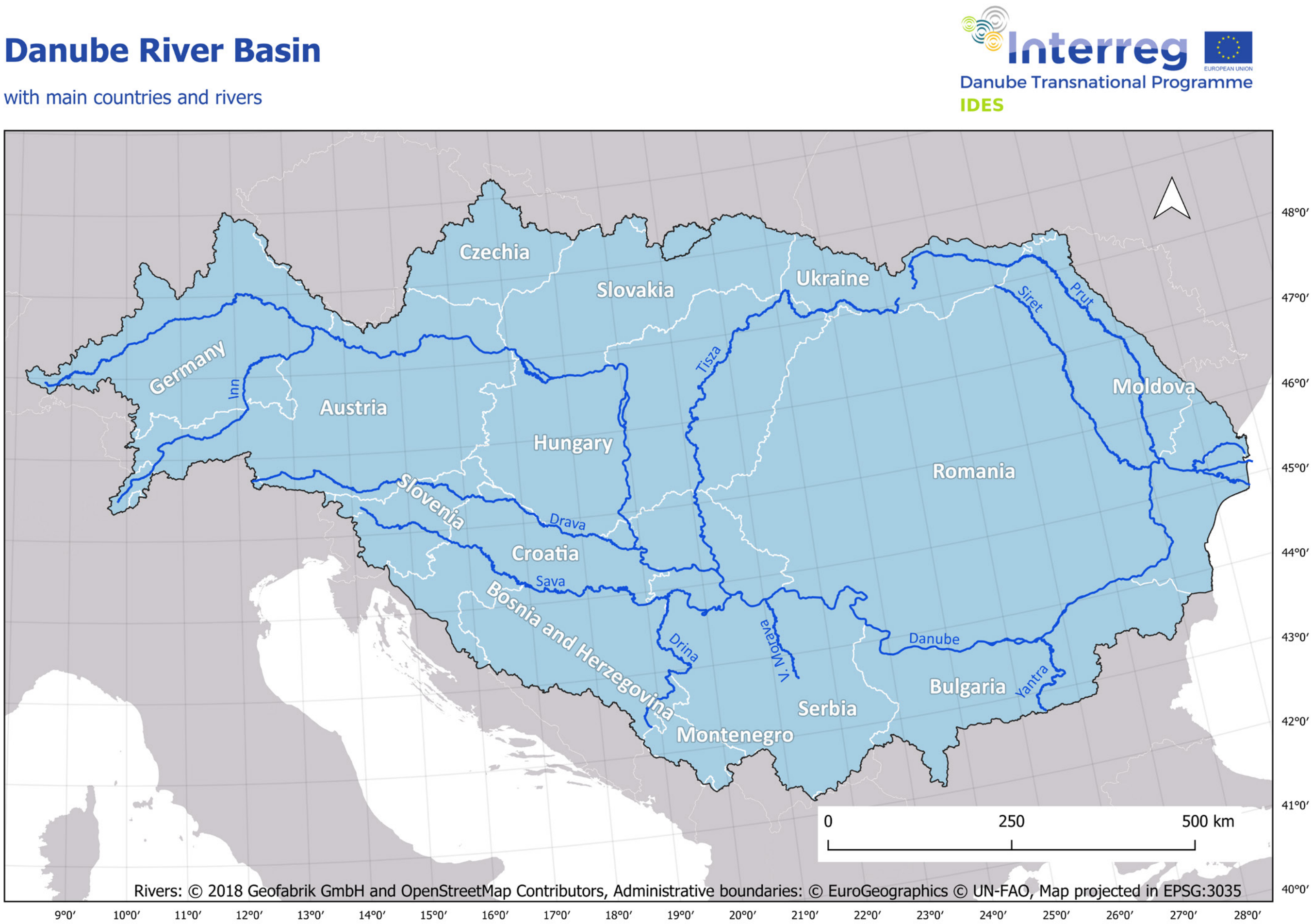

Figure 1.2.2 Danube river basin (DRB).

The protection and restoration of floodplain ecosystems and their services should be a key water management task. However, the heterogeneous prerequisites along the most international river make this task a major challenge. Funk at al. (2020, p. 431) stated that '...the diversity of human activities and policy targets, scarcity of data compared to the complexity of the systems, heterogeneity of environmental problems and strong differences in socio-economic conditions' make coordinated planning difficult.

Badura et al. (2018) analysed the current state of ES assessments in the DRB in general, but omitted a focus on floodplains. Besides the European level initiatives (e.g. MAES and the related ESMERALDA and opeNESS projects) which aim to map ES at the EU level and to deliver a flexible methodology for both pan-European and regional assessments, the researchers identified more than 60 ES studies in this region. Badura et al. (2018) concluded that indeed, the applied evaluation methods strongly varied. Except for the Czech Republic, all countries have significant gaps in the ES assessment for their entire national territory. However, in Austria and Germany a significant number of studies have been conducted. In addition, many ES regional assessments exist in many other countries along the Danube, for example Slovakia, Bulgaria, Hungary and Romania. Assessing entire territorial units in advance in order to improve the preparation of strategic decisions makes sense, but this practice is rarely done (Badura et al. 2018).

A few local authorities have begun to use ES assessment on a wider scale; mainly by using a participatory approach and involving stakeholders and citizens. Public participation supports the fostering of acceptance and understanding for the interests of nature and ES (Badura et al. 2018). While Badura et al. (2018) list only a few studies related to floodplains along the Danube, an increasing number of studies on ES in floodplains have been published since then (e.g. Stammel et al. 2020). In order to determine the ES value of the Danube floodplains, Perosa et al. (2021) carried out a meta-analysis of the monetary valuations of floodplains in the DRB according to the condition of the floodplains. Besides the significance of the described ES, landscape parameters (proportion of water bodies, of riparian area), water quality and the assessment method are also crucially important variables when calculating the monetary value of ES (Perosa et al. 2021). Establishing a coordinated assessment tool that reflects spatially explicit data is clearly needed to improve an ES-based integrative management of floodplains along the Danube and its tributaries; and that tool must be able to evaluate ES in floodplains. The theoretical background for the development and assessment framework of the IDES Tool is contained in this IDES Manual. For the purpose of making it applicable to water management in the Danube region, a clear description of the assessment method for all relevant ES are given. Best practice examples of the IDES Tool's implementation in five pilot areas, and the integration of local, regional and national stakeholders in the planning process are described as a means to demonstrate its potential.

CHAPTER 2

DEVELOPMENT OF THE IDES TOOL

Martin Tschikof,
Elisabeth Bondar-Kunze

2.1 Linking water quality and ecosystem services – approaches and limitations

Good surface water quality represents one of the key goals of water management and is highly valued by the public. Water quality refers to the chemical, physical, and biological characteristics of a water body. Water quality can be assessed by comparing different indicators with a set of standards. Commonly used indicators involve the concentration of beneficial or harmful substances (e.g. nitrate, oxygen, pesticides, minerals, suspended solids); their degradation (e.g. BOD - biochemical oxygen demand); water temperature; pH; colour; turbidity; or the presence or absence of indicative organisms (e.g. Ephemeroptera, *Escherichia coli*). Good surface water quality may provide other, better ES such as cultural ES and habitats for biodiversity to a much higher degree. Thereby, changes even in a single but important water quality parameter may affect multiple ES. Various ES, in turn, also affect water quality to different extents.

There is little literature about the interactions between ES and water quality, and no general quantitative assessment of their links is available. Hence, there is a lack of data and an understanding of these interactions. A comprehensive review, addressing the importance and limitations of water quality-related ES was published by Keeler et al. (2012). They argue that the interactions are complex and it is challenging to quantitatively link water quality metrics (e.g. nutrient concentration) to 'valued attributes' of other ES due to different means of assessment. A 'valued attribute' is defined as an endpoint at which a change in water quality could be measured (e.g. water clarity or fish productivity), but such an attribute is often a subjective evaluation; especially with respect to cultural ES (e.g. the value of a water body for bathing).

A proper understanding of the interactions between water quality improvements and ES is needed to become more aware of the possibilities, limitations and potential pitfalls of ES-based integrative floodplain management. Investigations into the relationships between water quality and ES might depend on a selected subset of ES. Generally, ES provided by aquatic ecosystems are affected in a stronger and more direct way than ES of terrestrial ones. In contrast, terrestrial and provisioning ES might contribute more to the degradation of water quality (e.g. through crop production). Figure 2.1.1 illustrates a conceptual example of how changes in water quality affect other ES.

However, it needs to be considered that degraded water quality represents only one of many human-induced stress factors. Changes to most ES are not solely caused by shifts in water quality. For example, besides overfishing, climate change, invasive alien species and habitat deterioration, impaired water quality constitutes only one driving influence for the decline in fish catch. Well-known examples of such multiple pressures on fisheries are the situations in Lake Victoria or the Black Sea (Oguz 2017).

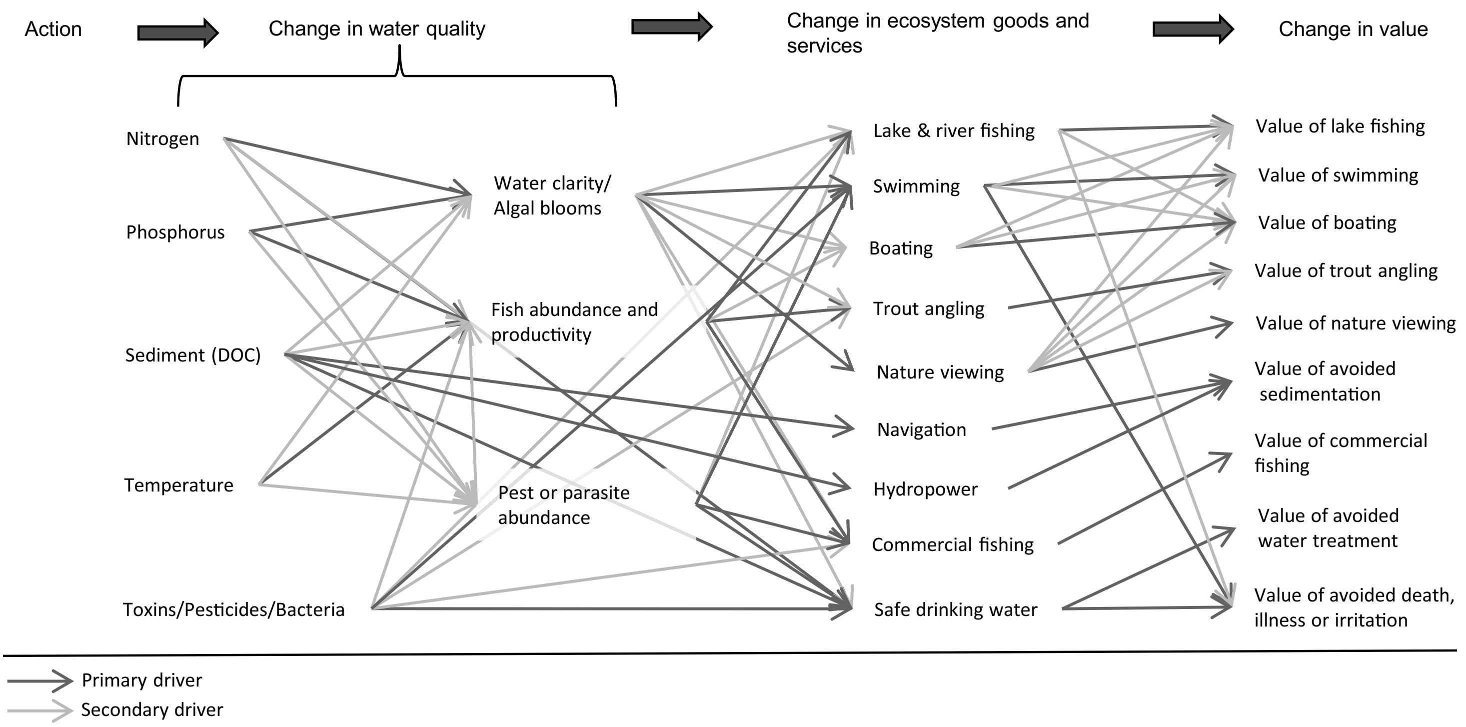

Figure 2.1.1 Direct and indirect relationships between water quality changes of selected ES and associated values (from Keeler et al. 2012). Changes in water quality could be caused by different water quality management measures, land-use or climate change.

Methodological considerations to evaluate the links

There is a plethora of methods how ES can be evaluated (Chapters 1 and 2.2.5). Similarly, there is a wide variety of methods to assess ES interactions. The following are a few examples:

- Rank correlation analyses represent a simple tool to assess interactions between ES and floodplain characteristics (e.g. in Stammel et al. 2020). However, this assessment methodology may not demonstrate the causality to explain the levels of ES or water quality when applied to the strongly reduced active floodplains in the DRB (Figure 2.1.2). In addition, rank correlation might not be able to describe the temporal patterns or lagged responses of water quality-dependent ES.

- Economic evaluations are attempts to cover the social dimension by estimating the monetary value of environmental changes. Methods include the willingness to pay for a certain ES, preferred method by choosing one ES over another, avoided costs by improving water quality, or increased health risk costs (Keeler et al. 2012). The total value of water quality can be expressed differently for various ES. For example, drinking water or bathing might be expressed as the cost of technical removal of excess pollutants plus the cost of human health risk of being exposed to toxic levels of said substances. Reviews of economic water quality evaluations are provided by Wilson and Carpenter (1999), Brauman et al. (2007), Olmstead (2010), and Griffiths et al. (2012). The value of good water quality as a habitat characteristic probably cannot be monetised.

- Integrated (modelling) studies represent additional approaches to quantify links of water quality to ES. A review of hydrological and water quality models for assessing freshwater ES is provided by Hallouin et al. (2018). One frequent shortcoming, however, is that economic models require very different inputs compared to those required by bio-physical water quality models (Keeler et al. 2012).

- A Bayesian Belief Network is a type of probabilistic graphical model which can define relationships between variables and be used to calculate probabilities. Recorded data or expert opinions are needed to gain an understanding of how target ES react to changes in water quality (e.g. Spence & Jordan 2013, Wagner & Zalewski 2016).

- Another option is to map the gains and losses of ES in specific scenarios, as depicted by Funk et al. (2021). The authors facilitated the spatial detection of synergies and trade-offs by using simple graphical representations (Figure 2.1.3).

- Fuzzy Cognitive Models (FCM) were used in the IDES Project (Chapters 2.3 and 3.2). Together with stakeholders, the relations between the elements of a system (here the ES) in a 'mental landscape' were evaluated to compute the strength of interactions between nutrient retention/self-purification and other ES (Figure 2.1.4).

In addition to the calculation method, it is important to consider adequate spatial and temporal scales to analyse the drivers of water quality and its relationships with the provision of different ES (Hallouin et al. 2018, figure 2.1.2). In the case of nutrients in large rivers of the DRB, water quality is driven by basin-wide controlling factors including the degree of urbanisation, the amount and efficiency of wastewater treatment or the intensity of agriculture (ICPDR 2021). Smaller-scaled processes like nitrogen (N) and phosphorus (P) retention in floodplains act more locally on water quality, but also affect the nutrient loads transported further downstream into the receiving water bodies (Tschikof et al. 2022). On the other hand, increased nutrient levels induce local effects on the provision of ES on the floodplain scale, but also further downstream or even in coastal water bodies. Likewise, the demand of ES connected to water quality can be variable in time. For instance, bathing is favoured during warm summer months, or spawning activities of fish require certain temperatures and oxygen levels. In addition, changes in one ES may demonstrate immediate effects in water quality, while in other cases the reaction is slower (e.g. by legacy nutrients in sediments or phosphorus release during low oxygen conditions). Consequently, water management strategies which also target ES should differ temporally (Wagner & Zalewski 2016).

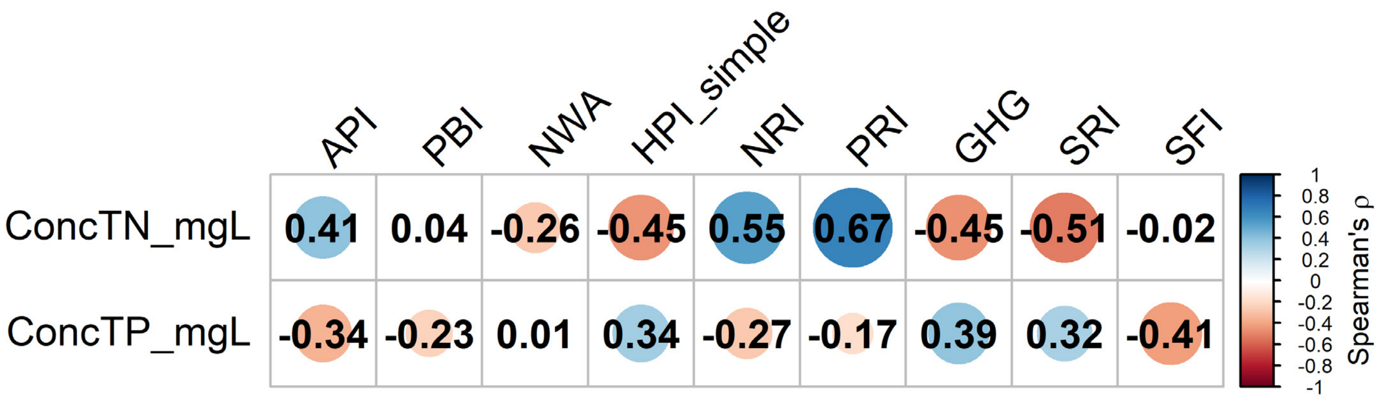

Figure 2.1.2 Spearman correlation matrix of ES and water quality metrics (total nitrogen (ConcTN_mgL) and total phosphorus (ConcTP_mgL) concentrations) in the active floodplains. ES were evaluated using the indicator approach of the IDES Tool. Even though many parameters suggest a high correlation (|ρ|> 0.6, p < 0.01), the causal link between basin-driven water quality patterns with local ES in floodplains must still be studied locally. API= arable crop production, PBI= plant biomass grassland, NWA=opportunities for non-water-related activities, HPI_simple= habitat provision (simplified assessment), NRI=nitrogen retention, PRI=phosphorus retention, GHG=greenhouse gas regulation, SRI=sediment regulation and SFI=soil formation in floodplains (Table 2.2.1).

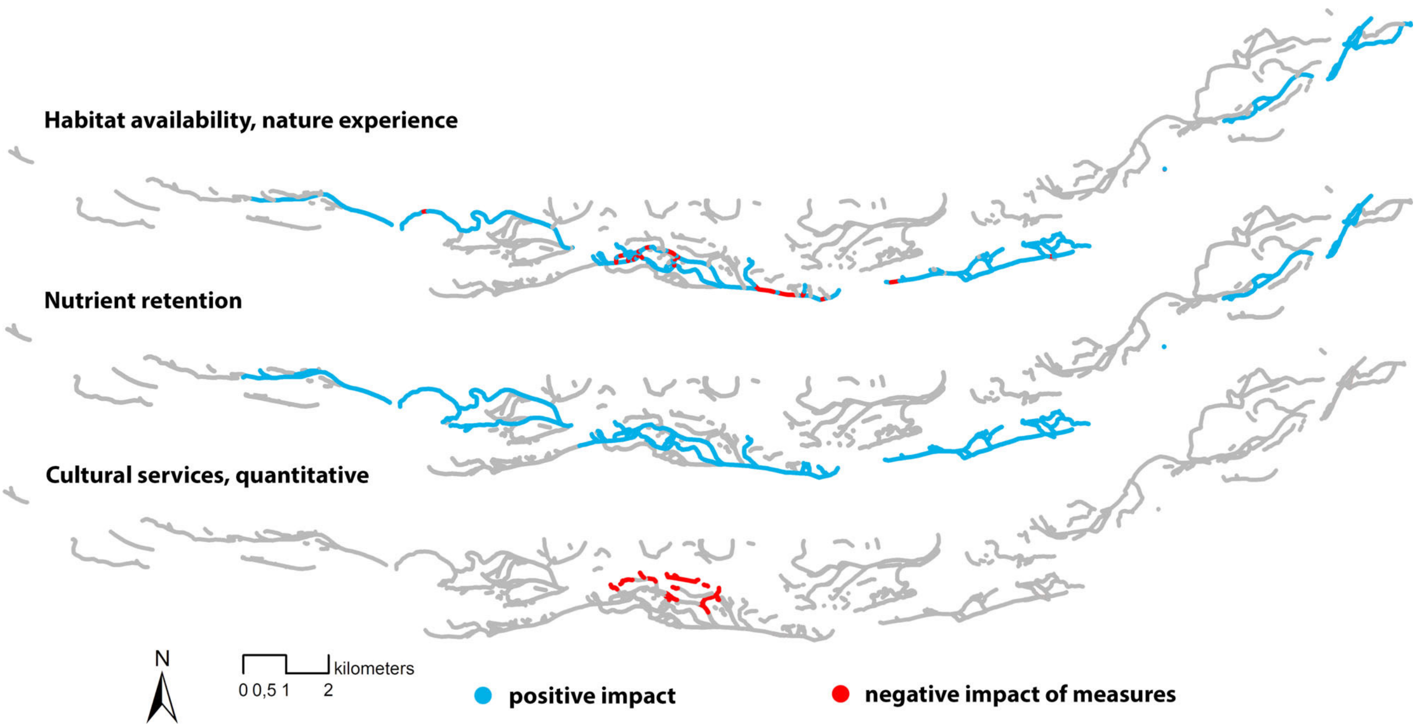

Figure 2.1.3 Modelled impacts of side arm reconnections and rip-rap removals on selected ES in the Donau-Auen National Park along the Austrian Danube. Strong synergies (same colour) and local trade-offs (different colour) can be estimated from the map.

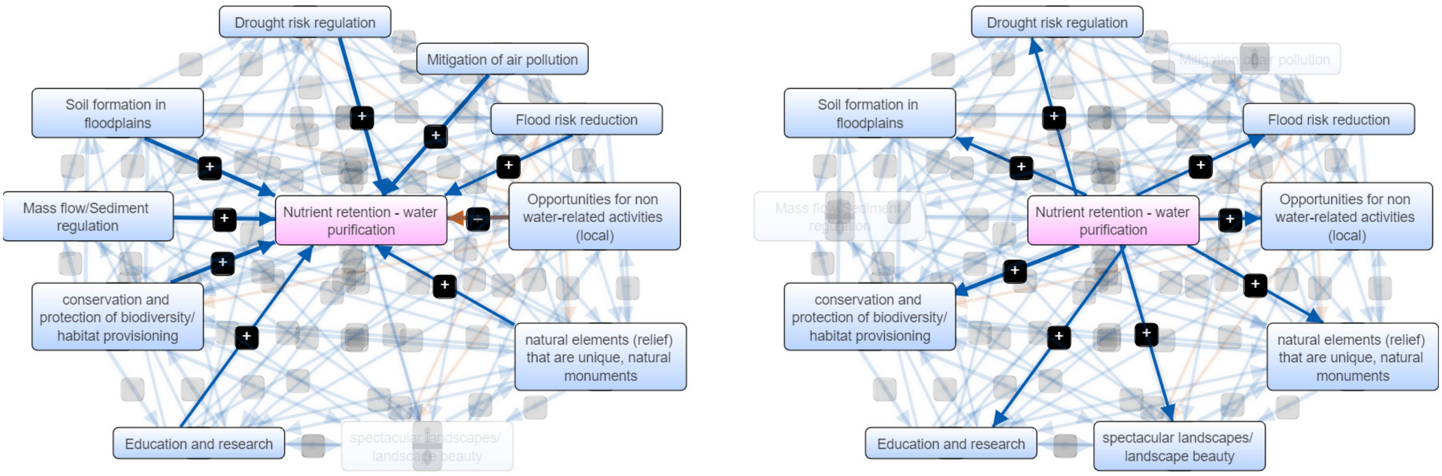

Figure 2.1.4 ES impacting nutrient retention, and thus water quality (left) and improved water quality through nutrient retention impacting other ES (right). The relative strength of positive (blue) and negative (orange) impacts are indicated by the arrow width. The FCM was created with stakeholders of the Austrian Donau-Auen National Park floodplain (Chapter 3.2).

2.2 Summary of the IDES Tool

Martin Tschikof, Elisabeth Bondar-Kunze

2.2.1 Aim of the IDES Tool

The IDES Tool represents a methodological approach to harmonise the evaluation of ES on floodplains, and to link it with water quality improvement. The IDES Tool has been developed and implemented in the DRB, but the concept is generally applicable elsewhere. This tool aims to support objective evaluations of river-floodplain management measures, communication between stakeholder groups, creation of awareness about the diversity of provided ES, and hence, improve effective decision-making.

2.2.2 Workflow and requirements

A stepwise approach was proposed (Figure 2.2.1) to cover the scope of ES evaluations and floodplain water quality assessments. For each work step in the DRB, a detailed description was provided that referred to implementation.

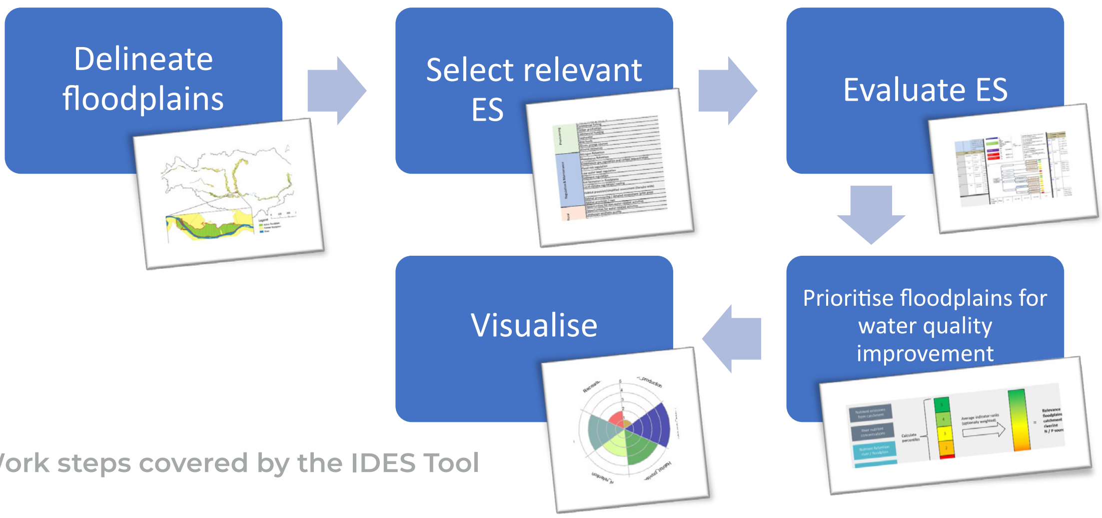

Figure 2.2.1 Work steps covered by the IDES Tool

Software, data processing and Geographic Information System (GIS) skills are required to successfully apply specific data to each work step. Useful prerequisites to implement the individual steps include, but are not limited to:

- Software and skills: basic GIS skills, data analysis and modelling (e.g. in R, a free software environment for statistical computing and graphics);
- Geodata: maps of floodplain areas (hydraulic model), land cover/land use, hydro-morphology, soil types, protected areas, digital terrain models, meteorological data and nutrient fluxes, etc.;
- Optionally specific data on fishing, hunting, forestry, hydropower, groundwater, drinking water and wells, etc.

2.2.3 Delineation of floodplains

A morphological floodplain is an entire area that, in the absence of human intervention, would be flooded. A morphological floodplain can be defined by data about (hydro-) morphological features, extreme flood events and the extent of fluvial deposits; or historical documents (Eder et al. 2022). There are compartments within morphological floodplains with specific physical characteristics and uses, and hence, the ES they provide differ. Many floodplains have been drastically transformed by anthropogenic flood protection structures (e.g. levees and dykes) to create agriculture land or areas of urban development. This has resulted in a separation of extensive areas from riverine dynamics. Therefore, it is important to differentiate between the active floodplains (areas subject to frequent floods) and the former floodplains (areas decoupled from flood dynamics). Eder et al. (2022) provided a comprehensive overview of how to delineate various floodplain compartments.

In order to ensure a spatially explicit assessment of ES for comparable spatial units, and to facilitate their visualisation (see also chapters 2.4 and 3.1), it is useful to longitudinally divide the compartments between river, active floodplain and former floodplain into equally sized segments. This segmentation is commonly made by placing equidistant transects along the river network (Podschun et al. 2018). The segment size should be chosen depending on the desired level of detail, the spatial resolution of input data, and the specific landscape characteristics of the area of interest.

Implementation in the DRB

The morphological floodplain along the Danube River and its Tisza, Mura, Sava, and Yantra tributaries were defined by using existing and available GIS data on riparian zones, flooding frequencies and risks. These were often derived from information meant for a larger scale, which meant that the data potentially contained spatial inaccuracies. Therefore, the morphological floodplain was defined by the outer border of the area of interest (AOI), and through the Copernicus Riparian Zones Land Cover/Land Use (LC/LU) dataset (EEA 2017a). This dataset was preferred over alternatives (e.g. the flood hazard maps of the Joint Research Center [JRC 2018], or the International Commission for the Protection of the Danube River [ICPDR]) because of the following qualities:

- Full coverage of the DRB;
- High-resolution vector data with detailed LC/LU mapping is provided (more classes, higher resolution than in Corine Land Cover) for the entire AOI;
- AOI approximates the morphological floodplain and areas with typical riparian characteristics. In narrow river sections with steep valleys, the AOI does not represent the floodplain, but rather an excessive buffer area around the rivers. These parts were manually removed to reduce erroneous labelling, and so only the river compartment was used.

The river compartment refers to the main river and the interconnected water bodies of the river system. The compartment was defined by MAES (Mapping and Assessment of Ecosystems and their Services) as level 4 classes '9.1.1.0 interconnected watercourses', and in some cases '9.0.0.0 UA - rivers and lakes' in the Copernicus Riparian Zones Land Cover/Land Use dataset.

Areas of active floodplains were adopted from the DTP Danube Floodplain Project (http://www.geo.u-szeged.hu/dfgis/). These areas represent the inundated parts larger than 500 ha following a flooding event with a 100-year return period, and which are wider than the width of the main channel and hydrologically connected. The Danube Delta, given its very distinct hydrology, was not demarcated as active floodplain using these criteria, and was excluded from some ES evaluations. The former floodplain is the remaining part of the morphological floodplain.

Based on the spatial resolution of the available input data and the visualisation at the river basin level, the entire morphological floodplain was divided into 10-km segments along the river course. This was achieved by creating point elements every 10 km (EEA 2012a, 2017b) and generating Voronoi polygons[1] in GIS around these points (Figure 2.2.2). A segment length of 1 km was applied to 5 pilot areas (Podschun et al. 2018, figure 2.2.3) to increase the level of detail. The resulting shape files can be found at https://www.interreg-danube.eu/approved-projects/ides/outputs.

1 The partition of a floodplain into regions close to a given set of points

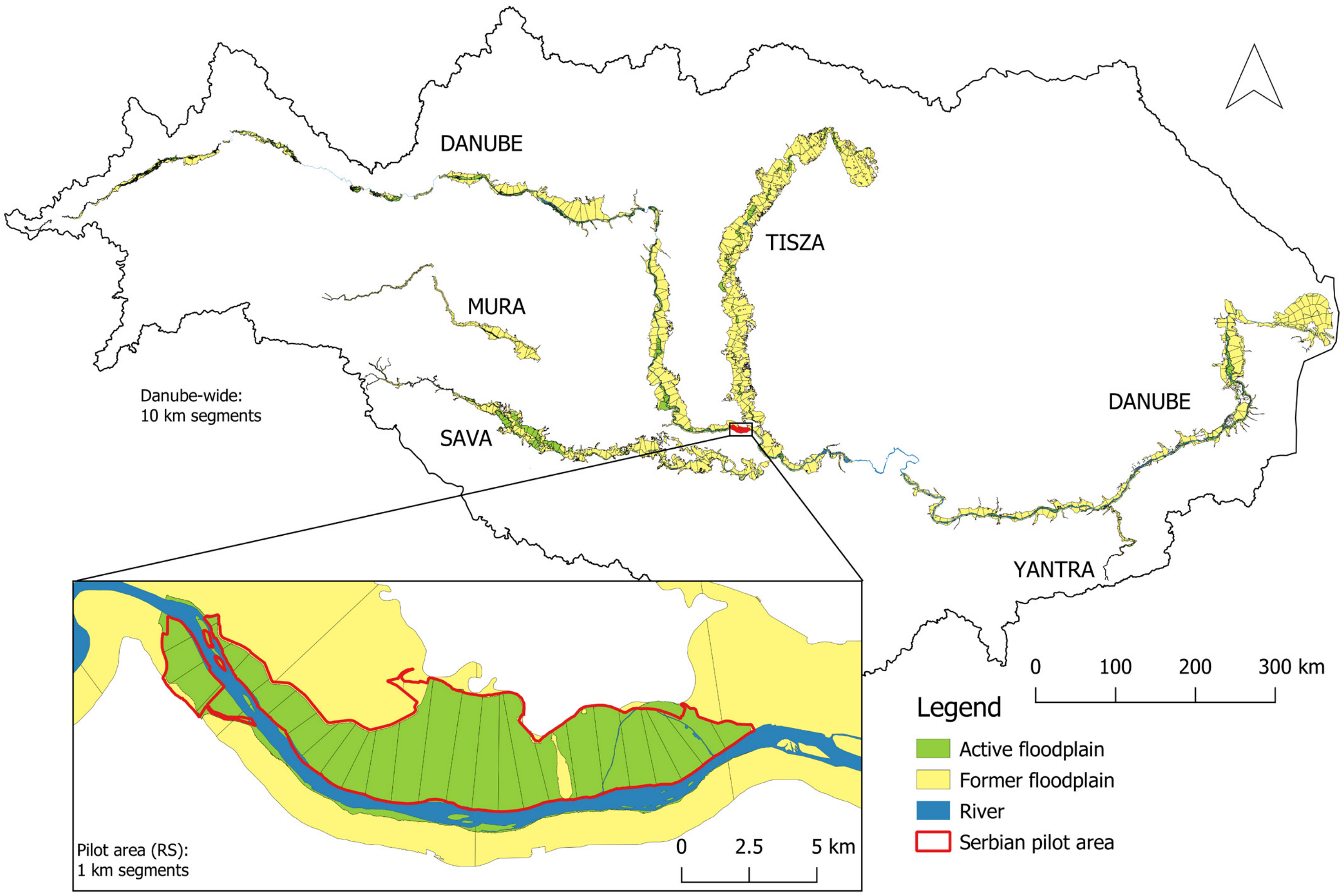

Figure 2.2.2 Delineation of the 3 compartments (river, active floodplain and former floodplain), and segmentation at the 10 km and 1 km levels (the Serbian pilot area for example) in the DRB.

2.2.4 Selection of relevant ES

Generally, it is recommended that the broadest possible range of ES for evaluation and mapping be used to better detect (unforeseen) changes (Podschun et al. 2018). A minimum number of selected ES should be representative of all main ES types: Provisioning, Regulation and Maintenance, and Cultural ES (Haines-Young & Potschin 2012). In the case of floodplains, ES should particularly be considered which are typically provided by the different floodplain compartments; for example ES provided by aquatic to terrestrial ecosystems. In addition, there might be regional differences in how ES interact with nutrient retention, and which ES will be most affected through (planned) measures (Chapter 2.1). A broad range of ES enables an unbiased assessment of trade-offs and synergies in different given scenarios (Chapter 2.4.1). However, the most common selection of ES is constrained by practical applications such as data required for the evaluation of ES (Chapter 2.2.5).

Implementation in the DRB

Based on the aspects described above, 26 ES which are typically provided by river-floodplain systems in the DRB were selected for evaluation from all 3 main types (Table 2.2.1).

Table 2.2.1: ES selected in IDES, their description, type and evaluation approach (indicator-based or capacity matrix).

Type	Ecosystem Service	Abbr.	Description	Evaluation approach
Provisioning	Arable crop production	API	Used arable crops (e.g. cereals, root crops, vegetables and fruit)	Indicator
	Plant biomass grassland	PBI	Plant biomass used for agricultural purposes (yield of meadows and pastures)	Indicator
	Commercial fishing	CFI	Commercial fish catches	Indicator
	Timber production	TPI	Timber production harvest from managed forests (used as material or for energy)	Indicator
	Commercial hunting	CHI	Commercial hunting yield	Indicator
	Freshwater provision	FW	Water withdrawal for drinking water purposes, irrigation or cooling purposes	Capacity Matrix
	Wild foods	WF	Food resources that can be foraged in the wild	Capacity Matrix
	Abiotic energy sources	AES	Energy generated by hydropower plants, wind etc.	Capacity Matrix
	Mineral resources	MR	e.g. sand/gravel quarries	Capacity Matrix
	N retention	NRI	Permanent elimination of nitrogen (N) by denitrification (conversion to N_2) or temporary retention by incorporation into stationary biomass (e.g. mussels and floodplain vegetation) or in river sediments (sedimentation)	Indicator
	P retention	PRI	Temporary or permanent retention of phosphorus (P) by incorporation into stationary biomass (e.g. bivalves, macrophytes and floodplain vegetation), or by uptake into sediments (deposition and sorption)	Indicator

Regulation and Maintenance	Greenhouse gas regulation and carbon sequestration	GHG	Emissions and sequestration of greenhouse gases such as carbon dioxide, methane, and nitrous oxide (CO_2 equivalents)	Indicator
	Flood risk regulation	FRI	Reduction of flood discharge and lowering of the flood peak: wave flattening (retention volume is used by overflow/flooding, river/ floodplain morphology influences turbulance)	Indicator
	Low flow regulation	LFI	Low flow regulation by hydrological self-regulation by macrophyte growth and morphology (reduction of water level); compensation by strong groundwater inflow if applicable (expert assessment)	Indicator
	Sediment regulation	SRI	Evaluation of the internal sediment balance of the river by the naturalness of morphological structures and effects of transverse structures on sediment consistency/morphological effects	Indicator
	Soil formation in floodplains	SFI	Evaluation of natural fen formation (peat accumulation) and anthropogenically caused fen degradation (lowering of the water body and groundwater level, changes in flood dynamics) and floodplain soil formation	Indicator
	Local climate regulation/cooling	LCR	Cooling potential of different land cover/land use types	Capacity Matrix
	Habitat provision/ simplified assessment (Danube-wide)	HPI_{simple}	Habitat provision describes the functional and structural quality of typical floodplain habitats, communities, and species that serve as a basis for a wide range of human uses. The habitats, with their typical diversity of animal and plant communities on the natural and cultural landscape, are an expression of the characteristic floodplain landscape conditions.	Indicator
	Habitat provisioning/ detailed assessment (pilot area)	HPI_{detail}	See 'Habitat provision/simplified assessment'	Indicator
	Habitat provision/ river	HPI_{river}	Evaluation of water quality as well as the functional and structural quality of biologically relevant water body structures in the river and the directly adjacent river bank	Indicator
Cultural	Opportunities for non-water-related activities	NWA	Experiencing animals, plants, and landscapes (e.g. nature observation, cycling and walking) for the purpose of recreation	Indicator
	Opportunities for water-related activities	WRA	Specific water-related activities for recreational purposes (recreational fishing, swimming, and boating)	Indicator
	Landscape aesthetic quality	LAQ	The aesthetics of the landscape is characterised by its diversity, uniqueness and perceived naturalness	Capacity Matrix
	Natural Heritage	NH	Natural sites and features of value from the point of view of science, conservation; or the natural beauty of objects	Capacity Matrix
	Cultural Heritage	CH	The human mental and cultural reflection of tangible natural assets and intangible living cultural expressions	Capacity Matrix
	Knowledge systems	KS	Value of the landscape for research projects, educational activities, etc. in the floodplain areas	Capacity Matrix

2.2.5 Evaluation of ES

A variety of ES assessment approaches exist, each of which is utilised depending on the relevant issue (see also Chapter 1). Neugarten et al. (2018) provided a comprehensive overview of different ES evaluation tools that proved to be a valuable guide to deciding which method to use. More details about the selection of appropriate evaluation tools can also be found at http://www.aboutvalues.net/. A spatially explicit and non-monetary evaluation scheme was chosen for the IDES Project.

Implementation in the DRB

Due to the heterogeneous data situation in the DRB, two complementary methods were selected to evaluate and map the floodplain ES. An adapted version of the comprehensive indicator-based RESI (River Ecosystem Service Index) approach by Podschun et al. (2018) was applied in countries/regions with better data availability. RESI was developed in Germany specifically for the evaluation of ES in river-floodplain systems. In data-scarce countries/ regions, capacity matrices (adopted from Burkhard et al. 2009, Stoll et al. 2015) were applied to compensate for areas or ES where the detailed indicator-based approach was not feasible (Figure 2.2.3). Capacity matrices is a simple, widely applicable method that makes use of expert evaluations of capacity of landscape features to provide ES (Burkhard et al. 2009, Campagne et al. 2017, Stoll et al. 2015). The evaluation approaches to assess each selected ES are given in Table 2.2.1.

A 5-level assessment scale of ES availability was chosen that visualises ES in an easily intelligible way, and which also enables comparisons to be made of the ES among floodplain compartments or segments. This framework is similar to other operational 5-level evaluation frameworks such as the EU WFD. Categorisation in this methodology reflects the range of provided ES from 'not provided' (0) to 'very high provision' (5). ES cannot be provided in cases where there are conflicts in the LC/LU (e.g. crop production in forested areas or peat bogs). The categories were individually defined for each ES by either the ratio to the maximum possible ES indicator value, reference values or quintiles.

The definition of evaluation categories using quintiles poses certain challenges. When using this method, the boundaries of each category are dependent on the number of evaluated segments or compartments and the range of their respective indicator values. Hence, when using quintiles on a homogeneous or small dataset, the resulting classes could be misleading and should be handled with caution.

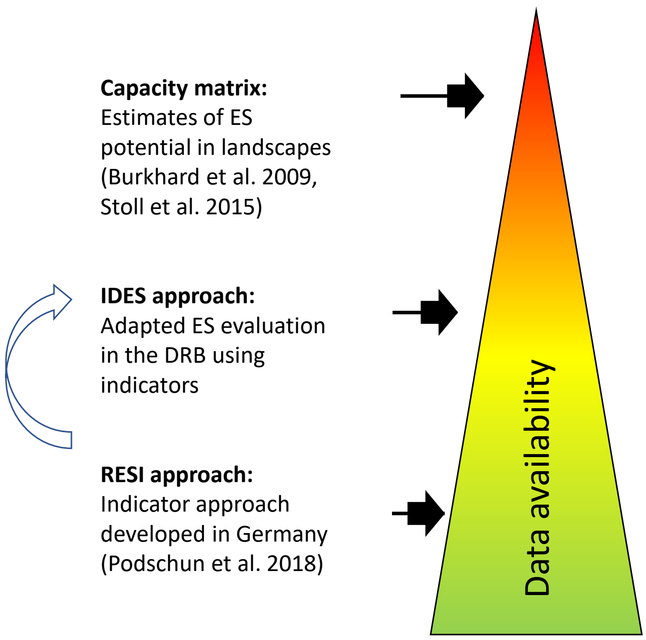

Figure 2.2.3 Selection scheme of ES evaluation approaches based on the quantity and quality of the required data in the DRB

Capacity matrices

To apply the capacity matrix approach to floodplains, ranking of the provided ES capacity are first assigned to LC/LU types (Table 2.2.2). The LC/LU ID of the matrix is combined with Corine (Burkhard et al. 2009) or Copernicus Riparian Zones (Stoll et al. 2015) LC/LU ID using GIS software to create a visualisation of this matrix in maps. Consisting of 44 classes in the hierarchical 3-level CLC nomenclature, a minimum mapping unit (MMU) for status layers of 25 ha, and a minimum mapping width (MMW) of 100 m, means that Corine Land Cover (CLC) data have greater spatial coverage but a lower resolution. By comparison, the Copernicus Riparian Zone dataset (deriving from satellite images) is based on a pre-defined nomenclature using MAES typology of ecosystems (level 1 to level 4) and CLC that provides 56 distinct thematic classes with an MMU of 0.5 ha and an MMW of 10 m. For this assessment, the MAES level 4 and the original ranking by Stoll et al. (2015) were used and aggregated at the compartment level by rounding their area-weighted mean. Gaps in the dataset were filled with Corine data and ranking by Burkhard et al. (2009). The rankings can be updated with expert opinions or local knowledge about LC/LU classes for specific topics.

Table 2.2.2 Extract of the capacity matrix adapted from Stoll et al. (2015) by applying the MAES level 4 land cover ID (Code04) of the Copernicus Riparian Zones LC/LU. The main categories Ecological Integrity, Regulating Services, Provisioning Services and Cultural Services represent the average value of the underlying ES. The complete Excel sheet is at https://www.interreg-danube.eu/approved-projects/ides/outputs

	Ecological Integrity	Exergy Capture (Radiation)	Entropy production	Storage capacity (SOM)	Reduction of Nutrient loss	Biotic waterflows	Metabolic efficiency	Abiotic heterogeneity	Biodiversity	**Regulating services**	Global climate regulation	Local climate regulation	Air Quality Regulation	Water flow regulation	Water purification	Nutrient regulation	Erosion Regulation	Natural hazard protection	Pollination	Pest and disease control	Regulation of waste
Code04	EI	EI 01	EI 02	EI 03	EI 04	EI 05	EI 06	EI 07	EI 08	RS	RS 01	RS 02	RS 03	RS 04	RS 05	RS 06	RS 07	RS 08	RS 09	RS 10	RS 11
1210	1	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
1220	1	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
1230	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0
1240	1	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1310	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0
1320	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0
1400	3	4	3	2	3	2	1	3	3	1	1	2	1	2	1	1	2	0	1	1	1
2110	3	5	4	4	1	3	4	3	2	1	1	2	0	1	0	0	0	1	1	1	1
2120	3	5	4	4	1	3	4	3	2	1	1	2	0	1	0	0	0	1	1	1	1
2200	3	4	3	3	2	3	2	2	2	1	1	2	1	1	1	0	1	1	0	0	0
2210	2	3	3	2	0	3	2	3	2	1	1	1	1	1	1	0	1	1	1	1	0
2220	3	3	2	3	2	4	2	4	3	2	2	2	2	2	1	1	2	2	5	3	2
2310	3	4	3	3	2	3	2	2	2	1	1	2	1	1	1	0	1	1	0	0	0
2320	3	4	3	3	1	3	2	4	3	1	1	2	0	1	0	0	1	1	1	3	2
2330	3	3	2	3	2	3	2	3	3	2	2	3	1	2	1	0	3	1	1	3	2
2340	4	4	4	4	4	4	3	4	4	1	1	2	1	2	1	1	2	1	3	1	1
3000	4	5	4	5	5	5	4	3	4	4	4	5	5	2	5	5	5	3	4	5	5
3110	4	5	4	5	5	5	4	3	4	4	4	5	5	2	5	5	5	3	4	4	4
3120	4	5	4	5	5	5	4	3	4	4	4	5	5	2	5	5	5	3	4	4	4
3210	4	5	4	5	5	4	4	3	4	4	4	5	5	2	5	5	5	3	4	4	4

	Provisioning services	Crops	Energy (Biomass)	Fodder	Livestock	Fibre	Timber	Wood Fuel	Capture Fisheries	Aquaculture	Wild Foods	Biochemicals / Medicine	Freshwater	Mineral resources	Abiotic energy sources	**Cultural services**	Recreation & Tourism	Landscape aesthetics , amenity and	Knowledge systems	Religious and spiritual experiences	Cultural heritage & cultural diversity	Natural Heritage & natural diversity
Code04	PS	PS 01	PS 02	PS 03	PS 04	PS 05	PS 06	PS 07	PS 08	PS 09	PS 10	PS 11	PS 12	PS 13	PS 14	CS	CS 01	CS 02	CS 03	CS 04	CS 05	CS 06
1210	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1220	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1230	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	1	0	1	0
1240	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1310	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
1320	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
1400	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	2	3	3	1	0	2	0
2110	1	5	3	2	0	2	0	0	0	0	1	1	0	0	0	1	1	1	2	0	2	0
2120	1	5	3	2	0	2	0	0	0	0	1	1	0	0	0	1	1	1	2	0	2	0
2200	2	5	5	5	5	0	1	1	0	0	1	5	0	0	0	1	1	1	1	0	1	1
2210	1	4	4	1	0	0	0	1	0	0	1	2	0	0	0	2	5	2	2	0	3	1
2220	1	5	1	0	0	0	3	3	0	0	1	0	0	0	0	2	5	2	2	0	3	1
2310	2	5	5	5	5	0	1	1	0	0	1	5	0	0	0	1	1	1	1	0	1	1
2320	1	4	1	3	0	3	0	0	0	0	0	1	0	0	0	2	2	2	2	0	3	1
2330	1	3	2	1	2	2	2	2	0	0	3	1	1	0	1	2	2	2	3	0	2	3
2340	2	3	3	2	3	2	3	3	0	0	3	3	1	0	0	2	3	2	2	0	3	3
3000	1	0	1	1	0	0	4	5	0	0	4	4	0	0	0	4	4	5	4	3	3	4
3110	2	0	1	1	0	0	5	5	0	0	5	4	0	0	0	4	5	5	4	3	3	5
3120	2	0	1	1	0	0	5	5	0	0	5	4	0	0	0	4	5	5	4	3	3	5
3210	1	0	1	0	0	0	4	4	0	0	4	3	0	0	0	4	4	5	4	3	4	5

Indicator-based approaches

RESI, the original indicator-based approach from Podschun et al. (2018), requires detailed data about soil parameters, topography, habitat types, etc., and is recommended to be applied wherever these data are available. As specific datasets were not available in all countries of the DRB, the initial calculation for the IDES approach was partly modified. A substitution was made with more widely available data (e.g. EU datasets) or proxies. The objective of the adjustments was to harmonise ES evaluation between the Danube countries, and to provide clear factsheets similar to Podschun et al. (2018). The factsheets describe the detailed evaluation methods of the original RESI approach and the adapted IDES approach described below. The IDES approach was reviewed by the original authors of the RESI project to validate its plausibility. The detailed methods for the quantification of ES in rivers and floodplains can be found at https://www.ufz.de/index.php?en=20939&ufzPublicationIdentifier=25846 (in German). Maps of ES evaluations using the indicator-based approach for the DRB (Chapter 3.1) and the pilot areas of the IDES Project (Chapter 3.2) are included in this Manual.

Factsheets for Indicator-based ES Evaluations

Provisioning Ecosystem Services

Interreg Danube Transnational Programme IDES

Arable Crop Production (API)

Original authors (RESI): A. Denhardt, M. Rayanow and A. Sander

Editors (IDES): FAUNS

Publication Date: November 2021

Interpretation

The indicator describes a usable ecosystem service which takes into account the impact of site conditions (yield potential and flooding regime) on existing arable land. The level of expected crop yields is indicated for the floodplain segments or compartments with reference to their size. For this purpose, the share of arable land in the reference area is multiplied by the respective yield potential. The result is corrected for average losses due to flood risk and then classified using the yield potential scale.

Human input (e.g. fertiliser) is not taken into account; only the natural site conditions. The level of the indicator reflects the possibilities for agricultural production. For example, wheat cultivation is only possible with high and very high yield potential. Due to the reference to the arable land share, the minimum yield in a segment is 0 t/ha.

The risk of flood-related yield losses in the floodplain can be calculated either by using an official flood risk map indicating floods during the agricultural growing season, or based on empirical knowledge about historic crop yield losses. As an example, a 50% crop loss every 5 years due to flooding may experience an average 10% reduction in annual crop yield.

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■ Original approach according to the River Ecosystem Service Index (RESI) (Podschun et al. 2018)

Class	Abbr.	Description	Spatial reference
Provisioning	API	Arable crops grown (e.g. grain, root crops, vegetables and fruit)	Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☐ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
Reference areas (segment or compartment)	A_{Seg} A_{Comp}	ha	Calculation of the area	- Floodplain segment - Floodplain compartment	
Arable land in the floodplain segment (separated into active and former floodplain)	AL_{act} AL_{for}	ha	Calculation of the area: arable land within the reference areas	- Corine Landcover Classification (CLC) - National Land Cover Model - Aerial photographs (optional)	
Site-specific yield potential for agricultural use	YP_i	t/ha	Weighting of arable land according to yield potential	- Agricultural site mapping (describing the value of the site for agricultural use, mainly depending on soil type)	Classification might differ between (federal) states
Flood-induced yield loss	YL_{Fl}	constant	Risk of flooding and yield loss on the active floodplain	- Flood hazard maps HQ_5, HQ_{10} and HQ_{20} - Water level data	Estimate

Calculation

Calculation steps	Indicator
1. Determination of the reference area size for each segment or compartment (j) (GIS); 2. Identification of all arable land (i) within the reference areas (j) from land use data (GIS) differentiated by location (active or former floodplain); 3. Intersection of arable land with agricultural site mapping, or with yield potential data (GIS); 4. Determination of the relevant flood probability for the active floodplain from water level records (tide gauge data) or flood hazard maps (simplified procedure); 5. Calculation of the indicator for each reference area; 6. Classification of the resulting arable crop yield into 5 classes.	Calculation of potential arable land yields within the river-floodplain segments (for j = river-floodplain segments) $API(j) = \sum_{i=1}^{n}(i) \frac{AL_{for_i} * YP_i}{A_{seg_j}} + \frac{AL_{act_i} * YP_i}{A_{seg_j}} * YL_{FI}$ j = 1, 2, …n Floodplain segments/compartments i = 1, 2, …n Partial area within segments/compartments

API	> 4 t/ha	> 3 - 4 t/ha	> 2 - 3 t/ha	> 1 - 2 t/ha	≤ 1 t/ha
Evaluation Class	**5**	**4**	**3**	**2**	**1**
Qualitative Evaluation	**Very High** Yields	**High** Yields	**Average** Yields	**Low** Yields	**Very Low** Yields

■ Adaption for Danube-wide application

Class	Abbr.	Description	Spatial reference
Provisioning	API	Arable crops grown (e.g. grain, root crops, vegetables and fruit)	Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☐ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
Reference areas (segment or compartment)	A_{Seg} A_{Comp}	ha	Calculation of the area	- Floodplain segment - Floodplain compartment	
Arable land in the floodplain segment (separated into active and former floodplain)	AL_{act} AL_{for}	ha	Calculation of the area: arable land within the reference areas	- Corine Landcover Classification (CLC)	
Site-specific yield potential for agricultural use	YP_i	Ordinal (1-5)	Weighting of arable land area according to yield potential	- Agricultural site mapping (describing the value of the site for agricultural use, mainly depending on soil type)	Classification might differ between (federal) states
Flood-induced yield loss	YL_{Fl}	constant	Yield loss on the active floodplain due to flooding	- Flood hazard maps HQ_5, HQ_{10}, HQ_{20}	Estimate

Calculation

Calculation steps	Indicator
1. Determination of the reference area size for each segment or compartment (j) (GIS); 2. Identification of all arable land (i) within the reference areas (j) from land use data (GIS), with differentiation according to location (active or former floodplain); 3. Intersection of arable land with yield potential data (GIS); 4. Determination of relevant flood probability for the active floodplain from flood hazard maps (simplified procedure) (GIS); 5. Calculation of the indicator for each reference area; 6. Classification of the resulting arable crop index into 5 classes.	Calculation of potential of arable land yields within the river-floodplain segments (for j = river-floodplain segments) $API(\mathrm{j}) = \sum_{i=1}^{n}(i)\frac{AL_{for_i} * YP_i}{A_{seg_j}} + \frac{AL_{act_i} * YP_i}{A_{seg_j}} * YL_{FI}$ j = 1, 2, …n Floodplain segments/compartments i = 1, 2, …n Partial area within segments/compartments

API	> 0.8 of max (API)	> 0.6 - 0.8 of max (API)	> 0.4 - 0.6 of max (API)	> 0.2 - 0.4 of max (API)	≤ 0.2 of max (API)	0
Evaluation Class	**5**	**4**	**3**	**2**	**1**	**0**
Qualitative Evaluation	**Very High** Yields	**High** Yields	**Average** Yields	**Low** Yields	**Very Low** Yields	**No agriculture**

■ Data sources

Data set	Data type	Spatial reference	Spatial resolution	Source	Creation date	Comments
A_{Seg}, A_{Comp}	Polygons	International / Former FP	1-10 km	River-floodplain segments	2021	
AL_{Act}, AL_{For}	Polygons	International	Minimum Mapping Unit: 25 ha	CLC_2018	2020	
YP classes	Polygons	National/ International		National soil datasets for Austria, Slovenia, and Serbia; SGDB for the other countries		YP is a relative value based on official soil fertility classification ranging from 1 = very low to 5 = very high. The classification was based on the opinions of soil experts and https://esdac.jrc.ec.europa.eu/public_path/shared_folder/dataset/45_biomass_prod/SoilProd_model_soiltype_tables.xlsx
YL_{FL} classes	Polygons	Active floodplain		National datasets (Romania, Austria, Germany, Hungary, Slovenia); http://www.geo.u-szeged.hu/dfgis/ for Serbia	2020	YL_{Fl} is defined as the average annual yield loss due to flooding. The calculation was not performed for AFP where data about flooding probability is missing (Croatia, Bulgaria, Slovenia (Sava).

Interreg
Danube Transnational Programme
IDES

Plant Biomass - Grassland (PBI)

Original authors (RESI): A. Denhardt, M. Rayanow and A. Sander

Editors (IDES): FAUNS

Publication date: November 2021

Interpretation

The indicator describes the usable biomass yield ecosystem service obtained from pastures and meadows, taking into account the site-specific conditions (yield potential and flooding regime) of grassland areas. Depending on their size, it indicates the level of grassland yields expected from floodplain segments or compartments. For this purpose, the proportion of grassland in the reference area is multiplied by the respective yield potential. The result is then classified. Due to the reference to the grassland share, the minimum yield in a segment may take the value of 0 kStE/ha (River Ecosystem Service Index) or < 0.2 of max [=1] (IDES). In a case where no grasslands exist in the respective segment/compartment, an evaluation classification of '0' should be assigned (as introduced in the Danube-wide assessment). Human input (e.g., fertiliser) is not taken into account; only the natural site conditions are included.

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■ **Original approach according to the River Ecosystem Service Index (RESI) (Podschun et al. 2018)**

Class	Abbr.	Description	Spatial reference
Provisioning	PBI	Plant biomass used for agricultural purposes (yield of meadows and pastures)	Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☐ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
Reference areas (segment or compartment)	A_{Seg} A_{Comp}	ha	Calculation of the area	- Floodplain segment - Floodplain compartment	
Grassland in the floodplain segment (separated into active and former floodplain)	GL_{act} GL_{for}	ha	Calculation of area: grassland area within the reference areas	- Corine Landcover Classification (CLC) - National Land Cover Model - Aerial photographs (optional)	
Site-specific yield potential of meadows and pastures	YP_i	kStU/ha (kilo starch units /ha)	Weighting of grassland area according to yield potential	- Agricultural site mapping (describing the value of the site for agricultural use, mainly depending on soil type)	Classification might differ between (federal) states
Flood-induced yield loss (restricted use)	YL_{Fl}	Constant	Risk of flooding and yield loss on the active floodplain	- Flood hazard maps HQ_5, HQ_{10}, HQ_{20} - Water level data	Estimate

Calculation

Calculation steps	Indicator
1. Determination of the reference area size for each segment or compartment (j) (GIS); 2. Identification of all grassland (i) within the reference areas (j) from land use data (GIS), and differentiated according to location (active or former floodplain); 3. Intersection of arable land with agricultural site mapping, or with data on yield potential (GIS); 4. Determination of the relevant flood probability for the active floodplain from water level records (tide gauge data) or flood hazard maps (simplified procedure); 5. Calculation of the indicator for each reference area; 6. Classification of the resulting arable yield into 5 classes.	Calculation of potential yields from meadows and pastures within the river-floodplain segments (for j = river-floodplain segments) $$PBI\ (j) = \sum_{i=1}^{n}(j)\frac{GL_{for_i} * YP_i}{A_{seg_j}} + \frac{GL_{act_i} * YP_i}{A_{seg_j}} * YL_{FI}$$ j = 1, 2, …n Floodplain segments/compartments i = 1, 2, …n Partial area within segments/compartments

PBI	> 4300 kStU/ha	> 3700 - 4300 kStU/ha	> 3100 - 3700 kStU/ha	> 2500 - 3100 kStU/ha	< 2500 kStU/ha
Evaluation Class	5	4	3	2	1
Qualitative Evaluation	**Very High** Yields	**High** Yields	**Average** Yields	**Low** Yields	**Very Low** Yields

■ Adaption for Danube-wide application

Class	Abbr.	Description	Spatial reference
Provisioning	PBI	Plant biomass used for agricultural purposes (yield from meadows and pastures)	Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☐ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
Reference areas (segment or compartment)	A_{Seg} A_{Comp}	ha	Calculation of the area	- Floodplain segment - Floodplain compartment	
Grassland in the floodplain segment (separated into active and former floodplain)	GL_{act} GL_{for}	ha	Calculation of area: grassland area within the reference areas	- Corine Landcover Classification (CLC)	
Site-specific yield potential of meadows and pastures	YP	Ordinal (1-5)	Weighting of grassland area according to yield potential	- Agricultural site mapping (describing the value of the site for agricultural use, mainly depending on soil type)	Classification might differ between (federal) states
Flood-induced yield loss (restricted use)	YL_{Fl}	Constant	Risk of flooding and yield loss on the active floodplain	- Flood hazard maps HQ_5, HQ_{10}, HQ_{20}	Estimate

Calculation

Calculation steps	indicator
1. Determination of the reference area size for each segment or compartment (j) (GIS); 2. Identification of all grassland (i) within the reference areas (j) from land use data (GIS), and differentiated according to location (active or former floodplain); 3. Intersection of grassland with agricultural site mapping, or use of data on yield potential (GIS); 4. Determination of the relevant flood probability for the active floodplain from flood hazard maps (simplified procedure) (GIS); 5. Calculation of the indicator for each reference area; 6. Classification of the resulting production biomass index into 5 classes.	Calculation of potential yields from meadows and pastures within the river-floodplain segments (for j = river-floodplain segments) $\boldsymbol{PBI\ (j) = \sum_{i=1}^{n}(j)\frac{GL_{for_i} * YP_i}{A_{seg_j}} + \frac{GL_{act_i} * YP_i}{A_{seg_j}} * YL_{FI}}$ j = 1, 2, …n Floodplain segments/compartments i = 1, 2, …n Partial area within segments/compartments

PBI	> 0.8 of max (PBI)	> 0.6 - 0.8 of max(PBI)	> 0.4 - 0.6 of max(PBI)	> 0.2 - 0.4 of max(PBI)	≤ 0.2 of max (PBI)	0
Evaluation Class	**5**	**4**	**3**	**2**	**1**	**0**
Qualitative Evaluation	**Very High** Yields	**High** Yields	**Average** Yields	**Low** Yields	**Very Low** Yields	**No grasslands**

■ **Data sources**

Data set	Data type	Spatial reference	Spatial resolution	Source	Creation date	Comments
A_{Seg}, A_{Comp}	polygons	International / Former FP	1-10 km	river-floodplain segments	2021	
GL_{Act}, GL_{For}	polygons	International	Minimum Mapping Unit: 25 ha	Corine land cover 2018 https://land.copernicus.eu/pan-european/corine-land-cover/clc2018	2020	
YP classes	polygons	National/ International		National soil datasets for Austria, Slovenia, and Serbia; SGDB for the other countries		YP is a relative value based on official soil fertility classification ranging from 1 = very low to 5 = very high. The classification is founded on the opinions of soil experts and https://esdac.jrc.ec.europa.eu/public_path/shared_folder/dataset/45_biomass_prod/SoilProd_model_soiltype_tables.xlsx
YL_{FL} classes	polygons	Active floodplain		National datasets (Romania, Austria, Germany, Hungary, Slovenia); http://www.geo.u-szeged.hu/dfgis/ for Serbia	2020	YL_{Fl} is defined as the average annual yield loss due to flooding. Calculations were not performed for AFP where data about flooding probability was missing (Croatia, Bulgaria, Slovenia (Sava).

Interreg Danube Transnational Programme IDES	**Commercial Fishing (CFI)** **Author (IDES):** G. Costea (IGB) **Publication date:** November 2021

Interpretation

The indicator, based on fish catch data as a multi-annual average, describes the commercial fishing yield as an ecosystem service. The indicator represents the weight of fish catch in the respective river segment. Fish catch data are usually available for only certain fishing sectors. In cases where there are several river sections with different fish yields, the values must be weight-averaged for the respective river segment. As an alternative to fish catch, the Total Allowable Catch (TAC) can be used where such data exist. TAC denotes the maximum fishing limits for certain fish species during a certain time period according to fisheries management plans.

Class	Abbr.	Description	Spatial reference
Provisioning	CF	The indicator assesses the commercial fishing ecosystem service based on fish catch data (as a multi-annual average) or Total Allowable Catch (TAC) in river fishing sectors.	Floodplain segment or compartment ☒ potential floodplain ☒ active floodplain ☐ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
Reference river segment	R_{seg}	m	Determination of the river segment	Floodplain segments	
Fishing section along the river	FS_{seg}	m	Calculation of the length of the fishing section within the reference river segment	Navigational map, land use map or topographic map	
Fish catch, or Total Allowable Catch in the fishing sections	FC_i	t km^{-1} $year^{-1}$	Statistics on the average annual commercial fishing yield, Normative Acts with Total Allowable Catch	Average multi-annual fish caught, Total Allowable Catch	

Calculation

Calculation steps	Indicator
1. Determination of the reference river segment (j) (GIS); 2. Identification of the fishing sectors (i) within the reference river segment (j) from River Km Map data (GIS); 3. Intersection of the fishing sectors with fish catch data (GIS); 4. Calculation of the indicator for each reference river segment; 5. Classification of the resulting yield into 5 classes.	Calculation of commercial fishing for river segments (for j = 1, 2, ...n river segments): $$Ind_{CF}\ (j) = \sum_{i=1}^{n}(j)\frac{FS_{seg,i} * FC_i}{R_{seg,j}}$$ j = 1, 2,...m River segments i = 1, 2, ...n Sub-segments (fishing sector) within the reference floodplain area in the respective segment

Ind_{CF}	> 80%	> 60% - 80%	> 40% - 60%	> 20% - 40%	≤ 20%	0
Evaluation Class	**5**	**4**	**3**	**2**	**1**	**0**
Qualitative Evaluation	**Very High** Catch	**Above Average** Catch	**Average** Catch	**Below-average** Catch	**Very Low** Catch	**No** Catch

Interreg Danube Transnational Programme IDES

Timber Production (TPI)

Author (IDES): G. Costea (IGB)

Publication date: November 2021

Interpretation

The indicator describes timber production as an ecosystem service, and is based on data relevant to the yield (as a multi-annual average) of timber harvested from forest used for commercial purposes. The value indicates the mass of harvested wood in the respective floodplain area in relation to the size of the timber stands in forest management plans. For this purpose, the areal share of the timber stands in forest management plans for a floodplain segment (or compartment) area is multiplied by the respective yield. The result of the calculation is classified using a yield scale. Alternatively, wood increment (growth) data or Timber Quotas (TQ) for wood harvest in commercial forest can be used if available. Since wood harvest tends to occur only irregularly, values should represent multi-annual averages e.g. for 10-year periods.

Class	Abbr.	Description	Spatial reference
Provisioning	TP	The indicator describes timber production based on yield data (as a multi-annual average) obtained for harvested timber from commercial forest.	Floodplain segment or compartment ☒ potential floodplain ☒ active floodplain ☐ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
Reference floodplain area in the whole segment, or in the compartment (active or potential floodplain)	A_{seg} A_{AFPseg} A_{PFPseg}	ha	Determination of the active floodplain and potential floodplain areas within the segment	100-year flood inundation maps for floodplain segments (e.g. those produced under the EU Flood Risk Management Directive)	
Forest management planning (stands/sections) in compartments (active and potential floodplain)	FS_{seg} FS_{AFPseg} FS_{PFPseg}	ha	Determination of the commercial forest area of within the reference floodplain area	Forest Cover Map	
Harvested wood or Timber Quotas from the forests managed for timber production	HW_i	t ha^{-1} year^{-1}	Weight of the harvested timber, Normative Acts with Timber Quotas	Harvested wood mass data, Timber Quotas (TQ)	

Calculation

Calculation steps	Indicator
1. Determination of the reference floodplain area size for each segment (j) (in GIS); 2. Identification of the forest stands (i) within the reference floodplain areas (j) from Forest Cover Map data (GIS), and differentiated according to location (active or potential floodplain); 3. Overlay of timber stands in forest management plans with data on yield/harvested timber mass (in GIS); 4. Calculation of the indicator for the reference floodplain areas in the active or potential floodplains; 5. Classification of the resulting yield into 5 classes.	Calculation of the timber production for floodplain segments (for j = 1, 2, ...n floodplain segments): $Ind_{TP}\ (j) = \sum_{i=1}^{n} (j) \frac{FS_{seg,i} * HW_i}{A_{seg,j}}$ j = 1, 2, ...m Floodplain segments i = 1, 2, ...n Sub-areas (forest management planning stands) within the reference floodplain area in the respective segment

Ind_{TP}	> 80%	> 60% - 80%	> 40% - 60%	> 20% - 40%	≤ 20%	0
Evaluation Class	5	4	3	2	1	0
Qualitative Evaluation	**Very High** Yield	**Above Average** Yield	**Average** Yield	**Below Average** Yield	**Very Low** Yield	**No** yield

Interreg Danube Transnational Programme IDES	**Commercial Hunting (CHI)** **Author (IDES):** G. Costea (IGB) **Publication Date:** November 2021

Interpretation

This ecosystem service only describes food availability from hunting. Recreation and experiences obtained through hunting is covered elsewhere under Cultural Ecosystem Services. The indicator is based on hunting yield data as a multi-annual average of harvest data for wild animals. It indicates the amount of wild animal meat withdrawal in relation to the size of hunting zones in the respective floodplain area; either for the whole segment, or just the respective compartment (active or potential floodplain). For this purpose, the areal share of the hunting zones in the reference area is multiplied by the respective areal yield. The result of the calculation is then classified using a yield scale. As an alternative to the hunting yield, Harvest Quotas (HQ) can be used where available. Harvest Quotas represent the number of animals that can be harvested based on the estimation of animal population sizes.

Class	Abbr.	Description	Spatial reference
Provisioning	HF	The indicator assesses hunting for food as an ecosystem service based on hunting yield data (as a multi-annual average) from potential hunting areas.	Floodplain segment or compartment ☒ potential floodplain ☒ active floodplain ☐ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
Reference floodplain area in the respective segment or compartment (active or potential floodplain)	A_{seg} A_{AFPseg} A_{PFPseg}	ha	Determination of active floodplain area, potential floodplain segment	100-year flood inundation maps of floodplain segments	
Hunting area in total segment or compartments (active and potential floodplain)	HA_{seg} HA_{AFPseg} HA_{PFPseg}	ha	Determination of the hunting zone within the reference floodplain areas	Hunting Areas Map or land use map	
Hunting yield or Harvest Quotas from the hunting areas	HY_i	no ha^{-1} $year^{-1}$	Statistics on commercial hunting, Normative Acts with Harvest Quotas	Average annual data on harvest of wild animals	

Calculation

Calculation steps	Indicator
1. Determination of the reference floodplain area size for each segment (j) (in GIS); 2. Identification of hunting areas (i) within the reference floodplain areas (j) using Hunting Areas Map data (GIS) or land use data (e.g. forest, rangeland and wetlands); and differentiated according to compartment (active or potential floodplain); 3. Overlay of hunting area with yield data/average annual harvest data for wild animals (in GIS); 4. Calculation of the indicator for each reference floodplain area; 5. Classification of the resulting yield into 5 classes.	Calculation of commercial hunting for floodplain segments (for j = 1, 2, ...n floodplain segments): $$Ind_{CH}(j) = \sum_{i=1}^{n}(j)\frac{HA_{seg,i} * HW_i}{A_{seg,j}}$$ j = 1, 2,…m Floodplain segments i = 1, 2, …n Sub-areas (hunting zones) within the reference floodplain area for the respective segment

Ind_{HF}	> 80%	> 60% - 80%	> 40% - 60%	> 20% - 40%	≤ 20%	0
Evaluation Class	5	4	3	2	1	0
Qualitative Evaluation	**Very High** Yield	**Above Average** Yield	**Average** Yield	**Below Average** Yield	**Very Low** Yield	**No** yield

Factsheets for Indicator-based ES Evaluations

Regulation and Maintenance Ecosystem Services

Danube Transnational Programme IDES

Nitrogen Retention (NRI)

Original authors (RESI): S. Ritz, H. Fischer, K. Linnemann, A. Becker, H.D. Kasperidus, M. Scholz, C. Schulz-Zunkel and M. Venohr

Editors (IDES): BOKU-IHG

Publication date: July 2022

Interpretation

The indicator describes the self-purification performance of a river-floodplain section with regard to the retention of introduced nitrogen. The value is comprised by the permanent removal of N through denitrification or the temporal retention of N as biomass or deposited material. In addition, it denotes the extent to which the N load of the water is reduced. Different turnover rates in different compartments (river or active floodplain) can be considered in the indicator according to their areal fractions. Inputs via nitrogen-fixing bacteria (e.g. cyanobacteria) can be considered as an additional variable.

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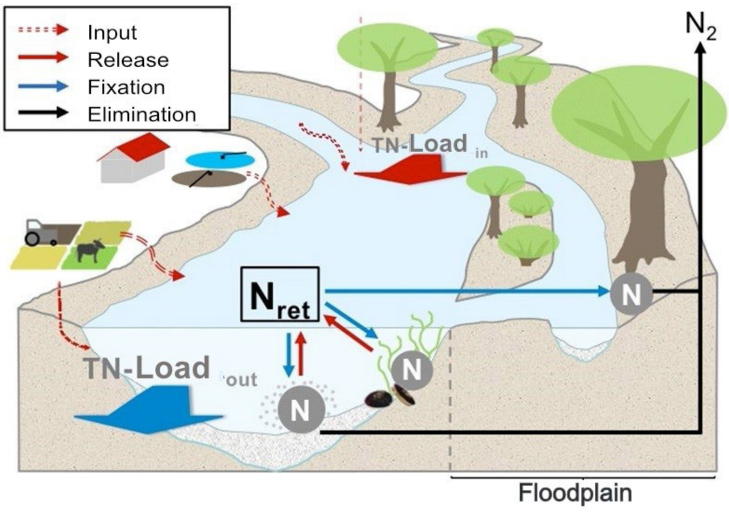
■ Original approach according to the River Ecosystem Service Index (RESI) (Podschun et al. 2018)

Class	Abbr.	Description		Spatial reference	
Regulation and Maintenance	N_{ret}	Permanent elimination of nitrogen (N) by denitrification (conversion to N_2), temporary retention by incorporation into stationary biomass (e.g. mussels and floodplain vegetation), or in sediments.		Floodplain segment or compartment ☐ former floodplain ☒ active floodplain ☒ river	
Variable	**Abbr.**	**Unit**	**Variable description**	**Data basis**	**Comment**
N-load	N_{load}	t a^{-1} at the inlet of the 1 km river section	Annual mean N-load entering the river-floodplain section	Modelling (QSim (BfG 2012) and/or MONERIS (Venohr et al. 2011), or calculations from monitoring data	
Retention/Release (+/-) of N in the river	RetR	t a^{-1} per 1 km river section	Annual N retention in the river section by denitrification, uptake into stationary biomass or into sediments	Modelling (QSim and/or MONERIS) or direct measurements	(+) in case of retention (-) in case of release
Retention of N in the active floodplain	RetFP	t a^{-1} per 1 km floodplain section	Annual N retention in the floodplain section by denitrification	Modelling (Schulz-Zunkel et al. 2012)	(+) No release is modelled in floodplains

Calculation

Pathways of N in rivers and on floodplains	Indicator



$$Nret = \frac{\sum(RetR, RetFP)}{N_{load}} * 1000$$

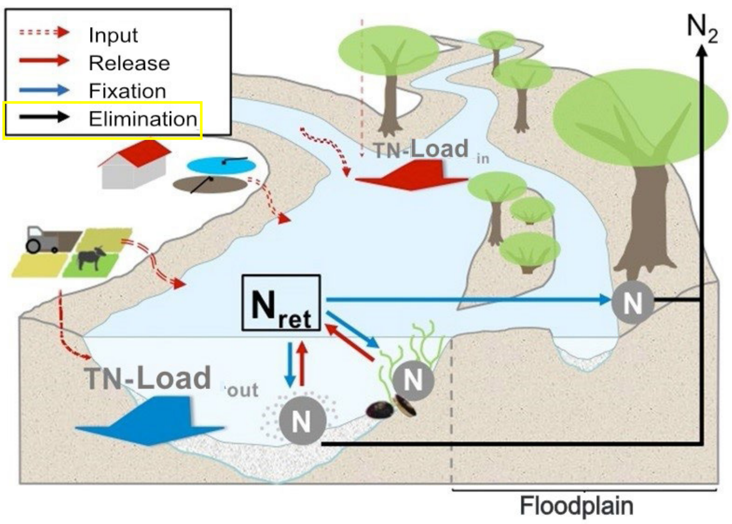
Scaling ☒ national ☐ local	Ind_{Nret} [‰]	> 0.4	> 0.2 - 0.4	> 0.06 - 0.2	> 0 - 0.06	≤ 0
Evaluation Class (Scale for discharges between 100 and 1000 $m^3 \cdot s^{-1}$)		**5**	**4**	**3**	**2**	**1**
Qualitative Evaluation		**Very High** Retention	**High** Retention	**Moderate** Retention	**Low** Retention	**Release or No** Retention

■ Adaption for Danube-wide application

Class	Abbr.	Description	Spatial reference
Regulation and Maintenance	N_{ret}	Permanent elimination of nitrate (NO_3) by denitrification in floodplains and rivers. NO_3 is the dominant N compound in the Danube River and substrate for denitrification.	Floodplain segment or compartment ☐ former floodplain ☒ active floodplain ☒ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
NO_3-load	N_{load}	t a^{-1} at the inlet of the 1 km river section	Annual mean NO_3-load entering the river-floodplain section	Modelling MONERIS (Venohr et al. 2011)	
Retention of DIN in the river	RetR	t a^{-1} per 1 km river section	Annual DIN retention in the river section	Modelling (MONERIS)	
Retention of NO_3 in the active floodplain	RetFP	t a^{-1} per 1 km floodplain section	Annual denitrification potential in the floodplain section during floods	Modelling considering flooding frequency (Tschikof et al. 2022)	

Calculation

Pathways of N in rivers and floodplains	Indicator
	$$Nret = \frac{\sum(RetR, RetFP)}{N_{load}} * 1000$$

Scaling ☒ national ☐ local	Quintiles of Ind_{Nret} (values in the DRB*)	**0.8 - 1** (> 3.9 ‰)	**0.6 - 0.8** (2.4 - 3.9 ‰)	**0.4 - 0.6** (1.8 - 2.4 ‰)	**0.2 - 0.4** (1.4 - 1.8 ‰)	**0 - 0.2** (< 1.4 ‰)
Evaluation Class		5	4	3	2	1
Qualitative Evaluation		**Very High** Retention	**High** Retention	**Moderate** Retention	**Low** Retention	**Very Low or No** Retention

*Quintile boundaries refer to calculations in the DRB (Chapter 2.2.5)

■ Data sources

Data set	Data type	Spatial reference	Spatial resolution	Source	Creation date	Comments
N_{load} Output table from MONERIS	Table	International/ rivers	Analytical units (AU)		2021	Intersection of AU (MONERIS) with river-floodplain segments
RetR MONERIS: discharge, water temperature, water surface area	Table	International/ rivers	Analytical units	Water surface area: https://land.copernicus.eu/local/riparian-zones/riparian-zones-2018	2021	
RetFP Soil organic carbon (SOC)	Raster	International/ Active FP	1 km	https://esdac.jrc.ec.europa.eu/content/european-soil-database-v2-raster-library-1kmx1km	2006	
RetFP Soil pH	Raster	International/ Active FP	500 m	https://esdac.jrc.ec.europa.eu/content/chemical-properties-european-scale-based-lucas-topsoil-data	2019	
RetFP Soil clay and silt content	Raster	International/ Active FP	1km	https://esdac.jrc.ec.europa.eu/content/european-soil-database-derived-data	2013	
RetFP Soil temperature	Raster	International/ Active FP	10km	https://www.ecad.eu/download/ensembles/download.php	2011-2019	
RetFP Soil mositure	Raster	International/ Active FP	10 m	https://land.copernicus.eu/pan-european/high-resolution-layers/water-wetness/status-maps/water-wetness-2018	2018	
RetFP Flooding frequency	Raster	International/ AFP	30 m	EU DTM: https://doi.org/10.5281/zenodo.4057883	2020	https://asnevents.s3.amazonaws.com/Abstrakt-FullPaper/25266/56778058d89c3-1046-564e91e004326-schleuter-25266_REV2overREV1-RE-WORK5.pdf

Interreg Danube Transnational Programme IDES	**Phosphorus Retention (PRI)** **Original authors (RESI):** S. Ritz, H. Fischer, K. Linnemann, A. Becker, H.D. Kasperidus, M. Scholz, C. Schulz-Zunkel, M. Venohr and M. Wildner **Editors (IDES):** BOKU-IHG **Publication date:** November 2021

Interpretation

The indicator describes the self-purification performance of a river-floodplain section with regard to the retention of introduced phosphorus. The value represents the extent to which the P-load of the water is reduced. Different turnover rates in different compartments (e.g. river and active floodplain) can be be used in the calculation. If hydrological data on flood duration and phosphorus concentrations are available, they can also be integrated into the models/proxies to supplement the calculations for retention in the floodplain.

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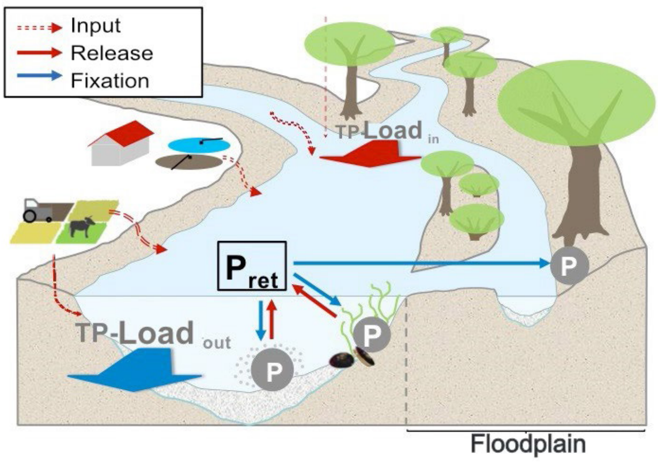
■ Original approach according to the River Ecosystem Service Index (RESI) (Podschun et al. 2018)

Class	Abbr.	Description	Spatial reference
Regulation and Maintenance	P_{ret}	Temporary retention of phosphorus (P) by incorporation into stationary biomass (e.g. bivalves, macrophytes and floodplain vegetation), or by deposition and sorption. For rivers with discharges between 100 and 1000 m^3s^{-1}.	Floodplain segment or compartment ☐ former floodplain ☒ active floodplain ☒ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
P-load	P_{load}	t a^{-1} at the inlet of the 1 km river section	Annual mean P-load entering the river-floodplain section	Modelling (QSim (BfG 2012) and/or MONERIS (Venohr et al. 2011), or calculations from monitoring data	
Retention/Release (+/-) of P in the river	RetR	t a^{-1} per 1 km river section	Annual P retention in the river section by uptake into stationary biomass or into sediments	Modelling (QSim and/or MONERIS) or direct measurements	(+) in case of retention (-) in case of release
Retention of P in the active floodplain	RetFP	t a^{-1} per 1 km floodplain section	Annual P retention in the floodplain section deposited during floods	Modelling (Schulz-Zunkel et al. 2012)	(+) No release is modelled in floodplains

<table>
<tr><th colspan="7">Calculation</th></tr>
<tr><th colspan="3">Pathways of P in rivers and floodplains</th><th colspan="4">Indicator</th></tr>
<tr><td colspan="3">
</td><td colspan="4">$$Pret = \frac{\sum(RetR, RetFP)}{P_{load}} * 1000$$</td></tr>
<tr><td>Scaling
☒ national
☐ local</td><td>IndInd_{Pret}
[‰]</td><td>> 0.05</td><td>> 0.02 - 0.05</td><td>> 0.005 - 0.02</td><td>> 0 - 0.005</td><td>≤ 0</td></tr>
<tr><td colspan="2">Evaluation Class
(Scale for discharges between 100 and 1000 m^3s^{-1})</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td colspan="2">Qualitative Evaluation</td><td>Very High Retention</td><td>High Retention</td><td>Moderate Retention</td><td>Low Retention</td><td>Release or No Retention</td></tr>
</table>

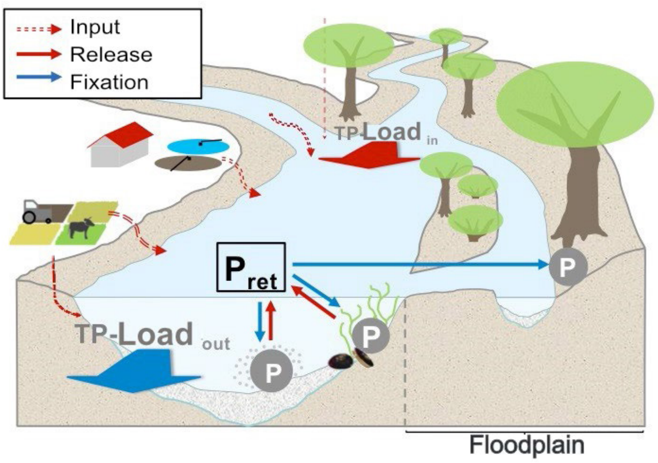
■ Adaption for Danube-wide application

Class	Abbr.	Description	Spatial reference
Regulation and Maintenance	P_{ret}	Temporary retention of phosphorus (P) using semi-empirical models and the deposition potential in floodplains	Floodplain segment or compartment ☐ former floodplain ☒ active floodplain ☒ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
P-load	P_{load}	t a^{-1} at the inlet of the 10 km river section	Annual mean P-load entering the river-floodplain section	Modelling (MONERIS (Venohr et al. 2011) or calculations from monitoring data.	
Retention of P in the river	RetR	t a^{-1} per 10 km river section	Annual P retention in the river section by uptake into stationary biomass or into sediments	Modelling (MONERIS)	
Retention of P in the active floodplain	RetFP	t a^{-1} per 10 km floodplain section	Annual P retention in the floodplain section by deposition during floods	Modelling (Schulz-Zunkel et al. 2021) considering flooding frequency (Schleuter 2016)	

Calculation

Pathways of P in rivers and floodplains



Indicator

$$Pret = \frac{\sum(RetR, RetFP)}{P_{load}} * 1000$$

Scaling ☒ national ☐ local	Quintiles of Ind_{Pret} (values in the DRB*)	0.8 - 1 (> 4.3 ‰)	0.6 - 0.8 (2.6 - 4.3 ‰)	0.4 - 0.6 (2.0 - 2.6 ‰)	0.2 - 0.4 (1.6 - 2.6 ‰)	0 - 0.2 (< 1.6 ‰)
Evaluation Class		5	4	3	2	1
Qualitative Evaluation		**Very High** Retention	**High** Retention	**Moderate** Retention	**Low** Retention	**Very Low or No** Retention

*Quintile boundaries refer to calculations in the DRB (Chapter 2.2.5)

■ **Data sources**

Data set	Data type	Spatial reference	Spatial resolution	Source	Creation date	Comments
P_{load} Output table from MONERIS	Table	International / rivers	Analytical units (AU)		2021	Intersection of AU (MONERIS) with river-floodplain segments
RetR MONERIS: discharge, slope, water surface area	Table	International / rivers	AU	Water surface area: https://land.copernicus.eu/local/riparian-zones/riparian-zones-2018	2021	
RetFP Copernicus riparian zones LCLU (MAES_1)	Polygon	International / Active FP	Minimum Mapping Unit: 0.5 ha Minimum Mapping Width: 10 m	https://land.copernicus.eu/local/riparian-zones/riparian-zones-2018	2012	
RetFP Corine Land Cover (CLC 2018)	Polygon	International / Active FP	Minimum Mapping Unit: 25 ha	https://land.copernicus.eu/pan-european/corine-land-cover/clc2018	2018	
RetFP Flooding frequency	Raster	International / Active FP	30 m	EU DTM: https://doi.org/10.5281/zenodo.4057883	2020	https://asnevents.s3.amazonaws.com/Abstrakt-FullPaper/25266/56778058d89c3-1046-564e91e004326-schleuter-25266_REV2overREV1-RE-WORK5.pdf

Interreg Danube Transnational Programme IDES

Greenhouse Gas Regulation and Carbon Sequestration in Bogs (GHG)

Original authors (RESI): D. Mehl, T. G. Hoffmann and J. Iwanowski

Editors (IDES): BOKU-IHG

Publication date: November 2021

Interpretation

The indicator represents fluctuations of carbon dioxide, methane and nitrous oxide, and takes into account the fact that organic peat soils are capable of naturally sequestering large quantities of carbon dioxide. Due to intensive land use and drainage measures, bogs have often lost their natural function as carbon sinks and now represent a significant source of greenhouse gases worldwide.

If data is available on areas experiencing fluctuating water levels due to renaturation in organic river floodplains, or at organic stream types (potential new sites of peatland formation or areas of peatland activation), these can be included in the assessment. In this case, the intended or realised change of land use should be taken into account.

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■ Original approach according to the River Ecosystem Service Index (RESI) (Podschun et al. 2018)

Class	Abbr.	Description		Spatial reference
Regulation and Maintenance	GHGI	Fluctuation of CO_2, CH_4 and N_2O (as CO_2-equivalents), and sequestration in bogs.		Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☐ river
Variable	**Abbr.**	**Unit**	**Variable description**	**Data basis**
Individual bog area	A_i	ha	Bog area in the morphological floodplain with assigned land cover	Floodplain segments Analysis of the soil potential Land cover/land use
Total bog area	A_{tot}	ha	Total bog area	Analysis of soil potential
Global warming potential (GWP100)	GWP_i	kg CO_2 eq $ha^{-1} \cdot a^{-1}$	as CO_2 equivalent corresponding to land use for area (i)	According to Höper (2007), Schäfer (2009) and Couwenberg et al. (2008); and slightly modified according to Scholz et al. (2012), Mehl et al. (2013)

Calculation

Indicator	Global warming potential (GWP100)		
Calculation of the area-weighted mean value of emissions from peatland areas in the floodplain segment:	**LC/LU**	**Assigned fen use**	**GWP100 in kg CO_2 eq $ha^{-1} \cdot a^{-1}$**
$$GHGI = \sum_{i=1}^{n} \frac{A_i}{A_{tot}} * GWP_i$$	Arable land	Arable land	**24,000**
	Wetlands	Natural/unused	**4,921**
	Waterbodies	No GWP	**0**
	Grassland	Grassland	**23,678**
	Settlements	Others	**17,835**
	No vegetation	Others	**17,835**
	Forest	Forest	**17,835**

Scaling ☒ **national** ☐ **local**	*GHGI*	**< 8,737** kg CO_2 eq $ha^{-1}a^{-1}$	**≥ 8,737** **-** **< 12,553** kg CO_2 eq $ha^{-1}a^{-1}$	**≥ 12,553** **-** **< 16,368** kg CO_2 eq $ha^{-1}a^{-1}$	**≥ 16,368** **-** **< 20,184** kg CO_2 eq $ha^{-1}a^{-1}$	**≥ 20,184** kg CO_2 eq $ha^{-1}a^{-1}$
Evaluation Class		**5**	**4**	**3**	**2**	**1**
Qualitative Evaluation		**Very Low** GHG Emission	**Low** GHG Emission	**Moderate** GHG Emission	**High** GHG Emission	**Very High** GHG Emission

■ Adaption for Danube-wide application

Class	Abbr.	Description	Spatial reference
Regulation and Maintenance	GHGI	Fluctuation of CO_2, CH_4 and N_2O (as CO_2-equivalents); and sequestration in peat soils	Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☒ river

Variable	Abbr.	Unit	Variable description	Data basis
Global warming potential (GWP100)	*GWP_i*	kg CO_2 eq $ha^{-1}\cdot a^{-1}$	GWP as CO_2 equivalent from intrinsic emission factors (IEF) corresponding to land use for area (i) in floodplain segments	Land cover/land use GWP according to UBA (2021): https://www.umweltbundesamt.de/sites/default/files/medien/5750/publikationen/2021-05-19_cc_43-2021_nir_2021_1.pdf
Carbon sequestration of peat soil	CSP_i	kg CO_2 eq $ha^{-1}\cdot a^{-1}$	Carbon sequestration rates in peatlands for area (i) in floodplain segments	Floodplain segments Carbon sequestration of peat soils according to Holmberg et al. (2021): https://doi.org/10.1016/j.scitotenv.2021.146668

Calculation

Indicator

Calculation of the area-weighted mean value of emissions from peatland areas in the floodplain segment:

$$GHGI = \sum_{i=1}^{n} GWP_i - CSP_i$$

Emission factors (according to UBA 2021 and Holmberg et al. 2021)

	CO2-onsite + DOC t CO2-C /ha/yr		CH4_land + CH4_ditch kg CH4 /ha/yr			N2O-onsite kg N2O-N/ha/yr			total CO2 eq. t/ha/yr
LC/LU Peat soil	**Implicit Emission Factor**	**95%-Perzentile**	**Implicit Emission Factor**	**95%-Perzentile**	**CH4 in CO2 eq. t/ha/yr (eq=28)**	**Implicit Emission Factor**	**95%-Perzentile**	**N2O in CO2 eq. t/ha/yr (eq=265)**	
Forest	2.57	(2.0 - 3.2)	4.91	(1.3 - 10.3)	0.14	2.75	(-0.6 - 6.0)	0.73	**3.44**
Agriculture	9.2	(5.2 - 11.0)	16.13	(6.9 - 30.9)	0.45	11	(1.8 - 40.1)	2.92	**12.57**
Grassland	7.5	(0.8 - 10.6)	46.85	(18.8 - 254)	1.31	4.49	(0.3 - 21.6)	1.19	**10.00**
Shrubs	2.55	(2.0 - 3.2)	6.56	(2.1 - 13.5)	0.18	2.73	(-0.6 - 6.0)	0.72	**3.46**
Wetlands	5.06	(0.3 - 10.3)	163.71	(3.5 - 371.8)	4.58	0.69	(-0.1 - 2.8)	0.18	**9.83**
Settlements	7.19	(3.4 - 9.1)	30.83	(12.8 - 59.2)	0.86	2.26	(0.1 - 10.9)	0.60	**8.65**
Water bodies	0		0		0	0		0	**0.00**
Uptake peat	-0.43	(-0.14-0.72)							**-0.43**

Scaling ☒ national ☐ local	*GHGI*	**< 2.5** kg CO_2 eq $ha^{-1}a^{-1}$	**2.5 - 5** kg CO_2 eq $ha^{-1}a^{-1}$	**5. - 7.5** kg CO_2 eq $ha^{-1}a^{-1}$	**7.5 - 10** kg CO_2 eq $ha^{-1}a^{-1}$	**> 10** kg CO_2 eq $ha^{-1}a^{-1}$
Evaluation Class		**5**	**4**	**3**	**2**	**1**
Qualitative Evaluation		**Very Low** GHG Emission	**Low** GHG Emission	**Moderate** GHG Emission	**High** GHG Emission	**Very High** GHG Emission

■ Data sources

Data set	Data type	Spatial reference	Spatial resolution	Source	Creation date	Comments
GWP_i Copernicus Riparian Zones LCLU (MAES_1)	Polygon	Active FP/ Former FP	Minimum Mapping Unit: 0.5 ha Minimum Mapping Width: 10 m	https://land.copernicus.eu/local/riparian-zones/riparian-zones-2018	2012	
GWP_i Corine Land Cover (CLC 2018)	Polygon	Active FP/ Former FP	Minimum Mapping Unit: 25 ha	https://land.copernicus.eu/pan-european/corine-land-cover/clc2018	2018	
CSP_i European Soil Data Base (ESDB) indicating peat soils	Polygon	Active FP/ Former FP	1:1,000,000	https://esdac.jrc.ec.europa.eu/content/european-soil-database-v20-vector-and-attribute-data	2001	

Flood Risk Regulation (FRI)

Original authors (RESI): D. Mehl, T. G. Hoffmann and J. Iwanowski

Editors (IDES): FVB.IGB

Publication date: November 2021

Interpretation

Flood risk regulation is assessed by averaging two indicators that refer to retained water volume and the slowing of flow velocity. The first sub-indicator is the ratio of the flood volume of the active floodplain to that of the former floodplain (Gleason & Labhan 2008, Mehl et al. 2018, Mehl et al. 2020). This sub-indicator shows the degree to which the actual area available in a floodplain segment for flood retention has been reduced in comparison to its original area. If there are no dykes, embankments or infrastructural impairments (e. g. road embankments) present on the floodplain, the flood volume remains unaffected. In a case where potential flooding areas have already been calculated (e. g. for flood hazard maps), these can be used directly for the determination of the water retention volume of the floodplain.

The second sub-indicator consists of the results of the hydro-morphological survey of the river segment; including the average value of the hydro-morphological assessment scores for the river bed, river bank and riparian zone. This sub-indicator is used as a proxy for the hydraulic roughness of the river corridor at high water level, and can effectively flatten the flood wave (peak attenuation) (Mehl et al. 2018, Mehl et al. 2020).

Averaging both sub-indicators enables one to consider both the amount of retained water and the mitigation of the flood wave (Mehl et al. 2018, Mehl et al. 2020). For scenario calculations (e. g. construction of dyked marsh areas), please see the *RESI Handbuch* (Podschun et al. 2018).

References

Gleason, R. A. & Labhan, M. K. (2008). Chapter A: Background and Approach to Quantification of Ecosystem Services, in: Gleason, R. A., Labhan, M. K. & Euliss, N. H. Jr. [eds.]: Ecosystem Services Derived from Wetland Conservation Practices in the United States Prairie Pothole Region with an Emphasis on the U.S. Department of Agriculture Conservation Reserve and Wetlands Reserve Programs. Professional Paper 175, U.S. Department of the Interior, U.S. Geological Survey, 3-14.

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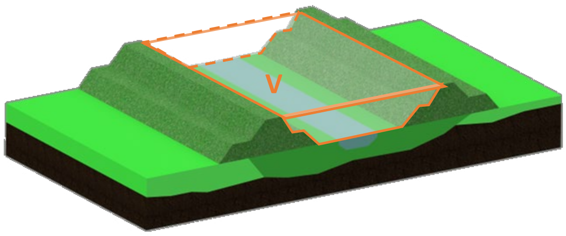
■ **Original approach according to the River Ecosystem Service Index (RESI) (Podschun et al. 2018)**

Class	Abbr.	Description		Spatial reference
Regulation and Maintenance	FRI	Reduction of flood discharge and lowering of the flood peak: wave flattening (retention volume is used by overflow/flooding, river/floodplain morphology to influence roughness)		Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☒ river
Variable	**Abbr.**	**Unit**	**Variable description**	**Data basis**
Volume of the active floodplain	V_{act}	m³	Volume between mean and high water level (full active floodplain)	- dykes and longitudinal structures - digital terrain model (DTM10) - flooding area of HQ100
Volume of the morphological floodplain	V_{morph}	m³	Volume between mean and high water level (height of the morphological floodplain stop line, transition from valley floor to valley border)	- dykes and longitudinal structures - digital terrain model (DTM10) - flooding area of HQ100
Flow length of the relevant mapping section within the river-floodplain segment	L_i	m	Length	hydro-morphological assessment (river structure quality mapping)
Ratings for riverbank (RB), floodplain (FP), riverbed (RB)	*RBai* *FPi* *RBei*	Ordinal 5 - 1	Rating class of hydraulic roughness	hydro-morphological assessment (river structure quality mapping)
Total length	L_{tot}	m	Length	hydro-morphological assessment (river structure quality mapping)

Calculation	
Assessment of the volume	**Sub-Indicator FRI_1**
	Calculation of the volume ratio of the active floodplain compared to the morphological floodplain: $FRI_1 = \frac{V_{act}}{V_{morph}}$

FRI_1	> 80 %	> 60 % - ≤ 80 %	> 40 % - ≤ 60 %	> 20 % - ≤ 40 %	≤ 20 %
FRI_1	5	4	3	2	1

Sub-Indicator FRI_2

Calculation of the length-weighted mean overall classification of the watercourse:

$$FRI_2 = \sum_{i=1}^{n} \frac{L_i}{L_{tot}} * \left(\frac{RBa_i + FP_i + RBe_i}{3}\right)$$

FRI_2	≤ 1.5	> 1.5 - ≤ 2.5	> 2.5 - ≤ 3.5	> 3.5 - ≤ 4.5	> 4.5
FRI_2	5	4	3	2	1

Indicator

Calculation of the overall indicator **FRI** as the average results of the sub-indicators **FRI_1** and **FRI_2**:

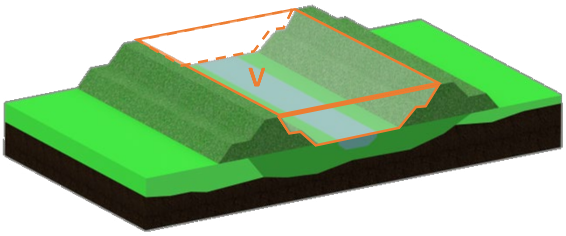
$$FRI = \frac{FRI_1 + FRI_2}{2}$$

Scaling ☒ **national** ☐ **local**	**FRI**	≥ 4.5	< 4.5 - ≥ 3.5	< 3.5 - ≥ 2.5	< 2.5 - ≥ 1.5	< 1.5
Evaluation Class		**5**	**4**	**3**	**2**	**1**
Qualitative Evaluation		**No or Very Little Loss** of active floodplain volume, **very high** wave reduction	**Little Loss** of active floodplain volume, **high** wave reduction	**Moderate Loss** of active floodplain volume, **moderate** wave reduction	**High Loss** of active floodplain volume, **little** wave reduction	**Very High Loss** of active floodplain volume, **no or little** wave reduction

■ Adaption for Danube-wide application

Class	Abbr.	Description		Spatial reference
Regulation and Maintenance	FRI	Reduction of flood discharge (by retaining water) and lowering of the flood peak (by slowing down flow velocity), resulting in a flattening of the flood wave in downstream sections		Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☒ river
Variable	**Abbr.**	**Unit**	**Variable description**	**Data basis**
Volume of the active floodplain	V_{act}	m³	Volume between mean and high water level (full active floodplain)	- digital terrain model (DTM25) - active floodplain delineated by Danube Floodplain Project
Volume of the morphological floodplain	V_{morph}	m³	Volume between mean and high water level (height of the stop line of the morphological floodplain, transition from valley floor to valley border)	digital terrain model (DTM25)
Reference areas (segment or compartment)		ha	Determination of active floodplain area, potential floodplain per floodplain segment	- floodplain segment - floodplain compartment
Flow length of the relevant mapping section within the river-floodplain segment	L_i	m	Length	hydro-morphological assessment (river structure quality mapping)
Ratings for floodplain (FP)	*FPi*	Ordinal 5 - 1	Rating class of hydro-morphological integrity and hydraulic roughness	Land Cover Model
Hydro-morphological status ratings for riverbank, floodplain and riverbed	*HyMo*	Ordinal 5 - 1	Rating class of hydro-morphological integrity and hydraulic roughness	hydro-morphological assessment (river structure quality mapping)
Total length	L_{tot}	m	Length	hydro-morphological assessment (river structure quality mapping)

Calculation

Assessment of the volume	Sub-Indicator FRI_1
	Calculation of the volume ratio of the active floodplain to the morphological floodplain: $$FRI_1 = \frac{V_{act}}{V_{morph}}$$

FRI_1	> 80 %	> 60 % - ≤ 80 %	> 40 % - ≤ 60 %	> 20 % - ≤ 40 %	≤ 20 %
FRI_1	5	4	3	2	1

Sub-Indicator FRI_2

Calculation of the length-weighted mean overall classification of the watercourse:

$$FRI_2 = \sum_{i=1}^{n} \frac{L_i}{L_{tot}} * \left(\frac{FPi + HyMo_i}{2}\right)$$

FRI_2	≤ 1,5	> 1,5 - ≤ 2,5	> 2,5 - ≤ 3,5	> 3,5 - ≤ 4,5	> 4,5
FRI_2	5	4	3	2	1

Indicator

Calculation of the overall indicator **FRI** as the average results of sub-indicators **FRI_1** and **FRI_2**:

$$FRI = \frac{FRI_1 + FRI_2}{2}$$

Scaling ☒ **national** ☐ **local**	**FRI**	≥ 4.5	< 4.5 - ≥ 3.5	< 3.5 - ≥ 2.5	< 2.5 - ≥ 1.5	< 1.5
Evaluation Class		**5**	**4**	**3**	**2**	**1**
Qualitative Evaluation		**No or Very Little Loss** of active floodplain volume, very high wave reduction	**Little Loss** of active floodplain volume, high wave reduction	**Moderate Loss** of active floodplain volume, moderate wave reduction	**High Loss** of active floodplain volume, little wave reduction	**Very High Loss** of active floodplain volume, no or little wave reduction

■ **Data sources**

Data set	Data type	Spatial reference	Spatial resolution	Source	Creation date	Comments
L_i, HyMo, L_{tot} Hydro-morphological assessment (river structure quality mapping - RSQM)	Line	Danube catchment		https://www.danubegis.org/	2015	If data is available on floodplain conditions, these can be directly applied to obtain a more accurate or alternative determination of the indicator; for example, assessments of the land, bank and bed of the river.
FPi Copernicus Riparian Zones LCLU (MAES_4)	Polygon	International /active floodplain	Minimum Mapping Unit: 0.5 ha, Minimum Mapping Width: 10 m	https://land.copernicus.eu/local/riparian-zones/riparian-zones-2018	2018	Land use in the active floodplain is categorised for this ES in terms of the flow resistance of the vegetation that is effective in the flattening of a flood wave (peak attenuation), hence: **FPi score of 1** is attributed to land use 3110, 3120, 3210, 3310 - natural & semi-natural forest, 6210 - beaches and dunes, 7000 - wetlands. **FPi score 2:** 3410 - transitional woodland and scrub, 3420 -lines of trees and shrubs, 3500 - damaged forest, 7100 - inland marshes. **FPi score 3:** 2320 - complex cultivation patterns. **FPi score 4:** 2210 - vineyards, fruit trees, berry plantation- 2330 - land principally occupied by agriculture with significant areas of natural vegetation, 4000, 4100 UA - grassland and managed grassland, 4210 - semi-natural grassland, 5000, 5110 - heath, scrub and moorland, 9110 -interconnected water courses. **A score of 5** is assigned to the remaining land use categories.
V_{AFP}, V_{FFP} Copernicus European Digital Elevation Model (EU-DEM, Version 1.0) EU-DEM25	Raster	Pan-European	25 m	https://www.eea.europa.eu/data-and-maps/data/copernicus-land-monitoring-service-eu-dem	2000-2011	
Segmentation	Polygon	Floodplain	1-10 km	river-floodplain segments	2021	

Interreg Danube Transnational Programme IDES	**Low Flow Regulation (LFI)** **Original authors (RESI):** D. Mehl, T. G. Hoffmann, J. Iwanowski **Editors (IDES):** FVB.IGB **Publication date:** November 2021

Interpretation

Water retention during low flow periods is first determined by the cross-sectional shape and hydraulic roughness of the river bed, including roughness produced by aquatic vegetation; and then by the curvature degree of the course of the river. The indicator captures the key hydraulic factors that contribute to the mitigation of the water level drop associated with low flows via the average values of the hydro-morphological assessments for the river bed and river banks. Water levels at low flow conditions are often artificially raised by weirs or dams that impound certain river stretches. Such impounded sections must be assessed with a high score for low water level regulation. Impounded sections then have to be averaged with the remaining free flowing sections in the floodplain segment on a length-weighted basis.

If enough data is available to allow a derision for natural impoundment effects (e. g. in places where a river enters a larger watercourse, a lake or the sea), such segments (or part of them) should be assessed using a very high low flow compensation.

If it is known (from expert assessment) that a certain river stretch receives significant inflow from groundwater, this may also be included in the assessment.

References

Mehl, D., Hoffmann, T. G., Iwanowski, J. (2020). Quantifizierung und Bewertung regulativer Ökosystemleistungen: Rückhalt von Treibhaus-gasen / Kohlenstoffsequestrierung, Hochwasser-, Niedrigwasser- und Sedimentregulation, Bodenbildung inAuen sowie Kühlwirkung der Gewässer und terrestrischen Böden. In: Fischer-Bedtke, C., Fischer, H., Mehl, D., Podschun, S., Pusch, M., Stammel, B. & M. Scholz (Eds.). River Ecosystem Service Index (RESI) - Methoden zur Quantifizierung und Bewertung ausgewählter Ökosystemleistungen in Flüssen und Auen. UFZ-Bericht 2/2020, 77-92. https://www.ufz.de/index.php?en=20939&ufzPublicationIdentifier=25846

■ Original approach according to the River Ecosystem Service Index (RESI) (Podschun et al. 2018)

Class	Abbr.	Description	Spatial reference
Regulation and Maintenance	DRI	Low water level regulation by hydrological self-regulation due to hydraulic roughness and river bed hydro-morphology (incl. aquatic macrophytes), thus mitigating the drop of water levels at low flow.	Floodplain segment or compartment ☐ former floodplain ☐ active floodplain ☒ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
Flow length of the relevant mapping section within the river-floodplain segment	L_i	m	Length	Hydro-morphological assessment (river structure quality mapping)	
Total length	L_{tot}	m	Length	Hydro-morphological assessment	
Ratings for riverbank (RB), riverbed (RB)	*RBai* *RBei*	Ordinal 5 - 1	Rating class (5 ≙ class 1 1 ≙ class 5)	Hydro-morphological assessment	
Possibility for extension of the used ES: backwater influence of transverse structures	BI		Site and influence of transverse structures/dams: backwater sections assigned to assessment class 1 (RBai, in which case Rbei will be skipped)	Information on backwater sections, e. g. from hydro-morphological assessment	Describes the used ecosystem service

Calculation

Indicator

Calculation of the length-weighted overall classification of the watercourse in the floodplain segment (and where possible, the calculation of the length-weighted mean classification from 'bank' and 'bed'):

$$LWRI = \sum_{i=1}^{n} \frac{L_i}{L_{tot}} \cdot \left(\frac{RBa_i + RBe_i}{2}\right)$$

Scaling ☒ national ☐ local	*DRI*	≤ 1.5	> 1.5 - ≤ 2.5	> 2.5 - ≤ 3.5	> 3.5 - ≤ 4.5	> 4.5
Evaluation Class		5	4	3	2	1
Qualitative Evaluation		**Very High** Low water compensation and/or very high groundwater inflow	**High** Low water compensation and/or high groundwater inflow	**Moderate** Low water compensation and/or moderate groundwater inflow	**Low** Low water compensation	**No or Very Low** Low water compensation

■ Adaption for Danube-wide application

Class	Abbr.	Description	Spatial reference
Regulation and Maintenance	DRI	Low water level regulation by hydrological self-regulation by macrophyte growth and morphology (reduction of water level drop); and compensation by strong groundwater inflow (expert assessment), if applicable.	Floodplain segment or compartment ☐ former floodplain ☐ active floodplain ☒ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
Flow length of the relevant mapping section within the river-floodplain segment	L_i	m	Length	Hydro-morphological assessment (river structure quality mapping)	
Total length	L_{tot}	m	Length	Hydro-morphological assessment	
Hydro-morphological status ratings for riverbank, floodplain and riverbed	*HyMo*	Ordinal 5 - 1	Rating class of hydro-morphological integrity and hydraulic roughness	Hydro-morphological assessment	

Calculation

Indicator

Calculation of the length-weighted overall classification of the watercourse in the floodplain segment (and where possible, the calculation of the length-weighted mean classification from 'bank' and 'bed'):

$$LWRI = \sum_{i=1}^{n} \frac{L_i}{L_{tot}} * (HyMo_i)$$

Scaling ☒ **national** ☐ **local**	***DRI***	≤ 1.5	> 1.5 - ≤ 2.5	> 2.5 - ≤ 3.5	> 3.5 - ≤ 4.5	> 4.5
Evaluation Class		**5**	**4**	**3**	**2**	**1**
Qualitative Evaluation		**Very High** Low water compensation and/or very high groundwater inflow	**High** Low water compensation and/or high groundwater inflow	**Moderate** Low water compensation and/or moderate groundwater inflow	**Low** Low water compensation	**No or Very Low** Low water compensation

■ Data sources

Data set	Data type	Spatial reference	Spatial resolution	Source	Creation date	Comments
L_i, HyMo, L_{tot} Hydro-morphological assessment (river structure quality mapping - RSQM)	Line	Danube catchment		https://www.danubegis.org/	2015	If data is available for floodplain conditions, these can be directly applied for a more accurate or alternative determination of the indicator; for example, assessments of the land, bank and bed of the river.

Interreg Danube Transnational Programme IDES	**Sediment Regulation (SRI)** **Original authors (RESI):** D. Mehl, T. G. Hoffmann and J. Iwanowski **Editors (IDES):** KÖTIVIZIG **Publication date:** November 2021

Interpretation

Sediment includes the bedload transported by the riverbed and as suspended load. The local hydrodynamic conditions (flow velocity and bed shear stress) determine which grain sizes are transported or deposited. Solids are kept in suspension by flow turbulence. In an undisturbed watercourse that has developed over a long period of time, a morphological equilibrium between erosion and sedimentation is (nearly) established. The indicator uses the hydro-morphological (structural quality) assessment of the river bed, as well as the impacts of transverse structures on the sediment continuity/morphological effect as a measure for sediment balance integrity.

If measured data or calibrated sediment transport models are available, these more accurate data can/should be referenced. In this case, the scale should be appropriately applied or modified.

References

Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (DWA) [Eds.] (2012). DWA-M 525 Sedimentmanagement in Fließgewässern – Grundlagen, Methoden, Fallbeispiele. Merkblatt.

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Mehl, D., Hoffmann, T. G., Iwanowski, J. (2020). Quantifizierung und Bewertung regulativer Ökosystemleistungen: Rückhalt von Treibhaus-gasen / Kohlenstoffsequestrierung, Hochwasser-, Niedrigwasser- und Sedimentregulation, Bodenbildung inAuen sowie Kühlwirkung der Gewässer und terrestrischen Böden. In: Fischer-Bedtke, C., Fischer, H., Mehl, D., Podschun, S., Pusch, M., Stammel, B. & M. Scholz (Eds.). River Ecosystem Service Index (RESI) - Methoden zur Quantifizierung und Bewertung ausgewählter Ökosystemleistungen in Flüssen und Auen. UFZ-Bericht 2/2020, 77-92. https://www.ufz.de/index.php?en=20939&ufzPublicationIdentifier=25846

■ Original approach according to the River Ecosystem Service Index (RESI) (Podschun et al. 2018)

Class	Abbr.	Description	Spatial reference
Regulation and Maintenance	DRI	Evaluation of the internal sediment balance of the river by the naturalness of morphological structures and effects of transverse structures on sediment consistency/morphological effects	Floodplain segment or compartment ☐ former floodplain ☐ active floodplain ☒ river

Variable	Abbr.	Unit	Variable description	Data basis
Flow length of each relevant mapping section within the river-floodplain segment	L_i	m	Length of the relevant river section along the traverse structure where sediment transport is affected	Hydro-morphological assessment (river structure quality mapping)
Total flow length	L_{tot}	m	Length	Hydro-morphological assessment (river structure quality mapping)
Evaluation of the riverbed category	RBe	Ordinal 5 - 1	Rating class (5 ≙ class 1 1 ≙ class 5)	Hydro-morphological assessment (river structure quality mapping)

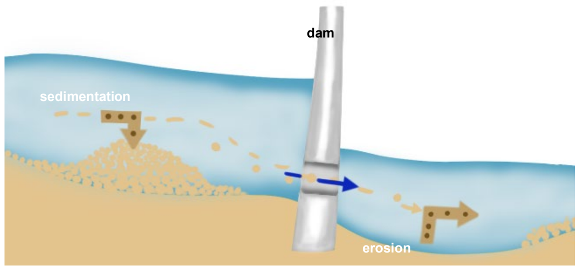
Calculation	
***RBI*: Calculation of the length-weighted mean bed assessment class of the watercourse**	***TSI*: Rapid Assessment of the hydraulic and morphological impacts of transverse structures in rivers according to LAWA (2017; modified)**

$$RBI = \sum_{i=1}^{n} \frac{L_i}{L_{tot}} * RBe_i$$

Construction type	TSI
No transverse structure	1
Low weir	1
Bed sill	2
Retaining weir and retaining sill	4
Movable weir and barrage	4
Pumping station and sluices	4
Weir	2
Culvert, pipework, hollowing out	3
Bottom ramp, bottom slope	2
Cascade	2
Dam	5

Indicator	Influence of cross construction type on sediment regulation.
Determination of the worst assessment between the RBI and TSI indicators (Worst-Case-Method):	

$$SRI = max(RBI, TSI)$$



Scaling ☒ national ☐ local	*SRI*	1	2	3	4	5
Evaluation Class		**5**	**4**	**3**	**2**	**1**
Qualitative Evaluation		**Undisturbed** sediment balance	**Slightly Disturbed** sediment balance	**Considerably Disturbed** sediment balance	**Heavily Disturbed** sediment balance	**Very Heavily Disturbed** sediment balance

■ Adaption for Danube-wide application

Class	Abbr.	Description	Spatial reference
Regulation and Maintenance	DRI	Evaluation of a river's internal sediment balance by the naturalness of morphological structures and effects of transverse structures on sediment consistency/morphological effects	Floodplain segment or compartment ☐ former floodplain ☐ active floodplain ☒ river

Variable	Abbr.	Unit	Variable description	Data basis
Flow length of each relevant mapping section within the river-floodplain segment	L_i	m	Length of the relevant river section along the traverse structure where sediment transport is affected	Hydro-morphological assessment (river structure quality mapping)
Total flow length	L_{tot}	m	Length	Hydro-morphological assessment (river structure quality mapping)
Evaluation of the riverbed category	RBe	Ordinal 5 - 1	Rating class (5 ≙ class 1; 1 ≙ class 5)	Hydro-morphological assessment (river structure quality mapping)

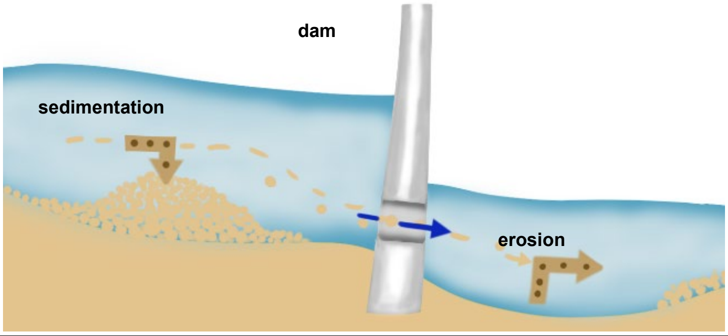
Calculation

***RBI*: Calculation of the length-weighted mean bed assessment class of the watercourse**

$$RBI = \sum_{i=1}^{n} \frac{L_i}{L_{tot}} * RBe_i$$

***TSI*: Rapid Assessment of the hydraulic and morphological impacts of transverse structures on rivers**

		Flow		Connectivity	
Structure	Value [-]	Effect [m]	Direction [upstream (U), downstream (D)]	Effect [m]	Direction [upstream (U), downstream (D)]
No transverse structures/ barriers	1	0	-	0	-
Groundsill	1	250	U	100	U: 50 m D: 50 m
Grade sill/submerged dyke	3	300	U	100	U: 50 m D: 50 m
Barrage	5	variable	U D: 250 m	variable	U + D
Bucket elevator/lock	3	100	U + D	5000	U: 50 m D: 50 m
Sluice gate	3	250	U + D	500	U: 50 m D: 50 m
Tube casing	3	100	U: 50 m D: 50 m m	0	-
Chute	3	75	D	5000	U: 2500 m D: 2500 m
Large dam	5	variable	D U: 250 m	variable	U + D
Bridge	3	400	-	200	-

Indicator		Influence of cross construction type on sediment regulation.				
Determination of the worst assessment between the RBI and TSI indicators (Worst-Case-Method): $SRI = max(RBI, TSI)$		 				
Scaling ☒ **national** ☐ **local**	***SRI***	1	2	3	4	5
Evaluation Class		**5**	**4**	**3**	**2**	**1**
Qualitative Evaluation		**Undisturbed** sediment balance	**Slightly Disturbed** sediment balance	**Considerably Disturbed** sediment balance	**Heavily Disturbed** sediment balance	**Very Heavily Disturbed** sediment balance

■ Data sources

Data set	Data type	Spatial reference	Spatial resolution	Source	Creation date	Comments
L_i	Line shape file	international / river		River-floodplain segments (1-10 km)	2021	Calculated from the segment polygon
L_{tot}	Line shape file	international / river		River-floodplain segments (1-10 km)	2021	Based on the location of the traverse structures
RBe Evaluation of the category riverbed	Water Framework Directive method of evaluation	international / river		https://www.vizugy.hu/vizstrategia/documents/988BF7DB-B869-46C6-9463-E9E4BFC81D2A/6_4_hatteranyag_hidromorfologiai_allapotertekeles.pdf	2021	Locations of the traverse structures are based on the data provided by the PP's. KÖTIVIZIG also collected data on dams, barrages and bridges, etc. from Google Maps and orthophotos

Interreg Danube Transnational Programme IDES	**Soil Formation in Floodplains (SFI)** **Original authors (RESI):** D. Mehl, T. G. Hoffmann and J. Iwanowski **Editors (IDES):** KÖTIVIZIG **Publication date:** November 2021

Interpretation

Using the soil science or soil assessment classification system, the indicator describes local conditions with regard to the soil water balance as an essential basis for peat formation in bogs and fens. The evaluation of soil formation is carried out by taking into account anthropogenically-caused peatland degradation stages that are area-weighted with the potential of floodplain soil formation (derived via sediment regulation in the floodplain segment).

If areal data is available on zones experiencing water level fluctuation due to renaturation in organic river floodplains, or at organic stream types (potential new sites of peatland formation or areas of peatland activation), these can be included in the assessment. In this case, appropriate assumptions for water stage enhancement should be made.

For scenario calculations (e. g. construction of dyked marsh areas), please see the *RESI Handbuch* (Podschun et al. 2018).

References

Mehl, D., Hoffmann, T. G., Iwanowski, J. (2020). Quantifizierung und Bewertung regulativer Ökosystemleistungen: Rückhalt von Treibhausgasen / Kohlenstoffsequestrierung, Hochwasser-, Niedrigwasser- und Sedimentregulation, Bodenbildung inAuen sowie Kühlwirkung der Gewässer und terrestrischen Böden. In: Fischer-Bedtke, C., Fischer, H., Mehl, D., Podschun, S., Pusch, M., Stammel, B. & M. Scholz (Eds.). River Ecosystem Service Index (RESI) - Methoden zur Quantifizierung und Bewertung ausgewählter Ökosystemleistungen in Flüssen und Auen. UFZ-Bericht 2/2020:,77-92. https://www.ufz.de/index.php?en=20939&ufzPublicationIdentifier=25846

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■ **Original approach according to the River Ecosystem Service Index (RESI) (Podschun et al. 2018)**

Class	Abbr.	Description	Spatial reference
Regulation and Maintenance	SRI	Evaluation of natural fen formation (peat accumulation) and anthropogenically-caused fen degradation (lowering of water body and of groundwater level, changes in flood dynamics) and floodplain soil formation	Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☐ river

Variable	Abbr.	Unit	Variable description	Data basis	VI	Comment
Individual peat area	A_i	ha	Area of individual fens in the morphological floodplain	- river-floodplain segments - soil maps indicating fens/mires/ bogs/peat		
Total peat area	$Abog_{tot}$	ha	Total fen area in the morphological floodplain	- river-floodplain segments - soil maps indicating fens/mires/ bogs/peat		
Mean distance to groundwater table	mGWD	m	mean difference between ground surface and groundwater level of the upper aquifer	- digital terrain model (DTM10) - water level layers (based on DTM10)		
Valuation index for the mean distance to groundwater table (mGWD)	VI	relative	*mGWD*	alternative: water levels	*VI*	Petersen (1952), Hundt (1957), (1964), compiled by Succow & Joosten (2001)
			≤ 0 m (Overflow or same as groundwater table, zone of fluctuating water levels)	6+, 5+	5	
			> 0 m … ≤ 0.35 m	4+, 3+	4	
			> 0,35 m … ≤ 0.70 m	2+	3	
			> 0.70 m … ≤ 1.20 m	2-	2	
			> 1.20 m	2- bis 5-	1	
Area of peat soils in the river-floodplain segment	R_{peat}	%	Percentage of peat soil	- river-floodplain segments - soil maps indicating fens/mires/ bogs/peat - land use (Corine)		
Area of alluvial soils in the floodplain segment	R_{as}	%	Percentage of alluvial soil	- river-floodplain segments - soil maps indicating fens/mires/ bogs/peat - land use (Corine)		
Area of alluvial soil within the former floodplain	Aas_{for}	ha	Calculation of the alluvial soil area in the former river floodplain	- river-floodplain segments - soil maps indicating fens/mires/ bogs/peat - land use (Corine)		
Area of alluvial soil within the active floodplain	Aas_{act}	ha	Calculation of the alluvial soil area in the active floodplain	- river-floodplain segments - soil maps indicating fens/mires/ bogs/peat - land use (Corine)		
Total area of alluvial soil	Aas_{tot}	ha	Calculation of the total alluvial soil area	- river-floodplain segments - soil maps indicating fens/mires/ bogs/peat - land use (Corine)		
Assessment of sediment regulation	V_{SR}	relative	Result of the ecosystem services assessment: sediment regulation of the floodplain segment	see Indicator of ES mass flow/ sediment regulation		

Calculation						
Sub-indicator ***SF**peat* (peat soils)			Sub-indicator ***SF**as* (alluvial soils)			
$SF_{peat} = (\sum_{i=1}^{n} \frac{A_i}{A_{tot}} * VI_i)$			$SF_{as} = \frac{(\sum_{i=1}^{n} Aas_{former_i}) + (\sum_{i=1}^{n} Aas_{act_i} * V_{SR})}{Aas_{tot}}$			
Indicator						
Calculation of the area-weighted indicator from the sub-indicator SF_{peat} and SF_{as}: $$SFI = SF_{peat} * R_{peat} + SF_{as} * R_{as}$$						
Scaling ☒ **national** ☐ **local**	**SFI**	≥ 4.5	< 4.5 - ≥ 3.5	< 3.5 - ≥ 2.5	< 2.5 - ≥ 1.5	< 1.5
Evaluation Class		**5**	**4**	**3**	**2**	**1**
Qualitative Evaluation		**Peat formation or extensive peat retention, No or Very Low** peatland degradation, very high alluvial soil formation	**Peat extraction, Low** peatland degradation, high alluvial soil formation	**Peat extraction, Moderate** peatland degradation, moderate alluvial soil formation	**Peat extraction, High** peatland degradation, low alluvial soil formation	**Peat extraction, Very High** peatland degradation, no or very low alluvial soil formation

■ Adaption for Danube-wide application

Class	Abbr.	Description	Spatial reference
Regulation and Maintenance	SRI	Evaluation of natural fen formation (peat accumulation) and anthropogenically-caused fen degradation (lowering of water body and of groundwater level, and changes in flood dynamics) and floodplain soil formation	Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☐ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
Individual peat area	A_i	ha	Area of individual fens in the morphological floodplain	- river-floodplain segments - soil maps indicating fens/mires/bogs/peat	
Total peat area	$Abog_{tot}$	ha	Total fen area in the morphological floodplain	- river-floodplain segments - soil maps indicating fens/mires/bogs/peat	
Occurrence of water and wet surfaces	*mWS*	m	The combined Water and Wetness product is a thematic product showing the occurrence of water and wet surfaces over the 2012 – 2018 period.	Water and Wetness (COPERNICUS)	
Water and Wetness index (WAW)	VI	relative	Classes of (1) permanent water, (2) temporary water, (3) permanent wetness, (4) temporary wetness, and dry (5)	Water and Wetness (COPERNICUS)	
Area of peat soils in the river-floodplain segment	R_{peat}	%	Percentage of peat soil	- river-floodplain segments - soil maps indicating fens/mires/ bogs/peat - land use (Corine)	
Area of alluvial soil in the floodplain segment	R_{as}	%	Percentage of alluvial soil	- river-floodplain segments - soil maps indicating fens/mires/ bogs/peat - land use (Corine)	
Area of the alluvial soil within the former floodplain	Aas_{for}	ha	Calculation of the alluvial soil area in the former river floodplain	- river-floodplain segments - soil maps indicating fens/mires/ bogs/peat - land use (Corine)	
Area of the alluvial soil within the active floodplain	Aas_{act}	ha	Calculation of the alluvial soil area in the active floodplain	- river-floodplain segments - soil maps indicating fens/mires/ bogs/peat - land use (Corine)	
Total area of the alluvial soil	Aas_{tot}	ha	Calculation of the total area of the alluvial soil	- river-floodplain segments - soil maps indicating fens/mires/ bogs/peat - land use (Corine)	
Assessment of sediment regulation	V_{SR}	relative	Result of ecosystem services assessment for sediment regulation of the floodplain segment	see ES mass flow/sediment regulation indicator	

Calculation						
Sub-indicator ***SF**$_{peat}$* (peat soils)				Sub-indicator ***SF**$_{as}$* (alluvial soils)		
$$SF_{peat} = (\sum_{i=1}^{n} \frac{A_i}{A_{tot}} * VI_i)$$				$$SF_{as} = \frac{(\sum_{i=1}^{n} Aas_{former_i}) + (\sum_{i=1}^{n} Aas_{act_i} * V_{SR})}{Aas_{tot}}$$		
Indicator						
Calculation of the area-weighted indicator from the sub-indicator SF_{peat} and SF_{as}: $$SFI = SF_{peat} * R_{peat} + SF_{as} * R_{as}$$						
Scaling ☒ **national** ☐ **local**	***SFI***	≥ 4.5	< 4.5 - ≥ 3.5	< 3.5 - ≥ 2.5	< 2.5 - ≥ 1.5	< 1.5
Evaluation Class		**5**	**4**	**3**	**2**	**1**
Qualitative Evaluation		**Peat formation or extensive peat retention, No or Very Low** peatland degradation, very high alluvial soil formation	**Peat extraction, Low** peatland degradation, high alluvial soil formation	**Peat extraction, Moderate** peatland degradation, moderate alluvial soil formation	**Peat extraction, High** peatland degradation, low alluvial soil formation	**Peat extraction, Very High** peatland degradation, no or very low alluvial soil formation

■ Data sources

Data set	Data type	Spatial reference	Spatial resolution	Source	Creation date	Comments
European Soil Database (ESDB) indicating peat and alluvial soils	Polygon	Active FP / Former FP	1:1,000,000	https://esdac.jrc.ec.europa.eu/content/european-soil-database-v20-vector-and-attribute-data	2001	
mWS COPERNICUS Water and Wetness	Raster	International/ river	10 m	https://land.copernicus.eu/pan-european/high-resolution-layers/water-wetness/status-maps/water-wetness-2018	2020	
Corine Land Cover (CLC 2018)	Polygon	Active FP / Former FP	Minimum Mapping Unit (MMU): 25 ha	https://land.copernicus.eu/pan-european/corine-land-cover/clc2018	2018	

Habitat Provision/Simplified (HPI_{simple})

Original authors (RESI): M. Scholz, H.D. Kasperidus, C. Fischer, C. Damm, L. Gerstner, B. Stammel, M. Gelhaus, F. Foeckler and A. Rumm

Editors (IDES): CUEI

Publication date: November 2021

Interpretation

The indicator reflects the quantity and quality of floodplain-typical habitats for the 1-10 km riverine floodplain compartments via 'integrating' features. For example, there is no explicit habitat or species data, but there is for land use and restrictions or protection status as proxies. Thus, it represents a measure of ES habitat provision on a Danube-wide scale.

Due to the heterogeneous nature of the data, and difficulties in spatial classification on the floodplain compartment level, no additional extensions were made; such as the inclusion of data for typical floodplain species. Currently, only the five parameters or variables selected and listed below were available for nationwide/basin-wide evaluations.

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Fischer, C., Damm, C., Foeckler, F., Gelhaus, M., Gerstner, L., Harris, R., Hoffmann, T.G., Iwanowski, J., Kasperidus, H., Mehl, D., Podschun, S.A., Rumm, A., Stammel, B. & Scholz, M. (2019). The "habitat provision" index for assessing floodplain biodiversity and restoration potential as an ecosystem service—Method and application. Frontiers in Ecology and Evolution, 7, 483; https://www.frontiersin.org/articles/10.3389/fevo.2019.00483/full

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■ Original approach according to the River Ecosystem Service Index (RESI) (Podschun et al. 2018)

Class	Abbr.	Description	Spatial reference
Regulating	HPI_{simple}	'Habitat Provision covers the functional and structural quality of habitats and their communities as a basis for multiple human uses. In this case, habitats provide a diversity of animal and plant communities typical for rivers and floodplains both of natural and cultural landscape'. (Fischer et al. 2019)	Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☐ river

Variable	Abbr.	Unit	Variable description	Data basis
Natura 2000 areas	Nat2000	Ordinal (1-5)	Proportion of Natura 2000 areas in the river-floodplain segment	Natura 2000 areas
Land use intensity	LUI	Ordinal (1-5)	Intensity of use	Corine Land Cover Classification (CLC) National Land Cover Model (LBM)
Wetland habitats	WH	Ordinal (1-5)	Proportion of wetland habitats and protected habitats	National mapping of wetland habitats (Biotopverbund)
Backwater influence	BI	Nominal (yes/no)	Penalty if backwater influence exists	Information on traverse structures; penalty: -1 in active floodplain; -0.5 in former floodplain
Former floodplain	FFP	Nominal (yes/no)	Penalty of -1 if floodplain is disconnected from river by anthropogenic structures	Delineation of river, active and former floodplain compartments

<table>
<tr><th colspan="7">Calculation</th></tr>
<tr><th colspan="3">Evaluation scheme</th><th colspan="4">Indicator</th></tr>
<tr><td colspan="3"></td><td colspan="4">Calculation of the Index:
The indicator integrates 5 variables. Three of them can obtain values between 1 and 5:
Nat2000: proportion of Natura 2000 areas in the river-floodplain segment
LUI: intensity of land use
WH: proportion of wetland habitats and protected habitats.
Two variables are rated as penalties when they occur:
BI: backwater influence (penalty: -1 in active floodplain; -0.5 in former floodplain)
FFP: former floodplain (penalty: -1 only where active floodplain is delineated)
$$HPI_{simple} = \frac{Nat2000+LUI+WH}{3} + (BI + FFP)^*$$
* Index cannot be less than 1</td></tr>
<tr><td>Scaling
☒ national
☐ local</td><td>HPI_{simple}</td><td>≥ 4.5</td><td>< 4.5 - ≥ 3.5</td><td>< 3.5 - ≥ 2.5</td><td>< 2.5 - ≥ 1.5</td><td>< 1.5</td></tr>
<tr><td colspan="2">Evaluation class</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td colspan="2">Qualitative Evaluation</td><td>Very High importance for habitat provision</td><td>High importance for habitat provision</td><td>Moderate importance for habitat provision</td><td>Low importance for habitat provision</td><td>Very Low importance for habitat provision</td></tr>
</table>

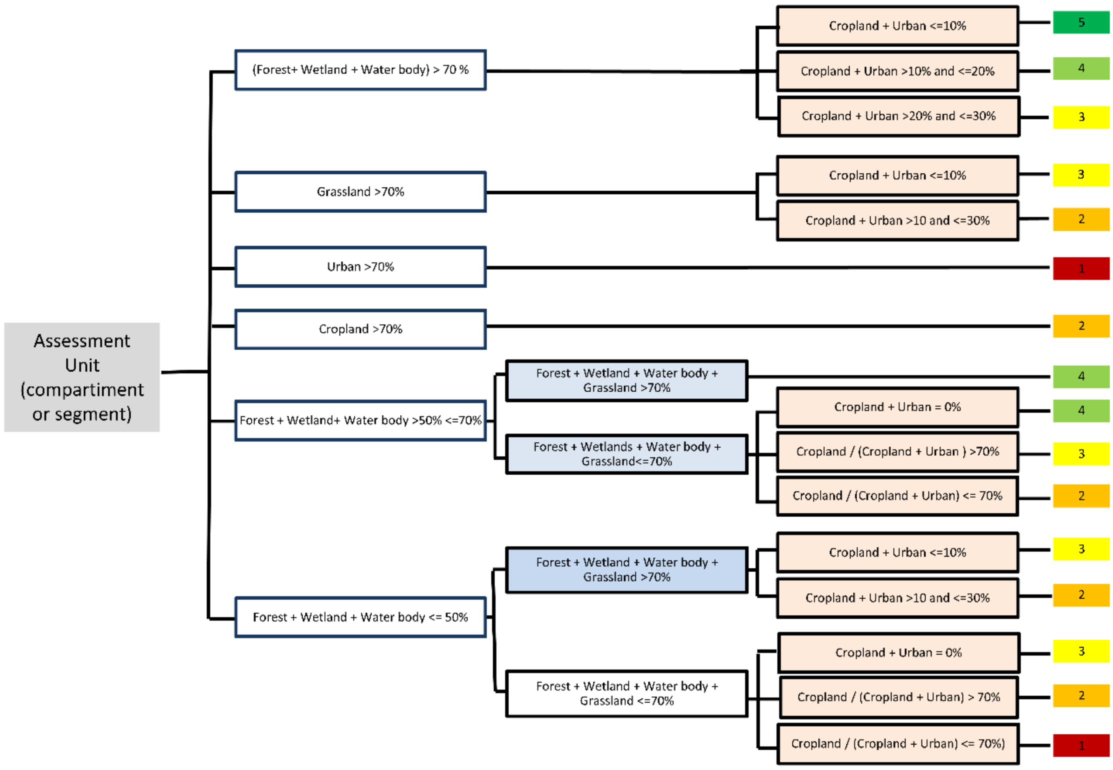
■ Adaption for Danube-wide application

Class	Abbr.	Description	Spatial reference
Regulating	HPI_{simple}	'Habitat Provision covers the functional and structural quality of habitats and their communities as a basis for multiple human uses. In this case, habitats provide a diversity of animal and plant communities typical for rivers and floodplains both of natural and cultural landscape'. (Fischer et al. 2019)	Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☐ river

Variable	Abbr.	Unit	Variable description	Data basis	Comments
Natura 2000 areas	Nat2000	Ordinal (1-5)	Proportion of Natura 2000 areas in the river-floodplain segment	Natura 2000 areas; or protected areas and habitats in non-EU countries	5: >75%, 4: >50%-75% 3: >25%-50% 2: >0%-25% 1: 0%
Land use intensity	LUI	Ordinal (1-5)	Intensity of land use	Corine Land Cover Classification (CLC)	see LUI decision tree for assessment
Wetland habitats	WH	Ordinal (1-5)	Proportion of wetland habitats and protected biotopes	Selection of wetland habitats based on the land use mappings of the Copernicus riparian zones LCLU (MAES_4)	MAES 4 codes: 3111, 3121, 3211, 3221, 3311, 3321, 7111, 7121, 8111, 8113, 8211, 8221, 9111, 9112, 9121, 9211
Backwater influence	BI	Nominal (yes/no)	Influence of hydrologic flow alteration by hydropower dams and traverse structures (impoundment)	Hydrological alterations – impoundments, Danube River Basin Management Plan (DRBMP)	Penalty: -1 in active floodplain; -0.5 in former floodplain
Former floodplain	FFP	Nominal (yes/no)	Former floodplain where regular flooding is inhibited by anthropogenic structures or could be reached by floods in a 300 year extreme flood event	Active floodplain delineated by the Danube Floodplain Project	Optional for the segments which only contain active floodplains from the Danube Floodplain Project

Calculation	
Evaluation scheme	**Indicator**
	Calculation of the Index: The indicator integrates 5 variables. Three of them can gain values between 1 and 5: Nat2000: proportion of Natura 2000 areas in the river-floodplain segment LUI: intensity of land use following the LUI decision tree below WH: proportion of wetland habitats and protected habitats. Two variables are rated as penalities when they occur: BI: backwater influence (penalty: -1 in active floodplain; -0.5 in former floodplain) FFP: former floodplain (penalty: -1 only where active floodplain is delineated) $HPI_{simple} = \frac{Nat2000+LUI+WH)}{3} + (BI + FFP)^{*}$ * Index cannot be less than 1

LUI



Scaling ☒ **national** ☐ **local**	**HPI**$_{simple}$	≥ 4.5	< 4.5 - ≥ 3.5	< 3.5 - ≥ 2.5	< 2.5 - ≥ 1.5	< 1.5
IDES class		**5**	**4**	**3**	**2**	**1**
Qualitative Evaluation		**Very High** importance for habitat provision	**High** importance for habitat provision	**Moderate** importance for habitat provision	**Low** importance for habitat provision	**Very Low** importance for habitat provision

■ Data sources

Data set	Data type	Spatial reference	Spatial resolution	Source	Creation date	Comments
Nat2000 Natura 2000 areas, protected areas in RS	Polygon	International/ segments		https://www.eea.europa.eu/data-and-maps/data/natura-13	2020	
LUI Corine Land Cover (CLC 2018)	Polygon	International/ Active FP	Minimum Mapping Unit: 25 ha	https://land.copernicus.eu/local/riparian-zones/riparian-zones-2012	2018	
WH Land use inside the Copernicus Riparian Zones LCLU (MAES_4)	Polygon	International/ Active FP	Minimum Mapping of landuse Units: 0.5 ha Minimum Mapping Width: 10 m	https://land.copernicus.eu/local/riparian-zones/land-cover-land-use-lclu-image	2012	
BI Hydrological alterations - impoundments from DRBMP	Line shape file	International/ river		https://www.danubegis.org/	2015	
FP Active floodplain delineated by Danube Floodplain Project	Polygon	International/ Former FP		http://www.geo.u-szeged.hu/dfgis/	2020	

Interreg Danube Transnational Programme IDES	**Habitat Provision/Detailed (HPI_{detail})** **Original authors (RESI):** M. Scholz, C. Fischer, C. Damm, L. Gerstner, B. Stammel, M. Gelhaus, F. Foeckler and A. Rumm **Editors (IDES):** CUEI **Publication date:** November 2021

Interpretation

The indicator provides a simplified, but more detailed sign (compared to HPI_{simple}) of the importance of the studied floodplain segment for the functional and structural quality of floodplain-typical habitats, biotic communities, and species as a basis for multiple human uses. The indicator reflects ES habitat provision.

If information is available on the conservation status of habitat types, or on the presence/absence of other value-adding characteristics included in the Flora Fauna Habitat Directive for an area under investigation, this can be added to the evaluation on habitat level.

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Finck, P., Heinze, S., Raths, U., Riecken, U. & Ssymank, A. (2017). Rote Liste der gefährdeten Biotoptypen Deutschlands. Dritte fortgeschriebene Fassung 2017. Bundesamt für Naturschutz (Eds.). Naturschutz und Biologische Vielfalt, 156.

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■ Original approach according to the River Ecosystem Service Index (RESI) (Podschun et al. 2018)

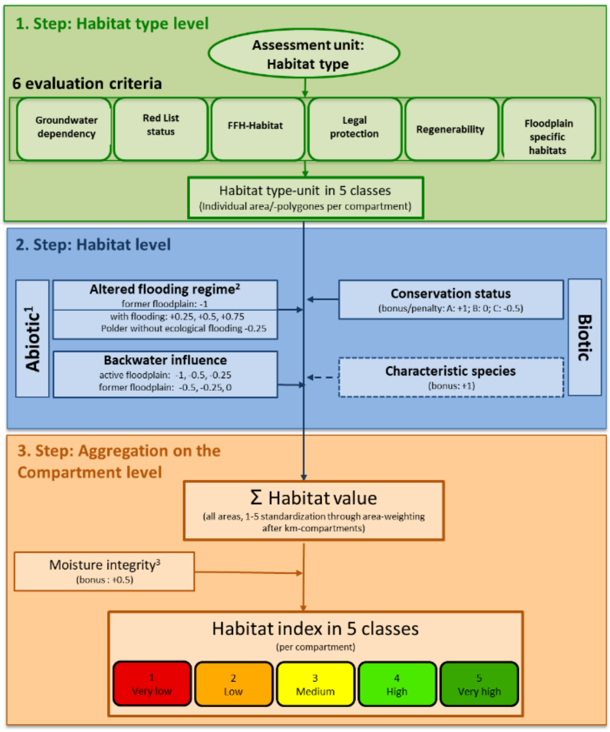
Class	Abbr.	Description	Spatial reference
Regulation and Maintenance	HPI_{detail}	'Habitat Provision covers the functional and structural quality of habitats and their communities as a basis for multiple human uses. In this case, habitats provide a diversity of communities (animal and plant) typical for rivers and floodplains both of natural and cultural landscape'. (Fischer et al. 2019)	Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☐ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
Habitat type value	HTVi	Nominal, evaluation ordinal (1-5)	Habitat types were classified and evaluated for 6 variables: GDi, RLi, FFHi, LPi, REi and FSi following Fischer et al. (2019). The mean of these 6 parameters is the HTVi for a specific habitat type.	Habitat mapping	Assign/adapt the occurring habitat types according to Finck et al. (2017)
Groundwater dependence of specific habitat type	GDi	Ordinal (5, 3, 1)	Groundwater dependence of HTVi according to the European Water Framework Directive (WFD)	Finck et al. (2017)	5: dependent 3: depending on certain characteristics 1: independent
Red List status of specific habitat type	RLi	Ordinal (5, 3, 1)	Red List status (Germany) of HTVi	Finck et al. (2017)	5: strongly endangered to destroyed 3: endangered/affected 1: not endangered
Habitat type listed in Annex I of the Habitats Directive	FFHi	Ordinal (5, 3, 1)	Classification of HTVi as habitat type in Annex I of the Habitats Directive	Finck et al. (2017)	5: FFH-type 3: depending on certain characteristics 1: not FFH-type
Legal Protection Status of the specific habitat type	LPi	Ordinal (5, 3, 1)	Legal Protection Status of the HTVi	Finck et al. (2017)	5: protected by law 3: depending on certain characteristics 1: not protected
Regenerability of the specific habitat type	REi	Ordinal (5, 3, 1)	Regenerability (recoverability/ development time) of HTVi: regeneration by natural succession or restoration	Finck et al. (2017)	5: minimal or none 3: very limited 1: limited
Floodplain-specific habitat type	FSi	Ordinal (5, 3, 1)	Binding of HTVi to floodplains and their functionality	Expert opinion	5: exclusive floodplain characteristic 3: medium floodplain characteristic 1: not a floodplain characteristic
Conservation status of the specific FFH habitat	CShab	Ordinal (1; 0; -0,5)	Conservation status of a specific habitat assessed according to the Habitats Directive	FFH habitat mapping	bonus/penalty at the habitat level A: 1 B: 0 C: -0.5
Additional biological quality feature	Value _add	Bonus	Higher quality of HTVi in terms of nature conservation	Project-specific data	Bonus at habitat level

Altered flooding regime	FR	Penalty	Anthropogenic changes to flooding frequency or exclusion	Local Data	Penalty at habitat level
Backwater influence	BI	Penalty	Influence of impoundment/ backwater of transverse structures (e.g. barrage)	data on impoundments	Penalty at habitat level
Moisture integrity	MI	Bonus	Completeness of habitats for the entire moisture gradient within the floodplain segment	Expert opinion	Bonus at compartment level

Calculation

Evaluation scheme



[1] Penalty/Bonus only for floodplain-typical/near-natural habitat types (habitat types with floodplain connection 3 and 5)
[2] Summer polders and other floodplain areas protected by dykes, floodplains with inlet sills or controllable inlet structures (e.g. the reed stream on the Danube) and controlled polders (possibly with stages of ecological flooding)
[3] Only for habitat types with FS_i = 5 (exclusive floodplain habitats)

Indicator

1. Step: General assessment of habitat type value by calculating the mean of 6 parameters (Fischer et al. 2019)

$$HTV_i = \frac{GD_i+RL_i+FFH_i+LP_i+RE_i+Fs_i}{n}$$

n=number of criteria

Mean value calculated from the individual variables of the habitat quality elements. If individual values are missing, the mean value is determined from the remaining variables.

2. Step: Assessment of individual habitats

$$HV_i = HTV_i + CShab_i + FR_i + BI_i + Value_{add_i}$$

The general assessment is based on the value of the habitat type (HTV) and additional abiotic (FR, BI) site-specific parameters.

3. Step: Area-weighted aggregation of index for floodplain segment or compartment

$$HPI_{detail} = \frac{\sum_{i=1}^{n}(HV_i * A_i)}{\sum_{i=1}^{n} A_i} + MI$$

Area-weighted averaging of all HV_i of a compartment (A_i). Bonus for moisture gradient (MI).

Scaling ☐ **national** ☒ **local**	HPI_{detail}	≥ 4.5	< 4.5 - ≥ 3.5	< 3.5 - ≥ 2.5	< 25 - ≥ 1.5	< 1.5
Evaluation Class		**5**	**4**	**3**	**2**	**1**
Qualitative Evaluation		**Very High** importance for habitat provision	**High** importance for habitat provision	**Moderate** importance for habitat provision	**Low** importance for habitat provision	**Very Low** importance for habitat provision

■ Adaption for Danube-wide application

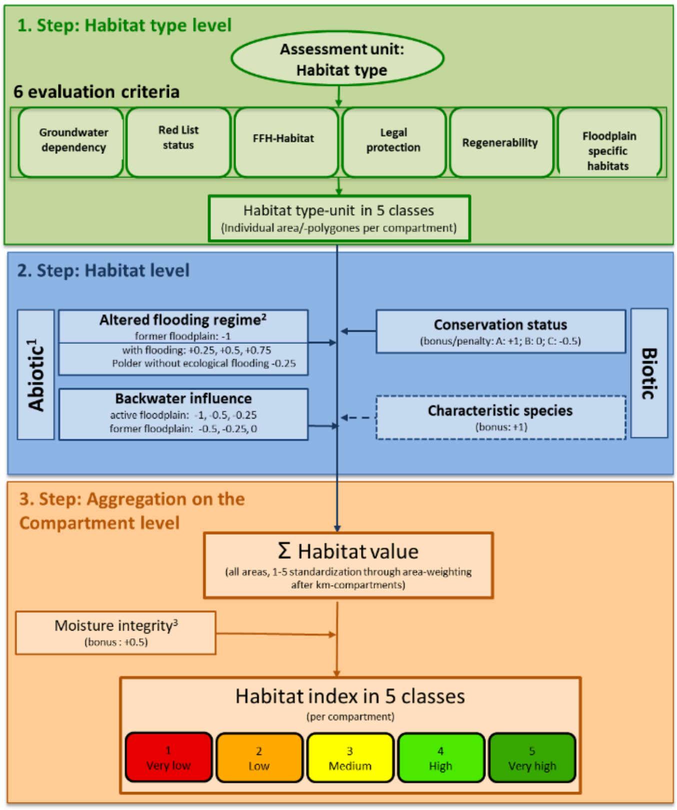
Class	Abbr.	Description	Spatial reference
Regulation and Maintenance	HPI_{detail}	'Habitat Provision covers the functional and structural quality of habitats and their communities as a basis for multiple human uses. In this case, habitats provide a diversity of communities (animal and plant) typical for rivers and floodplains both of natural and cultural landscape'. (Fischer et al. 2019)	Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☐ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
Habitat type value	HTVi	Nominal, Evaluation ordinal (1-5)	Habitat types classified and evaluated for 6 variables GDi, RLi, FFHi, LPi, REi and FSi following Fischer et al. (2019). The mean of these 6 parameters is the HTVi for a specific habitat type.	Habitat mapping; selective/no habitat maps completed/ substituted by Copernicus Riparian Zone (MAES_4) and Corine Land Cover	assign/adapt the occurring habitat types according to Finck et al. (2017) and Fischer et al. (2019)
Groundwater dependence of specific habitat type	GDi	Ordinal (5, 3, 1)	Groundwater dependence of HTVi according to the European Water Framework Directive (WFD)	Habitat list (Finck et al. 2017)	5: dependent 3: depending on certain characteristics 1: independent
Red List status of specific habitat type	RLi	Ordinal (5, 3, 1)	Red List status (Germany) of HTVi	Habitat list (Finck et al. 2017)	5: strongly endangerd to destroyed 3: endangered/affected 1: not endangered
Habitat type listed in Annex I of the Habitats Directive	FFHi	Ordinal (5, 3, 1)	Classification of HTVi as a habitat type in Annex I of the Habitats Directive	Habitat list (Finck et al. 2017)	5: FFH-type 3: depending on certain characteristics 1: not FFH-type
Legal Protection Status of the specific habitat type	LPi	Ordinal (5, 3, 1)	Legal Protection Status of the HTVi	Habitat list (Finck et al. 2017)	5: protected by law 3: depending on certain characteristics 1: not protected
Regenerability of the specific habitat type	REi	Ordinal (5, 3, 1)	Regenerability (recoverability/development time) of HTVi by natural succession or restoration	Habitat list (Finck et al. 2017)	5: minimal or none 3: very limited 1: limited
Floodplain-specific habitat type	FSi	Ordinal (5, 3, 1)	Binding of HTVi to floodplains and their functionality	Fischer et al. (2019)	5: exclusive floodplain characteristic 3: medium floodplain characteristic 1: not floodplain characteristic
Altered flooding regime	FR	Penalty	Anthropogenic changes to flooding frequency or exclusion	Active floodplain delineated by Danube Floodplain Project	Penalty for former floodplain for the segments only which contain active floodplains from the Danube Floodplain Project (optional)
Backwater influence	BI	Penalty	Influence of impoundment/ backwater of traverse structures (e.g. barrage)	Hydrological alterations – impoundments, Danube River Basin Management Plan (DRBMP)	Penalty at habitat level
Moisture integrity	MI	Bonus	Completeness of habitats of the whole moisture gradient within the entire floodplain segment	Fischer et al. (2019)	Bonus at compartment level

Calculation

Evaluation scheme	Indicator

Evaluation scheme



Indicator

1. Step: General assessment of habitat type value by calculating the mean of 6 parameters (Fischer et al. 2019)

$$HTV_i = \frac{GD_i + RL_i + FFH_i + LP_i + RE_i + Fs_i}{n}$$

n=number of criteria

Mean value calculated from the individual assignments of the habitat types to groundwater (GD), Red List status (RL), FFH status (FFH), legal protection (LP) and regenerability (RE) according to Finck et al. (2017). Floodplain-specific habitat (FS) was determined by experts. No assessment was made for 'no classification meaningful' for GW and RE according to Finck et al. (2017). If these values were missing, the mean value was calculated from the remaining variables.

2. Step: Assessment of individual habitats

$$HV_i = HTV_i + CShab_i + FR_i + BI_i + Value_{add_i}$$

The assessment is based on abiotic and biotic site parameters. The first group includes an altered flooding regime (FR) and location of the floodplain compartment in the backwater area of a dam. The second group includes FFH conservation status (CShab) and value-adding features ($Value_{add}$). Bonus (CShab, $Value_{add}$) and penalty (FR, CShab, $Value_{add}$) may be added.

3. Step: Area-weighted aggregation of index for floodplain segment or compartment

$$HPI_{detail} = \frac{\sum_{i=1}^{n}(HV_i * A_i)}{\sum_{i=1}^{n} A_i} + MI$$

Area-weighted averaging of all HVi of a compartment (Ai). Bonus for moisture gradient (MI).

Scaling ☒ national ☒ local	HPI_{detail}	≥ 4.5	< 4.5 - ≥ 3.5	< 3.5 - ≥ 2.5	< 2.5 - ≥ 1.5	< 1.5
Evaluation Class		**5**	**4**	**3**	**2**	**1**
Qualitative Evaluation		**Very High** importance for habitat provision	**High** importance for habitat provision	**Moderate** importance for habitat provision	**Low** importance for habitat provision	**Very Low** importance for habitat provision

■ Data sources

Data set	Data type	Spatial reference	Spatial resolution	Source	Creation date	Comments
HTVi Landuse inside the Copernicus riparian zones LCLU (MAES_4)	Polygon	International /National, segment		Riparian Zone/Copernicus LULC: https://land.copernicus.eu/local/riparian-zones/land-cover-land-use-lclu-image?tab=download Corine Land Cover: https://land.copernicus.eu/pan-european/corine-land-cover/clc2018?tab=download Site-specific habitat mapping		Assignment of the Copernicus Land Use types to the habitat types of Fischer et al. (2019) and Finck et al. (2017)
FSi, MI	Table			Fischer et al. (2019): https://www.frontiersin.org/articles/10.3389/fevo.2019.00483/full		
FR	Polygon	International /FFP		http://www.geo.u-szeged.hu/dfgis/	2020	
BI	Line shape file	International /River		https://www.danubegis.org/	2015	

Interreg Danube Transnational Programme IDES

Habitat Provision/River (HPI_{river})

Original authors (RESI): M. Nissl, A. Lentz, A. Rumm, F. Foeckler, C. Fischer, B. Stammel, M. Gelhaus, C. Damm, L. Gerstner and M. Scholz

Editors (IDES): CUEI

Publication date: November 2021

Interpretation

The indicator depicts the importance of functional and structural quality to aquatic habitats, as well as their biotic communities and species in a river and on its banks in the studied floodplain segment. Moreover, it reflects the performance of the assessed ecosystem in terms of provisioning typical habitats of rivers and the directly adjacent river bank.

The quantification of habitat provision in a river is mainly based on parameters obtained from hydro-morphological (river structure mapping), biological (Water Framework Directive (WFD) reporting) and water quality assessment (in terms of chemical status according to the WFD).

However, the procedure and parameters of the hydro-morphological assessment (river structure mapping) may vary from (federal) state to state; or do not exist at all. Accordingly, the selection of the HPI_{river} calculation parameters from the hydro-morphological assessments must be made following content-related criteria.

The values for biological quality elements (BQE) are strongly interpolated because they are only recorded at the WFD monitoring sites located far away from each other.

References

Förster, J., Halle, M. & Müller, A. (2017). Entwicklung eines Habitatindexes zur Beurteilung biozönotisch relevanter Gewässerstrukturen. Korrespondenz Wasserwirtschaft, 8. 466-471.

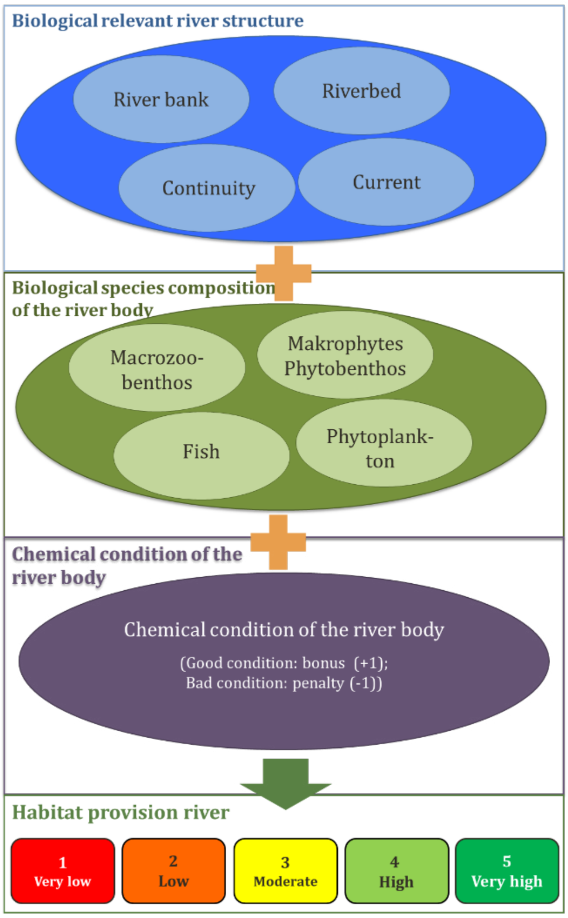
Nissl, M., Stammel, B., Lentz, A., Foeckler, F., Parzefall, C., Fischer-Bedtke, C., Damm C., Gelhaus, M., Gerstner, L., Kasperidus, H.D., Scholz, M. & Rumm, A. (2020). Quantifizierung und Bewertung der Ökosystemleistung Habitatbereitstellung im Fluss – AquaRESI. UFZ-Bericht 2/2020: 171 – 180. https://www.ufz.de/index.php?en=20939&ufzPublicationIdentifier=25854

■ Original approach according to the River Ecosystem Service Index (RESI) (Podschun et al. 2018)

Class	Abbr.	Description		Spatial reference	
Regulating	HPI_{river}	The Habitat Provision/River Index considers the water quality as well as the functional and structural quality of biologically relevant waterbody structures in the river and the directly adjacent river bank.		Floodplain segment or compartment ☐ former floodplain ☐ active floodplain ☒ river	
Variable	**Abbr.**	**Unit**	**Variable description**	**Data basis**	**Comment**
Riverbed	RBe	Ordinal (1-7)	Mean value of the individual parameters (IP) concerning the riverbed: usually substrate, substrate diversity, lining, structure and load	Hydro-morphological assessment (river structure mapping)	Might be different between federal states
Flow	Flow	Ordinal (1-7)	Mean value of the IP concerning the flow: usually backwater, cross-banks, depth variance and flow diversity	Hydro-morphological assessment	Might be different between federal states
River bank	RBa	Ordinal (1-7)	Mean value of the IP concerning the bank: usually vegetation cover, pollution, embankments, shading and structure	Hydro-morphological assessment	Might be different between federal states
Continuity	Con	Ordinal (1-7)	Mean value of the IP concerning the continuity: usually transverse structures, pipes and culverts	Hydro-morphological assessment	Might be different between federal states
Phytoplankton	PP	Ordinal (1-5)	Biological quality elements (BQE): phytoplankton	Water Framework Directive (WFD) reporting	Categories of WFD earn the following values (reverse order!): High: 5, Good: 4, Moderate: 3, Poor: 2, Bad: 1
Macrozoobenthos	MZB	Ordinal (1-5)	BQE: macrozoobenthos	WFD reporting	Categories of WFD earn the following values (reverse order!): High: 5, Good: 4, Moderate: 3, Poor: 2, Bad: 1
Fish	Fish	Ordinal (1-5)	BQE: fish	WFD reporting	Categories of WFD earn the following values (reverse order!): High: 5, Good: 4, Moderate: 3, Poor: 2, Bad: 1
Macrophytes/ Phytobenthos	MPPB	Ordinal (1-5)	BQE: macrophytes/phytobenthos	WFD reporting	Categories of WFD earn the following values (reverse order!): High: 5, Good: 4, Moderate: 3, Poor: 2, Bad: 1
Chemical status (optional)	Chem	Nominal (not good, good)	chemical status of the river body	WFD reporting	

Calculation

Evaluation scheme



Indicator

1. Habitat provision in the section (in general 100 m)

a) Biologically relevant river structure per reach (HP_{river}) (following Förster et al. 2017)

$$HP_{river} = \frac{RBe + Flow + RBa + Con}{n}$$

with n = number of parameters

Transfer to 5-level IDES scale: if individual parameters are missing, the mean value is calculated from the remaining individual parameters.

b) Biological species composition per reach (Bio_{river})

$$Bio_{river} = \frac{Fish + MZB + PP + MPPB}{4}$$

Calculation of the mean value from the individual parameters of the biological quality element. If there are no values, the mean value is calculated from the remaining variables.

c) Calculation of the Habitat Index for a stretch of river

Average of HP_{river} and Bio_{river}, plus malus (chem)

$$Hab_{river100} = \frac{HP_{river} + Bio_{river}}{2} + chem$$

2. Assessment of the habitat provision for a river compartment

Length-weighted averaging of all $Hab_{River100}$ of a km segment, where L_i = length of the section.

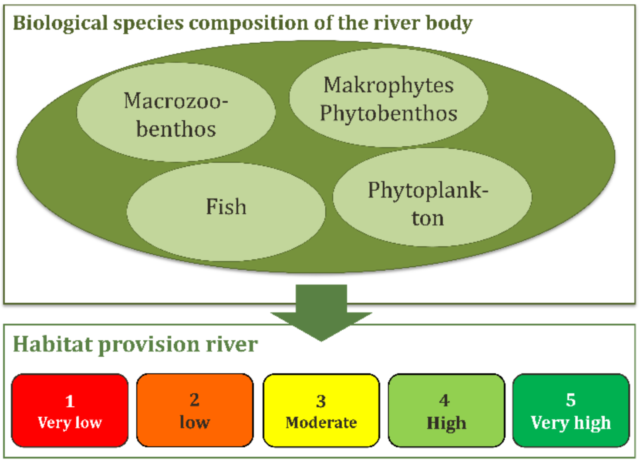
$$HPI_{river} = \frac{\sum_{i=i}^{n}(Hab_{river100} * L_i)}{\sum_{i=i}^{n}(L_i)}$$

Scaling ☐ **national** ☒ **local**	**HPI_{river}**	≥ 4.5	< 4.5 - ≥ 3.5	< 3.5 - ≥ 2.5	< 2.5 - ≥ 1.5	< 1.5
Evaluation Class		5	4	3	2	1
Qualitative Evaluation		**Very High** importance for habitat provision	**High** importance for habitat provision	**Moderate** importance for habitat provision	**Low** importance for habitat provision	**Very Low** importance for habitat provision

■ Adaption for Danube-wide application

Class	Abbr.	Description		Spatial reference	
Regulating	HPI_{river}	The Habitat Provision/River Index should consider the water quality as well as the functional and structural quality of biologically relevant water body structures in the river and the directly adjacent river bank. Only biological variables can be used where river quality mapping is unavailable.		Floodplain segment or compartment ☐ former floodplain ☐ active floodplain ☒ river	
Variable	**Abbr.**	**Unit**	**Variable description**	**Data basis**	**Comment**
Phytoplankton	PP	Ordinal (1-5)	Biological quality elements (BQE): phytoplankton	Water Framework Directive (WFD) reporting	Categories of WFD have the following values (reverse order!): High: 5, Good: 4, Moderate: 3, Poor: 2, Bad: 1
Macrozoobenthos	MZB	Ordinal (1-5)	BQE: macrozoobenthos	WFD reporting	Categories of WFD have the following values (reverse order!): High: 5, Good: 4, Moderate: 3, Poor: 2, Bad: 1
Fish	Fish	Ordinal (1-5)	BQE: fish	WFD reporting	Categories of WFD have the following values (reverse order!): High: 5, Good: 4, Moderate: 3, Poor: 2, Bad: 1
Macrophytes/Phytobenthos	MPPB	Ordinal (1-5)	Macrophytes/Phytobenthos	WFD reporting	Categories of WFD have the following values (reverse order!): High: 5, Good: 4, Moderate: 3, Poor: 2, Bad: 1
Ecological status (WFD)	ES	Ordinal (1-5)	Final evaluation of the ecological status according to the WFD	WFD reporting	Where no single species group data (PP, MZZB, fish, MPPB) is available, the ecological status according to WFD can be used instead.
Confidence of evaluation	conf	Ordinal (1-5)	Confidence of the evaluation	WFD reporting	categories were translated to factors: High: 1, Moderate: 0,7, Low: 0,3
Length of river stretch	L	m	Stretch being evaluated	WFD reporting	

Calculation

Evaluation scheme	Indicator
	**1. Ecological status of the river section (in general 100 m)** Biological species composition per stretch (Bio_{river}) $Bio_{river} = \frac{Fish + MZB + PP + MPPB}{4}$ Calculation of the mean value from the individual parameters of the biological quality elements. If individual variables are missing, the mean value is calculated from the remaining parameters. If all variables are missing, ES should be used instead. **2. Assessment of the habitat provision per river compartment** Length- and confidence-weighted average of all Bio_{river} of a 1km-compartment, where L_i = length of a sections and $conf_i$ = the confidence of its evaluation: $HPI_{river} = \frac{\sum_{i=i}^{n}(Bio_{river\,i} * conf_i * L_i)}{\sum_{i=i}^{n}(conf_i * L_i)}$

Scaling ☐ national ☒ local	HPI_{river}	≥ 4.5	< 4.5 - ≥ 3.5	< 3.5 - ≥ 2.5	< 2.5 - ≥ 1.5	< 1.5
IDES class		**5**	**4**	**3**	**2**	**1**
Qualitative Evaluation		**Very High** importance for habitat provision	**High** importance for habitat provision	**Moderate** importance for habitat provision	**Low** importance for habitat provision	**Very Low** importance for habitat provision

Data set	Data type	Spatial reference	Spatial resolution	Source	Creation date	Comments
PP, MZB, Fish, MPPB, ES, conf Evaluation according to the WFD taken from the DanubeGIS	Line shape file	International/River		https://www.danubegis.org/	2015	

Factsheets for Indicator-based ES Evaluations

Cultural Ecosystem Services

Interreg
Danube Transnational Programme
IDES

Opportunities for Non-Water-Related Activities (NWA)

Original authors (RESI): J. Thiele, C. v. Haaren and C. Albert

Editor (IDES): RCSES

Publication date: November 2021

Interpretation

The indicator estimates the opportunities provided by a river landscape for non-water-related activities on the riverine landscape (e.g. walking, cycling, nature observation, as well as other relaxing recreation such as having a picnic, etc.). For regional analyses, the calculation can be expanded to include an additional variable using half the weighting in the summation formula.

For a more detailed representation of specific management areas, the grid cells can be considered with a relative rating between 0-100. For the overall assessment in the context of other ES, this Cultural ES assessment was transferred to the 5-level RESI scale (Podschun et al. 2018).

References

Grizzetti, B., Lanzanova, D., Liquete, C. & Reynaud, A. (2015). Cook-book for water ecosystem service assessment and valuation, JRC Science and policy Report. European Commission Luxembourg.

Rabe, S.-E., Gantenbein, R., Richter, K.-F. & Grêt-Regamey, A. (2018). Increasing the credibility of expert-based models with preference surveys – Mapping recreation in the riverine zone. Ecosystem Services, 31, 308-317.

Thiele, J., Albert, C., Hermes, J., & von Haaren, C. (2020). Assessing and quantifying offered cultural ecosystem services of German river landscapes. Ecosystem Services, 42, 101080

Thiele, J., Albert, C., von Haaren, C. (2020). Erfassung und Bewertung kultureller Ökosystemleistungen von Flusslandschaften. UFZ-Bericht 2/2020, 213-252. https://www.ufz.de/index.php?en=20939&ufzPublicationIdentifier=25846

Villamagna, A. M., Mogollón, B. & Angermeier, P. L. (2014). A multi-indicator framework for mapping cultural ecosystem services. The case of freshwater recreational fishing. Ecological Indicators, 45, 255–265

■ Original approach according to the River Ecosystem Service Index (RESI) (Podschun et al. 2018)

Class	Abbr.	Description	Spatial reference
Cultural	NWA	Experiencing animals, plants and landscapes (e.g. nature observation, cycling and walking) for the purpose of recreation	Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☒ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
Bank and waterbody availability	BWA	0-100	Sum of normalised bank density per 100m² and normalised density of water area per 100m² with final normalisation	National Land Cover Model	
Possibility to experience the terrain	EoT	0-100	Possibility to experience the environment depending on land cover/use classification	National Land Cover Model	
Number of overlapping protected area categories	NPA	0 = no protected area; 100 = protected area	Presence of protected areas as an indirect sub-indicator for the potential of nature observation and experience (Grizzetti et al. 2015; Peña et al. 2015)	National parks, biosphere reserve, nature parks, nature reserves, landscape conservation areas, Natura 2000 Network	

<table>
<tr><th colspan="7">Calculation</th></tr>
<tr><th colspan="2">Calculation steps</th><th colspan="5">Indicator</th></tr>
<tr><td colspan="2">Nationwide:
Calculation of BWA, EoT and NPA variables in grid cells with 100 m resolution.
Calculation of the indicator (see column on the right) with a normalisation between 0-100
Floodplain compartment level:
Calculation of the area-weighted mean for the river floodplain compartments, active floodplain and former floodplain (right and left bank respectively).
For scaling:
Classification on the five-level rating scale via the calculation of quintiles for all model regions.</td><td colspan="5">$$f_{(NWA)} = \sum BWA,\ EoT,\ NPA$$
→ normalise raster between 0-100 (Rabe et al. 2018):
$$\frac{max_{new} - min_{new}}{max_{old} - min_{old}} \cdot (v - max_{old}) + max_{new}$$
v is the resulting raster generated by $f_{(NWA)}$</td></tr>
<tr><td>Scaling
☒ national
☐ local</td><td>Quintiles</td><td>> 33.0 - 73.0</td><td>> 23.4 - 33.0</td><td>> 17.9 - 23.4</td><td>> 14.7 - 17.9</td><td>0 - 14.7</td></tr>
<tr><td colspan="2">Evaluation Class</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td colspan="2">Qualitative Evaluation</td><td>Very High provision</td><td>High provision</td><td>Moderate provision</td><td>Low provision</td><td>Very Low provision</td></tr>
</table>

■ Adaption for Danube-wide application

Class	Abbr.	Description	Spatial reference
Cultural	NWA	Experiencing animals, plants and landscapes (e.g. nature observation, cycling and walking) for the purpose of non-specific recreation	Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☒ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
Bank and waterbody availability	BWA	Category	People's preference to perform various activities next to water are calculated as the length of banks per area unit within a 1000 m radius using Line Density Tool, then normalised per segment length.	Land Cover Model	
Possibility to experience the terrain	EoT	Category	Different categories of land use land cover are converted into ordinal data using a lookup table revealing pedestrian accessibility between 0 and 95 (Thiele et al 2020).	Land Cover Model	
Number of overlapping protected area categories	NPA	Category	presence of protected areas per segment	National parks, biosphere reserves, nature parks, nature reserves, landscape conservation areas, Natura 2000 areas	

Calculation

Indicator

$$f_{(NWA)} = \sum BWA,\ EoT,\ NPA$$

→ normalise raster between 0-100 (Rabe et al. 2018):

$$\frac{max_{new} - min_{new}}{max_{old} - min_{old}} \cdot (v - max_{old}) + max_{new}$$

v is the resulting raster generated by $f_{(NWA)}$

Scaling ☒ national ☐ local	Quintiles*	> 33.0 - 73.0	> 23.4 - 33.0	> 17.9 - 23.4	> 14.7 - 17.9	0 - 14.7
Evaluation Class		5	4	3	2	1
Qualitative Evaluation		**Very High** provision	**High** provision	**Moderate** provision	**Low** provision	**Very Low** provision

*Quintile boundaries refer to calculations in the DRB (Chapter 2.2.5)

■ **Data sources**

Data set	Data type	Spatial reference	Spatial resolution	Source	Creation date	Comments
BWA, EoT Copernicus Riparian Zones LCLU (MAES_4)	Polygon	International /Active FP	Minimum Mapping Unit: 0.5 ha Minimum Mapping Width: 10 m	https://land.copernicus.eu/local/riparian-zones/land-cover-land-use-lclu-image	2012	
NPA e.g. Natura 2000 areas, protected areas	Polygon	International/ Segments		https://www.eea.europa.eu/data-and-maps/data/natura-12	2020	

Opportunities for Water-Related Activities (WRA)

Original authors (RESI): J. Thiele, C. v. Haaren and C. Albert

Editors (IDES): UB-RCSES

Publication date: November 2021

Interpretation

The indicator identifies the opportunities provided by a river landscape for water-related activities (bathing, non-motorised boating and motorised boating and fishing). The indicator can be supplemented by additional options (see next section). The availability of sand and sandbars reflects a feature supporting the 'swimming' activity. Further information (e.g., sanitary water quality, flow velocity and depth of visibility) can be added if regional data for those variables are available. Stream width is a variable that determines potential navigability by (motor) boat.

For a more detailed representation of individual management areas, the grid cells can be considered with a relative rating scale ranging between 0-100. In order to enable direct comparison with other ES, assessment scores were transferred to the 5-level RESI scale (Podschun et al. 2018).

Extension possibilities for regional quantifications with the inclusion of regionally produced data:

- Hygienic water quality via assessment of intestinal Enterococci (cfu/100 ml) and Escherichia coli (cfu/100 ml) concentrations (EU Bathing Water Directive (Directive 76/160/EEC) (cf. Paracchini et al. 2014);
- Quantification of riparian vegetation from hydromorphological (river structure) mapping data: expert-based assessment of riparian vegetation between 0-100 against the background of performing water-related activities (e.g. bathing);
- Water transparency: indirectly via suspended sediment concentration g/m³ (interpolate and classify if median May-September record is less than 10 g/m³) (Morrison n.d.);
- Minimum water depth of 60 cm, as calculated from 5-year averaged water levels. A five-year observation period is suggested to compensate for possible extreme events (for example, from 2011-2015): relevant for non-motorised boating;
- Varied curvature of the water course: quantification using data from hydromorphological (river structure) quality assessment (100 ≙ meandering and 0 ≙ straight);
- Flow velocity: relevant for whitewater canoeing or rafting;
- Minimum depth of 90 cm, as calculated from a 5-year averaged water levels: relevant for motorised boating; and
- Hydromorphological (river structure) quality rating as a parameter for anglers' preference to fish in near-natural or natural water bodies (Arlinghaus 2004; Hunt 2005): normalise structure quality rating 1-7, with 7 reflecting the lowest and 1 the best hydromorphological status.

References

Arlinghaus, R. (2004). Angelfischerei in Deutschland - eine soziale und ökonomische Analyse. Leibniz-Institut für Gewässerökologie und Binnenfischerei (IGB) im Forschungsverbund Berlin e. V. Berlin (ed.). Berichte des IGB, 18/2004.

Hunt, L. M. (2005). Recreational Fishing Site Choice Models. Insights and Future Opportunities. Human Dimensions of Wildlife, 10, 153–172.

Morrison, W. Water transparency in Willamette River at Portland. Data from U.S. Geological Survey. https://or.water.usgs.gov/will_morrison/images/secd_tbdy_linear_graph.png .

Richtlinie 76/160/EEC vom 15. Februar 2006 über die Qualität der Badegewässer und deren Bewirtschaftung und zur Aufhebung der Richtlinie 76/160/EWG

Paracchini, M. L., Zulian, G., Kopperoinen, L., Maes, J., Schägner, J. P., Termansen, M., Zandersen, M., Perez-Soba, M., Scholefield, P.A. & Bidoglio, D. (2014). Mapping cultural ecosystem services. A framework to assess the potential for outdoor recreation across the EU. Ecological Indicators, 45, 371–385.

Rabe, S.-E., Gantenbein, R., Richter, K.-F. & Grêt-Regamey, A. (2018). Increasing the credibility of expert-based models with preference surveys – Mapping recreation in the riverine zone. Ecosystem Services.

Russi, D., ten Brink, P., Farmer, A., Badura, T., Coates, D., Förster, J., Kumar, R. & Davidson, N. (2013). The Economics of Ecosystems and Biodiversity for Water and Wetlands. IEEP, London and Brussels, Ramsar Secretariat, Gland.

Thiele, J., Albert, C., Hermes, J., & von Haaren, C. (2020). Assessing and quantifying offered cultural ecosystem services of German river landscapes. Ecosystem Services, 42 https://doi.org/10.1016/j.ecoser.2020.101080

■ Original approach according to the River Ecosystem Service Index (RESI) (Podschun et al. 2018)

Class	Abbr.	Description	Spatial reference
Cultural	WA	Specific water-related activities for recreational purposes (recreational fishing, swimming, non-motorised boating and motorised boating)	Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☒ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
Normalised density of sand/sandbanks	DSB_{danube}	1 - 100	Normalisation of the nationwide density calculation between 1 and 100	Land Cover Model	
Minimum width of 5m (for non-motorised boating)	$MW5_{danube}$	100 ≙ yes 0 ≙ no	Prerequisite for non-motorised boating: at least 5-metre-wide section of water with as	Land Cover Model	
minimum width of 12m (for motorised boating)	$MW12_{danube}$	100 ≙ yes 0 ≙ no	Prerequisite for motorised boating: at least 12-metre-wide section of water	Land Cover Model	

Calculation

Calculation steps	Indicator
Nationwide: Calculation of the variables DSB_{danube}, $MW5_{danube}$ and $MW12_{danube}$ in grid cells with 100 m resolution Calculation of the indicator (see column on the right) with a normalisation between 0-100 **Floodplain compartment level:** Calculation of the area-weighted mean for the river floodplain compartments, active floodplain and former floodplain (right and left bank respectively) **For scaling:** Classification into the five-level rating scale via the calculation of quintiles for the all model regions	$f(WA) = \sum DSB_{danube}, MW5_{danube}, MW12_{danube}$ → normalise raster between 0-100 (Rabe et al. 2018): $\frac{max_{new} - min_{new}}{max_{old} - min_{old}} \cdot (v - max_{old}) + max_{new}$ *v* is the resulting raster generated by $f_{(WA)}$

Scaling ☒ national ☐ local	Quintiles	> 2.6 - 68.9	> 1.1 - 2.6	> 0.4 - 1.1	> 0.02 - 0.44	0 - 0.02
Evaluation Class		**5**	**4**	**3**	**2**	**1**
Qualitative Evaluation		**Very High** provision	**High** provision	**Moderate** provision	**Low** provision	**Very Low** provision

■ Adaption for Danube-wide application

Class	Abbr.	Description	Spatial reference
Cultural	WA	Specific water-related recreational activities (recreational fishing, swimming, non-motorised boating and motorised boating)	Floodplain segment or compartment ☒ former floodplain ☒ active floodplain ☒ river

Variable	Abbr.	Unit	Variable description	Data basis	Comment
Normalised density of sand/sand bars	DSB_{danube}	m²	Area of sand/sand banks per segment area	Land Cover Model	
Minimum width of 5m (for non-motorised boating)	$MW5_{danube}$	100 ≙ yes 0 ≙ no	Prerequisite for non-motorised boating: at least 5-metre-wide section of water with as	Land Cover Model	
minimum width of 12m (for motorised boating)	$MW12_{danube}$	100 ≙ yes 0 ≙ no	Prerequisite for motorised boating: at least 12-metre-wide section of water	Land Cover Model	

Calculation

Calculation steps	Indicator
Nationwide: Calculation of the variables DSB_{danube}, $MW5_{danube}$ and $MW12_{danube}$ in grid cells with 100 m resolution Calculation of the indicator (see column on the right) with a normalisation between 0-100 **Floodplain compartment level:** Calculation of the area-weighted mean for the river floodplain compartments, active floodplain and former floodplain (right and left bank respectively) **For scaling:** Classification into the five-level rating scale via the calculation of quintiles for the all model regions	$f(WA) = \sum DSB_{danube}, MW5_{danube}, MW12_{danube}$ → normalise raster between 0-100 (Rabe et al. 2018): $\frac{max_{new} - min_{new}}{max_{old} - min_{old}} \cdot (v - max_{old}) + max_{new}$ *v* is the resulting raster generated by $f_{(WA)}$

Scaling ☒ **national** ☐ **local**	**Quintiles**	0.8 - 1	0.6 - 0.8	0.4 - 0.6	0.2 - 0.4	0 - 0.2
Evaluation Class		**5**	**4**	**3**	**2**	**1**
Qualitative Evaluation		**Very High** provision	**High** provision	**Moderate** provision	**Low** provision	**Very Low** provision

■ Data sources

Data set	Data type	Spatial reference	Spatial resolution	Source	Creation date	Comments
BWA, EoT Copernicus Riparian Zones LCLU (MAES_4)	Polygon	International /Active FP	Minimum Mapping Unit: 0.5 ha Minimum Mapping Width: 10 m	https://land.copernicus.eu/local/riparian-zones/riparian-zones-2012	2012	

2.2.6 Prioritisation of areas with high potential for water quality functions

The IDES Tool can also be used to evaluate the relevance of active floodplains for water quality and water quality improvement (Chapter 2.1). Floodplains are able to retain nutrients transported by rivers (i.e. from upstream sources) and may act as natural riparian buffer zones by intercepting nutrients from upslope sources. 'Areas of high relevance' are defined in this Manual as floodplains or segments of high nutrient retention potential (Factsheets NRI and PRI) located in areas of high nutrient pollution (Figure 2.2.4). The assessment focuses on nitrogen (N) and phosphorus (P) for which a combination of indicators is used to prioritise the areas on basin-wide and national levels. 'Nutrient emissions from catchment', 'river nutrient concentrations', 'nutrient retention river/floodplain' and 'flooding frequency' indicators can be estimated for N and P using established models (Heinen 2006, Schulz-Zunkel et al. 2021, Tschikof et al. 2022, Venohr et al. 2011). The indicator values are then classified utilising percentiles and the class values (ranks) that are further aggregated to retention ranks. A high ranking indicates a high relevance for water quality improvement, distinguished between upstream riverine sources and upslope catchment sources for N and P (Figure 2.2.4).

Implementation in the DRB

The Deliverable T1.1.1 (https://www.interreg-danube.eu/approved-projects/ides/outputs) provides a detailed methodological description, results and replicable files that can be employed to visualise and adapt the prioritisation approach in active DRB floodplains.

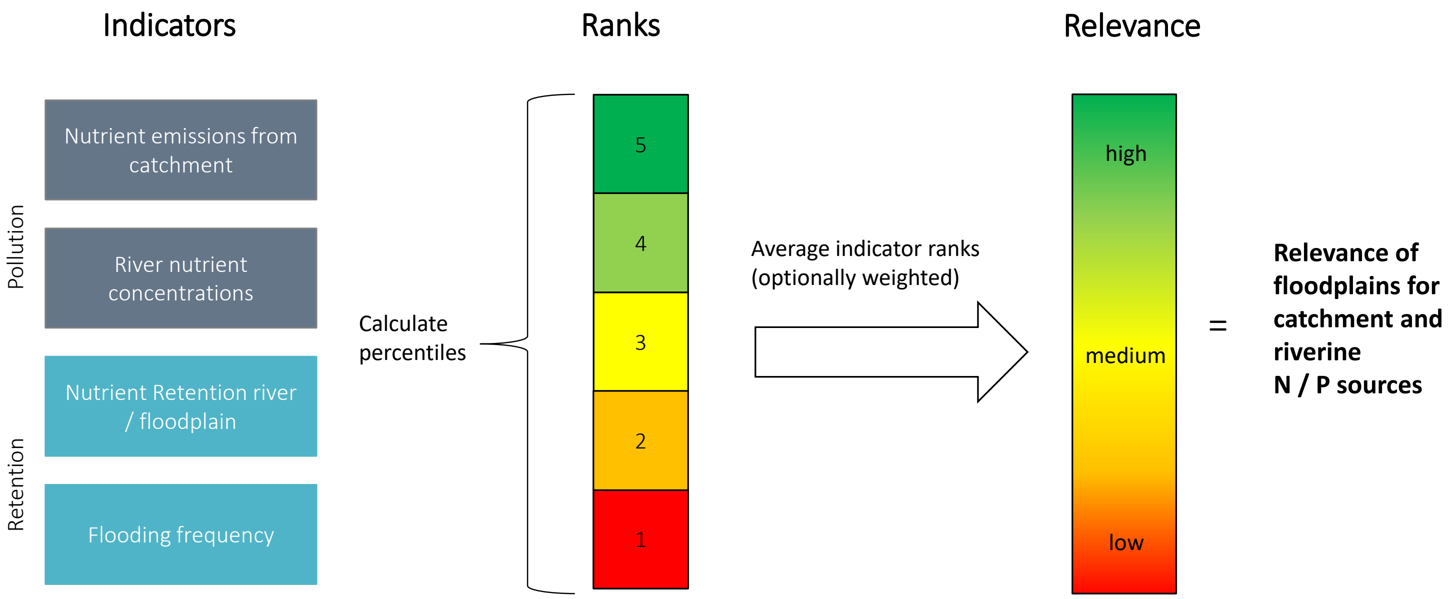


Figure 2.2.4 Evaluation scheme for estimating the relevance of rivers and active floodplains for water quality

2.3. Scenarios for the pilot areas in the Danube region

Cristian Mihai Adamescu, Gabriela Costea, Relu Constantin Giuca

2.3.1 Theoretical background

Building scenarios and aggregating them into visions of a better future is a logical way forward, especially when aiming to integrate the multiple uses of ES across manifold spatial-temporal scales. If the scenario building and the vision development is done collaboratively with different stakeholders, using knowledge and data generated and synthesised over decades, then it will be a win-win situation for all groups (less discussion during the implementation phase, less conflict, more social learning over longer time periods).

Scenarios are descriptions of possible futures that facilitate analysis for a variety of purposes (Allan 2022). Both qualitative and quantitative models have been used to envisage the future, from the use of mathematical models to predict future trends (trend analysis) or pure and simple narratives like storylines. At the same time, the future is uncertain. In order to tackle this uncertainty, alternatives can be taken into consideration in the form of future scenarios. Usually, ecological scenarios are based on describing the initial situation, the key driving forces and the changes envisaged to describe a future situation.

Socio-ecological systems are highly complex, mainly due to multiple links and cause-and-effect relations. The DPSIR Framework (Drivers, Pressures, State, Impact, and Response) was applied to better structure/organise this complexity in the IDES Project. According to this framework, social and economic developments exert pressure on the environment and, as a consequence, the state of the environment and provision of ES changes. Finally, this leads to impacts on human wellbeing and ecosystems that may elicit a societal response. Through adaptation or curative action, this response directly affects the driving forces or pressures, states and impacts. Obviously, the real world is far more complex than can be expressed in simple causal relations.

2.3.2 Implementation in the Danube region

The implementation of water quality management measures is often limited by the lack of support among local and regional stakeholders (Chapter 1). The IDES Project aimed to integrate stakeholders early in the planning stage, and to implement the ES approach together with the decision-makers as a means to overcome this potential obstacle. Stakeholder workshops were conducted (Chapter 3.2) to collaboratively identify the benefits (ES), pressures (with a negative impact on the ES), and possible measures (as a societal response to reduce the negative impact on ES that the pressures exert), and eventually co-develop and co-create the vision and scenarios for five pilot areas

A stepwise approach was implemented for each pilot area, as follows:

1. ES were identified by the stakeholders in each pilot area using a harmonised list of ES (Chapter 2.2.4);
2. Stakeholders identified the specific pressures for their pilot area (by selecting from a defined list of pressures);
3. A collective socio-ecological system analysis was carried out using FCM;
4. Stakeholders identified possible responses (e.g. management options and restoration measures).

Fuzzy Cognitive Models (FCM) are signed directed graphs that represent the relative strengths of positive and negative impacts by elements (ES, pressures and measures) on other elements. For scenario analyses, the stakeholders can manipulate the states of elements and observe the changes of others. FCM tools like the MentalModeler (https://www.mentalmodeler.com/) used in IDES facilitate the assessments and visualise the changes as relative values from -1 to +1.

An FCM (Figure 2.1.4 and 2.3.1) was developed in cooperation with the stakeholders to integrate the ES and the DPSIR Framework for each study area that considered the variability in site conditions and stakeholder perceptions. This step was done in order to understand the linkages between the DPSIR Framework and the ES for each of the five pilot areas. It was presupposed that several drivers and pressures, as well as the status and the responses, are characteristic to the entire DRB and not pilot area specific. Water quality considerations were integrated within the Framework as the ES 'water purification/water quality improvement'. The FCM were used to identify the pressures and trade-offs among the ES as well as the measures proposed in each of the five pilot areas.

The FCMs of the five pilot areas were merged into a single FCM (Figure 2.3.1), and then the most important measures were identified and integrated into four management options:

A) Nature-based solutions (NBS);

B) Grey solutions (GS);

C) Hybrid solutions (NBS-GS);

D) Business as usual (BAU).

a) Nature-based solutions are inspired and supported by nature; are cost-effective; provide multiple environmental, social and economic benefits; and improve resilience. Implementation of NBS can result in the improvement of biodiversity and a range of ecosystem services. Measures selected by the stakeholders include a range of NBS: a) Floodplain restoration (M_floodplain rest. see figure 2.3.1); b) Restoration of longitudinal connectivity (M_rest. long. connect.) c) Habitat improvement (M_habitat improv.); d) Use of autochthonous plants and trees (in forests) (M_autoch. plants); e) Establishment of riparian buffer zones (M_buffer zones); and f) Restoration of the natural flow regime (M_rest. nat. flow).

b) Grey solutions are usually management options that are more related to active human intervention on the landscape. GS suggested by the stakeholders include: a) dyke relocation, slotting or dismantling (M_dyke relocation); b) construction or upgrade of wastewater treatment plants (M_wtp); c) prevention or control of the adverse impacts of invasive species (M_invasive sp. prevention); d) fish stocking (M_stocking); and f) flood risk reduction on agricultural land (M_flood risk red.).

c) NBS-GS is a combination of NBS and GS that actually much more closely represents the reality than both of them individually.

d) BAU means that the activities in the floodplain will remain the same.

For didactical purposes, the measures were divided into 'green' and 'grey'. However, a number of measures that are important for the implementation of the scenarios such as Environmental Education & Awareness campaign (M_env. edu. & awareness) or Streamlining the decision-making process (M_decision making), could not be assigned to either of these categories. Actually, implementation of purely green measures is less probable in any given area. In all likelihood, the

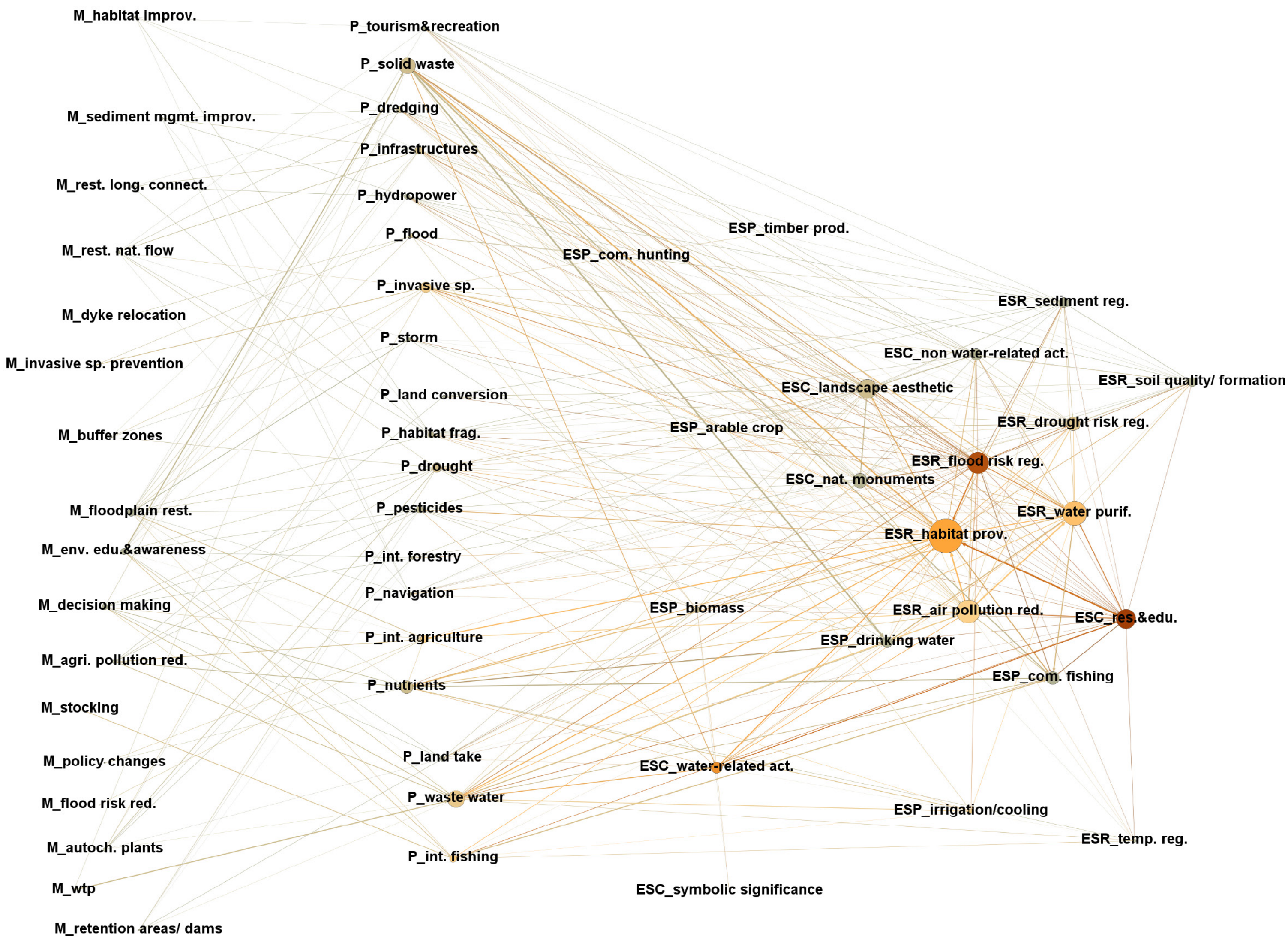


Figure 2.3.1 Merged FCM (the five pilot areas combined). M - Measures; P - pressures; ESP - Provisioning ES; ESC - Cultural ES; ESR – Regulation & Maintenance ES (some explained in more detail in the main text); explanations of the abbreviations in the main text.

selected scenarios would be a combination of different green and grey strategies.

The FCM approach was used with the stakeholders in order to analyse the effects of different scenarios and assess how changes in pressures or measures affect ES. An 'ideal' scenario was defined as a reduction of all pressures. The next step was to identify the options agreed by stakeholders. This was done by reducing a set of pressures to a certain degree between -1 and +1, and then considering the result in the FCM for each ES as an 'improvement coefficient' (Chapter 2.4). Based on a set of five measures or management options local stakeholders agreed and recommended to implement in their pilot area, an 'optimal' water quality improvement scenario was developed for each (Figure 2.3.2).

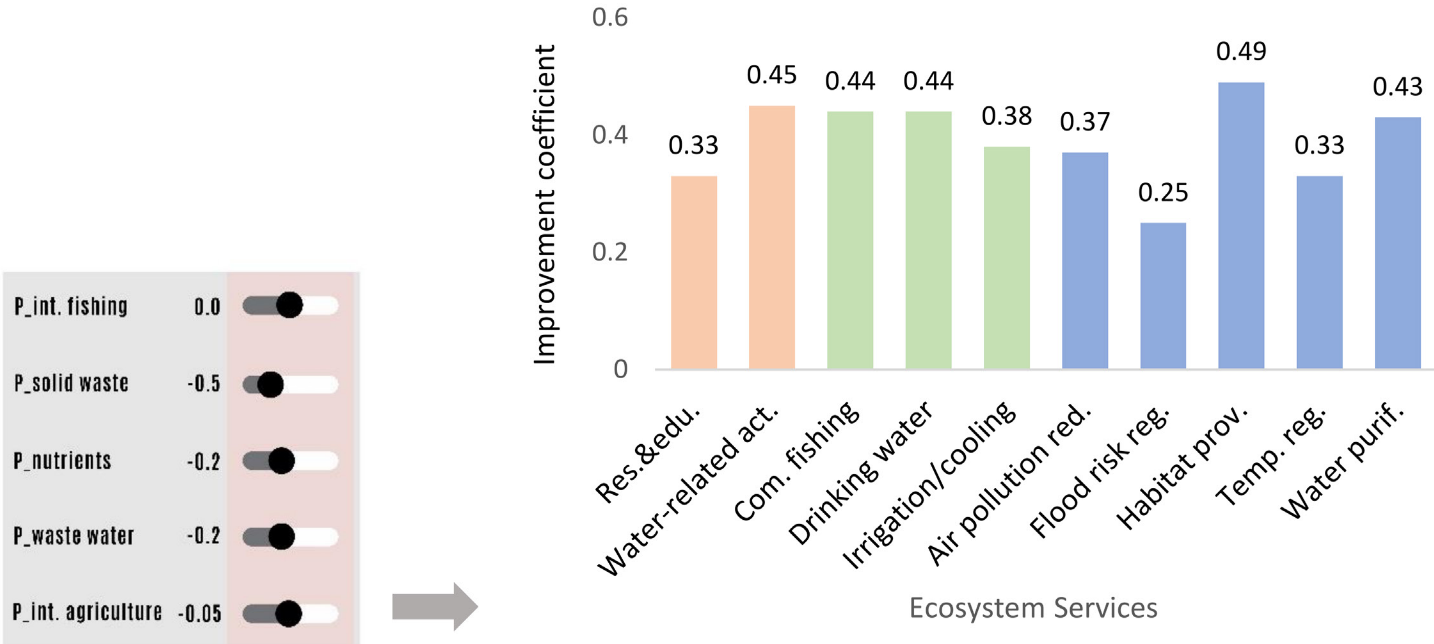


Figure 2.3.2. Chart generated by FCM indicating the improvement coefficient for different ES (ranging from -1 to +1). Shown here is the 'optimal' scenario for the Brăila Islands pilot area in Romania. Colours distinguish 'cultural ES' (orange), 'provisioning ES' (green) and 'Regulation & Maintenance ES' (blue) ES groups. ES names as in figure 2.3.1.

2.4. Synthesis and visualisation of cross-sectoral benefits in scenarios

Andreas Gericke, Martin Pusch, Markus Venohr, Cristian Mihai Adamescu, Constantin Cazacu, Tim Borgs, Barbara Stammel, Zorica Srđević, Gabriela Costea

Assessments of ES to support decision-making in water quality management should cover a broad spectrum of ES in order to identify the multiple benefits that floodplains may provide to humans. The provision of ES can be visualised for the status quo and for different scenarios. An assessment of an array of ES from all main groups of ES enables the diversity of the available ES for specific river reaches or floodplains to be represented. Such detailed assessments often need to identify and discuss cross-sectoral benefits of measures, and be condensed and summarised for communication purposes. Summaries of ES assessments can be calculated at different levels of detail, depending on the purpose and the target group. Optionally, the visualisation can focus on those ES that have been identified as important by different stakeholders with different interests (Chapter 2.3).

Spatially explicit ES assessments such as IDES require a large amount of data, but facilitate the visualisation and the comparison of management scenarios (Podschun et al. 2018, Stammel et al. 2020). Any changes may be precisely calculated for each ES, for each floodplain compartment, and for each river segment. However, applying this methodology to complex scenarios may need a considerable amount of resources, appropriate data and expertise. As the value of ES depends on their appreciation by humans, the perception of various stakeholders should be integrated into the development of a common scenario, which for example, aims at improving nutrient retention in floodplains (Chapters 2.3 and 3.2).

The visual comparison of ES in the status quo and in such scenarios represents an established way for joint discussions on the effect of nature-based solutions (NBS) upon stakeholders and decision-makers (e.g. Schröter et al. 2021). Following the identification of NBS that are effective for reaching specific management targets, ES assessments can also be used to show the cross-sectoral benefits of those measures to other ES and related management goals. In this way, not only the status quo of ES availability can be visualised, but also the benefits of management scenarios to various management goals and related stakeholders. Although the IDES Project mainly focused on water quality, the concept and workflow are generally applicable in water or floodplain management.

2.4.1. Comparing and summarising ES assessments to demonstrate cross-sectoral benefits of measures

There are various options available to compare and aggregate ES assessment results in order to represent the current state of the availability of several ES (the calculated ES scores). Summarising indices may facilitate the identification of the positive or negative effects of specific measures or scenarios. The choice of the aggregation level of ES data depends on the aim of the study, the desired level of spatial or technical detail, the target group, and the purpose of the communication. The following options are used to summarise IDES ES assessments:

a) Comparative maps and charts that show the distribution of ES scores for the status quo and scenarios (Figures 2.4.1-2).

b) Maps derived by a Fuzzy Cognitive Model (FCM) tool provide simple charts to visualise scenario effects and a synthesis of synergies and trade-offs between ES (Chapters 2.3 and 3.2). A FCM, which represents the trade-offs among the ES and the measures proposed for different case studies can be merged into a single model for the entire catchment (Figure 2.3.1).

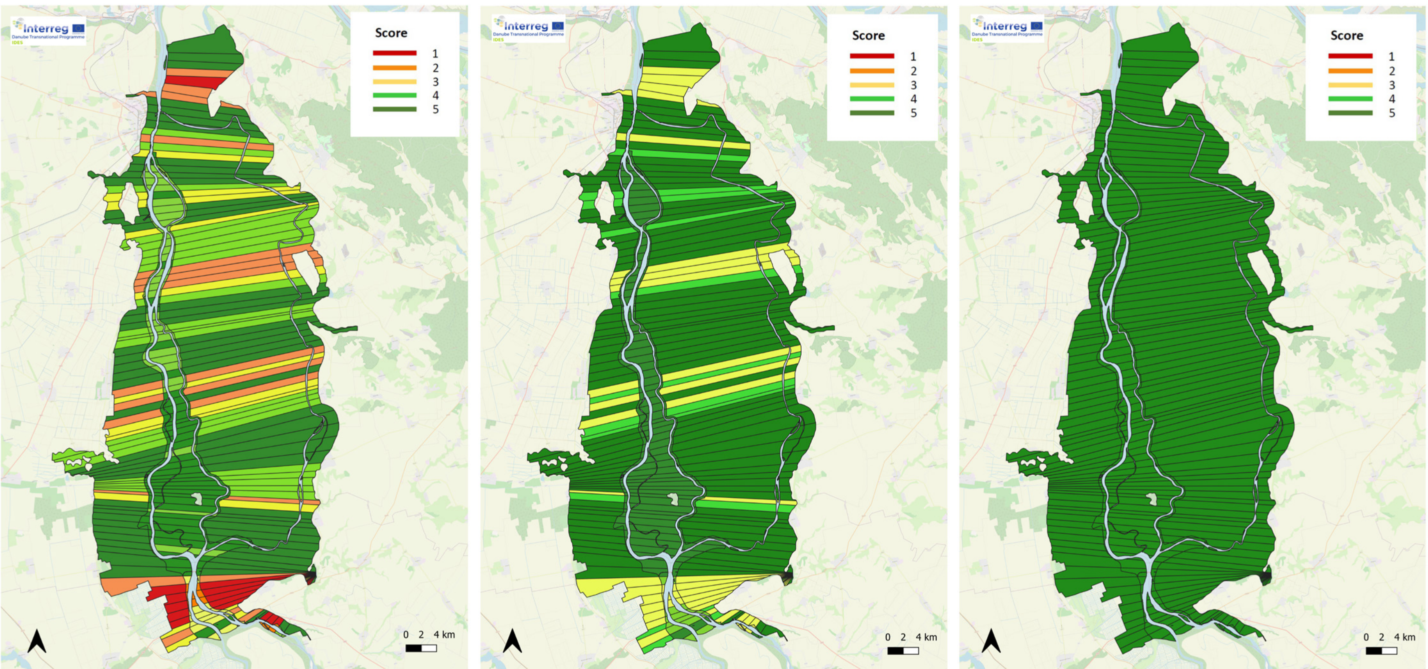


Figure 2.4.1 Cultural ES in the active and former floodplains for the status quo (left), 'optimal' (middle) and 'ideal' scenarios (right) as calculated by equation 2.4.2 (Chapter 2.4.2), Brăila Islands IDES pilot area in România.

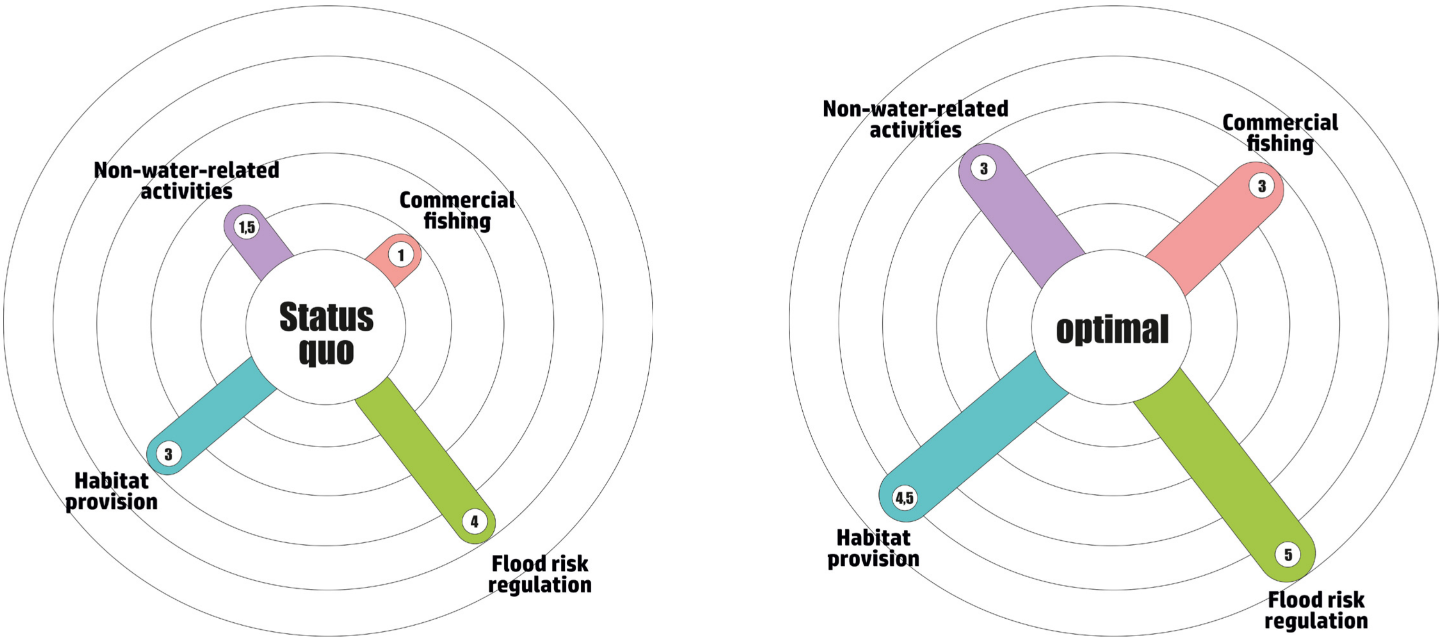


Figure 2.4.2 Distribution of the average values of the four ES for the status quo and the 'optimal' scenario as agreed among the stakeholders for one of the segments in figure 2.4.1.

c) Comparative diagrams of stakeholders' preferences for specific ES demonstrate the regional variation of ES perception. In large river basins, decisions on river basin management have to be co-ordinated among different states and countries. Knowledge about such differences enables stakeholders from different countries managing the same aquatic resource to consider differences or similarities in the perception and valuation of ES (Figures 2.4.3-4).

d) Assessments of multiple ES can be summarised by integrative indices such as the ES Average Index, ES Sum Index, ES Multi-Functionality Index, and the Floodplain Specificity Index (Podschun et al. 2018).

d1) ES Average Index
The ES Average Index is calculated from the average of ES scores. This value can be derived for all or selected ES in single segments and compartments, or

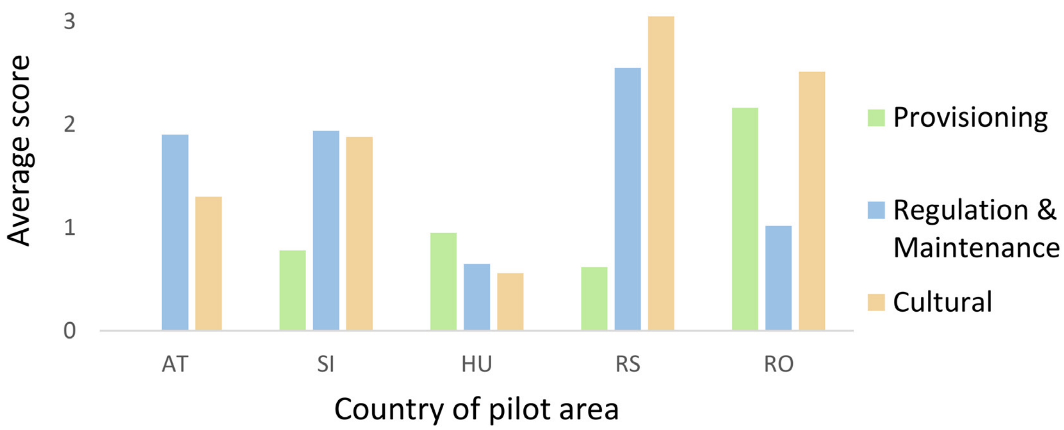


Figure 2.4.3 Example of cross-site comparison in the IDES Project: importance of ES groups as perceived by stakeholders in pilot areas of different countries along the Danube.

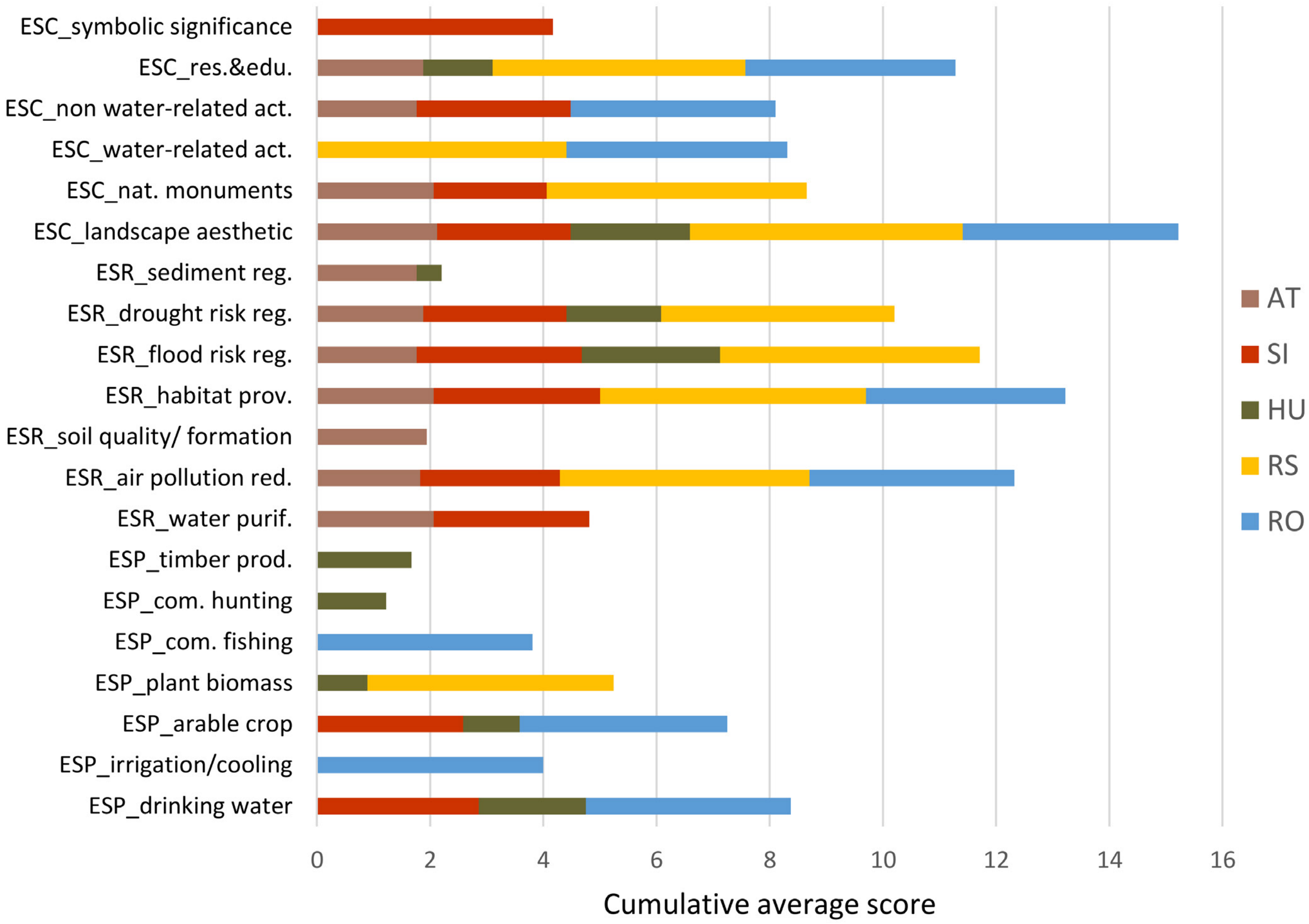


Figure 2.4.4 Example of cross-site comparison in the IDES Project: importance of ES as perceived by stakeholders in different countries along the Danube. ESP – Provisioning ES, ESR – Regulation & Maintenance ES, ESC – Cultural ES (abbreviations as in figure 2.3.1).

combinations of both. The ES Average Index is easy to calculate but its interpretation is limited: While low (or high) values reveal that the majority of ES are hardly (or fully) available, mean values (in IDES around 3) can either occur due to predominantly moderate ES scores or by a mix of low and high ES scores which balance each other. Typically, (visual) differentiation is difficult using this index because intermediate values occur most frequently (Figure 2.4.5).

d2) ES Sum Index

The ES Sum Index is calculated as the sum of the individual ES. For a correct interpretation, it should be combined with the number of assessed ES or with the maximum possible sum (= number of assessed ES multiplied by number of scores, in IDES = 5). Its transparency is similar to the ES Average Index, but it also implicitly provides information on the number of assessed ES. Depending on the goals of the ES assessment, this may also serve as a quality criteria.

d3) ES Multi-functionality Index

The more complex ES Multi-functionality Index represents the ratio of the number of ES with high scores to the number of the remaining ES per segment. A calculation is made using the number of ES with the scores 4 or 5 divided by the number of ES with scores 1 to 3. The higher the index, the higher the multi-functionality. In contrast, index values below 1 reveal that lower scored ES dominate. Since the value range is limitless, the advantage of this index is the differentiated representation of multi-functionality that is independent of the total number of ES.

d4) Floodplain Specificity Index

The Floodplain Specificity Index is the ratio of the floodplain-specific ES to the other ES which may also be available outside of floodplains. Unlike the previous indices which consider all ES as equally important, this index highlights the availability of ES that are not, or rarely available outside riverine landscapes. These river/floodplain-specific ES include:

» ES related to surface water bodies such as rivers or floodplain lakes; alluvial groundwater aquifers, i.e. the provision of freshwater; the retention of N, P, and organic C load of a river; regulation of flood risk, low water and sediment; and opportunities for water-related activities;

» ES in the terrestrial realm that are predominantly provided by floodplains; namely the provision of habitats typical to floodplains, river/floodplain-specific natural and cultural heritage, and river/floodplain-related opportunities for education and science.

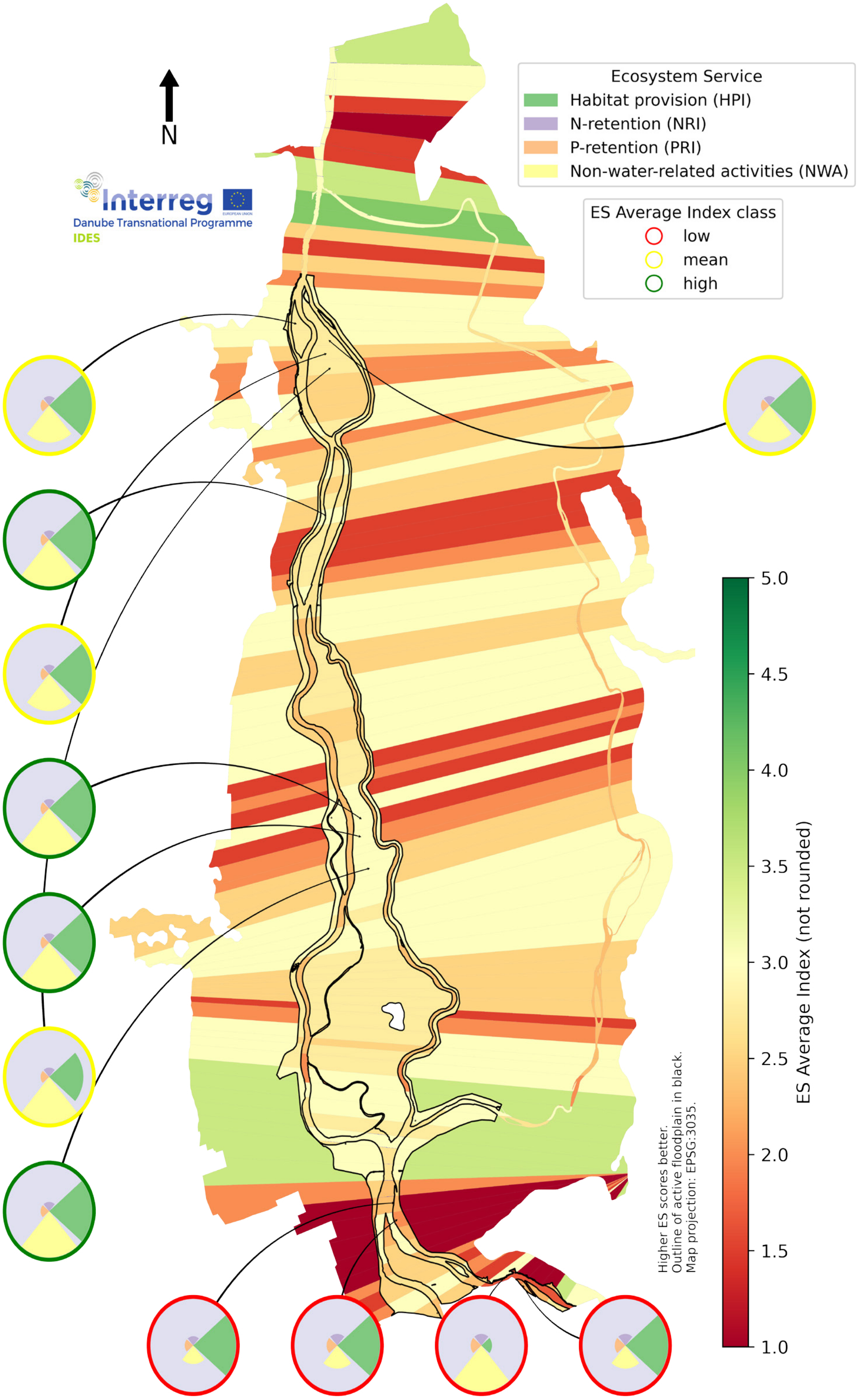


Figure 2.4.5 Map of the Brăila Island IDES pilot area showing the ES Average Index of four ES for all compartments, and their distribution for exemplary compartments of the active floodplain (black line) in the status quo. Note: The ES Average Index 'low', 'mean' and 'high' categorisation were derived from the distribution of available values and do not cover the full range of ES scores in IDES (1-5).

2.4.2. Calculation of optimal scenarios agreed by stakeholders

In the IDES Project, the management scenarios for the pilot areas were based on the interactions with and among stakeholders, and the co-creation of FCM (Chapters 2.3 and 3.2). The availability of ES for the status quo and for the scenarios were derived using the two approaches of the IDES Tool (Chapter 2.2.5). For each pilot area, the 'optimal' scenario was based on a set of five measures or management options negotiated with and agreed to by local stakeholders. Moreover, the specific measures were recommended specifically by the local stakeholders to be implemented in their pilot areas in order to improve water quality. The results obtained with the stakeholders can (a) be quickly/ directly viewed and compared using FCM or (b) be mapped applying the improvement coefficient derived from FCM to the status quo.

a) Fuzzy Cognitive Models and scenarios
FCM represent a quick and efficient way for visualisation and communication of ES availability. They allow stakeholders to immediately see the effects of different management measures and options on various ES (Figure 3.2.2). FCM facilitate interactions among participants in stakeholder workshops, negotiation of management measures to be implemented, and the making of final comparisons of their effects on ES. For the latter, the relative changes need to be translated into changes in ES scores.

Selected pressures and ES in the different scenarios are considered to obtain valid FCM results for the respective area. However, as the results are specific for the respective region or pilot area, they should not be extrapolated to other areas and groups of stakeholders. Another limitation is that the results apply to the whole pilot area, and hence do not provide spatially detailed information. If a higher spatial resolution is desired, more detailed scenarios (or 'sets of agreed measures') would be needed that enable assessors to calculate different results for individual segments or compartments within the pilot areas.

b) Mapping the FCM scenarios to ES
The outcomes of the FCM scenario analyses were used in the IDES Project as improvement coefficients for the status quo ES scores. These improvement coefficients can be applied proportionally to the current ES score, or proportionally to the possible ES improvement potential. Hence, the resulting change in ES scores can be determined either by applying the relative change for each ES to its status quo score (Equation 2.4.1) or to the reverse score (Equation 2.4.2).

Equation 2.4.1: new score = status quo score + (status quo score * improvement coefficient)

Equation 2.4.2: new score = status quo score + (reverse score * improvement coefficient)

In IDES, the ES scores range from 1 to 5 (Chapter 2.2.5). Whereas the maximum of the new score is limited to 5, the reverse score is calculated as 6 minus the ES score and represents the potential to improve the ES availability.

Example: A segment or compartment currently has an ES score of 2. The improvement coefficient for this ES by applying a set of agreed measures is 0.6. According to equation 2.4.1, the new score will be $2 + 2 * 0.6 \approx 3$ while equation 2.4.2 results in $2 + (6–2) * 0.6 \approx 4$.

The results obtained by the two equations slightly differ. While the approach using equation 2.4.1 maintains the maximum range of scores (=5) and stresses the differences between compartments and segments, equation 2.4.2 emphasises the changes (potential benefits) of measures especially for areas with low scores (Table 2.4.1). Thus, the choice of the approach affects spatial differences and scenario effects.

Table 2.4.1 Effects of improvement coefficients derived with FCM (here 0.1-0.7) on the status quo ES scores according to equation 2.4.1 (top) and equation 2.4.2 (bottom). The application of equation 2.4.2 assumes that improvements of ES already start at lower improvement coefficients.

Scores for the scenario using equation 2.4.1 and assuming an improvement of the following coefficients							
Current score	0.1	0.2	0.3	0.4	0.5	0.6	0.7
1	1	1	1	1	2	2	2
2	2	2	3	3	3	3	3
3	3	4	4	4	5	5	5
4	4	5	5	5	5	5	5
5	5	5	5	5	5	5	5
Scores for the scenario using equation 2.4.2 and assuming an improvement of the following coefficients							
1	2	2	3	3	4	4	5
2	2	3	3	4	4	4	5
3	3	4	4	4	5	5	5
4	4	4	5	5	5	5	5
5	5	5	5	5	5	5	5

2.4.3. Types of visualisation

Coloured and graphic representations of monitoring data have been utilised in environmental policy for decades. Similarly, graphical representation of ES offers an opportunity to summarise complex results and facilitate the understanding of distributions, relationships and outliers. From a formal point of view, the appropriate types of visualisation and communication should be selected according to the following categories (Klein et al. 2015):

a) Representation type: e.g. thematic map, text, table, chart;

b) Display scale: local – global;

c) Display type: e.g. spatially/temporally explicit/ aggregated or selectable/filterable;

d) Application setting: for the general public, a group (of colleagues or stakeholders) or personal use;

e) Application function: e.g. information, exploration, communication, support of decisions and scenario development.

In the context of ES, the survey by Klein et al. (2015) highlights the need for specific representation types and the broad range target group demands and requirements. Nonetheless, it suggests a preference for:

a) Texts for communication and discussion support;

b) 2D maps to support scenario development in public applications;

c) Charts and tables, in combination with maps, for analysis;

d) (abstract) 3D landscape visualisations for analysis, exploration and group applications - especially in urban landscapes which fall outside the scope of IDES and this manual.

Mapping of ES typically relies on static and dynamic interactive maps produced with GIS. The limited spatial extent of rivers and many active floodplains may constrain the readability of (small-scale) static maps, (e.g. the river compartment in figure 2.4.6 (top)) or when showing the ES for all floodplains in large river basins. Interactive maps can overcome these limitations, but require a server to host the data and a web-based application. Another option is to generalise maps such as using cartographic techniques to simplify the spatial information in a trade-off between precision and readability. Such techniques comprise the displacement, smoothing, aggregation and exaggeration of data (e.g. figure 2.4.6 bottom).

Unlike maps, charts enable the comparison of multiple ES, segments or compartments. Charts can convey multiple layers of information by using different colours, shapes and sizes of elements; for instance the strength and direction of correlations between ES (Figure 2.1.2) or the impacts of ES on water quality (Figure 2.1.4). Multiple layers can also be achieved by combining charts and maps (Figure 2.4.5), or by using treemaps (Figure 2.4.7). The latter is especially useful for the space-efficient visualisation of hierarchical data. Figure 2.4.7 is an example where the colour and the area represent the combination of the mean ES scores for the floodplain segments of a country (main category) and river (sub-category), and thus also represents spatial relationships. Treemaps are also useful to compare the area proportions between the categories and can resemble an ES Sum Index. Although the same figure could depict the ES groups in different colours and thus provide another layer of information without any size change, redundancy may help to convey the information more accurately. Reliance on a single colour can assist readers who, for example suffer from colour blindness. Different types of analyses (correlation, distribution and comparison) and data require different types of chart. A brief overview of common charts is provided below using data from the Brăila Islands pilot area in Romania (Figure 2.4.8, chapter 3.2.3). A more comprehensive and systematic overview can be found in Ribecca (2022) among other references.

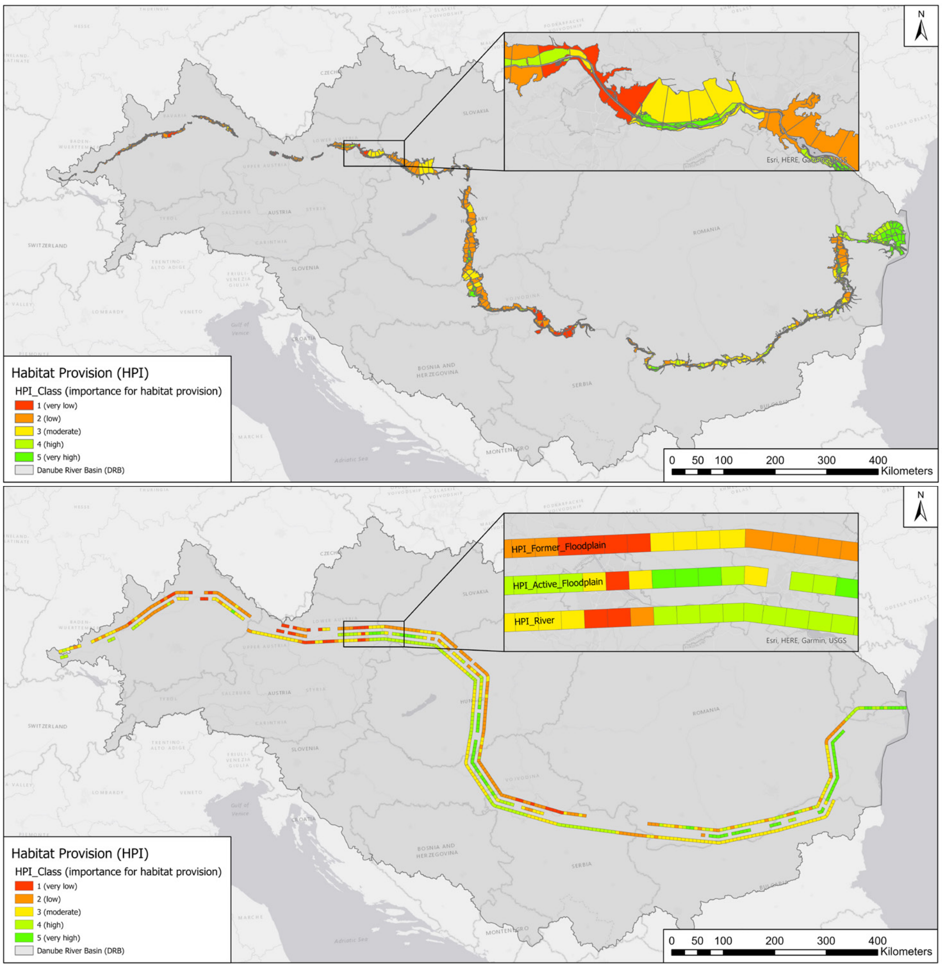


Figure 2.4.6 Original (top) and generalised map (bottom) of the ES 'habitat provision' provided by the Danube River and its active and former floodplains. The upper, middle and lower bars in the generalised map represent the compartments, i.e. former floodplain, active floodplain and river. Note: Their position, form and area differ from the original map. Tributaries are not shown.

(Stacked) bar charts, box plots and rose charts are widely used to compare ES scores of scenarios, compartments or ES (groups). Bar charts are used to compare values across categories (variables). One variant is the stacked bar chart which allows the sub-division of large categories, represented either as absolute numbers or as percentages. Figure 2.4.8a contains stacked bar charts side-by-side to visualise the frequency (number) of segments per ES score (1-5). The colours distinguish the calculated ES scores. This exemplary figure reveals the shift towards higher ES scores in the 'optimal' management scenario agreed among the local stakeholders. The comparison of sub-categories in stacked bar charts, here the compartments and the scenarios, can be difficult as they are not vertically aligned.

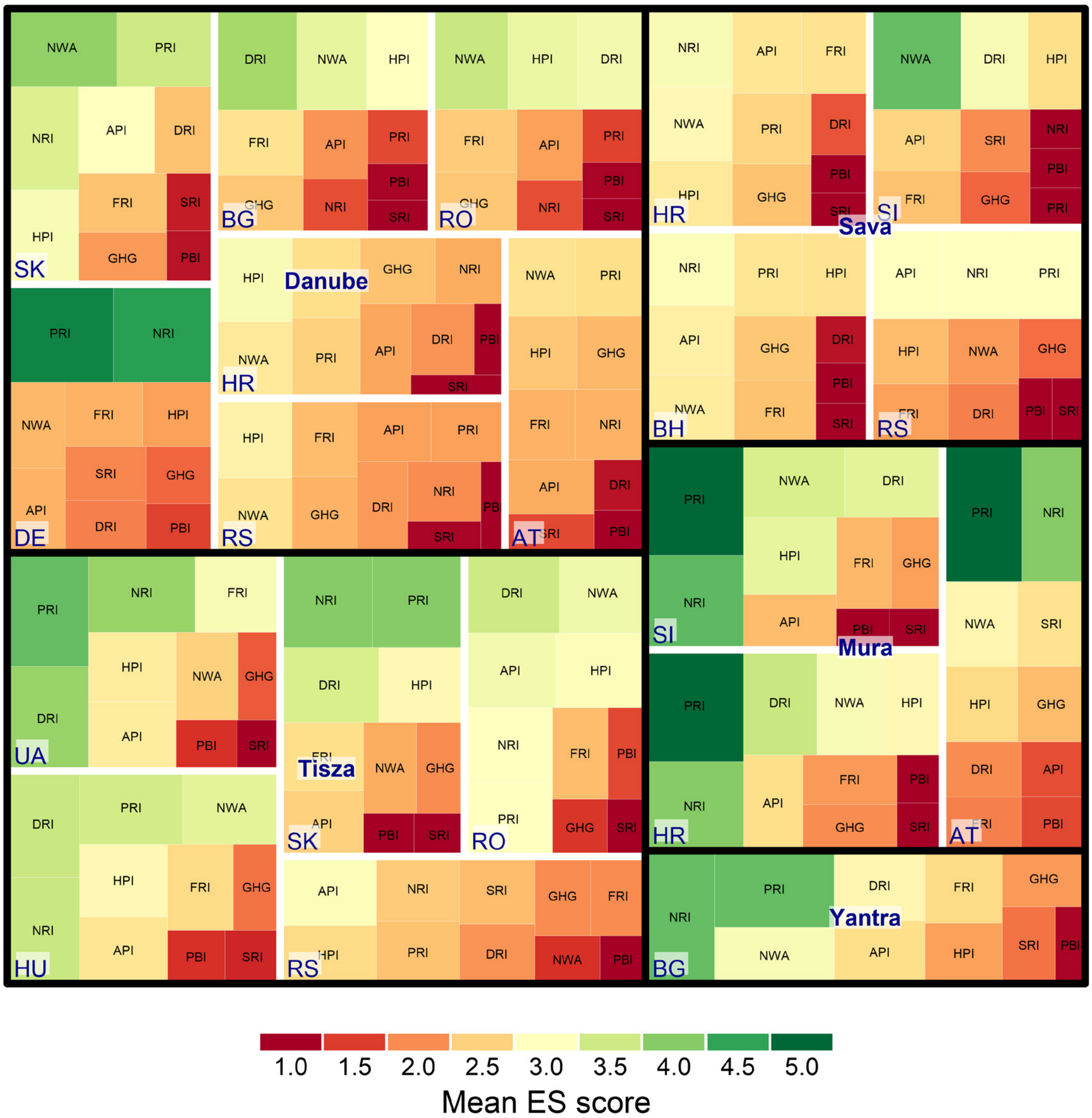
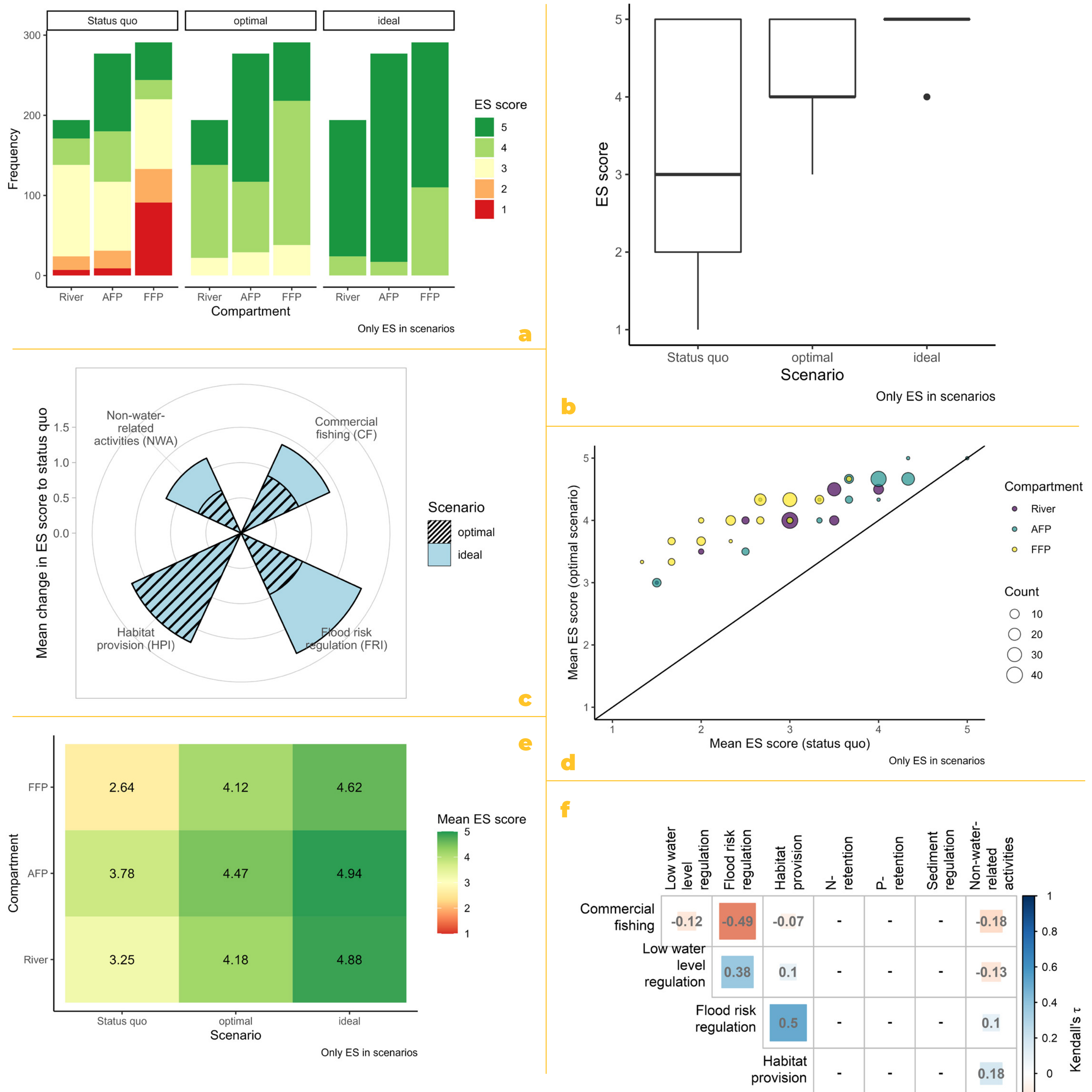


Figure 2.4.7 ES calculated utilising the IDES indicator approach within the Danube river basin for floodplain compartments along different rivers and in different countries. The area and colour of the boxes show the average ES score of all compartments. Note: Different approaches exist to the placement of the areas within each group. Here, the highest scores are in the top left corner. ES scores were assigned to all countries for segments in multiple countries. Country codes according to ISO 3166-1 alpha-2, ES codes according to Table 2.2.1.



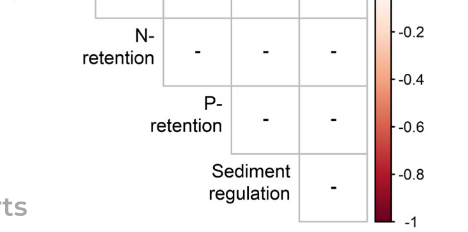


Figure 2.4.8 Exemplary charts based on the scenario analyses for the Brăila Island IDES pilot area in Romania: a) bar chart, b) box chart, c) rose chart, d) scatter chart, e) heatmap, and f) corrgram for the status quo (Kendall's τ). (Mean) ES scores were calculated for the active floodplain (AFP), former floodplain (FFP) and river compartments. Note: Equation 2.4.2 was applied for the 'optimal' and 'ideal' scenarios. For charts a, d, and e, the flood risk regulation was assigned to all compartments. More details on the chart types in the main text.

Box plots visualise the value distribution using quartiles, sometimes including outliers. Box plots require less space compared to histograms, which makes side-by-side plots like figure 2.4.8b feasible. Similar to figure 2.4.8a, the graph shows the general shift to higher ES scores in the management scenario compared to the status quo. The median – depicted with a black line within the boxes – is higher for the scenarios than for the status quo.

Rose charts are (stacked) bar charts transformed into polar coordinates. Each segment corresponds to a bar. However, in contrast to bar plots, the higher values are more emphasised. Figure 2.4.8c exemplarily shows the changes in ES scores between the status quo and the four example ES scenarios (non-water related activities, commercial fishing, flood risk regulation and habitat provision). Again, it demonstrates the general increase (all differences are non-negative) as well as changes in the 'ideal' scenario results in a stronger manner than the 'optimal' scenario. The combination of a colour and a pattern allows chart segments to be overlapped. Alternative approaches may consist of side-by-side charts or transparent colours.

In its simplest form, a scatter chart is used to show relationships (correlations) between two categories as well as outliers. Colours or shapes of points may distinguish additional categories (e.g. ES groups, scenarios or compartments). In addition, the diameter or area of points can be used to consider numerical categories such as the frequency (bubble chart). Size, transparency or jitter (random variation) can be used to avoid overlapping points becoming hidden. Figure 2.4.8d compares the paired ES scores of the status quo and the 'optimal' scenario, and uses colour to distinguish the compartments and the size for the number of ES scores. Most points are above the diagonal line of identity, illustrating that the management scenario increases the ES scores. The current ES scores for the active floodplains are higher than the values for the former floodplains. The yellow points deviate more from the line of identity than the turquoise points, indicating that the scenario effect is stronger for the former floodplains than for the active floodplains.

Heatmaps (Figure 2.4.8e) represent another option to show relationships across multiple categories. Two categories are assigned to the x and y axes respectively, and a third one is shown as colours. The colours represent the values in a more generalised way, and this limits accurate assessment. Figure 2.4.8e shows the ES Average Index for the respective compartments and scenarios. It also reveals that the scenario effect (comparing scenario with status quo) is stronger for the former floodplains than for the active floodplain.

Corrgrams (or correlograms) are charts of correlation matrices. Relationships between pairs of categories can be analysed and are often used to explore the dataset. According to figure 2.4.8f, the ES flood risk regulation and commercial fishing are negatively correlated in comparison to flood risk regulation and habitat provision. Consequently, a good flood risk regulation coincides here with a lower suitability for commercial fishing; but with better conditions for habitat provision. While interpreting corrgrams, it is important to keep in mind that even strongly positive or negative correlations may occur without causal relationships.

Ideal data visualisation conveys the data accurately, is aesthetically pleasing and convinces the audience. Manuals like Wilke (2019) cover the many aspects that have to be considered to achieve these goals in detail, not just the chart type.

IMPLEMENTATION OF THE IDES TOOL

3.1 Danube-wide implementation of the IDES Tool

Martin Tschikof, Elisabeth Bondar-Kunze

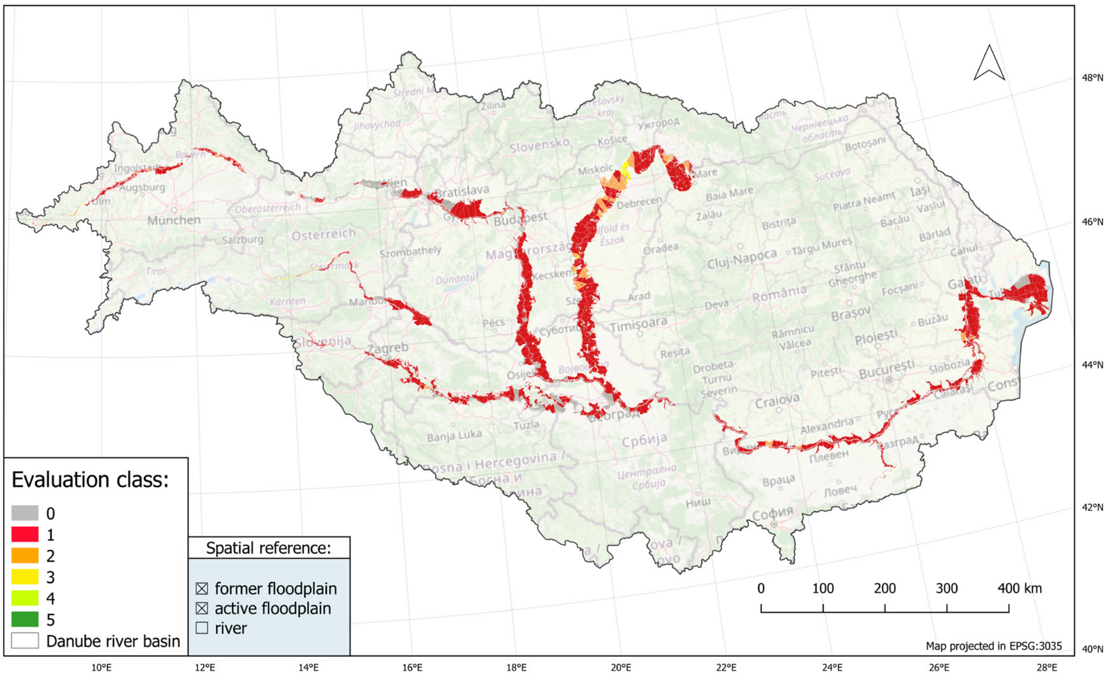
The IDES Tool (Chapter 2.2) was applied to 10 km segments along the Danube River as well as selected tributaries in the Danube river basin. Researchers evaluated and mapped the potential of 14 selected (of 26) ES to improve water quality in the selected floodplain areas. The ES were quantified using either the indicator-based or the capacity matrix approach (Chapter 2.2), depending on the available data (Chapter 2.2.5). In this chapter, the focus is placed on the ES quantified using the indicator-based approach, however, one example of the applied capacity matrix approach is given for each ES type. Additionally, a shapefile of the complete capacity matrix approach for the Danube region can be reviewed at https://www.interreg-danube.eu/approved-projects/ides/outputs after Stoll et al. (2015).

Due to data scarcity, not all ES could be calculated for all segments in the following maps. The selection of river sections was limited by the delineation of active floodplains (Chapter 2.2). Rather than interpreting individual floodplain segments, the basin-wide application with short descriptions below aims to provide an overview of large-scale ES patterns. A Mann-Whitney U Test was performed to compare the ES scores between active and former floodplains. The significance levels are given in the map descriptions. The application of the IDES Tool in the five pilot areas (Chapter 3.2) creates an opportunity to gain a more detailed interpretation of ES on the floodplain-scale.

3.1.1 Provisioning ES

Plant biomass - grassland (PBI)

Interreg
Danube Transnational Programme
IDES



Arable crop production (API)

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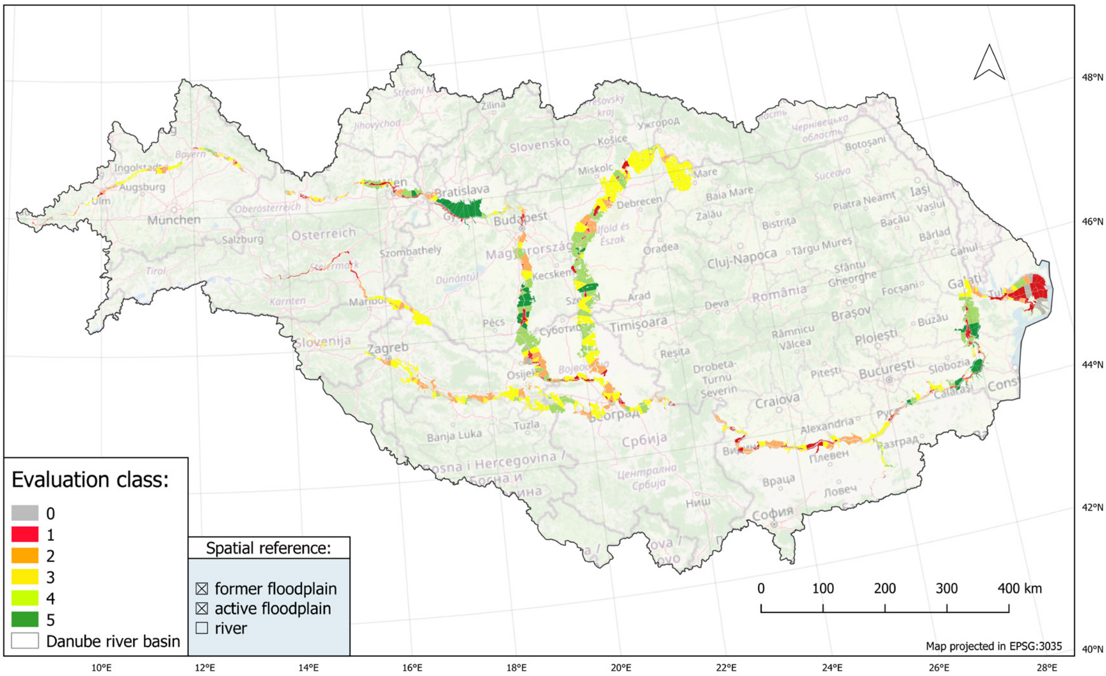

Figure 3.1.1

Arable crop production (API): Compared to the active floodplains, former floodplains with high agricultural land use intensity show a greater potential for crop production ($p < 0.001$). However, there are a few scattered active floodplain segment compartments where medium to high crop yields are feasible (e.g. Sava, Lower Tisza). The spatial patterns in the DRB largely coincide with other agricultural land use intensity assessments (EEA 2012b).

Plant biomass grassland (PBI): Generally, biomass yields are low in floodplain grasslands. Slightly higher scores are indicated in active floodplain grasslands compared to former floodplains ($p = 0.01$).

Commercial fishing (CFI)

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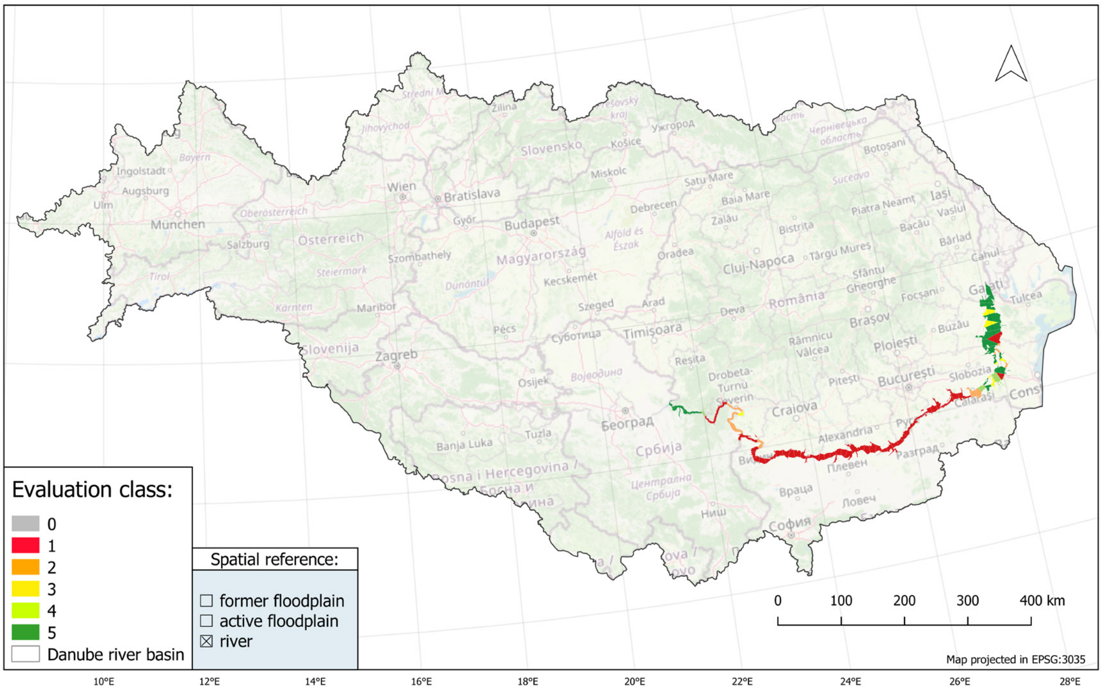

Wild foods (WF)

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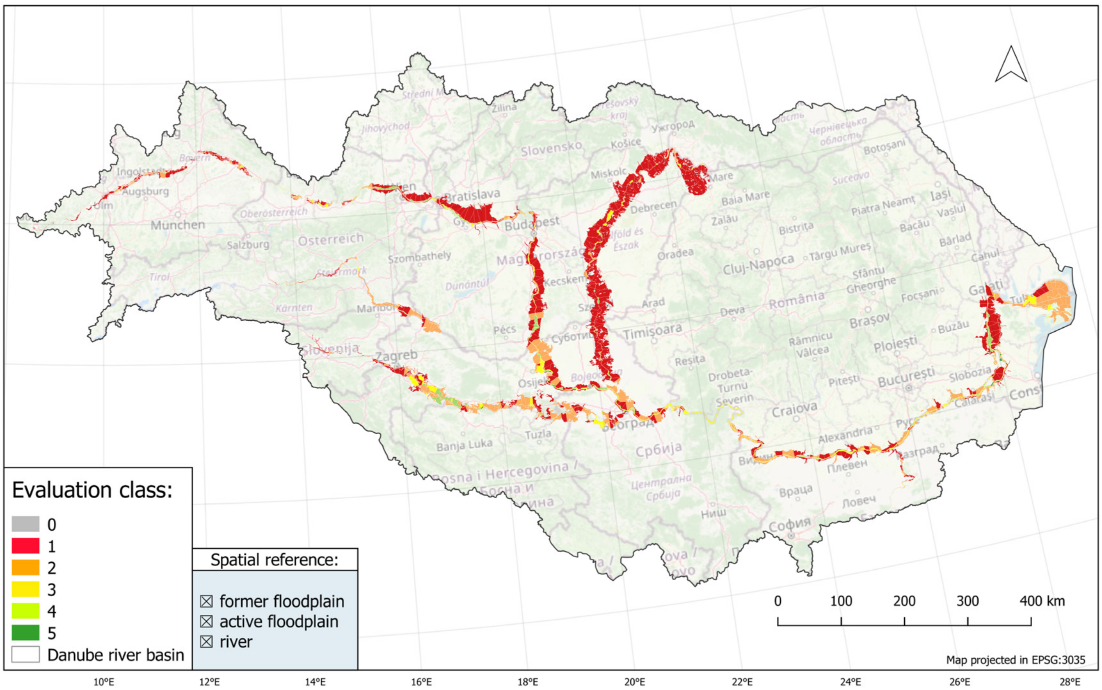
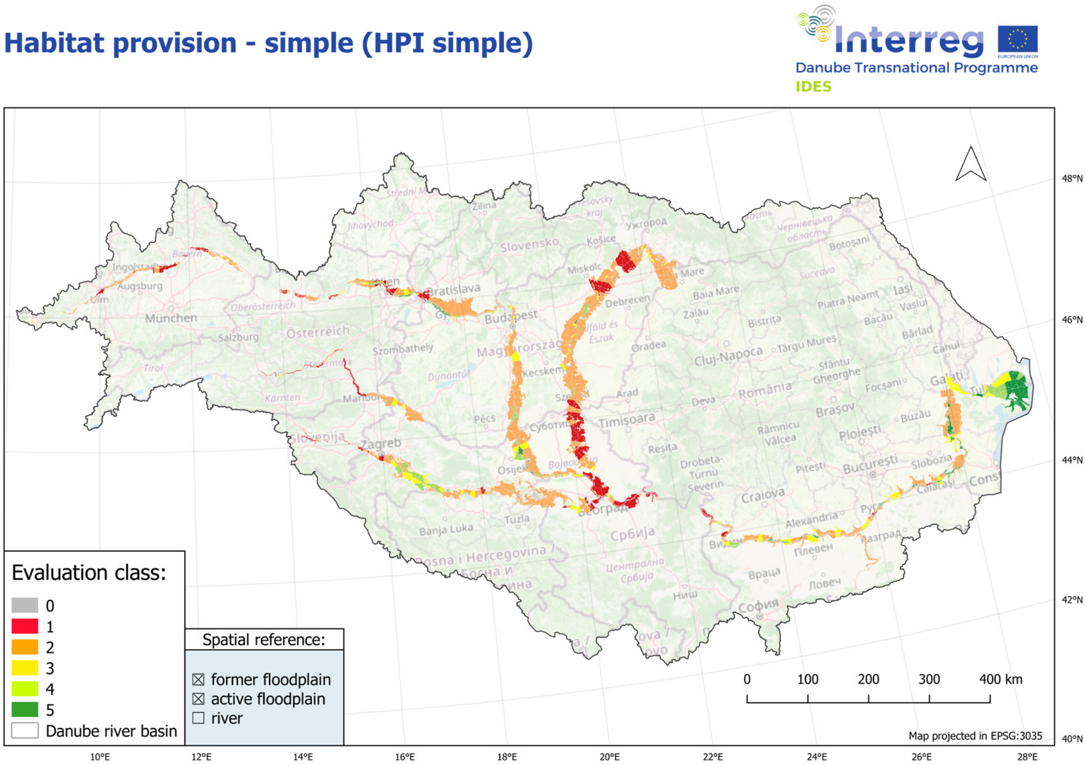


Figure 3.1.2

Commercial fishing (CFI): CFI was evaluated in the Romanian section of the Danube River. High fish yields exist around the Brăila Islands and at the Serbian-Romanian border upstream from the Iron Gates Dam Reservoir.

Wild foods (WF): WF was evaluated using the capacity matrix approach. Unlike the very low to medium potential in former floodplains, the land cover types in the active floodplains promote a medium to high potential to provide wild food resources ($p < 0.001$). Average scores are found in the river network and lakes.



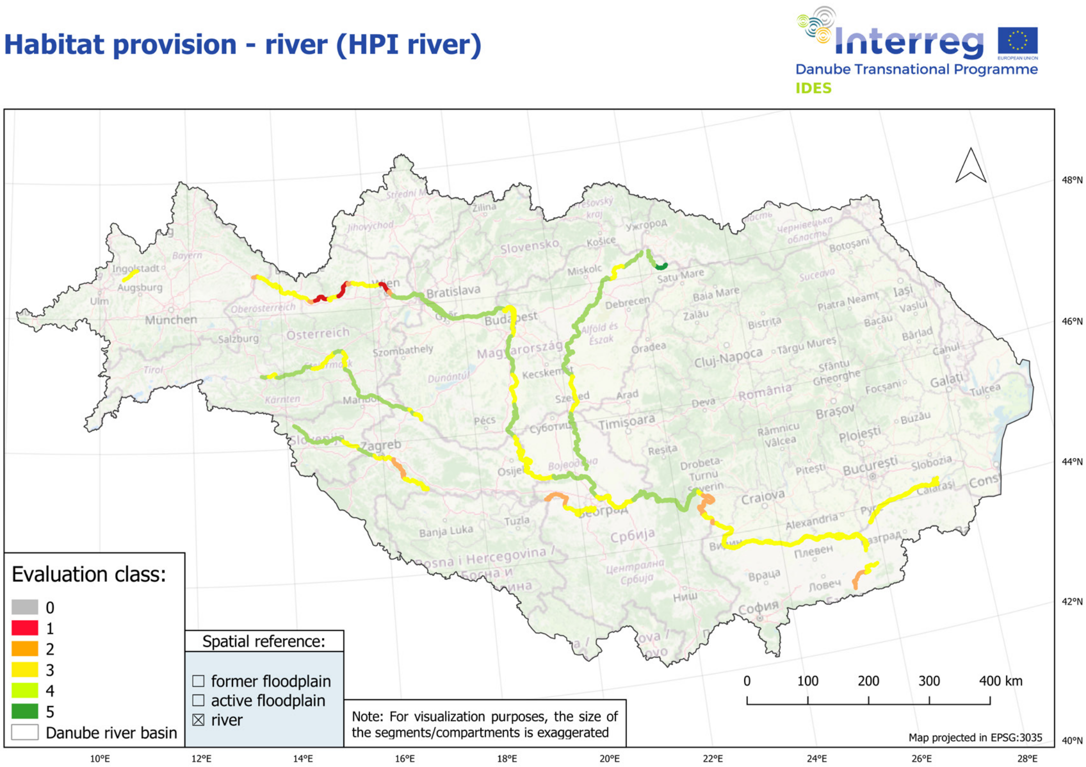
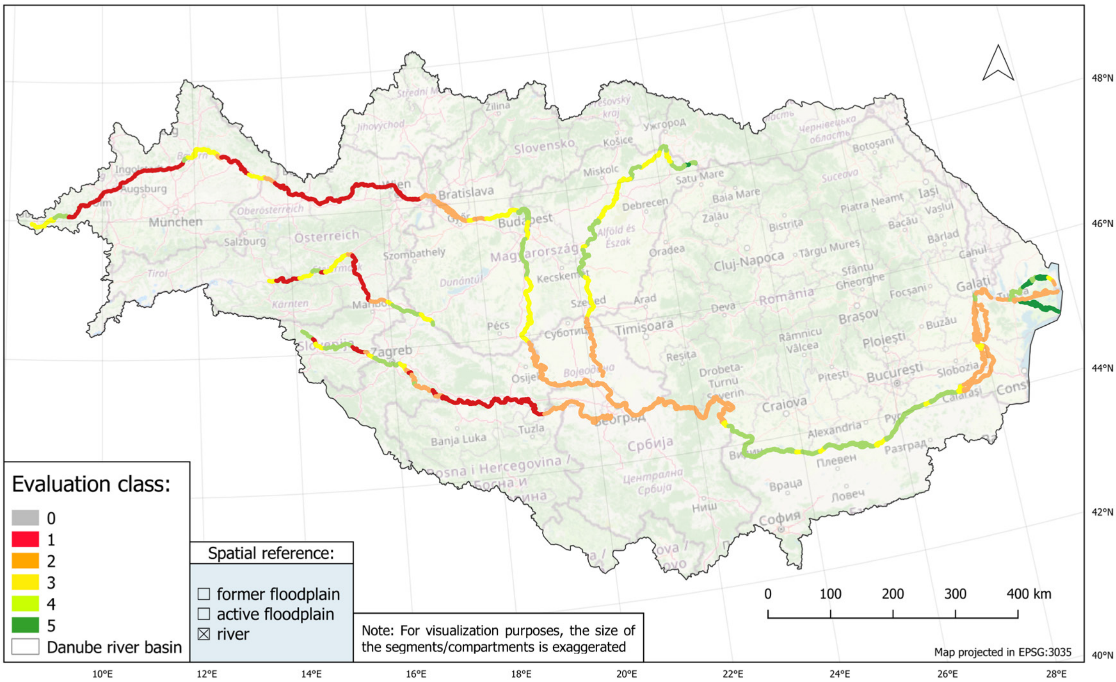


Figure 3.1.3:

Habitat provision – simple (HPI_{simple}): HPI_{simple} reveals that typical floodplain habitat features can only be found in active floodplains. Former floodplains received low scores ≤ 3 ($p < 0.001$). Hotspots (class 5) are located on the active floodplains upstream and downstream of Bratislava, along the Lower Danube in Romania, on the Upper Tisza, the Mura River in Slovenia, at the confluence of the Danube and Drava Rivers, and at the Danube Delta.

Habitat provision – river (HPI_{river}): The Upper Tisza River represents a section of very high importance for riverine habitat provision. In contrast, with the exception of the section where it borders the Middle Danube (Donau-Auen National Park in Austria), limited HPI_{river} quality was found along the Upper Danube River.

Low flow regulation (LFI)



Flood risk regulation (FRI)

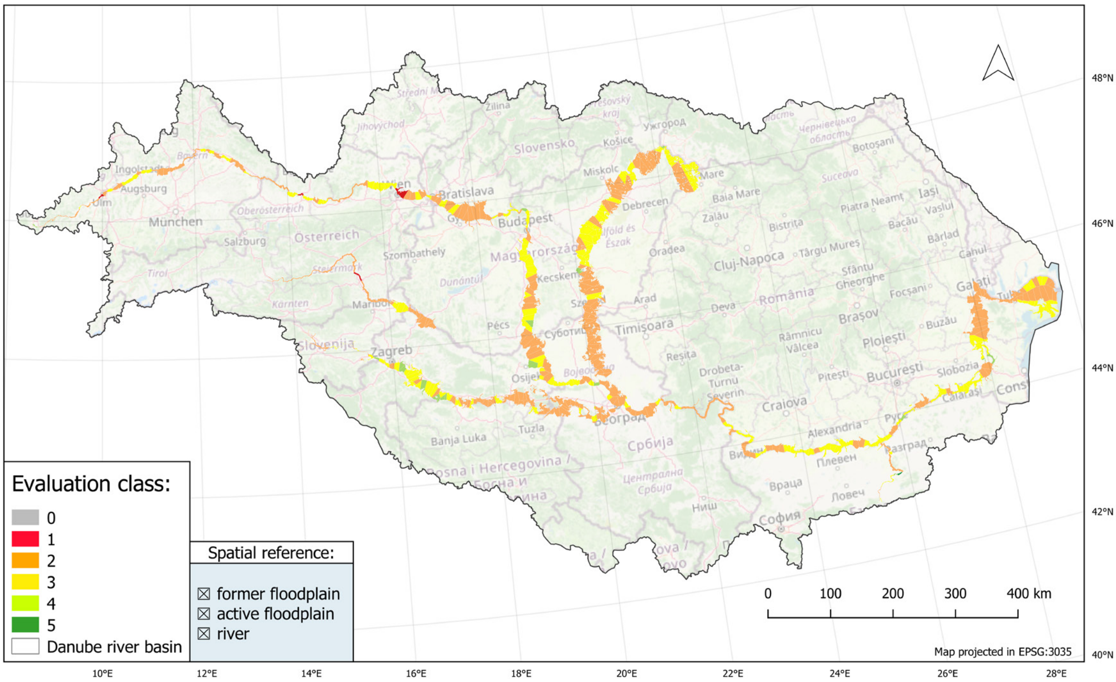


Figure 3.1.4

Low flow regulation (LFI): The highest LFI scores occur in the Danube Delta. Mainly due to their poor hydro-morphological status (according to the WFD), the Upper Danube, Upper Mura and Upper Sava Rivers received low LFI scores.

Flood risk regulation (FRI): Generally, there is a moderate to high loss of active floodplain volume compared to that of the morphological floodplain. The flood risk regulation in the DRB seeks to address this issue. The few segments with high scores (> 3) can be found along the Upper Sava and the Middle Danube Rivers.

Nitrogen retention (NRI)

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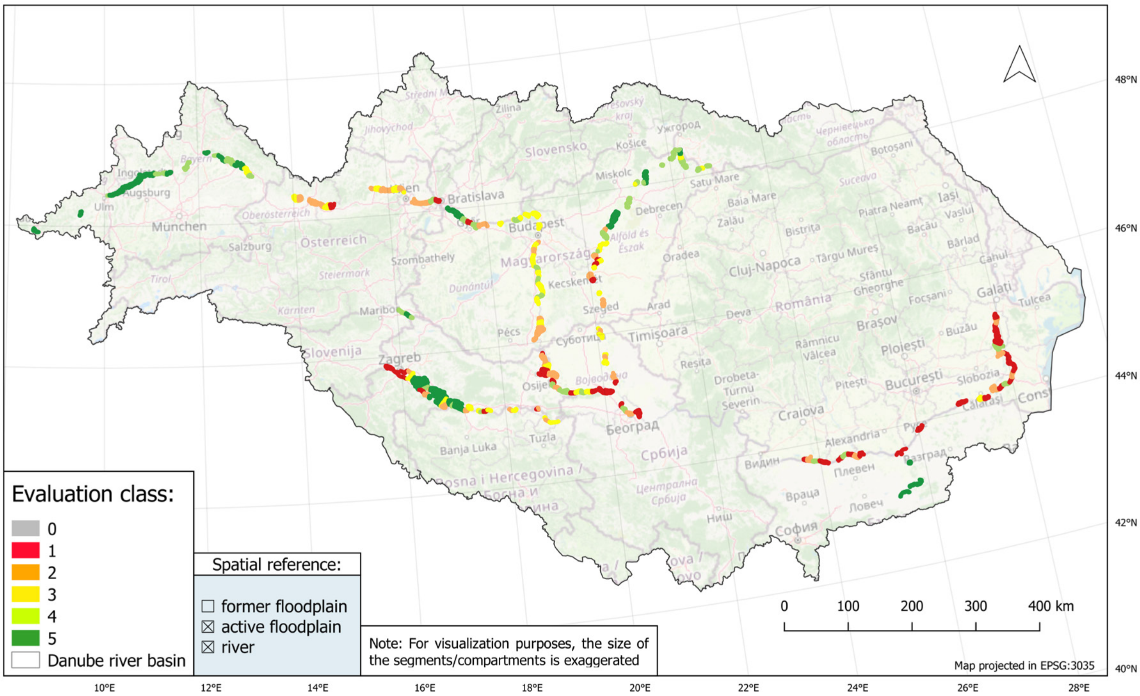

Phosphorus retention (PRI)

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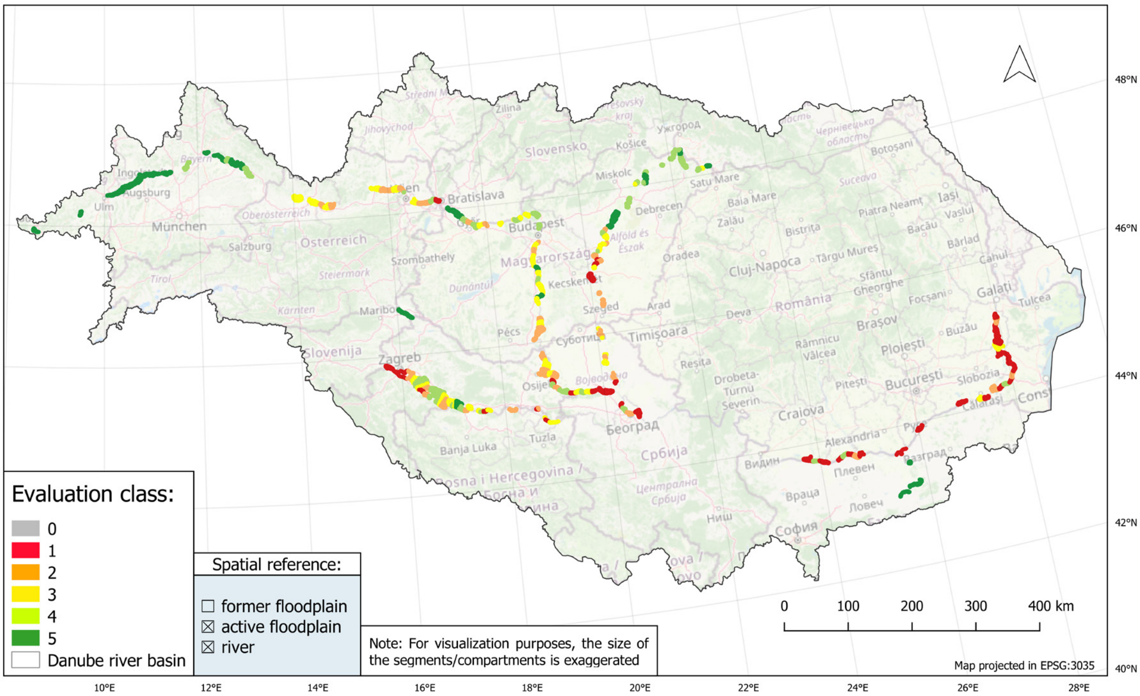

Figure 3.1.5
Nitrogen and phosphorus retention (NRI, PRI): The NRI and PRI indicators represent the retained fractions of the N and P loads in the active floodplains and the river. A decline in the NRI and PRI from upstream to downstream sections can be observed as the nutrient loads increase along the river network. However, the absolute amount of retained nutrients (tonnes/year) can increase towards the river mouth (Tschikof et al. 2022). NRI exceeds PRI in the Sava floodplains, whereas PRI exceeds NRI along the Middle Danube.

Greenhouse gas regulation (GHG)

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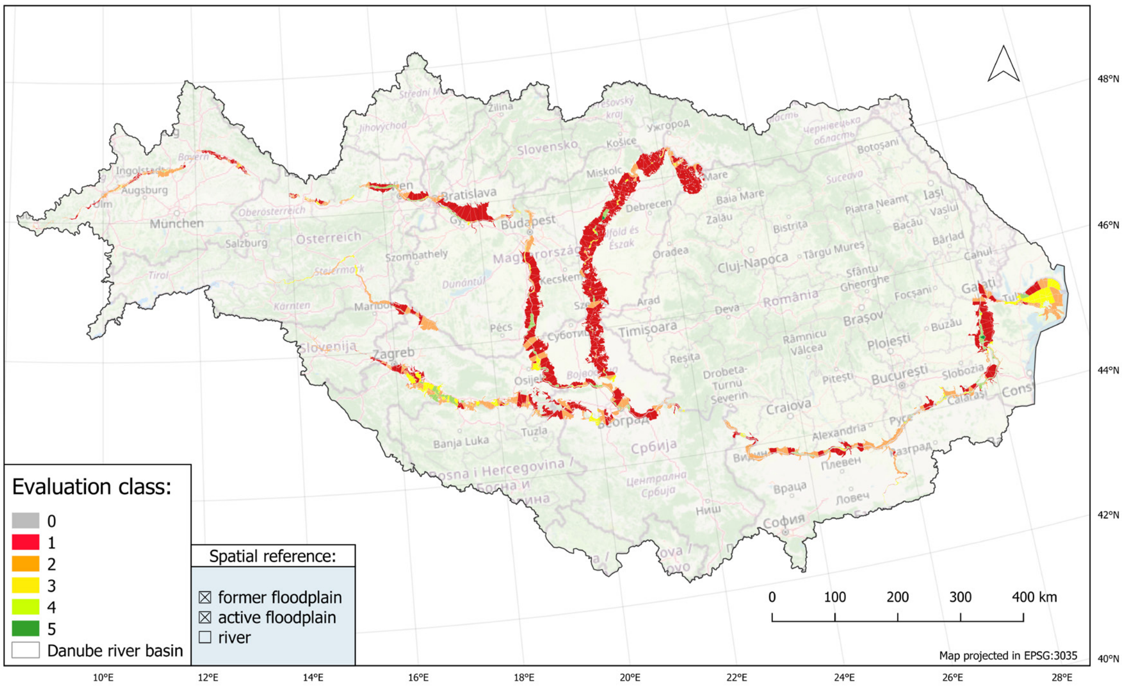

Local climate regulation (LCR)

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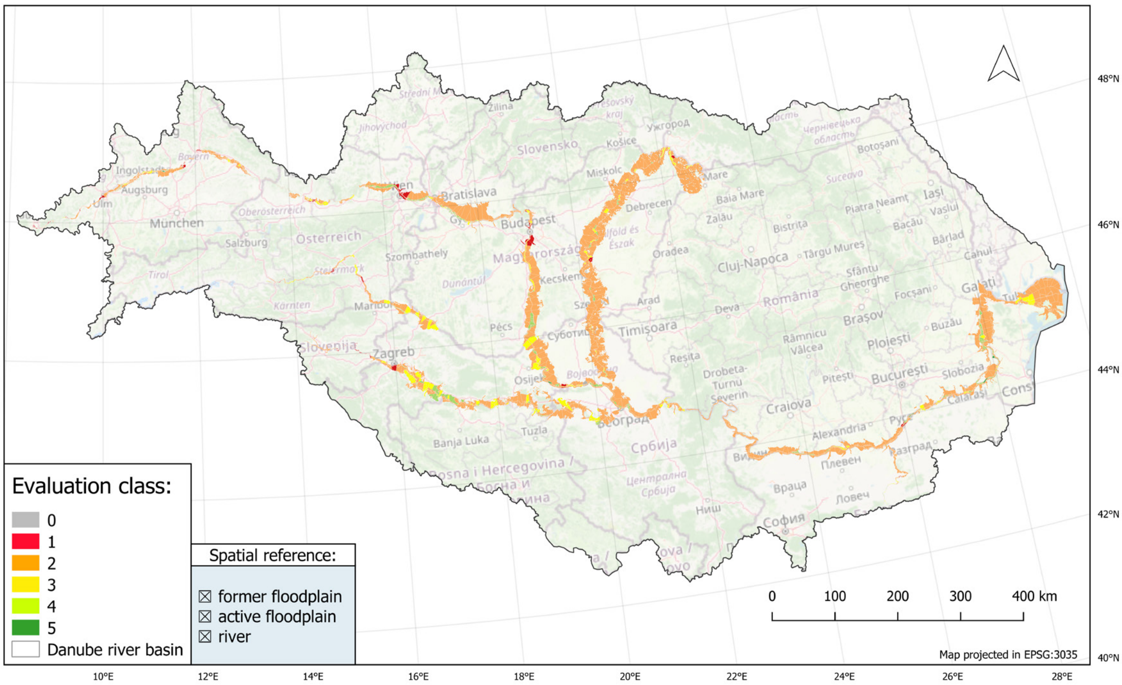

Figure 3.1.6
Greenhouse gas regulation (GHG): Compared to former floodplains ($p < 0.001$), the differences in land use and the abundance of peat soil in active floodplains result in significantly lower greenhouse gas emissions (= higher scores).

Local climate regulation (LCR): LCR was evaluated using the capacity matrix approach. Segments with a large share of forests and wetlands show especially high potential to regulate the local climate. Therefore, active floodplains scored higher evaluation classes compared to former floodplains ($p < 0.001$).

3.1.3 Cultural ES

Non-water-related activities (NWA)

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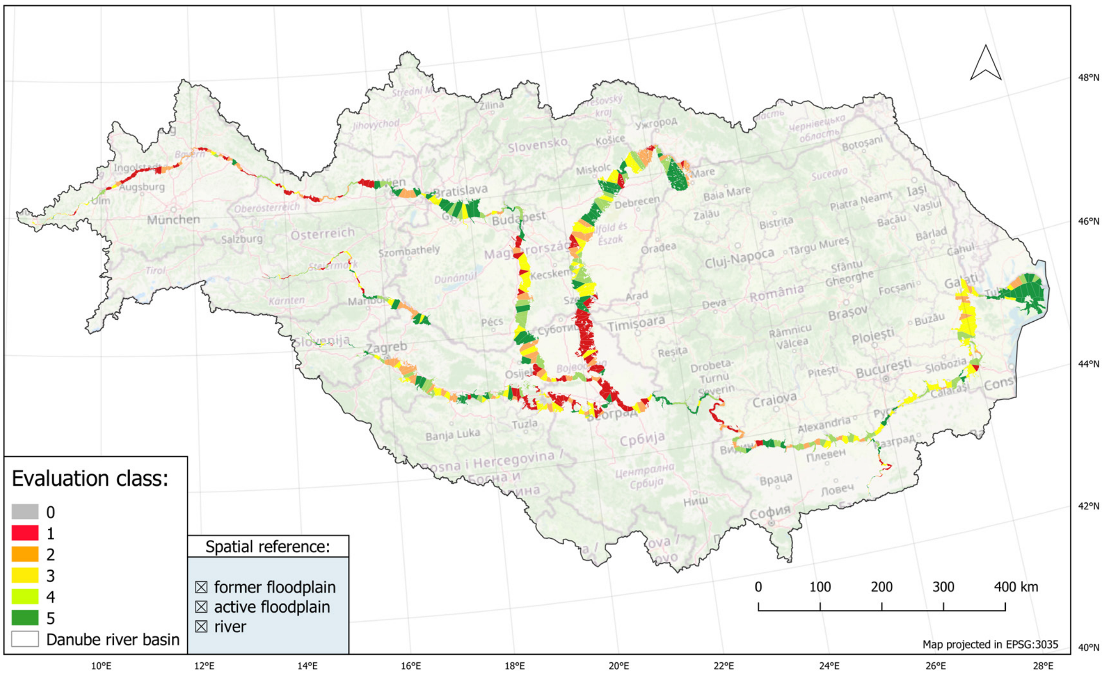

Landscape aesthetic quality (LAQ)

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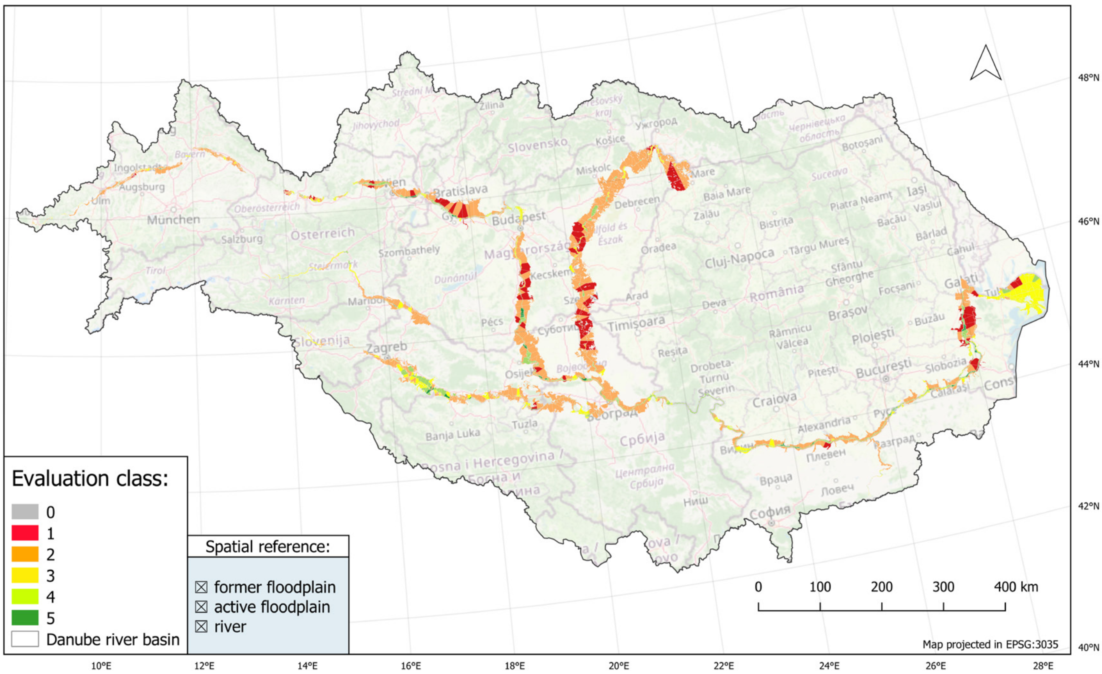

Figure 3.1.7
Non-water-related activities (NWA): The NWA indicator reveals that the Danube Delta and floodplains along the Upper Tisza and the Middle Danube provide good recreational opportunities to experience the landscape, while low scores appear in the Upper Danube and the Lower Tisza.

Landscape aesthetic quality (LAQ): LAQ was evaluated using the capacity matrix approach. The analysis revealed that forests and scrublands prevailing in active floodplains exhibit greater aesthetic quality compared to more intensive land use types dominant in former floodplains (p > 0.001). High scores (4) were achieved by rivers and lakes.

3.1.4 Relevance for water quality improvement

Figure 3.1.8 exemplarily shows that the active floodplains along the Sava River, at the Brăila Islands, and around Vienna have very high water quality relevance compared to the Tisza River. For more specific applications, floodplains could also be prioritised differently by using the material provided on the IDES website (https://www.interreg-danube.eu/approved-projects/ides/outputs). For example, a nationwide selection of active floodplains with low N or P retention potential in areas of high pollution could be used to prioritise areas in which measures could efficiently foster water quality improvement.

Relevance for water quality improvement (basin-scale)

Nitrogen and phosphorus retention from upstream and terrestrial upslope sources

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Danube Transnational Programme
IDES

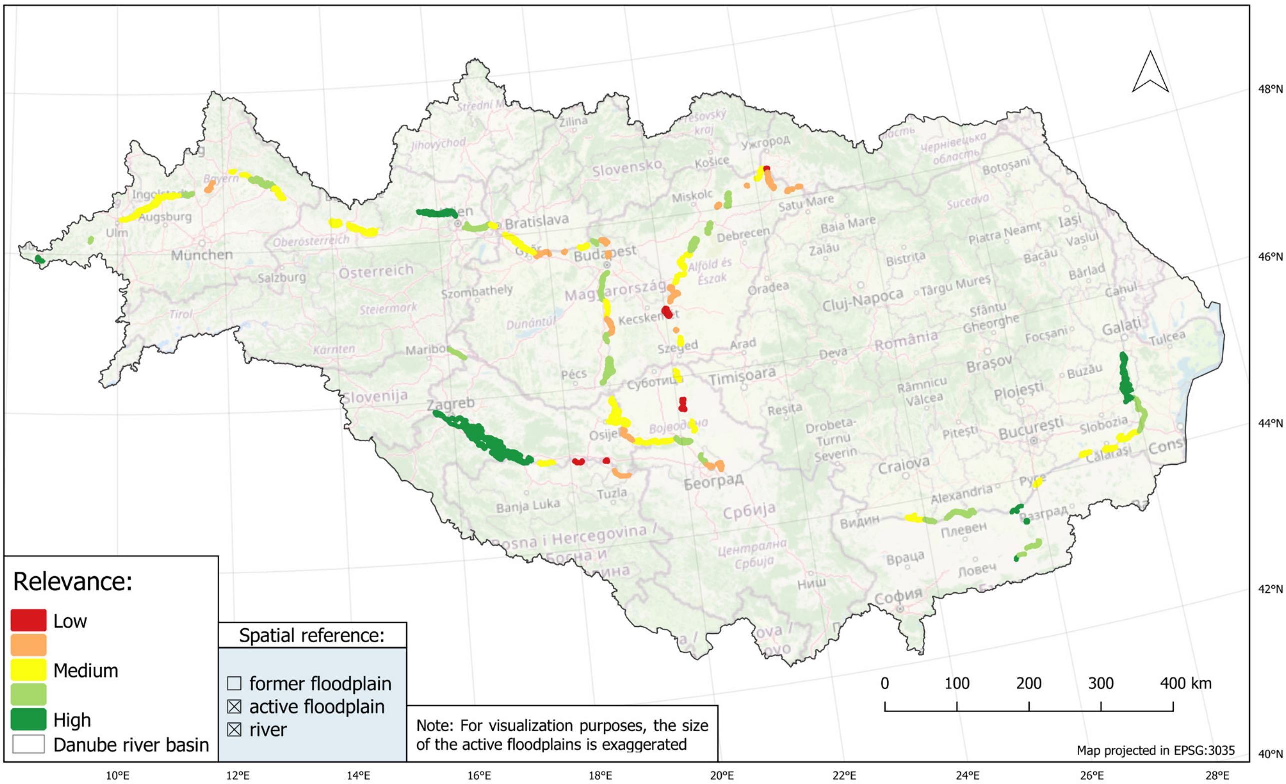


Figure 3.1.8
Aggregated evaluation ranks for water quality improvements on the basin scale in the investigated active floodplains. The map summarises the potential to retain nitrogen (N) and phosphorus (P) from riverine upstream and terrestrial upslope sources in relation to the nutrient concentrations and emissions (Chapter 2.2.6).

3.2 Implementation of the IDES Tool in five pilot areas

Relu Constantin Giuca, Cristian Mihai Adamescu, Constantin Cazacu, Corina Gheorghiu, Miha Varga, Peter Suhadolnik, Zorica Srđević, Pavel Benka, Bojan Srđević, Milica Ilić, Jasna Grabić, Martin Tschikof, Dávid Béla Vizi

This chapter describes the identification and prioritization process of the ES (Table 2.2.1) in the five pilot areas in Austria, Hungary, Romania, Serbia and Slovenia (Figure 3.2.1). The results are based on the basin-wide implementation of the IDES Tool (Chapter 3.1) and stakeholder contributions to the co-created FCM (Chapter 2.3) aimed at highlighting the current ES situation in these areas. The multiple benefits of working in pilot areas were already mentioned in other chapters, but to reiterate them, pilot areas were used to:

- demonstrate the potential of the IDES Tool;
- present best practice examples of the IDES Tool's implementation;
- demonstrate best practice examples for the integration of local, regional and national stakeholders in the planning process;
- show the potential of several different applied visualisation methods;
- co-develop and co-create the vision and scenarios for the pilot areas;
- integrate stakeholders at an early stage of planning, and to implement the ES approach together with decision-makers;
- jointly identify the benefits of ES, the pressures, and possible measures that could be implemented;
- to consider the variability in site conditions and stakeholder perceptions.

Local stakeholders identified and prioritised the most important Regulation & Maintenance ES, Provisioning ES and Cultural ES in the pilot areas via a survey. The survey questions and survey form were agreed upon at the consortium level in English, and then translated into national languages. Apart from the ES, stakeholders prioritised pressures and measures (also agreed on the consortium level). The results of the questionnaire were analysed to rank the ten most important ES, five pressures and five measures. These three lists were used as input for the FCM during the first stakeholder workshop.

During the second workshop, stakeholders and researchers together examined the existing situation and ideal scenarios with the objective to identify the impact of the relevant pressures on the selected ES and water quality. Participants tried to understand and categorise the pressures based on their impact on ES. The outcome of a co-development activity was utilised to co-create optimal scenarios for the pilot areas (Chapter 2.3.2).

3.2.1 The Donau-Auen National Park, Austria

The Donau-Auen National Park (NP) is located along the Danube River and represents a green belt connecting the capital cities of Vienna and Bratislava (Figure 3.2.2). Exhibiting the main characteristics of an alpine river, it is the longest free-flowing section (36 km) of the Austrian Upper Danube. It is the largest (near-) ecologically intact natural riverine environment of its kind in Central Europe, and was declared a national park in 1996. National park status provided not just national protection, but also international protection under Natura 2000, as a European Nature Reserve and as a Ramsar wetland. The interplay between the river and its floodplain has led to an enormous variety of habitats, creating refuges for many endangered plant and animal species. From a total of 9,600 ha, 65% are riparian forest, 15% meadow, and approximately 20% is covered by water. The NP is

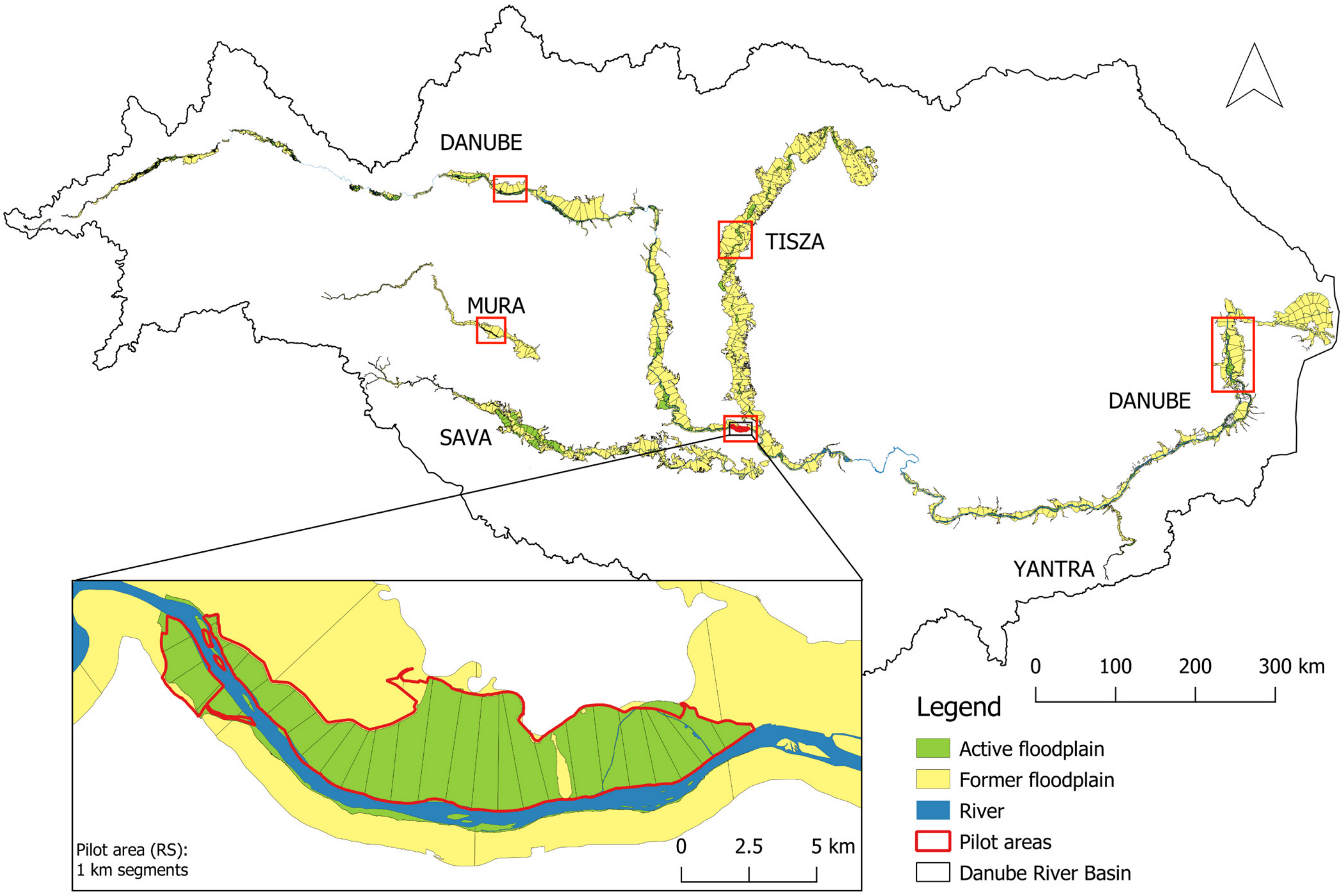


Figure 3.2.1 Location of the five pilot areas showing the 10-km segmentation (for Danube floodplain) and 1-km segments (for pilot areas) (Chapter 2.2).

divided into three zones: a nature zone with no human interference and no commercial use permitted; a management zone where direct human interference addressing conservation objectives are allowed (e.g. mowing meadows); and an outer zone for tourism, administration, fields, levees, and waterways.

This section of the Danube River also represents an important waterway for the transportation of goods and passengers. Still keeping the needs of navigation in mind, there have been recent advances in enhancing hydrological connectivity to improve the ecological state of the river. Since its declaration as a national park, progressive side-arm reconnections, removal of rip-raps, and integrated river engineering measures have been applied. The actions were followed up by scientific monitoring. The proximity of the two capitals makes the area an attractive destination for recreation and tourism, and a site of intensive research.

A. ES selection

During the first workshop, the participating stakeholders ranked the ES of the Austrian pilot area according to their beliefs. Most of the selected ES belonged to the category of Regulating ES, followed by Cultural ES. Due to the protection status of the NP, stakeholders believed that Provisioning ES only play a minor role.

Regulation and Maintenance ES

According to the stakeholders, the most important Regulating ES is providing habitat for many (endangered) species.

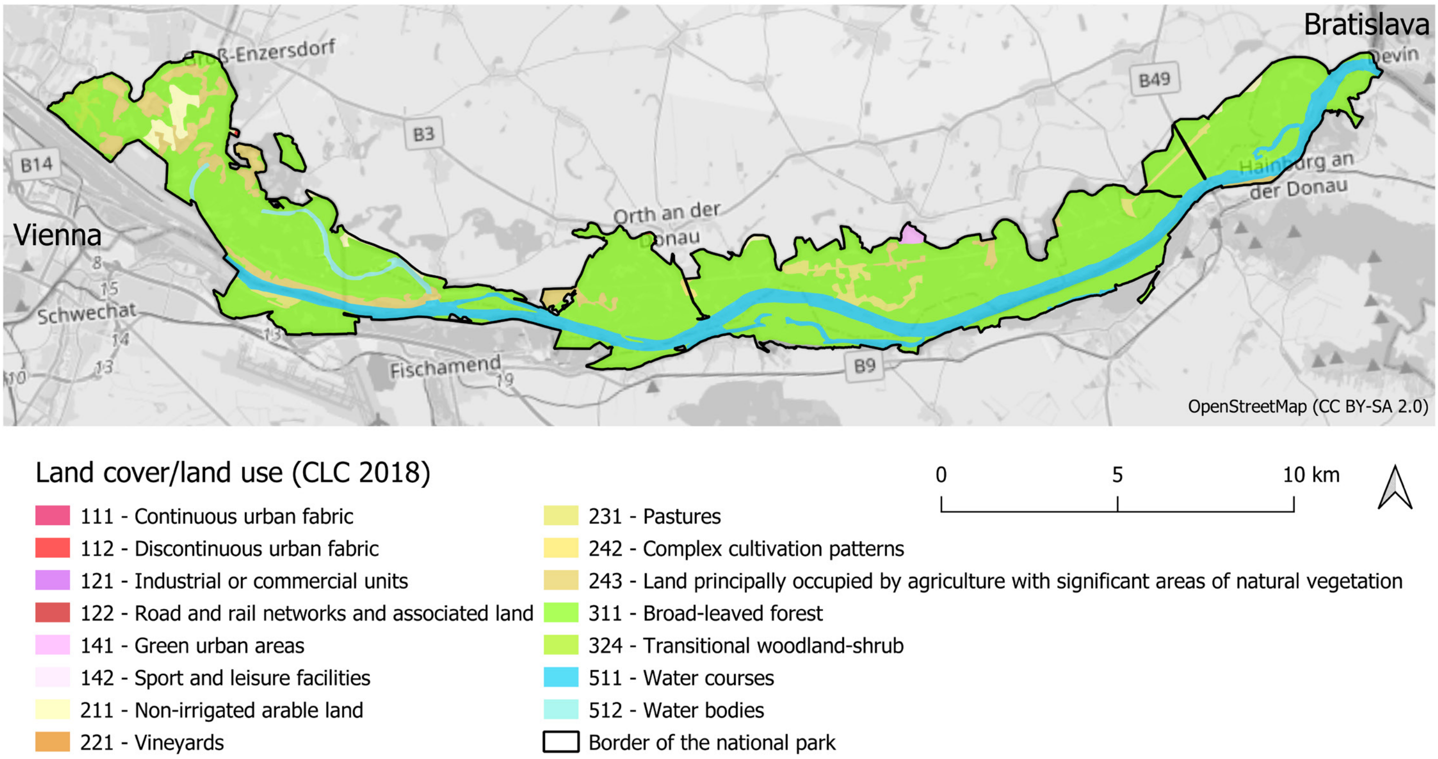


Figure 3.2.2 Overview of the Donau-Auen National Park

In fact, the area is home to more than 800 species of vascular plants, 30 mammal species, 100 breeding bird species, 8 reptile species, 13 amphibian species, around 60 fish species, and an abundance of invertebrates (www.donauauen.at/en). Of equal importance to the participants were water purification and nutrient retention in the river-floodplain system. The site also contributes to soil formation and quality, low flow regulation/reduction of drought risk, natural floodwater retention, mitigation of air pollution and sediment regulation.

Provisioning ES

Stakeholders held the provision of drinking water to be the most important Provisioning ES, followed by hunting and sourcing of wild food. There is a well system in the NP that guarantees the drinking water supply for Vienna in times of high demand, drought, or in case of maintenance work on the main water pipeline. The filtration properties of the floodplain soil ensure high water quality. Arable crop production and plant biomass production for fodder play a minor role in the NP. Non-commercial angling and net fishing are only allowed for recreational purposes.

Cultural ES

The NP impresses with its great natural beauty. The stakeholders selected the aesthetic and spectacular landscape and natural monuments to be the most relevant Cultural ES. Given the extensive opportunities for boating, cycling, hiking and recreational fishing, the NP is of great recreational value for the of the local population. The Viennese part of the pilot area (Lobau) is a particularly popular recreational area. In addition, the stakeholders praised the great research and education value of the area.

B. Results/Status quo IDES Tool

An assortment of Regulating, Provisioning and Cultural ES supplied by the pilot area was chosen with the help of the IDES Tool. The selection was then evaluated and mapped by 1-km segments (Figure 3.2.3). Consistent with the stakeholders' opinions, the evaluation revealed that the pilot area has great potential for providing habitat, especially on the active floodplain; including nurseries for different species (Figure 3.2.3). Another highly ranked ES on the active floodplain was the regulation of greenhouse gas fluctuations. Low-flow regulation and reduction of drought risk were highly appraised by both the IDES Tool and stakeholder perceptions. Compared to other pilot areas in the DRB, the nitrogen and phosphorus retention function is average to low (Natho et al. 2020, Tschikof et al. 2022). The potential for arable crop and grass biomass (fodder) production is low or non-existent.

C. Evaluation/mapping of scenarios in pilot area using the FCM results

During the second workshop, the 'optimal scenario' for improving water quality, among other local challenges, was jointly negotiated and simulated using the FCM co-developed for the pilot area (Figure 3.2.4). Here, a realistic change of pressures by a set of measures was discussed and agreed upon by the stakeholders. The strategies included stricter regulations and increased efficiencies in navigation, improved implementation of the WFD, lateral and longitudinal reconnection measures, bedload management, and regulating visitor numbers in the outer zones of the NP.

The co-developed optimal scenario resulted in strong positive effects, including the improvement of ES habitat provision and the biodiversity conservation, followed by sediment regulation and flood risk reduction. A moderately positive impact on water quality was simulated by the increased nutrient retention in the reconnected side-arms. There

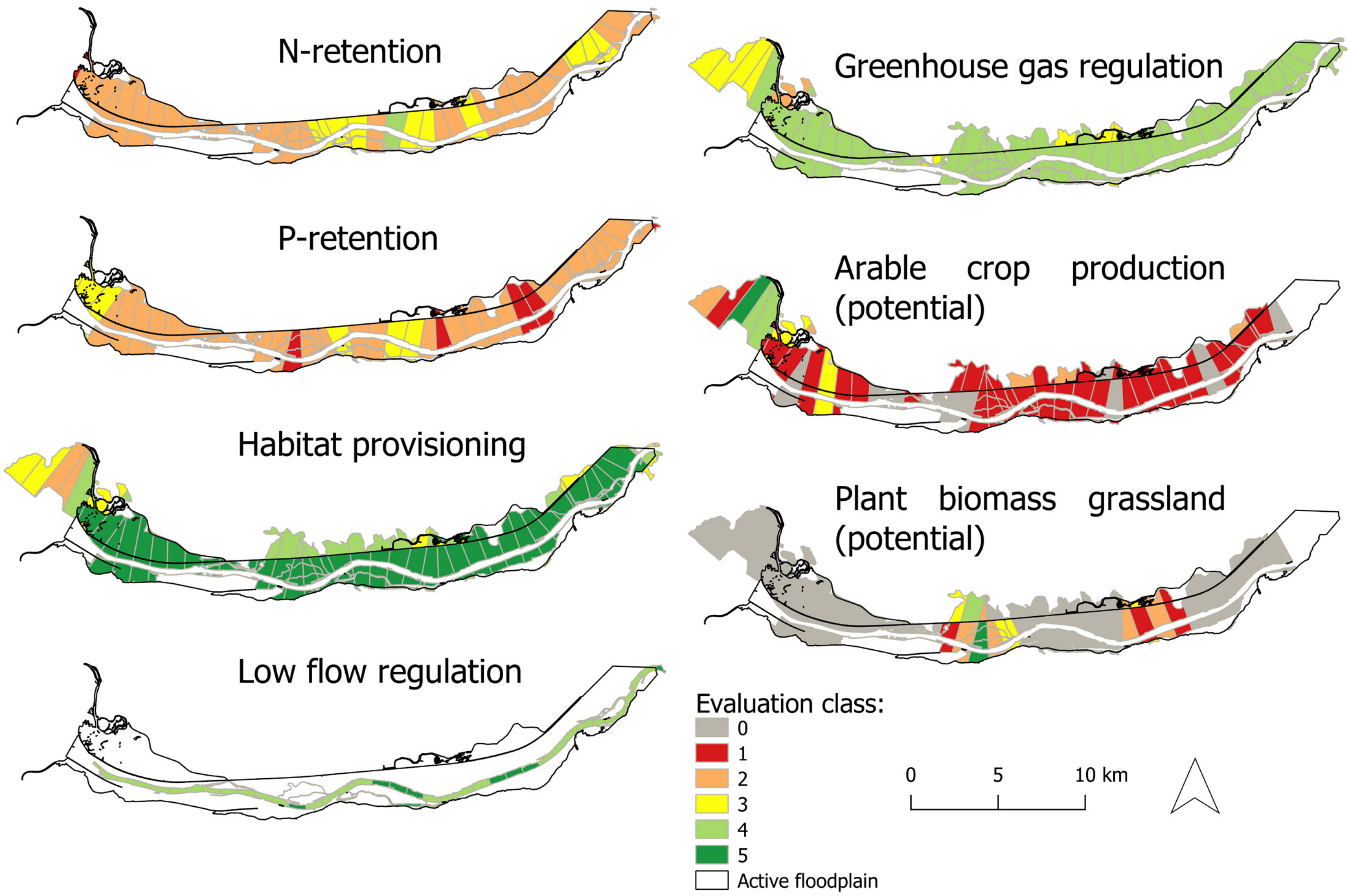


Figure 3.2.3 Selection of ES evaluated with the IDES Tool (indicator approach). The evaluation classes range from 0 (= no ES provision) to 5 (= very high ES provision). Because of its low relevance to the NP (arable crop production, grassland plant biomass), only the potential for Provisioning ES was evaluated.

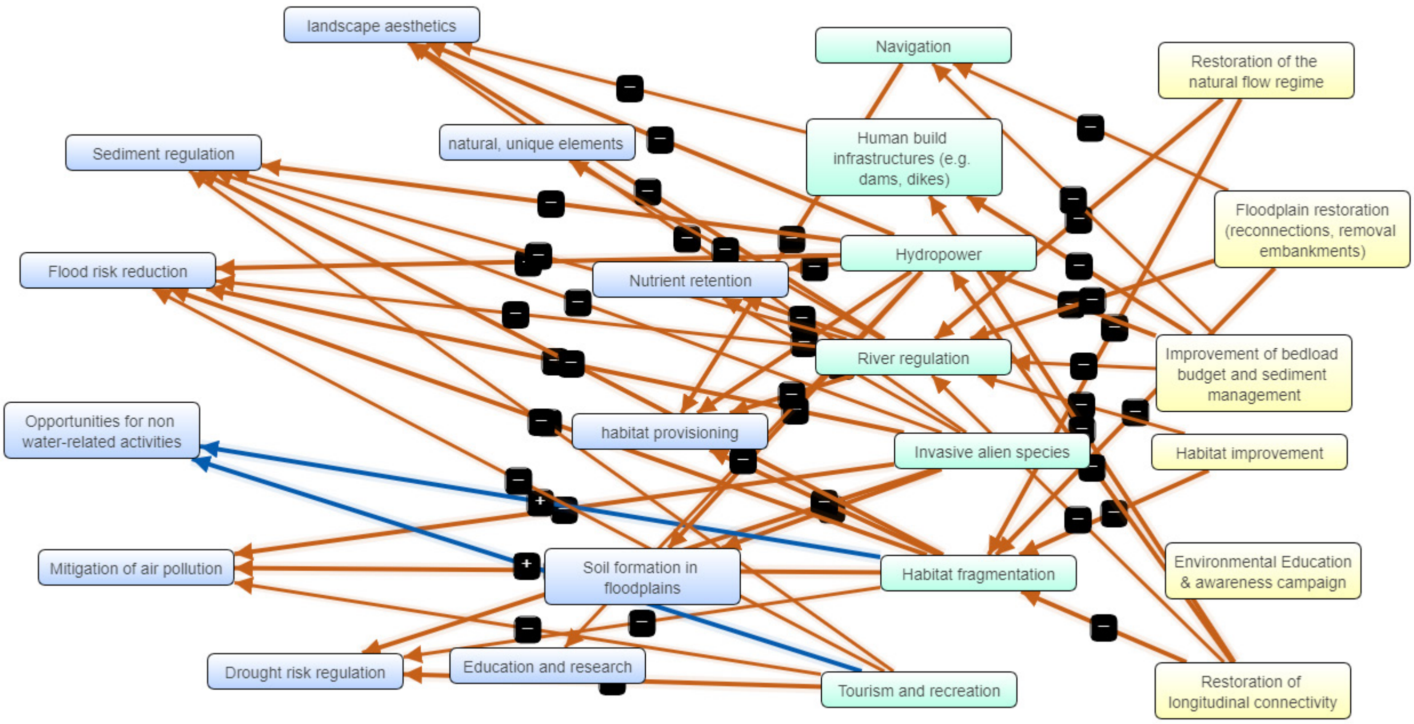


Figure 3.2.4 FCM of the Austrian pilot area.

was a distinct trade-off with opportunities for non-water-related activities in the area caused by the decommissioning of footpaths along restored river banks and modified visitor regulations (Figure 3.2.5). These results are in line with the findings of Funk et al. (2021) (Figure 2.1.3, Chapter 2.1), who modelled an enhanced habitat provision, a better nutrient retention function, and local trade-offs for Cultural ES after implementing reconnection measures.

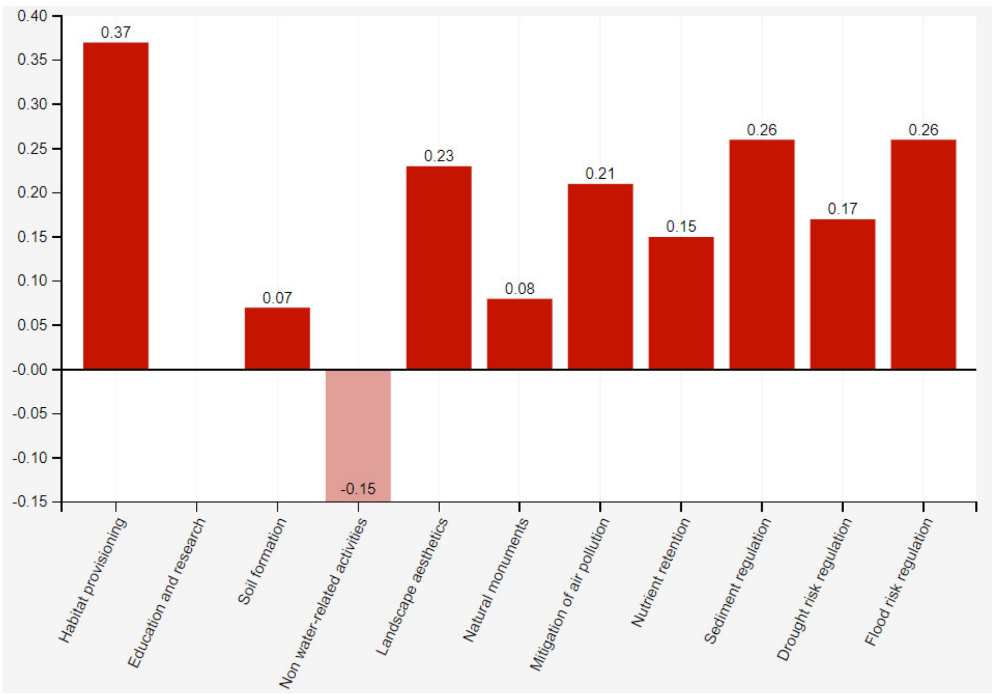


Figure 3.2.5 Relative change in ES provision for the optimal scenario (max. range: -1 to 1).

3.2.2 Tisza River Floodplain near Szolnok, Hungary

The Hungarian pilot area (Figures 3.2.6-7) is located in the middle of the Great Hungarian Plain. The area of the floodplain between Kisköre and Szolnok is 9,197 ha. Eighty-one percent is agriculturally usable. This Tisza River has been constricted between dykes for more than 100 years. Despite this, the area still includes a well-preserved complex of wetlands and forest ecosystems. Although only a few parts can still be found in their natural or near-natural state, the floodplains and wetlands along this section of river remain uniquely valuable ecosystems. These protected floodplain areas not only provide habitats for endangered species, but they also help to cut flood peaks and reduce flood damage by storing surplus water.

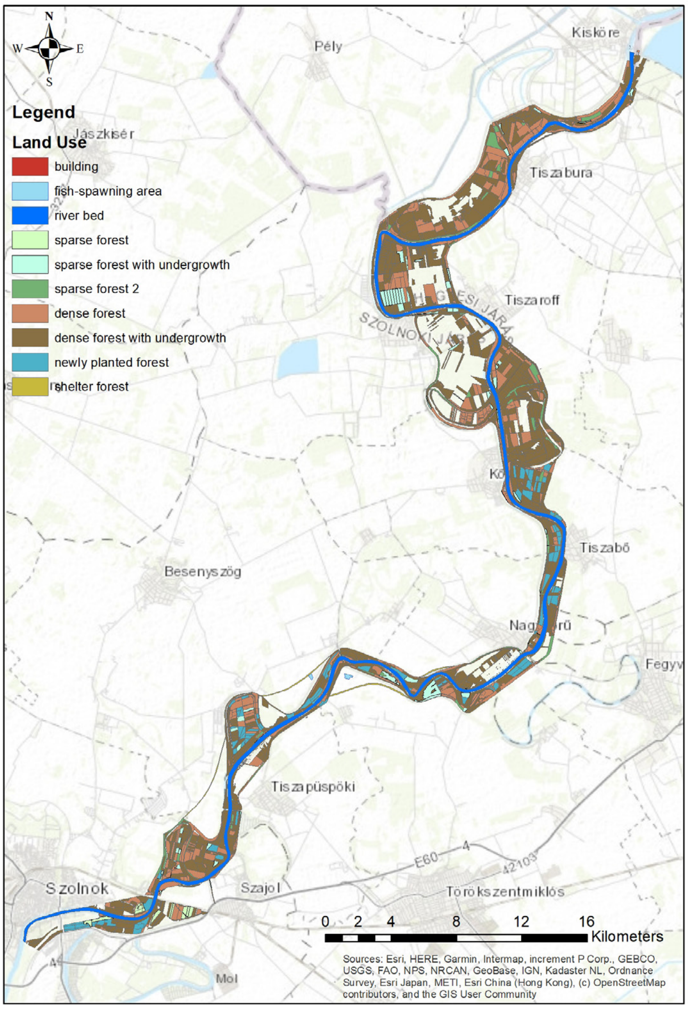


Figure 3.2.6 Tisza River near Szolnok pilot area.

In 1930, the forest only covered 591 ha. However, by the 1960s the floodplain forest area had increased to 2,809 ha; 3,334 ha in 1980; and approximately 5,576 ha by 2014.

Planners did not expect afforestation would cause significantly higher sediment deposition that would reduce the water absorption capacity of the floodplain. Based on these expectations, plantation-like forests of fast-growing *Populus x euramericana* were planted. These stands produce much higher timber yields than autochthonous *Populus alba* stands.

Even though this landscape was created by water engineers and foresters, the floodplain is considered by many local people to be a natural formation. This artificially created floodplain has grown over time into a diverse protected habitat with high nature conservation value; especially along oxbow lakes, gravel pits and the river banks.

Due to the frequent floods and severely declining groundwater levels in summer droughts, as well as a very mosaic-like soil surface, the trees of the floodplain forest in the Middle Tisza countryside differ from the typical forest-steppe associations. Many non-indigenous tree species can be found in the area, dominated by American ash (*Fraxinus pennsylvanica*), green maple (*Acer negundo*) and *Amorpha fruticosa*. The floodplain provides these species with optimal living conditions, but they represent a major threat to nature. With their abundant seed yield, fast growth, and good germination ability, they make it extremely difficult for native plants to regenerate. Additionally, they increase the topographical irregularity of the area that acts to form run-off barriers to flood waters.

A. ES selection

The most important ES were determined together with the stakeholders attending the workshops. The fact that many of the stakeholders are also connected with individual

Figure 3.2.7 Floodplain forest on the Tisza River near the Szolnok pilot area.

services facilitated the process. We received useful comments in the questionnaire and during the workshops.

Regulation and Maintenance ES

The stakeholders asserted that flood risk regulation is the most important Regulation and Maintenance ES; in fact, very significant among all ES. Since there have been many extraordinary flood events in the region over the past decades, flood-related developments are considered very important. The other two ES identified within this group were protection against drought and sediment regulation.

Provisioning ES

The stakeholders pointed out that Provisioning ES are the most important for local people, and most ES were selected from this group. Those ES included drinking water, timber production, arable crop production, commercial hunting and biomass production.

However, the most important ES of all is the drinking water supply. Szolnok and the region around this city (almost 100,000 people) are supplied with drinking water directly from the Tisza River.

A large portion of the floodplain was used for agriculture during the first half of the 20th century. Since then, the proportion of cultivated area has gradually decreased. Although the importance of animal husbandry in the region has declined recently, there are efforts to increase the grazing rate.

Cultural ES

The stakeholders indicated the high importance of landscape aesthetics among the group of Cultural ES. The other important Cultural ES is research and education. Much research on the challenges related to the Tisza floodplain is conducted in Hungary. According to the stakeholders, it is necessary to deepen the research on flood risk management, drought management, water retention and forestry.

B. Results/Status quo IDES Tool

Changes in the aquatic and riparian zone are noticeable. The changes are distinguished by features such as oxbow lakes, flood logs and smaller water bodies that fill with water from the Tisza or groundwater. The banks are fortified with stone blocks, and levees were built bordering the floodplain areas.

The entire pilot area is an active floodplain, sandwiched between dykes since the end of the 19th century. This has resulted in a completely new situation in which flooding only affects the area between the embankments and consequently, has also decreased the flood risk to that area.

In order to maintain the appropriate conditions in the floodable area, certain factors must be particularly addressed in the area: management

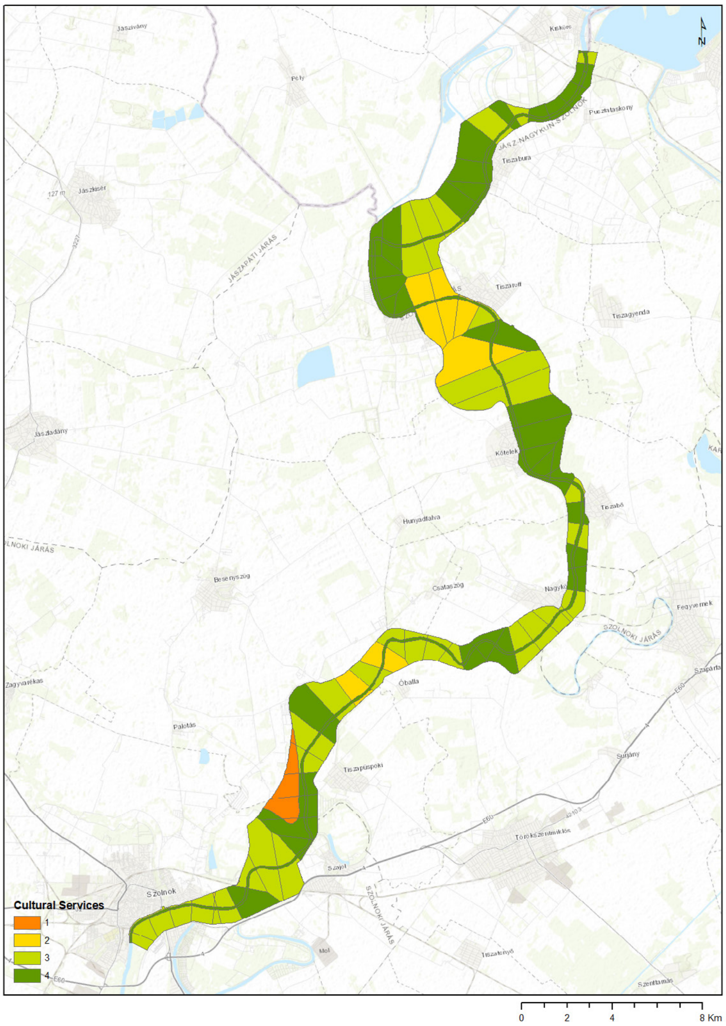


Figure 3.2.8 ES assessment (timber production) with the IDES Tool in the Tisza River pilot area near Szolnok.

of floodplain forests; sediment regulation; and maintenance of pastures, oxbow lakes and agricultural lands. Several measures have been carried out in recent years, including relocation of dyke sections with floodplain restoration, creation of wetlands and the removal of invasive species.

Among the many ES provided by the area, timber is actually the main Production ES (Figure 3.2.8).

Considering the complexity of the Tisza floodplain, the IDES Tool provided an excellent opportunity to carry out local and basin-wide condition assessments. The Tool enabled the prediction of different scenarios, given a change in the levels of different pressures or measures; and how some ES and water quality would change along the Tisza River as a result.

While strongly dependent on data availability and model resolution, the IDES Tool produced good results for the Tisza River pilot area.

C. Evaluation/mapping of scenarios by FCM results in the Tisza River pilot area

The most important ES, pressures and measures (Figure 3.2.9) were identified together with the stakeholders in the first workshop.

In the second workshop, stakeholders collaborated on creating different scenarios to assess the impact of various pressures on the ES. The stakeholders took into account that extreme hydro-meteorological events will become more frequent in the near future.

Droughts and floods are considered to be the most significant pressures in the region. According to the participants, the other three pressures (extreme natural events, invasive species and land use change) can have a synergic effect on the first two. The participants agreed that reducing pressures from droughts and floods should be prioritised. Since the weather in the region has become more extreme in recent decades, this may eventually lead to even more severe water shortages or floods. A further increase in flood risk is posed

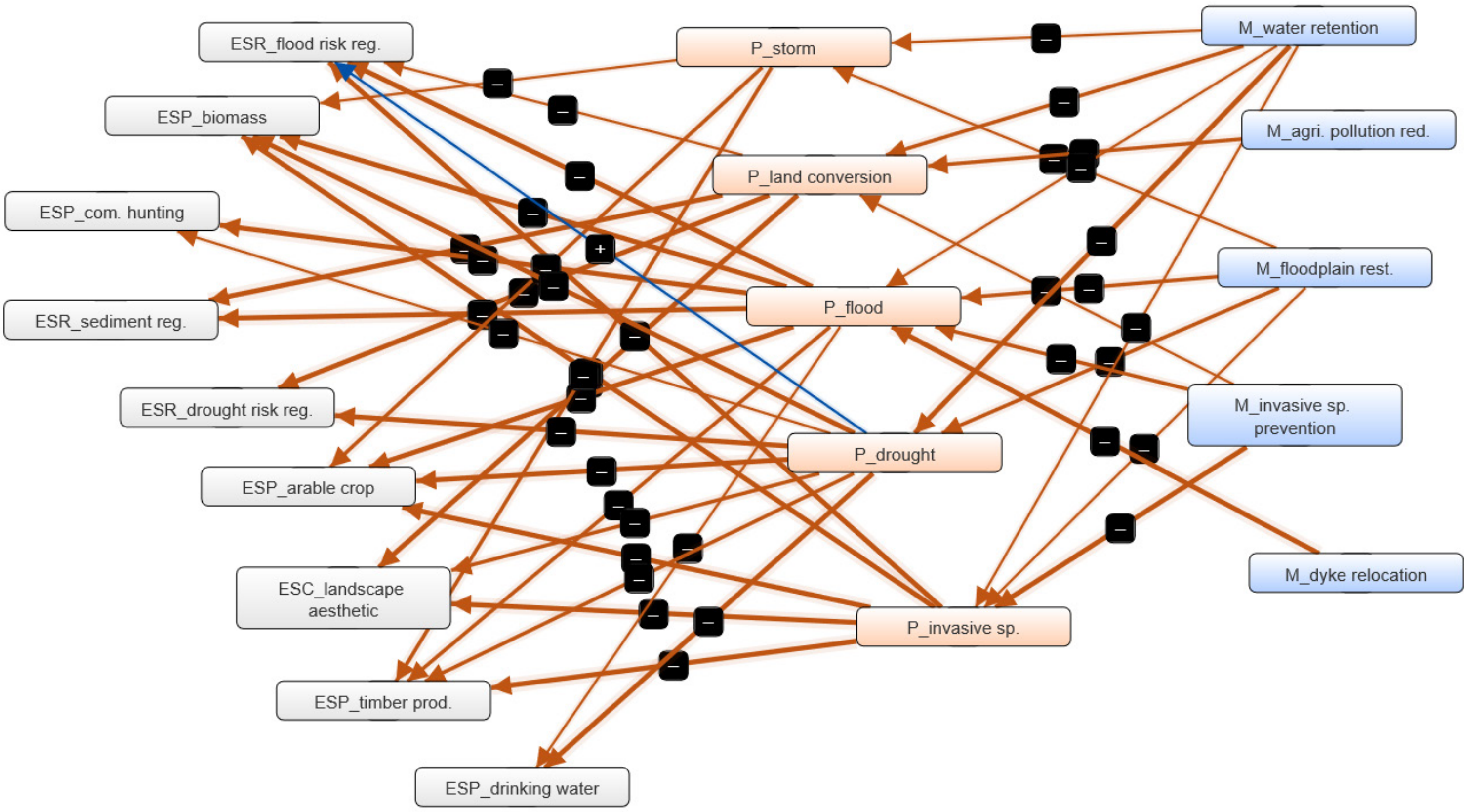


Figure 3.2.9 FCM for the Hungarian pilot area.

by invasive species that reduce the water conveyance capacity of the active floodplains.

During the first workshop, the stakeholders identified the five most effective measures in the pilot area and then analysed how realistic it would be to implement those strategies. The selected measures included water retention, prevention or control of the adverse impacts of invasive species, floodplain restoration, dyke relocation with complex measures, and reduction of agricultural pollution. The stakeholders in the second workshop identified virtually the same actions: floodplain restoration, dyke relocation with complex measures and reduction of agricultural pollution.

Therefore, the optimal scenario for the Tisza River is to execute a range of measures selected by stakeholders to reduce the flood risk and water scarcity/drought (Figure 3.2.10). According to the participants, the best solution is to expand the floodplain by moving the dykes and increasing water retention. For this, it is necessary to assess the areas where dyke relocation is possible and where water retention may occur after a flood.

3.2.3 Brăila Islands, Romania

The Brăila Islands (Figure 3.2.11) are a group of islands in the southeast of Romania. The islands cover a total surface area of over 2,600 km^2 along a 78 km stretch of the Danube River between the cities of Hârşova and Brăila. The area crosses four counties and comprises 20 administrative territorial units. It also contains nine EUNIS (European Nature Information System) level 1 habitats; including aquatic, terrestrial and socio-ecological systems.

The Brăila Islands are divided into the Big Island of Brăila and the Small Island of Brăila. Once a wetland characterised by large numbers of lakes, ponds and marshes that were linked to each other and connected to the river, the Big Island of Brăila now consists of heavily modified ecosystems where 96.4% of the island has been converted into agricultural land.

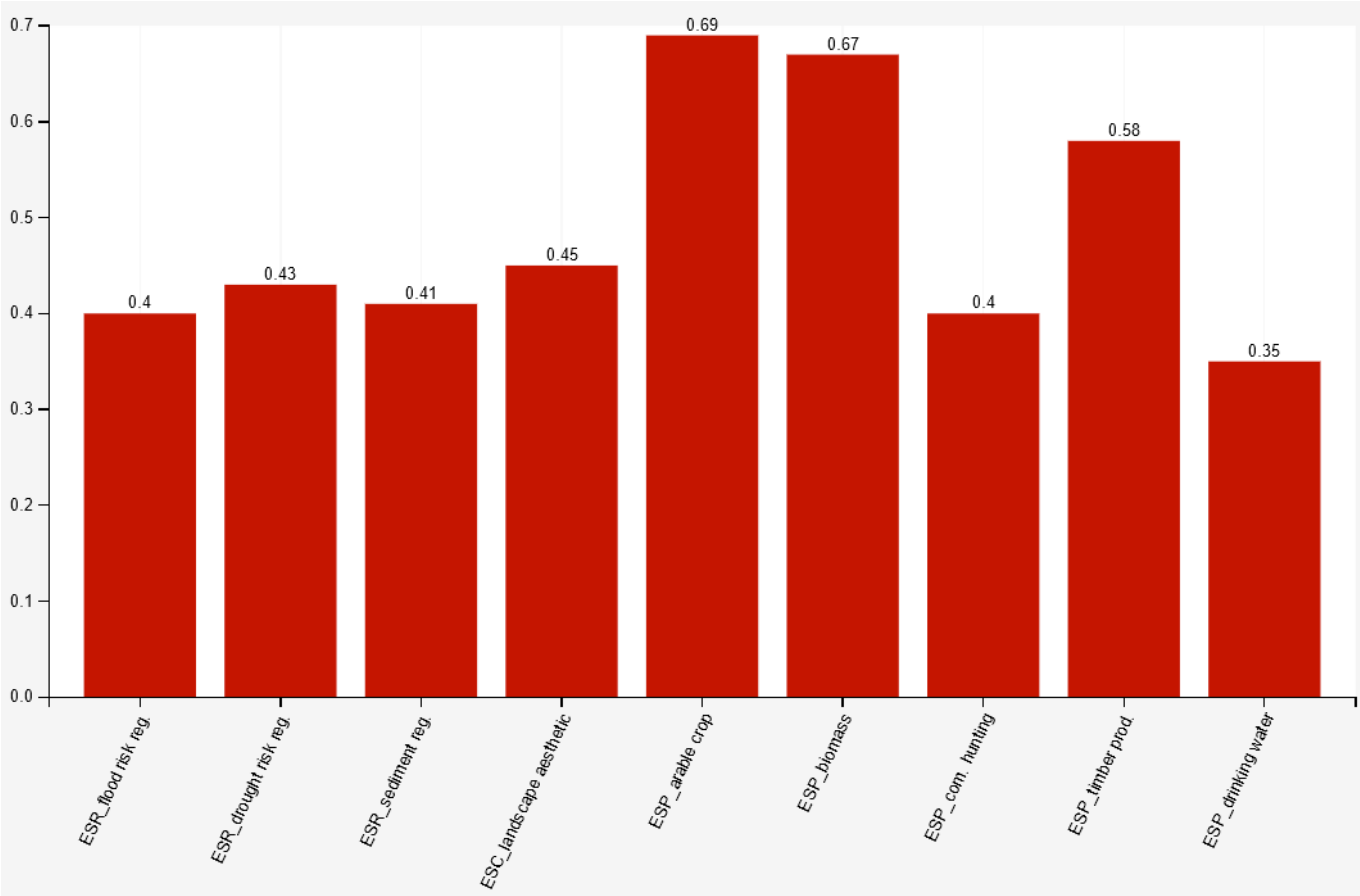


Figure 3.2.10 Optimal scenario for water quality improvement in the Tisza River pilot area near Szolnok.

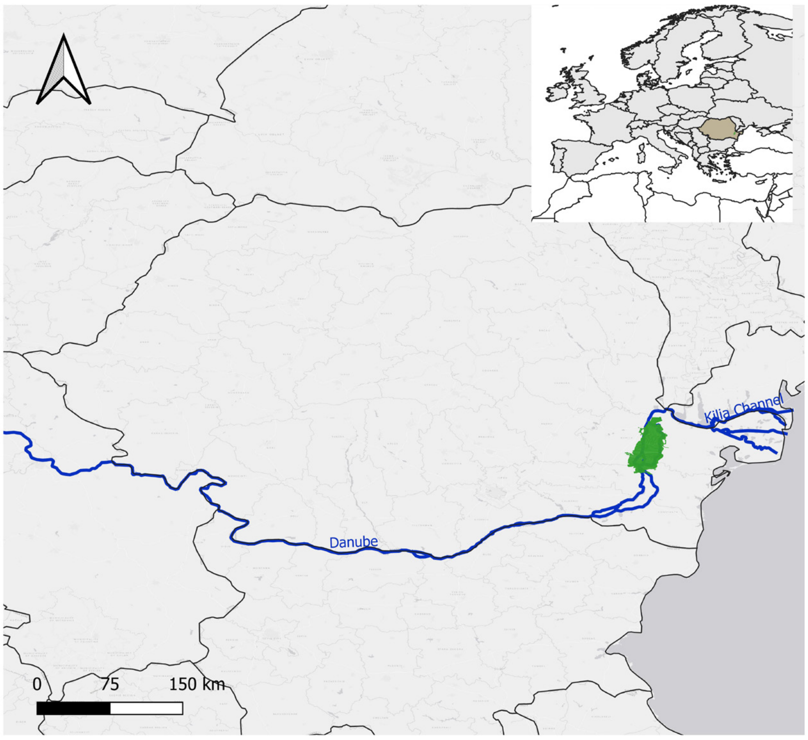


Figure 3.2.11 Location of Brăila Islands pilot area.

Conversely, the Small Island of Brăila maintains ecosystems under a natural functional regime and has preserved its natural hydrological conditions. The smaller island represents the main remnant of floodplains in the area, making its preservation crucial. The island is protected both on the national level (Natural Park - 06/03/2000) and international level (Ramsar Convention- 15/06/2001, Natura 2000).

A. ES selection

The stakeholders who selected the ES provided by the Brăila Islands were representatives from local, regional and national public authorities, research institutions and NGOs.

Regulation and Maintenance ES

The stakeholders identified Regulating and Maintenance ES as the most important to the site; and within that group selected five ecosystem services: ecosystem conservation and protection of biodiversity/habitat; reducing air pollution; forest curtains protecting farmland, roads and households against strong winds and snow-drifts; water purification/water quality improvement; and protecting the area against floods.

Provisioning ES

Among the Provisioning ES, the stakeholders identified the following three ES as having a high relative importance in the pilot area: commercial fishing; drinking water, water for animals; and water for cooling or irrigation (household or industrial use).

Cultural ES

Stakeholders identified two Cultural ES as significant for this area: research and education; and attracting tourists to the area for recreational fishing, swimming, non-motorised boating and motorised boating.

B. Results/Status quo IDES Tool

The evaluation of the Brăila Islands pilot area using the IDES Tool (Figure 3.2.12) revealed, as expected, that its potential for contributing to flood risk regulation has decreased compared to the pre-conversion state. Thus, the area now has only a medium potential of assisting flood risk regulation.

The Big Island of Brăila has a very low habitat provision potential, while the Small Island of Brăila has a high and very high potential.

As a result of the conversion to agricultural land, the Big Island of Brăila taken alone offers few Cultural ES. However, the presence of several Natura 2000 sites on the surrounding Danube arms increases its Cultural ES potential to mostly high and very high. The Small Island of Brăila has a very high potential for supplying Cultural ES.

Although the conversion to agricultural land on the Big Island of Brăila has higher provisioning services available to human communities, primary production is higher on the Small Island of Brăila. However, on the Small Island of Brăila provisioning services are not entirely available to human populations. Instead, maintaining high diversity and different ecological processes; and allowing the other groups of ES to be sustained (e.g. regulating carbon retention, nutrient and sediment retention, and flooding regulation, as well as cultural and habitat provisioning) are consumed within the systems.

C. Evaluation and mapping of different scenarios for the Braila Islands using the FCM results

The optimal scenario (Figure 3.2.14) for improving water quality in the Brăila Islands was negotiated and agreed to by the stakeholders based on the FCM of the pilot area (Figure 3.2.13).

Discussions regarding an optimal scenario focused on an anticipation of an increase in intensive agriculture in the near future, and hence the need to reduce nutrient use. Some detailed measures were proposed by the stakeholders:

- promoting subsidising/stimulating nitrogen-fixing crops (soybeans, peas, beans and alfalfa);
- crop rotation;
- cover crops to reduce the use of synthetic nutrients;
- use of organic fertilisers and organic herbicides (with N- and P-fixing bacteria);
- new technologies;

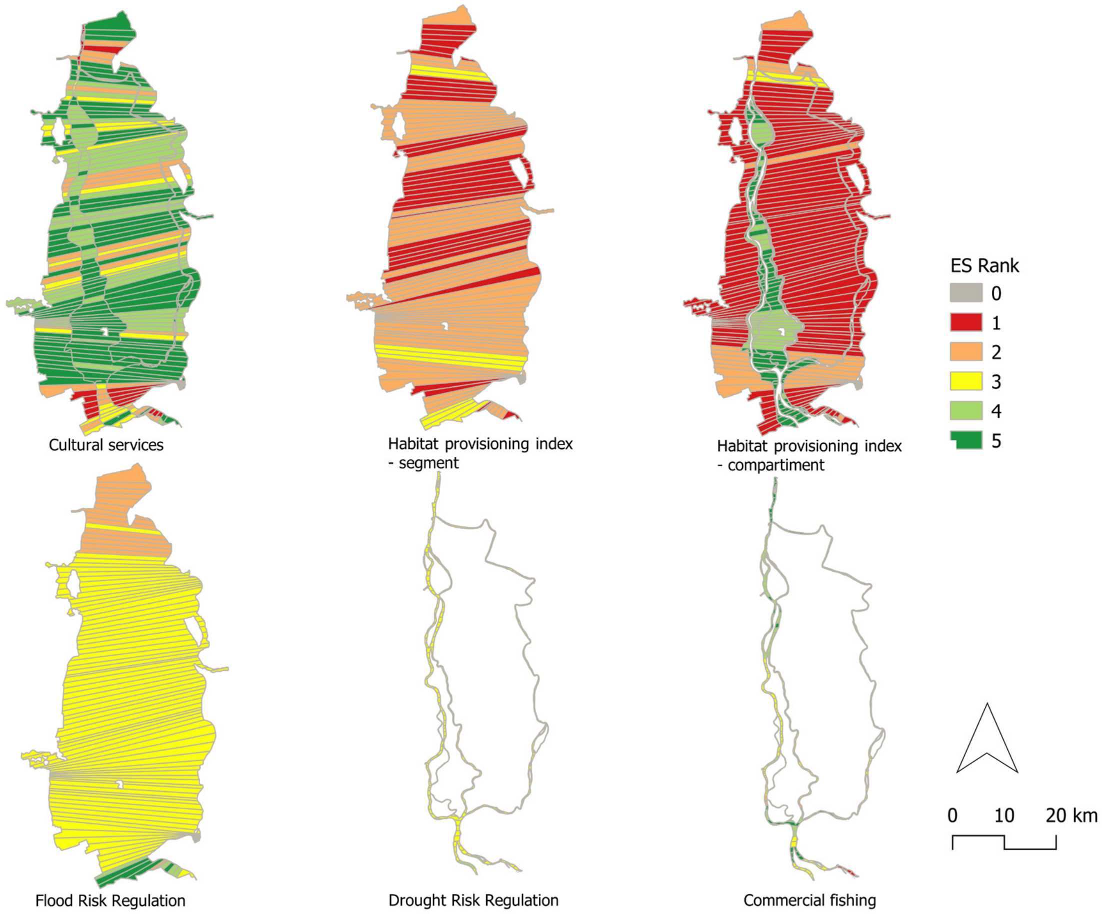


Figure 3.2.12 Selection of ES evaluated with the IDES Tool for the Brăila Islands. The evaluation classes range from 0 (= no ES provision) to 5 (= very high ES provision).

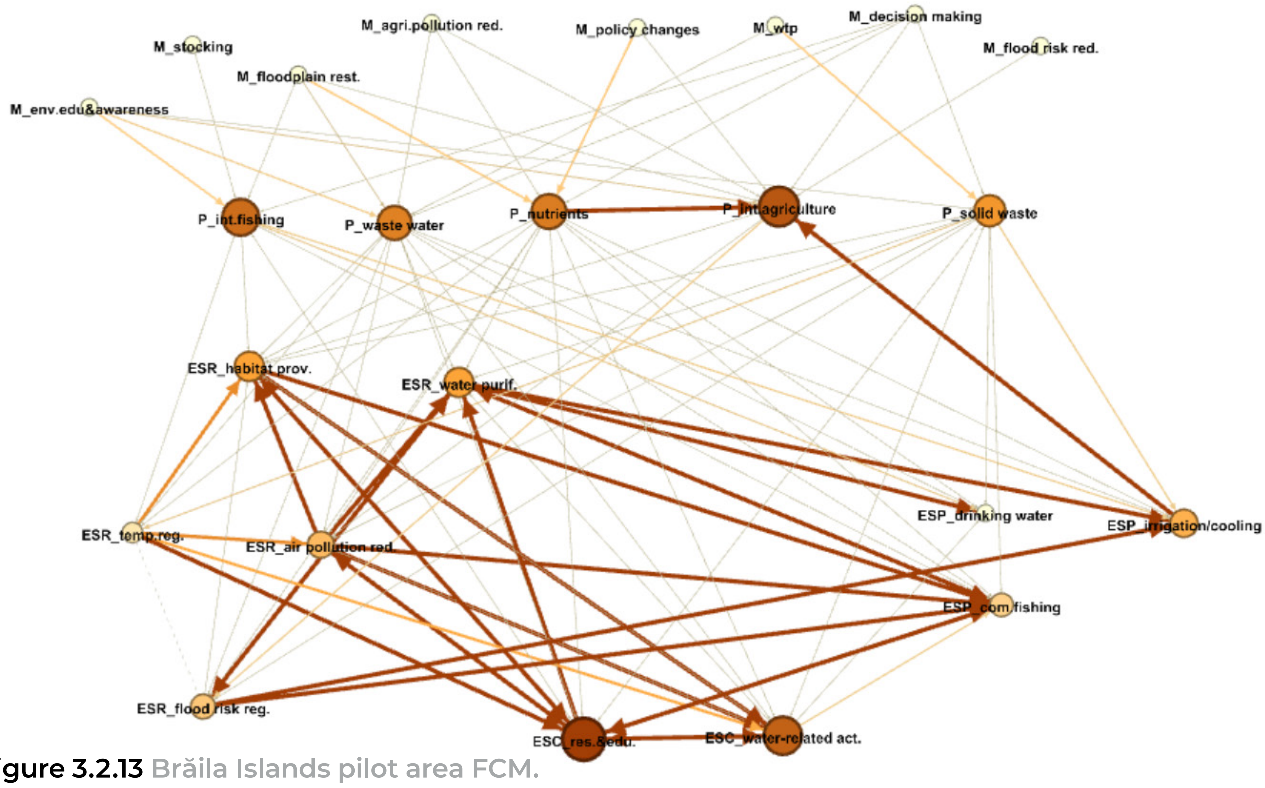


Figure 3.2.13 Brăila Islands pilot area FCM.

- updating courses at universities/technical colleges;
- introduction of permaculture;
- upgrading existing wastewater treatment plants;
- changing consumption habits.

The stakeholders also agreed that simple compliance with waste and wastewater legislation would lead to a reduction of the impact on water quality.

3.2.4 Koviljsko-petrovaradinski rit Special Nature Reserve (KPR), Serbia

The Koviljsko–petrovaradinski rit Special Nature Reserve (Figures 3.2.15-16) is located in the Autonomous Province of Vojvodina, Serbia to the northeast of Fruška Gora Mountain on both banks of the Danube River. The reserve encompasses the inundated region of the Danube River near the settlements of Kovilj and Petrovaradin. It represents a compact bogland complex that is located entirely within the Danube floodplain.

The KPR Reserve consists of two separate parts that are connected by the Danube River. The smaller Petrovaradin Bogland is located on the right bank, and the significantly larger area occupies the left bank. The Reserve area on the left bank consists of the Kovilj Bogland nestled against Krčedin Island, and part of the Gardinovci Bogland. The Reserve acts as a valuable ecological corridor for amphibians and birds during their seasonal migrations.

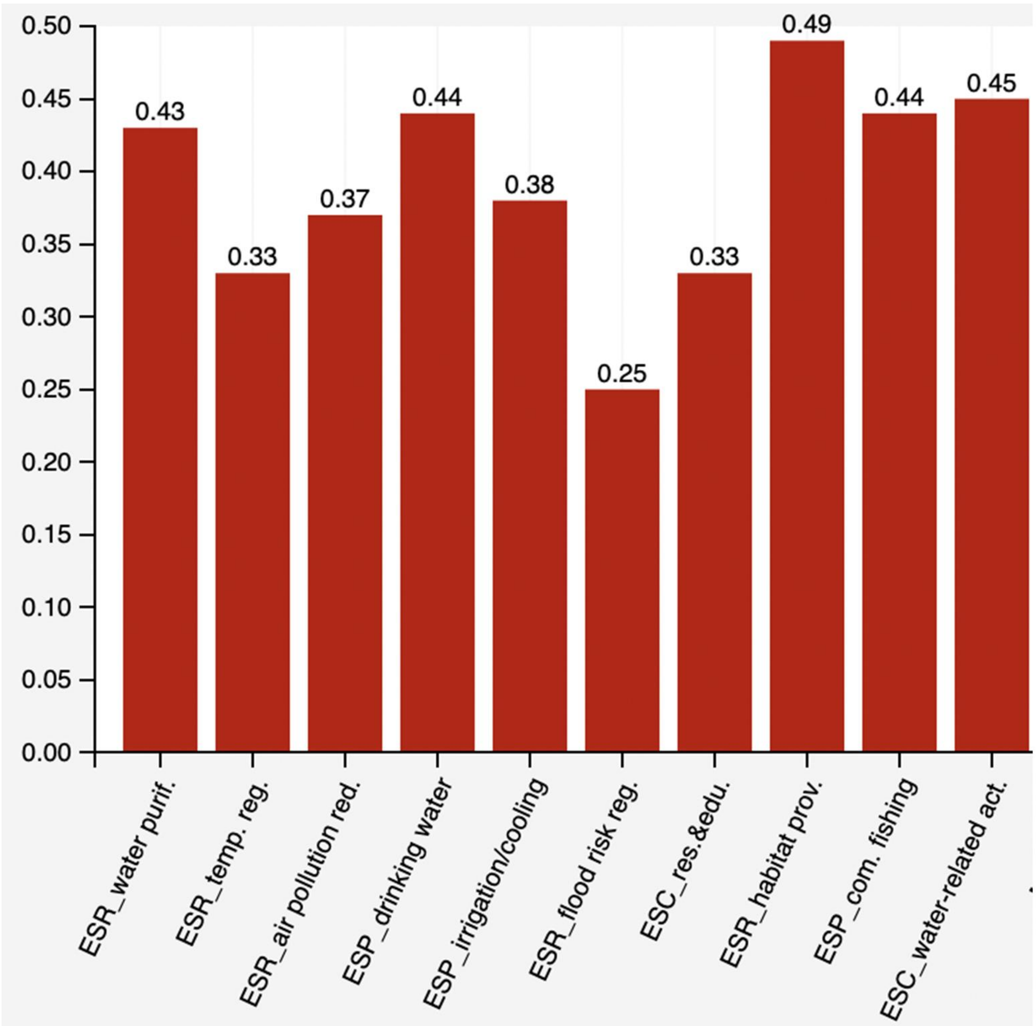


Figure 3.2.14 Optimal scenario for water quality improvement in the Brăila Islands.

The pilot area of 4,840 ha was divided into forest areas (69%), meadows and pastures 15%, and water 8%. KPR is protected at both the national (Special Nature Reserve, three-stage protection) and international levels. The Reserve's ecological value attained international recognition as an Important Bird and Biodiversity Area, Important Plant Area, DANUBEPARKS and EMERALD status.

As a significant protected area located near populated areas and intensively used for traditional livestock farming, KPR offers a wide variety of ES, for example:

» cattle grazing/livestock breeding;
» commercial fishing and hunting;
» timber production;
» water and groundwater;
» use of reeds as natural material (provisioning services);
» carbon sequestration;
» regulating air quality;
» water treatment;
» flood protection;
» pollination;
» control of invasive species (regulation services);
» recreation, tourism, aesthetic charm, scientific research, cultural and historical significance, and spiritual importance (cultural services).

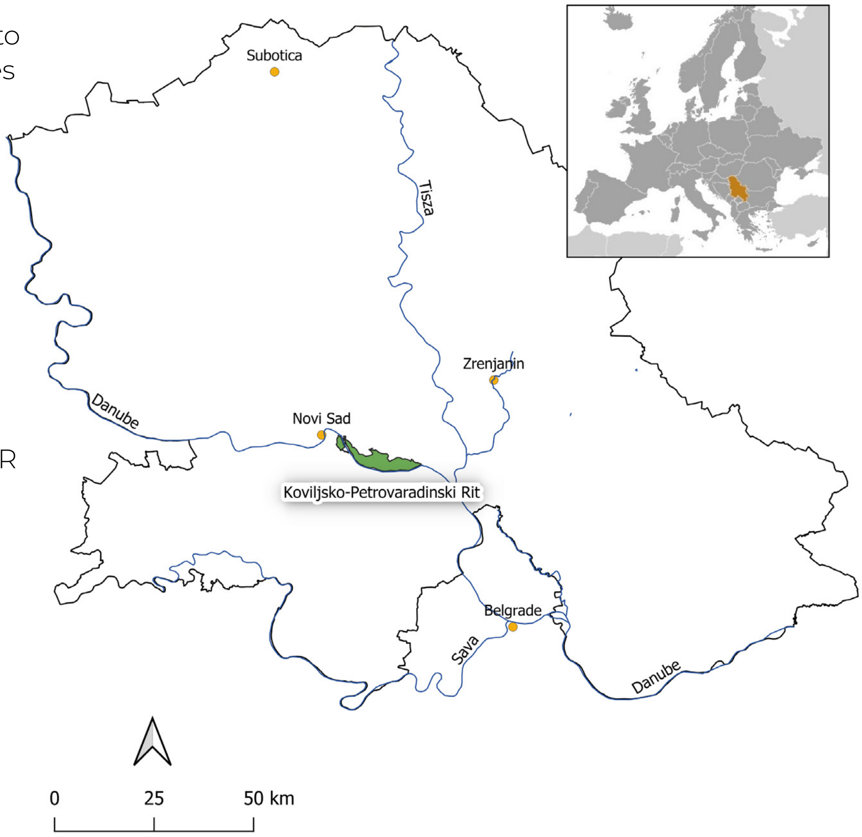


Figure 3.2.15 Location of the KPR in Europe and Serbia.

A. ES selection

Stakeholders participating in the process were gathered from the nature protection sector, forest management companies, water management companies, provincial secretariats (environmental protection, agriculture and water management), local authorities, NGOs, the association of farmers, 'other' land owners and users (small and medium local enterprises), the association of anglers and academia.

Regulation and Maintenance ES

For the KPR stakeholders, four of the ten most important ES belong to the Regulation and Maintenance ES; namely provision of habitat, flood protection, reduction of air pollution and protection of the area against drought.

Provisioning ES

Only one Provisioning ES was selected among the ten most important: grazing areas for livestock.

Cultural ES

KPR stakeholders recognised Cultural ES as the most important ES group. The top-ranked ES among the ten was landscape aesthetic quality (the site includes a number of spectacularly beautiful landscapes). Since a 13th century Orthodox monastery is located in the KPR, stakeholders also recognised the prominent sacred/religious/spiritual/symbolic significance of the place. The other three ES within this group are its: unique natural monuments; opportunities for research and education; recreational fishing, swimming,

Figure 3.2.16 KPR Special Nature Reserve.

non-motorised boating and motorised boating for tourists.

B. Results/Status quo IDES Tool

The co-creation of the FCM (Figure 3.2.17) and the ES map for habitat provision (Figure 3.2.18) obtained using the IDES Tool was considered for the status quo scenario.

C. Evaluation/mapping of scenarios in the KPR pilot area using the FCM results

1. Ideal case scenario (all pressures minimised)

If pressures were minimised (set their value to -1 in FCM), the ES potential of the landscape would be increased to the maximum. For example, habitat potential would be increased by 0.37 (the sigmoid function used to calculate the potential increase ranges from 0 to 1), meaning an increase from 100% status quo value in the attribute table to 137%. Therefore, the values in the attribute table were changed accorvding to equation 2.4.1 (Chapter 2.4) to create an ideal case scenario map for habitat provision (Figure 3.2.19). In this case, if the class of the given cell in the formula was 3, the new value would be 3+3*0.37=4.11. Results above 5 are considered as class 5.

2. Maximising wastewater, the most significant pressure

If the pressure from wastewater is maximised (set value to 1, others set to 0), the landscape's ES potential will be decreased (example scenario, just to illustrate the effects of pressure maximisation), and habitat will be decreased to 0.31. In this example, if the class of the given cell in equation 2.4.1 was 3, the new value will be 3-3*0.31=2.07 (Figure 3.2.20).

3. Optimal scenario

The creative discussion during the workshop regarding the value of each of the five most important pressures was supported by professional expertise, but also by the local knowledge of stakeholders who possess a deep understanding of the real-life situation and problems in the pilot area. The optimal scenario (defining the reduction of the single pressures, Figure 3.2.21) was agreed among the stakeholders and used to calculate and visualise the effects on the ES; including habitat provisioning.

During the second workshop, the stakeholders selected the following measures as appropriate and necessary to realistically reduce the prevalent pressures: construction or upgrades

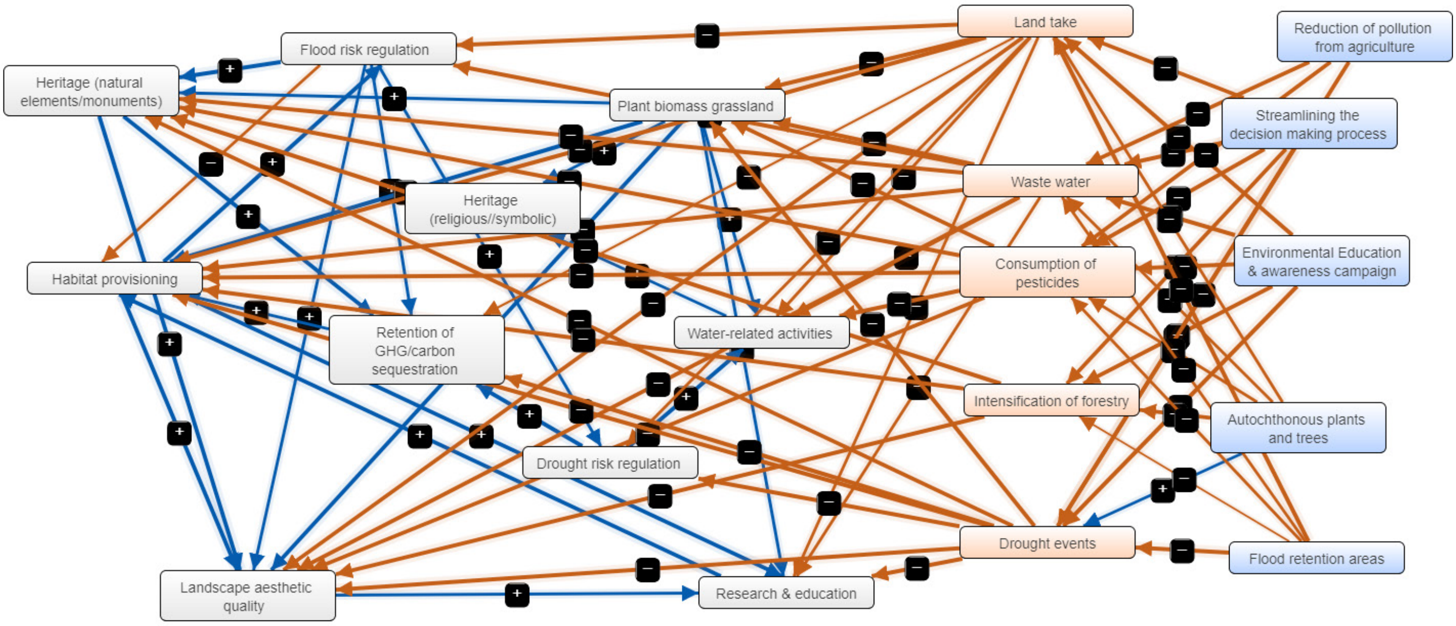


Figure 3.2.17 ES pressures-measures relationship FCM for KPR.

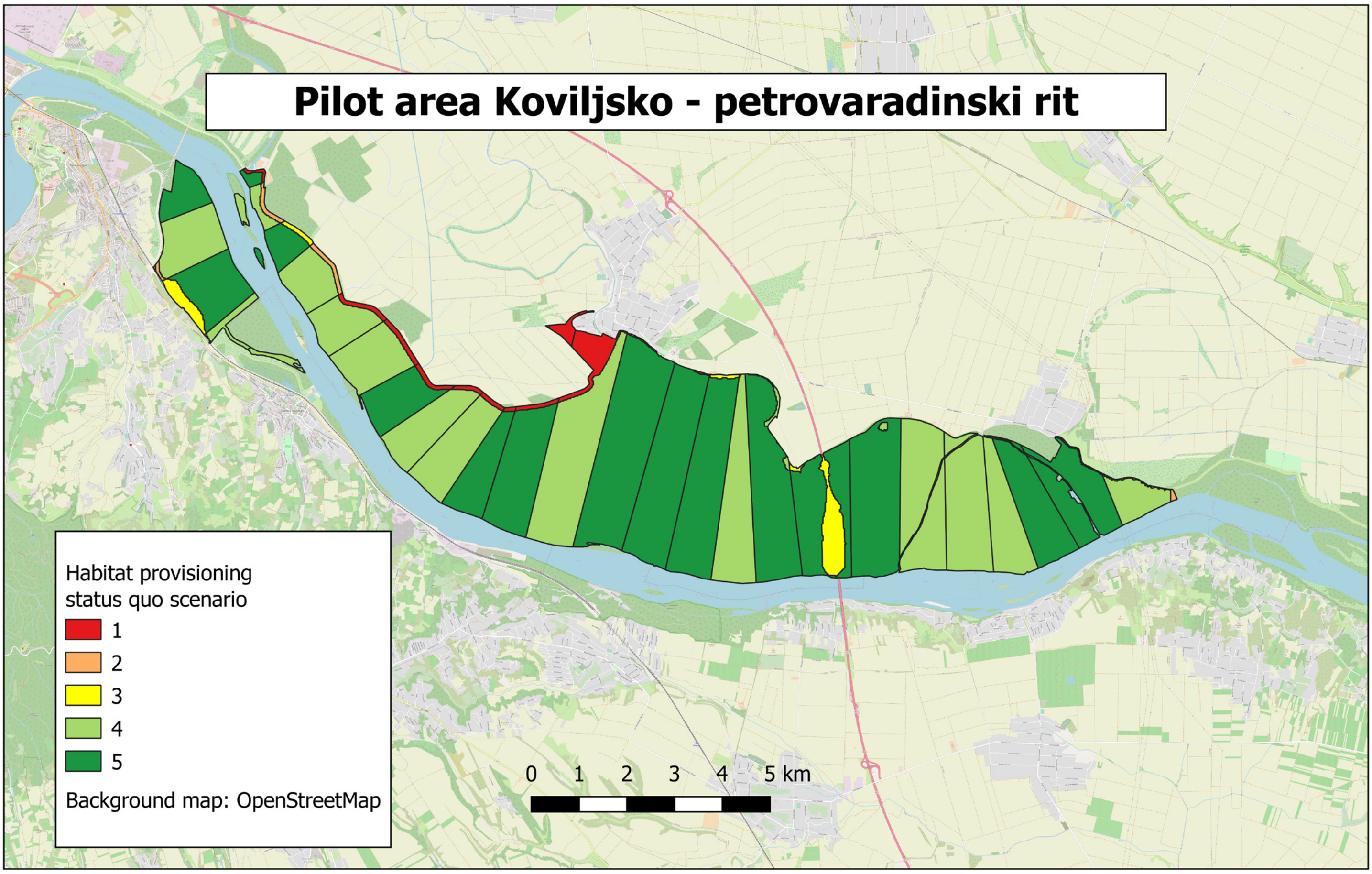
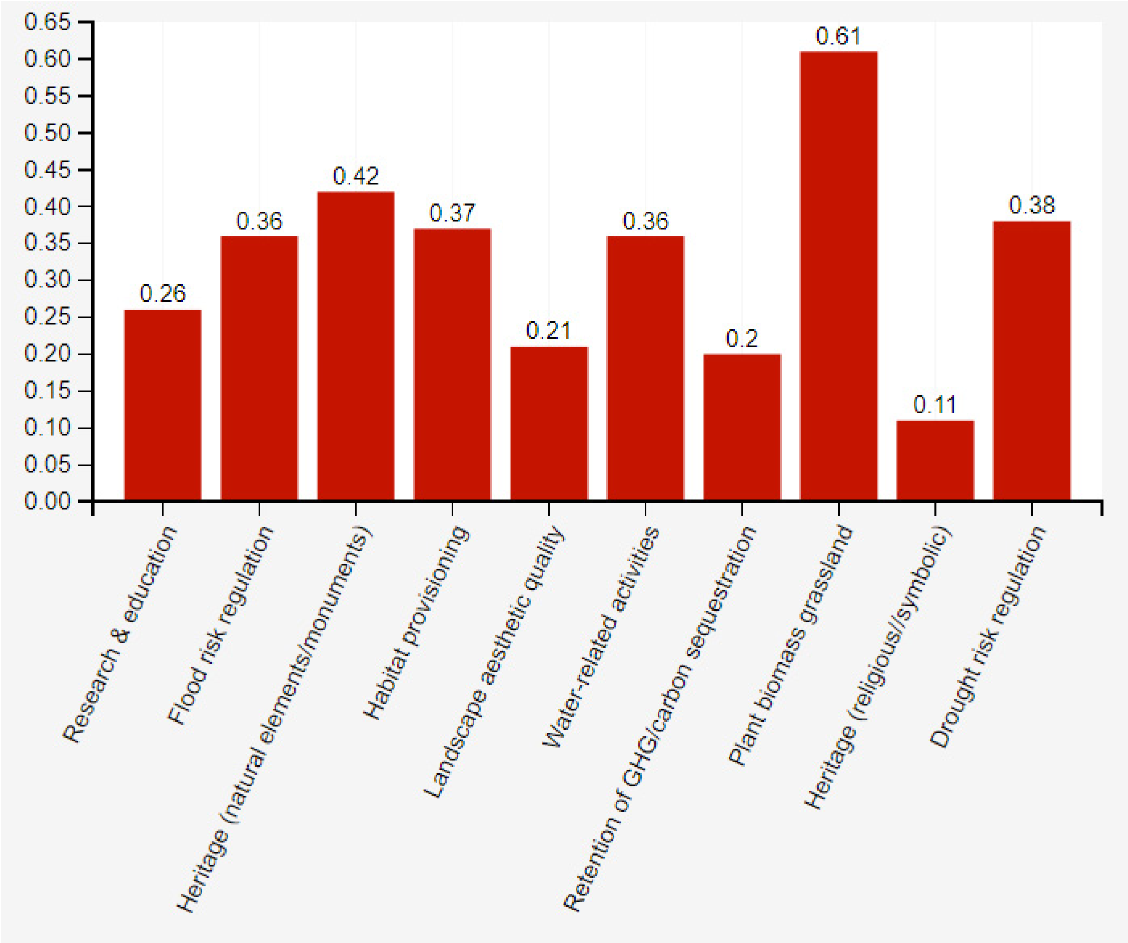


Figure 3.2.18 Status quo for the ES habitat provision in KPR.



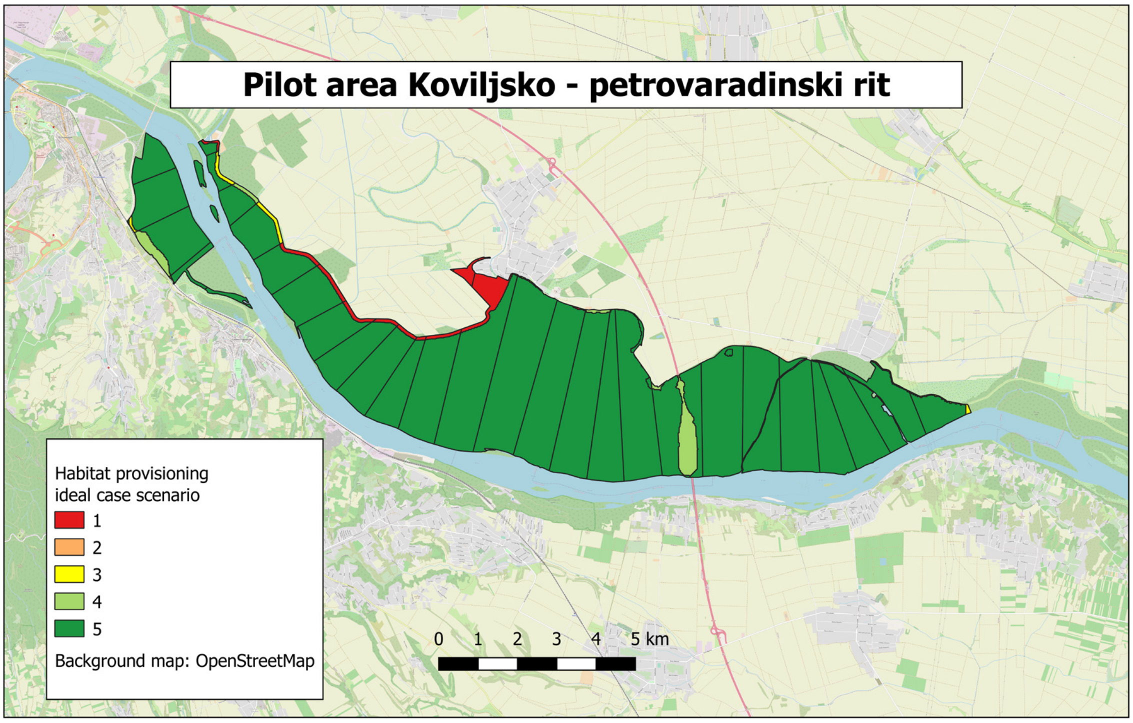
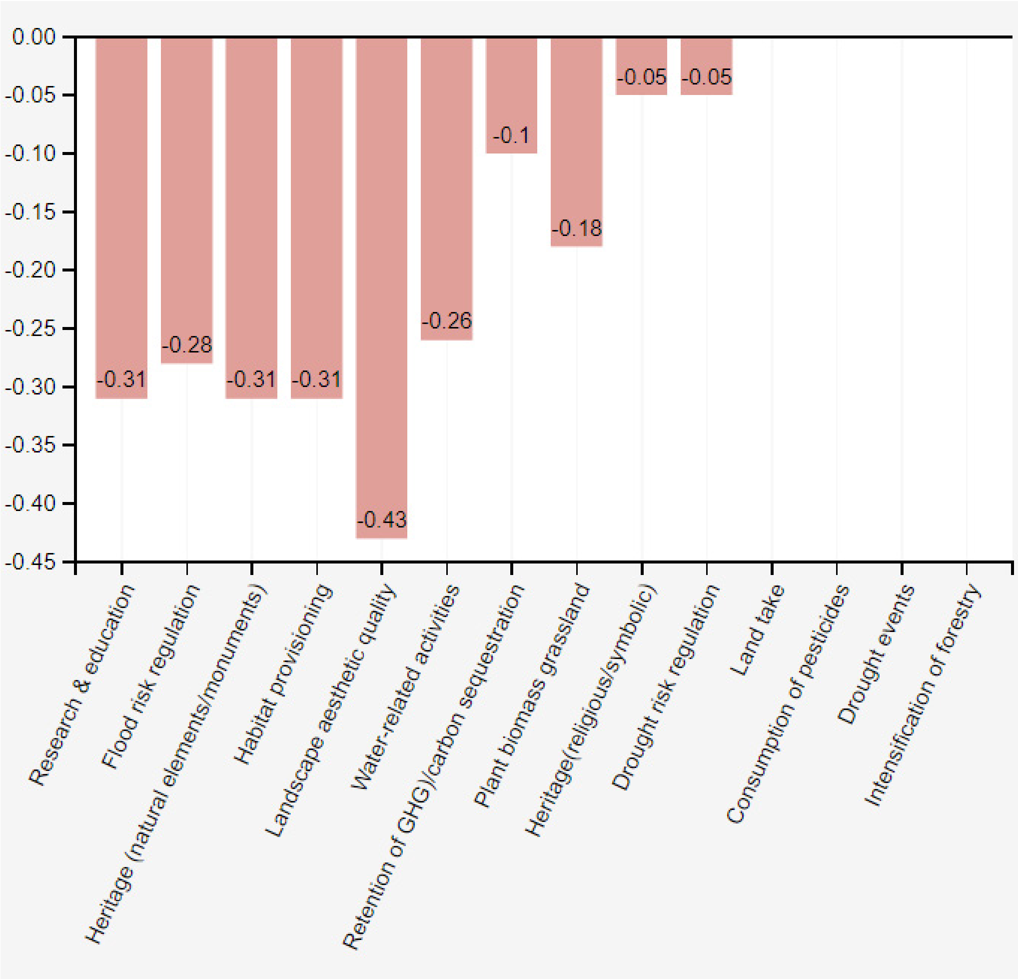


Figure 3.2.19 FCM ideal case scenario and related map for habitat provision.



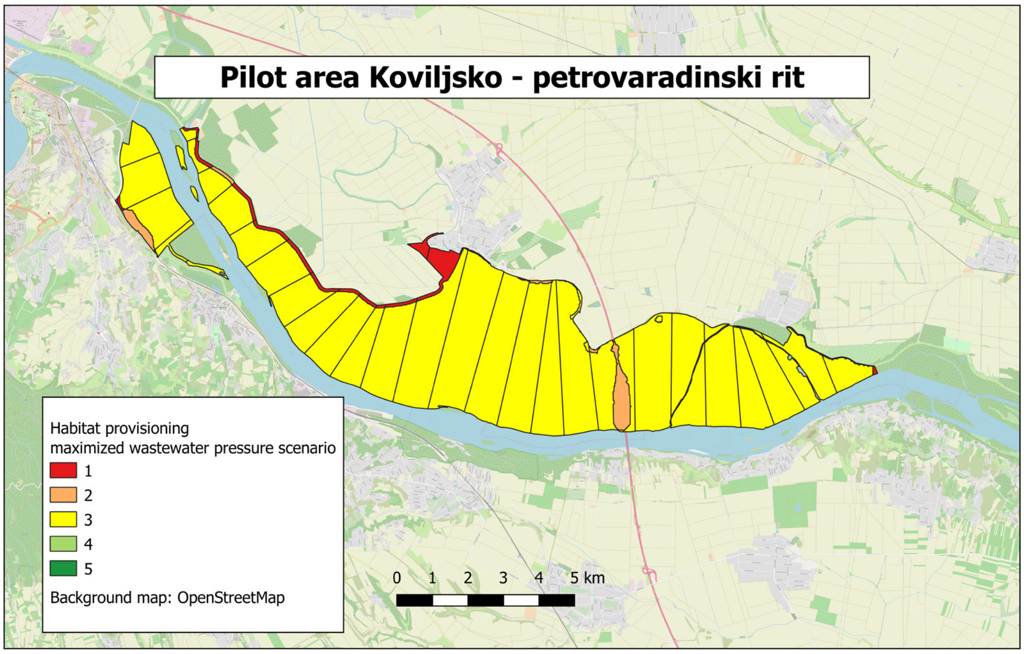
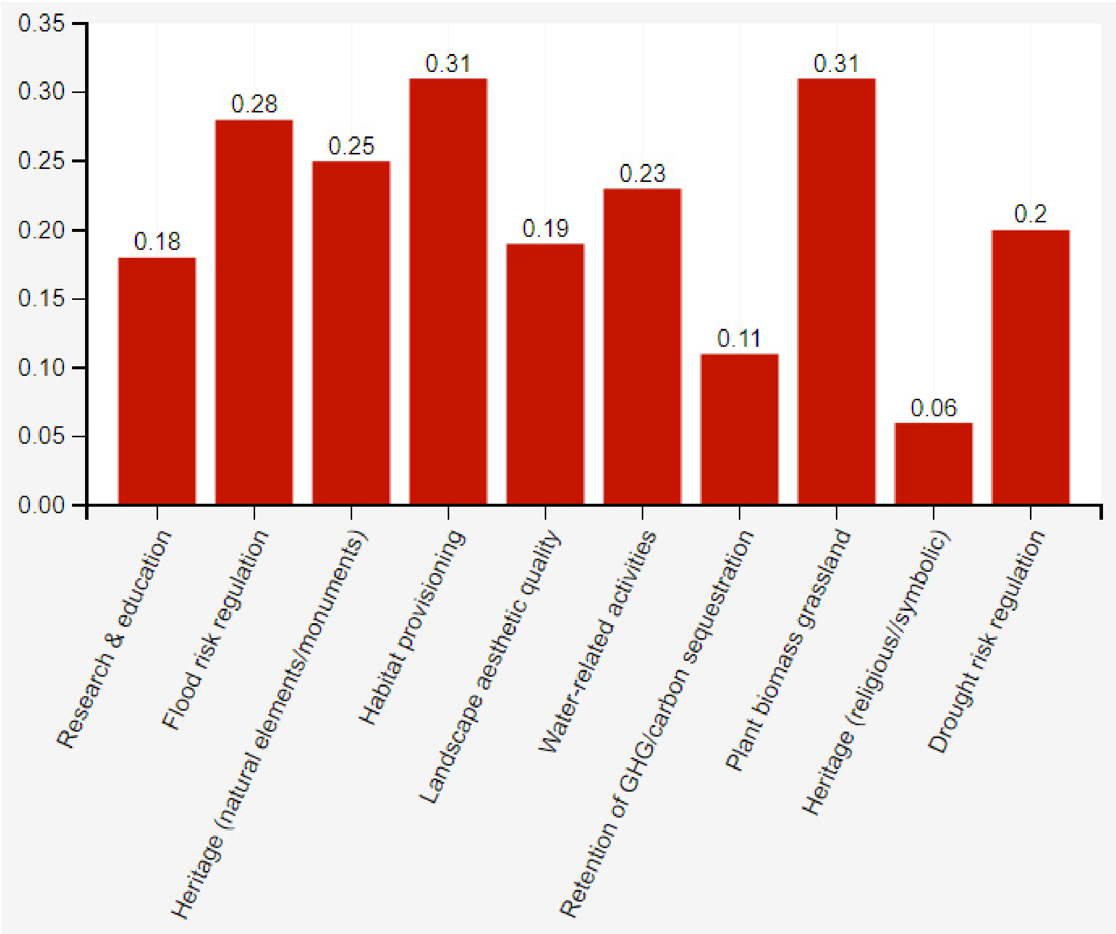


Figure 3.2.20 Effects of maximised wastewater pressure on ES in the FCM and related map for habitat provision.



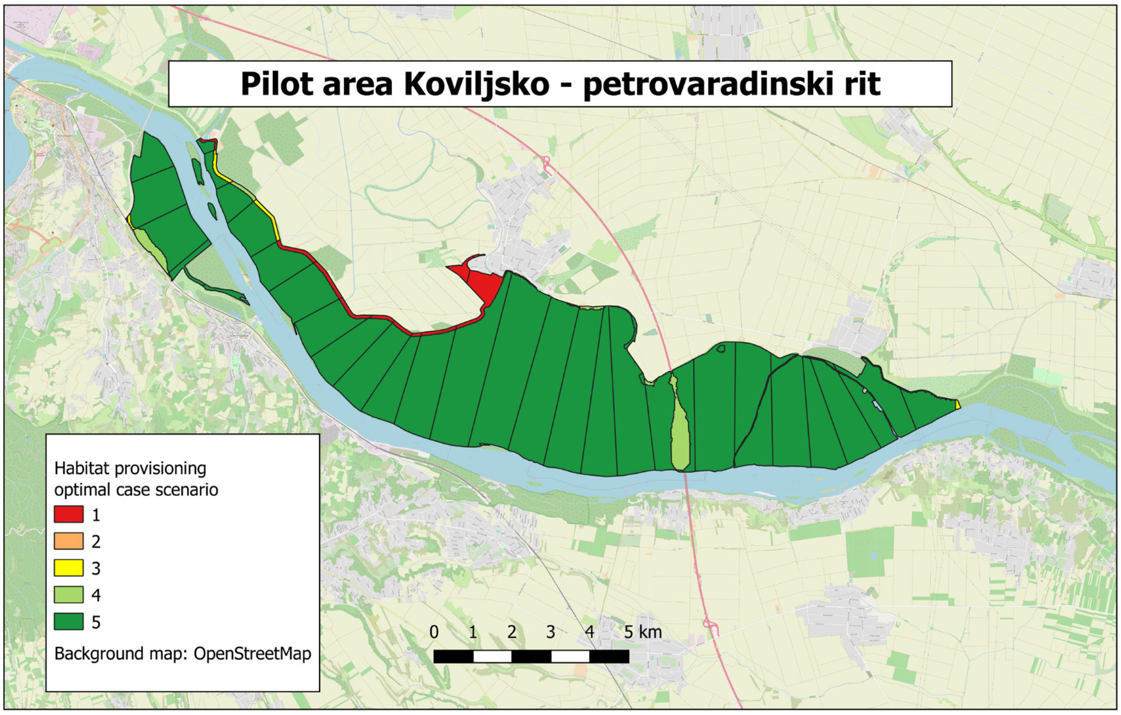


Figure 3.2.21 Resulting ES potential in KPR when the optimal scenario is applied.

of wastewater treatment plants; reduction of pollution from agriculture; establishment of buffer zones; floodplain restoration; prevention or control of the adverse impacts of recreation; and an environmental education and awareness campaign.

3.2.5 Mura River, Slovenia

The pilot area in Slovenia is located in the north-eastern part of the country along the Mura River (Figure 3.2.22). The Mura is a tributary of the Drava River, and subsequently the Danube. The 28 km-long stretch of the pilot area is located between the town of Radenci (upstream) and the confluence with the Ščavnica River (downstream). The expanse presents the largest preserved complex of floodplain habitats in Slovenia (UNESCO 2019). The intertwining of natural factors with the millennial presence of humans has shaped an exceptional riparian cultural landscape characterised by the linkages between the river and its habitats. The floodplain forest complexes are offset by the distinctive agricultural cultural landscape in the hinterland. In some places, the landscape features complexes of wet meadows, mosaic fields and villages on the edge of floodplain forests. The large number of rare, nationally and internationally endangered habitat types and wild plant and animal species in area has formed one of the most biodiverse areas of Slovenia (Ministrstvo za okolje in prostor 2015, UNESCO 2019).

In the past, water and floods have played an important role in the lives of local residents. They adapted to its rhythm, built dykes on both banks of Mura River, and used the geomorphologic characteristics of the area to protect their homes, livestock and fields from the high waters and floods.

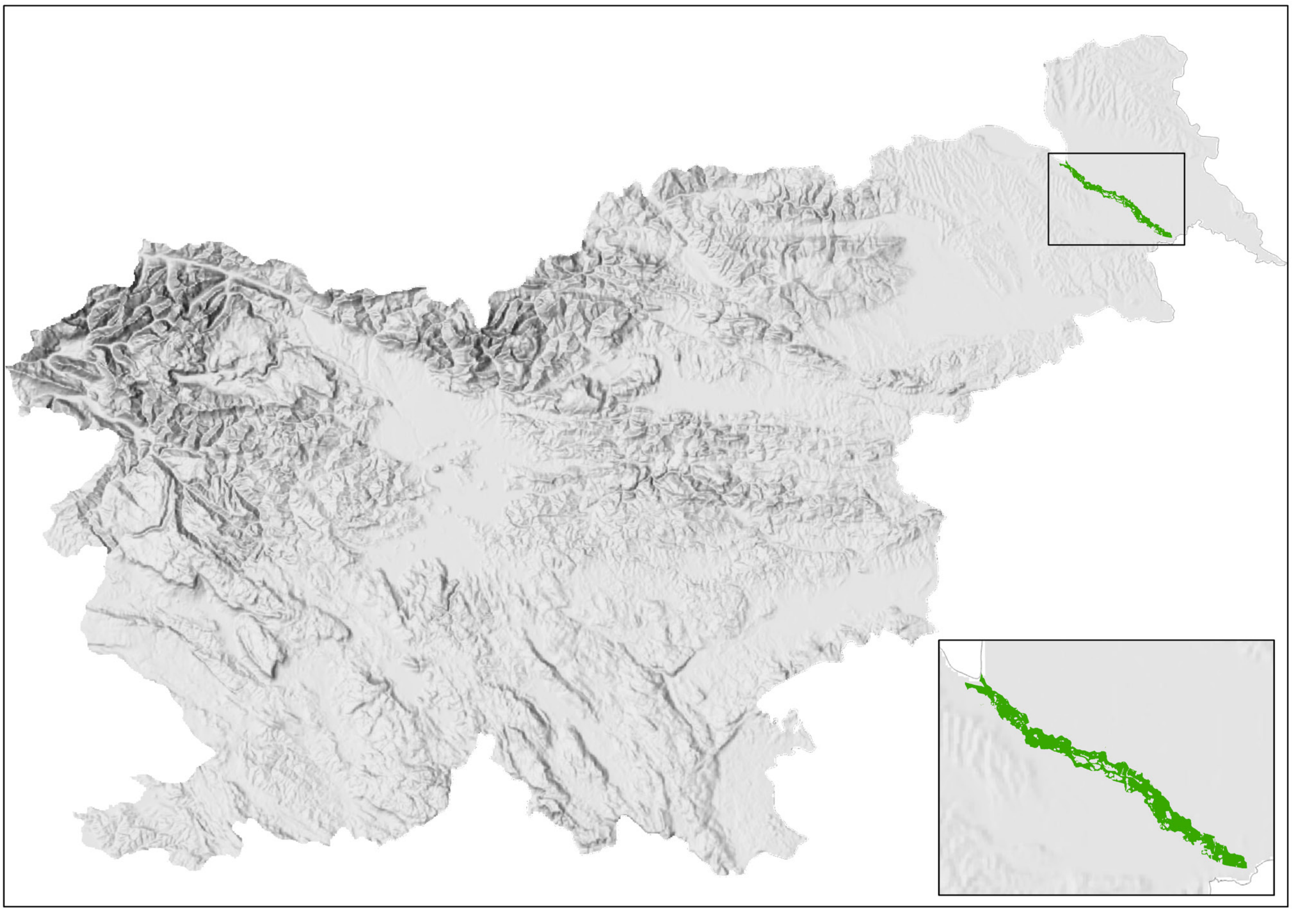


Figure 3.2.22 Location of Mura River pilot area.

At one time, the Mura River was predominantly used for transport, food provision and water supply. Nowadays, tourism is one of the most important uses for the waterway. The section where the pilot area is located is also widely used for recreation (e.g. fishing, cycling, kayaking, canoeing, running and hiking).

A. ES selection

ES play a very important role in the daily lives of local residents, stakeholders and visitors utilising the pilot area. During consultations with local stakeholders, we were able to understand how they relate to this pilot area and its ES. Discussions, questionnaires and workshops with stakeholders, emphasised the need to protect the area and the importance of ES for the stakeholders.

Regulation and Maintenance ES

Regulation and Maintenance ES was the most important ES group for stakeholders in this pilot area. Five of the ten most important ecosystem services belong to this group. The site contributes to protecting the area against floods, ecosystem conservation, protection of biodiversity (habitat provisioning), water purification/water quality improvement, reducing air pollution, and protecting the area against drought.

Provisioning ES

Stakeholders highlighted drinking water (water for animals) and arable crop production (cereals/root crops/vegetables obtained from the farmland within the site) from the Provisioning ES group.

Cultural ES

The pilot area, and the Mura River in general, play very important roles in offering Cultural ES to local residents, tourists and other visitors. The site includes a number of spectacularly beautiful landscapes, natural elements (relief) and natural monuments that are unique to Slovenia. Stakeholders pointed out landscape aesthetics as a very important Cultural ES that largely supports good physical and mental health, as well as relaxation. This pilot area in particular contributes to attracting tourists to the area that are interested in observing nature, cycling and walking.

B. Results/Status quo IDES Tool

Benthic invertebrates, organisms that live on the bottom of a water body (or in the sediment) and have no backbone, on the Kučnica Mura Petajnci – Gibina enjoyed moderate ecological status between 2016-2019. The ecological status of the upstream Mura Ceršakak - Petanjci and downstream Mura Gibina - Podturen held good ecological status during the same period.

The chemical status of these water bodies between 2014-2019 was assessed as good. However, monitoring in 2020 showed that two substances exceeded permittable levels. Tests showed the presence of ubiquitous mercury (Hg) more than once (45 µg/kg, standard 20 µg/kg), and brominated diphenylethers (BDE) more than eight times (0.0685 µg/kg, standard 0.0085 µg/kg) in Kučnica Mura Petajnci - Gibina.

Various interventions in the riverbed and in the catchment area of the Mura River in the VT Kučnica Mura Petanjci - Gibina during the past hundred years means that the eco-hydrological condition is no longer completely natural. The increase of agricultural areas, regulation of the catchment area, and the reduction of floodplains have had a major impact and changed the area's hydro-morphological status. A section of the inner Mura is largely regulated and hydro-morphologically altered. Changes in the water and riparian zone are noticeable; characterised by oxbow lakes, flood logs and smaller water bodies that fill with water from the Mura and groundwater. High-water dykes were built along the riverbed and the banks were strengthened with stone blocks. The fortification of the river banks and construction of dykes narrowed the riverbed. Consequently, these interventions have prevented lateral erosion while increasing bed erosion and deepening of the river. With the regulation of the riverbed, the water level decreased and the velocity of water flow increased. A strip of floodplain forest predominates on the dykes and behind them, with agricultural land beyond that.

The IDES Tool (Figures 3.2.23-26) was also tested in the Mura pilot area. Comparing the results with the real situation in the pilot area, researchers concluded that the downstream part of pilot area achieves higher ES assessments than the upstream part. The reasons for this are unclear, but it is thought that this is the case because the downstream riverbed has been less regulated in the past, and the ownership of land is divided between fewer owners than in the upper part where plots of land are more fragmented.

C. Evaluation/mapping of scenarios in the Mura River pilot area using FCM results

Taking as the starting point that politics and stakeholders will hopefully be in favour of protecting the area, stakeholders can use the FCM to work more intensively to improve water quality (Figure 3.2.27) in the pilot area. The future development of the pilot area may include improved tourism-recreation infrastructure, but no big interventions will be allowed. Local people will better understand how they can reduce their impacts when exposed to ES educational activities.

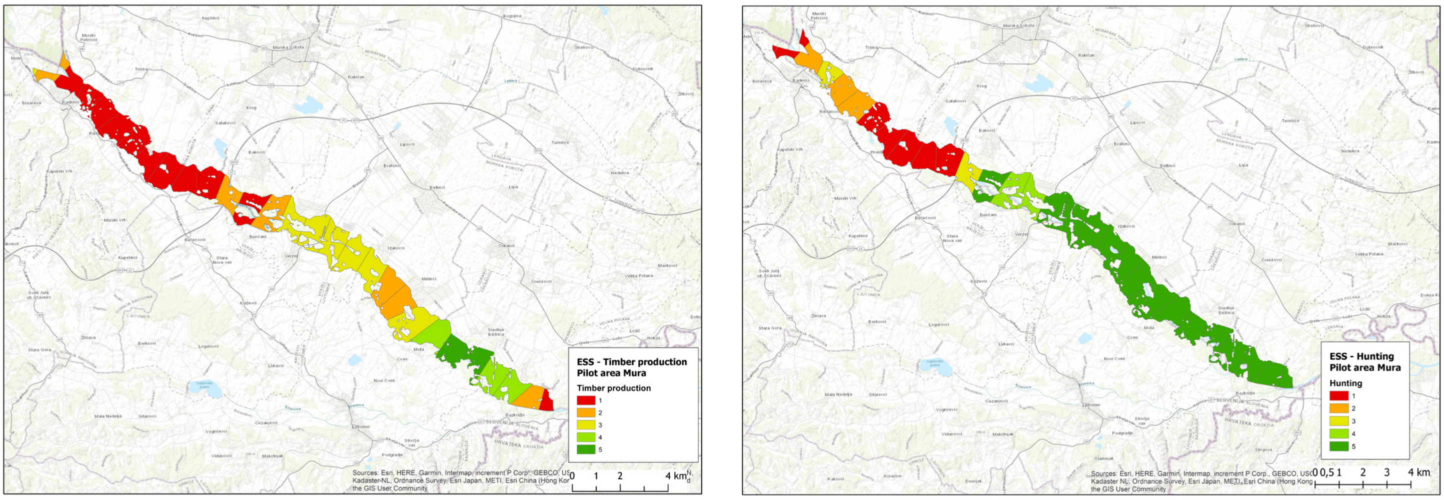


Figure 3.2.23-24 ES assessment (timber production, hunting) using the IDES Tool in the Mura River pilot area.

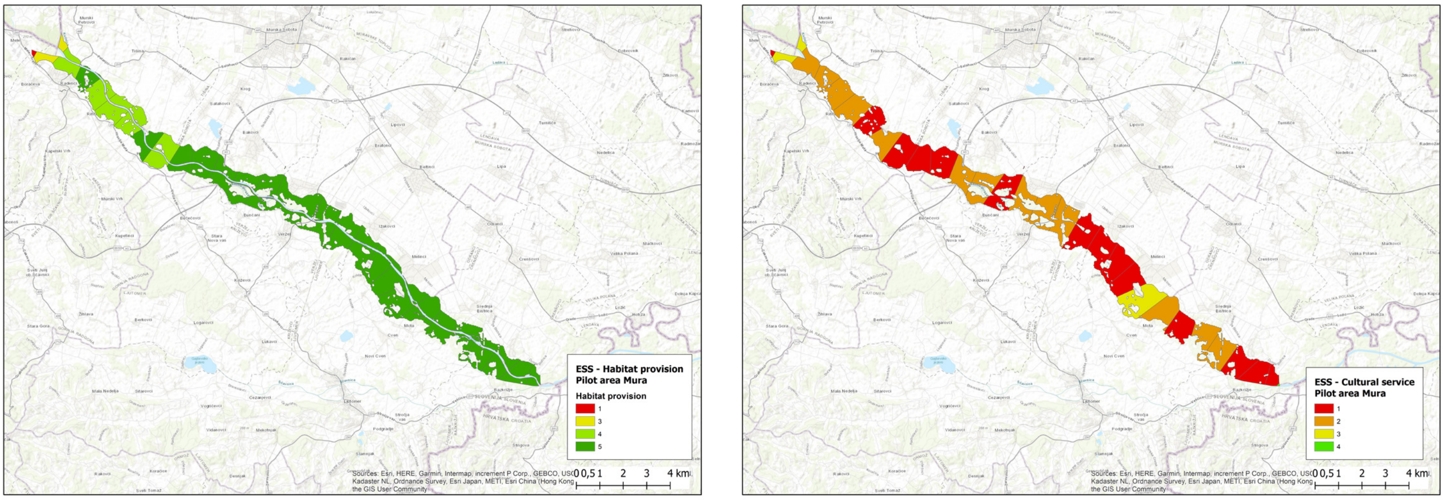


Figure 3.2.25-26 ES assessment (habitat provision, cultural) IDES Tool in the Mura River pilot area.

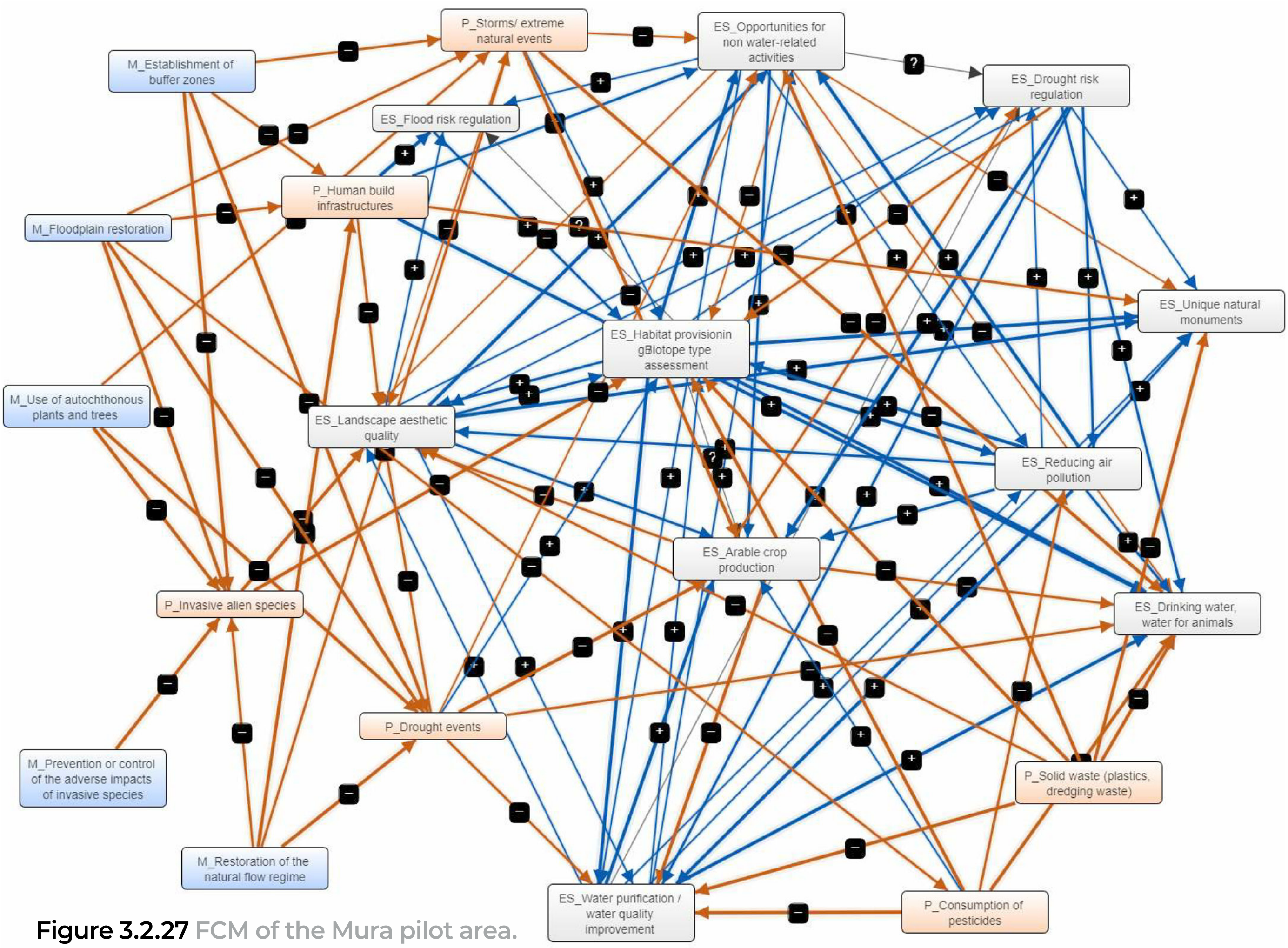


Figure 3.2.27 FCM of the Mura pilot area.

In the first workshop, stakeholders identified five measures that they perceived as being the most important. Each measure's feasibility was discussed, its importance, how to implement it and when, and the technology needed to make it happen. The measures included the use of autochthonous plants and trees (in case of forests); prevention or control of the adverse impacts of invasive species; establishment of buffer zones; restoration of the natural flow regime; and floodplain restoration.

In the second workshop, stakeholders identified the most important measures to improve water quality.

Later, these measures were integrated into an optimal scenario (Figure 3.2.28) on how to improve water quality in the Mura River. This scenario is based on NBS, building on the idea that healthy and well-managed ecosystems provide essential benefits and services to people.

Therefore, the scenario for the Mura River includes a range of measures that were selected by stakeholders as the most important ones to improve water quality. These measures are the use of autochthonous plants and trees (in case of forests), establishment of buffer zones; and restoration of the natural flow regime.

3.2.6 Conclusions from the implementation in the pilot areas

Among the most important factors that hinder the implementation of existing strategies and visions aiming to improve water quality and

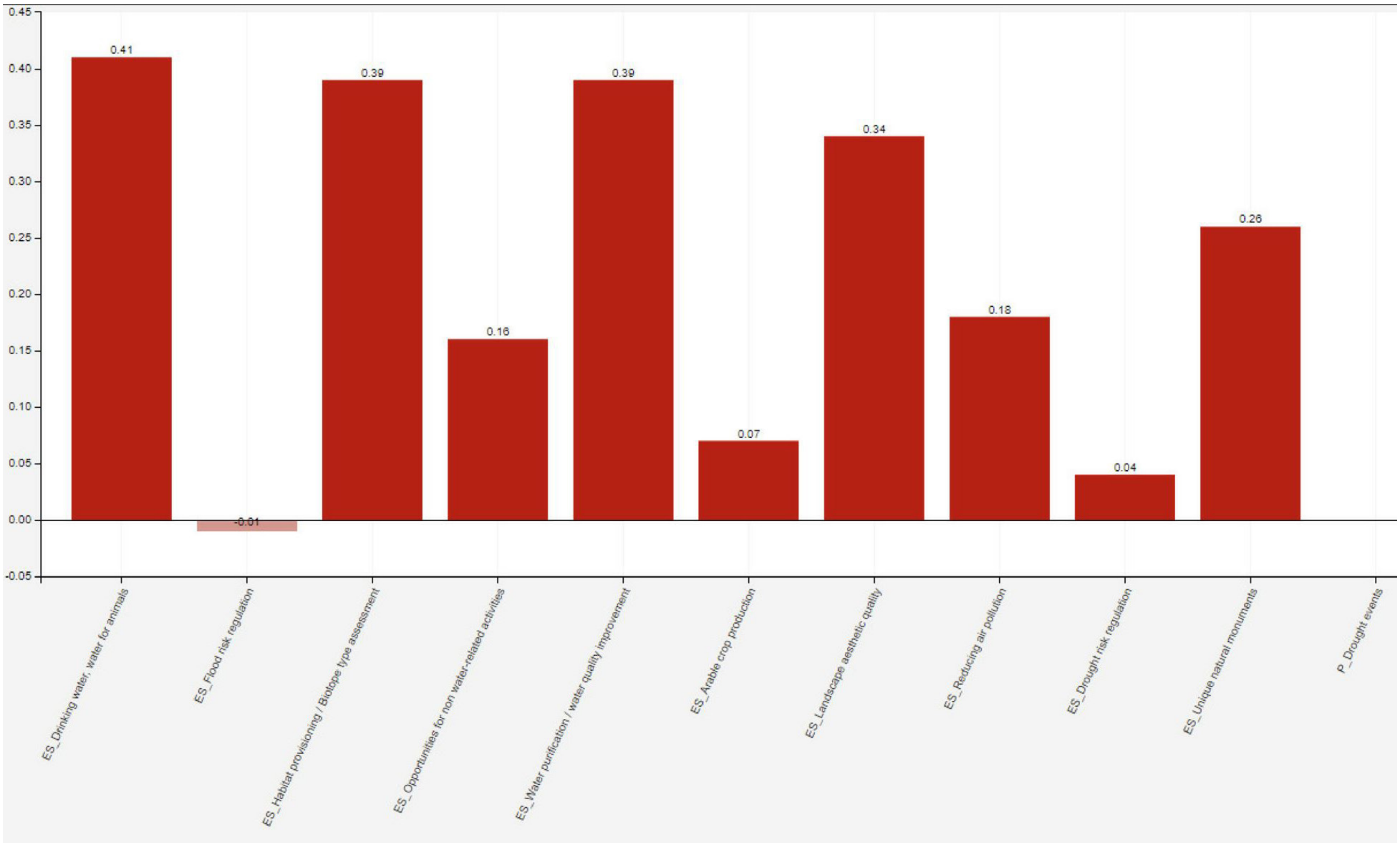


Figure 3.2.28 Optimal scenario for water quality improvement in the Mura River pilot area.

quantity in the river basins, and in particular in the Danube River, include the ways in which society deals with the various competing societal interests supporting navigation, hydropower, agriculture, nature conservation and tourism; as well as flooding, and nutrient and pollutants retention.

At the same time, many of the existing ES methodologies and assessments are divergent or have the capacity of producing results with a high degree of variability. The IDES Tool was developed to tackle the challenge of these insufficiently settled methodological difficulties. Relying mainly on input from various stakeholders, ‘beneficiaries’ of the ecosystem services, the Tool uses a simple, quick, relatively low-cost methodology that can support a complex assessment in a relatively short time and for a relatively large number of ecosystem services.

Nowadays, we are witnessing international interest in including ecosystem services to support management decision-making in sectoral activities in general, and in the Danube Basin in particular.

Any assessment of ecosystem services must start from recognising that such services are socially defined. The stakeholders are the ones who distinguish what represents a benefit, as well as the relevance or the value of such benefit. Thus, the value of ecosystem services is relative, rather than absolute. It is relative because both the range of services recognised socially, and their value, are subject to the system of attitudes and values of the people evaluating them.

ES and their value vary in time and space depending on how the benefits generated by the ecosystem resources are socially defined.

The same ecosystem resource has one value for the local community and a totally different value for the scientific community, or to people from outside the local communities.

The IDES Project demonstrated that different communities on the Danube floodplain have the same understanding of ES regardless of the country, but their relative importance is different from place to place. The rank of an ES's importance is mostly based on the interest of the local communities. So, even if the pressures are the same throughout the Danube Basin, the specificity of the values that local communities are placing upon the ES are locally defined. Consequently, the scenarios for improving water quality must take into consideration not only other ES, but also the specific local needs.

Using pilot areas facilitated a better harmonisation of the concurring societal interests, and led to the building of a conceptual framework (management options, ideas, values, visions) that was co-created with the local stakeholders.

3.3 Lessons learnt from pilot areas

Zorica Srđević, Barbara Stammel, Bojan Srđević

3.3.1 Introduction

One of the main achievements of the IDES Project has been to strengthen cooperation between project partners and local/regional stakeholders through joint implementation of pilot actions. The five IDES pilot areas (Chapter 3.2) played a special role in achieving the primary goal to improve understanding and implementation of an ES-based approach to water management, and will serve as a blueprint for further concrete measures and solutions.

This chapter presents lessons learnt from the workshops held during the pilots and national trainings in terms of understanding the ES approach and its application by stakeholders; difficulties in the application of the approach; identification of the main drivers of water quality changes in the pilot areas; the potential of use of the IDES Tool, and suggestions for the Tool's improvement. All these aspects have been compared across the five pilot areas to identify common points, identify differences and present best practice examples.

3.3.2 Understanding the ES approach and experience by stakeholders

Screening and analysis of the information gathered from stakeholders during the IDES workshops and national trainings on the implementation of the IDES Tool showed that the ES approach is generally widely understood in most of the partner countries. The level of familiarity with the ES concept mostly varied due to the different composition of stakeholder groups in the pilot areas. For instance, stakeholders coming from universities and managing institutions in Serbia, Croatia, and Bulgaria had knowledge of ES, however, these stakeholders generally did not have a competent knowledge and understanding of the ES concept, related assessments, real life implementation or application.

Stakeholders in the pilot areas (Table 3.3.1) understood the approach, but had varied levels of knowledge about it. Overall, stakeholders significantly lacked experience in applying ES. A good example of ES application can be found in Austria, where the Donau-Auen National Park has linked every aspect of its management in the national park to ES. Other Austrian stakeholders are also using ES in forest management to increase resilience against climate change or improve e.g. drinking water supply, flood protection, groundwater provision, local climate regulation.

Table 3.3.1. Comparison across the pilot areas of understanding and experience in applying the ES approach

Country	Understanding the ES approach	Experience in applying the ES approach
Austria	Yes	Yes
Hungary	Yes	No
Romania	Yes (different levels)	No
Serbia	Generally No	No
Slovenia	Yes (different levels)	Yes

3.3.3. Challenges in the application of the ES approach

Only Austria and Slovenia have experience applying the ES approach (Table 3.3.1); even though this has sometimes only been indirectly. An overall lack of awareness persists about the ecosystem functions and the values or benefits of the floodplains. This is especially true regarding several partner countries, where the institutions responsible for floodplain management (belonging to different sectors and having different interests) are not aware of the approach and how useful it can be for improving the management and comprehensive status of floodplain ecosystems.

The full potential of the ES approach can only be realised following the appropriate capacity-building and training of stakeholders. From the beginning, stakeholders must understand the ES approach and how the IDES Tool can be used to assess ES. For example, key water management actors should be trained how to calculate the indicator-based evaluation of ES using GIS (IDES Tool). Stakeholders can acquire the knowledge and skills necessary to identify important ES, as well as the ES measures and pressures in their area. Users of the IDES Tool will then be able to visually interpret the results and jointly determine the necessary measures that should be integrated into water management. Easy access to examples of good practices related to solving different issues (water quality, nutrient management, forest management, resolving conflicts, etc.) can support the capacity-building process.

Comparison of scenarios is an effective way to provide a better understanding of the value of ES and the area concerned. This is especially recommended for large and expensive restoration projects. However, many stakeholders, including those already implementing the ES approach in their work, emphasise the lack of available tools for combined non-monetary and monetary evaluation. Therefore, it is difficult to compare alternative management scenarios.

In some countries, such as Serbia, ES are mentioned in the law, but are not implemented in practice. Stakeholders suggested that an adaptation of by-laws that more precisely regulate the methodological implementation of ES is needed to enable the wider application of the ES approach in Serbia.

3.3.4 Identifying the main drivers of water quality changes by co-creating water management concepts

Taking advantage of local stakeholder knowledge to identify the main drivers of water quality change in pilot areas, a harmonised survey of stakeholders' opinions was implemented in all pilots to rank the most important ES, pressures and measures. A closer examination identified that similar pressures/drivers forcing undesirable changes in water quality (deterioration) are present in almost all the pilot areas: especially intensification of agriculture, presence of wastewater and solid waste, use of pesticides and extreme natural events.

Stakeholders integrated the experience and knowledge of all stakeholders into their decision-making when they co-developed Fuzzy Cognitive Models (FCM, chapter 3.2) to identify potential measures that could cope with these pressures. Participants were able to communicate their own opinions while also coming to understand the perceptions of other stakeholders. The process lead to a common understanding of how the ecosystem works and how ES, measures and pressures are related. On this more general level, concepts and agreements are easier to find for a specific area.

Bringing all FCMs together, it was observed that even if most pressures appear to be present in all the pilot areas, the measures (besides floodplain restoration) appear to be site-specific (Chapter 2.3). This could have the following explanations: (1) specific local conditions in selecting measures to address common pressures and/or (2) lack of generalisability of measures across pilot areas and stakeholders.

3.3.5 Potential use of the IDES Tool and suggestions for improvement

After the IDES Tool training, stakeholders provided feedback regarding the potential use of the Tool and suggestions for its improvement.

Stakeholders at the trainings foresaw the potential for IDES Tool application in the following areas:

- use by water management or protected area authorities, as well as by environmental assessment process and urban planning institutions;
- support for communication with local stakeholders and municipalities;
- improvement of communication between sectors, and more stringent implementation of strategies and concepts;
- take note of societal interests through public participation as part of the IDES Tool to improve management decisions;
- support for decision-making regarding public policies and cost-benefit analyses.

Requiring specific legal and technical solutions for the implementation of ES in the floodplains on a strategic level would facilitate the use of the IDES Tool. Society would significantly benefit if the ES concept were promoted and continually developed in properly structured education courses at all levels. A suggestion was made to include ES at university faculties of law, agriculture, engineering, and social science courses.

Stakeholders made several important suggestions that should be considered for further development of the IDES Tool:

- explicit visualisation of different ES to show their spatial distribution and diversity;
- web-based and interactive maps of ES in floodplains;
- monetarisation of ES as a useful extension of the IDES Tool;
- enable access to input data;
- translation of the *IDES Manual* into different languages;
- continuity to have a real added value benefit of the experience, knowledge and practicality of the examples.

CHAPTER 4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THE ADDED VALUE OF IDES IMPLEMENTATION

4.1. Introduction

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Rivers, lakes, transitional and coastal waters, as well as groundwater constitute just some of the vital natural resources in the Danube river basin. These natural resources supply drinking water, host crucial habitats for many different types of wildlife, and are an important resource for industry, agriculture, transport, energy production and recreation. A significant proportion of water resources are exposed to environmental pollution or other potentially damaging pressures.

The recently estimated Danube river basin-wide nutrient emissions for 2015-2018 are 500,000 tonnes/year total N (TN) and 31,000 tonnes/year total P (TP). Diffuse pathways for nitrogen (87%) and phosphorus (78%) clearly dominate the overall emissions (ICPDR 2021). Riparian buffer strips as well as nearby natural floodplains have a high potential to reduce such diffuse nutrient input into rivers, and also may have positive effects on other ES (Gericke et al. 2020, Tschikof et al. 2022). Therefore, relatively small subareas may significantly (above average) contribute to the reduction of nutrient pollution, and thus advance nature-based solutions (NBS) with multiple positive side effects. However, in order to activate the important functions and services of those areas,floodplains need to be designated and introduced into spatial planning. Floodplains must be recognised as an official element in planning or permitting procedures.

The IDES Tool with its ES-based evaluation scheme may identify areas with a high potential for improving the generation of key ES, and may also facilitate the reduction of target conflicts with other societal sectors and stakeholders. Thus, the IDES Tool could support improving water quality management along the Danube by a) identifying the areas and most efficient strategies for increasing ES availability, and b) identifying synergies with other sectoral water policies and stakeholder interests. Since space is limited in river floodplains, it is important to take into consideration all possibly conflicting societal interests in that given area. Spatial planning may serve most aims and interests if it intends to establish multi-functional uses of floodplains; not only water quality management, but also socio-economic interests and sectoral goals of relevant national and EU framework legislation (Flood Risk, Water Framework, and Habitats Directives). However, the operationalisation of the ES concept to improve natural resource management and support decision-making is still at an early stage and needs more effort from both scientists and decision-makers to bring the effort to fruition. The IDES approach aims at a sustainable multifunctional management of floodplains that enables win-win situations for multiple stakeholders, which is another reason why it is crucially important to involve a wide range of stakeholders in the process.

4.2. Foundations of the IDES approach

The ecosystem-based approach utilised by the IDES Tool constitutes an interdisciplinary management approach that acknowledges the complex nature of ecological systems and integrates social, ecological, and good governance principles to achieve a sustainable use of natural resources in an equitable way (Domínguez-Tejo et al. 2016). NBS addressing the usage and management of natural resources have had a positive impact on EU-level policies such as the WFD, Marine Strategy Framework Directive, Biodiversity Strategy, and more recently, the proposal for the Nature Restoration Law. Ecosystem-based approaches integrate the complexity of ecosystems and the interaction between humans and ecological systems through management decisions (Buhl-Mortensen et al. 2017).

ES represent the core elements of ecosystem-based approaches that lead to increased human well-being (Chapter 1, figure 1.2.1). In land use management, ecosystem-based approaches are also used to establish common ground in communication with and among different sectors like forestry, agriculture, aquaculture, extractive industries, energy and tourism. Therefore, identifying synergies and trade-offs between these many 'users of ES' must be part of the solutions; eventually leading to the achievement of sustainable development.

Business as usual destroys and degrades ecosystems, the bases for our societies and economies, and thus generates environmental (external) costs for our society. The shift towards alternatives based on ecosystems/nature requires adaptations and the replacement of current practices by fresh approaches. The new strategies must ensure that natural assets and their benefits to society and the economy are recognised and integrated into economic development strategies.

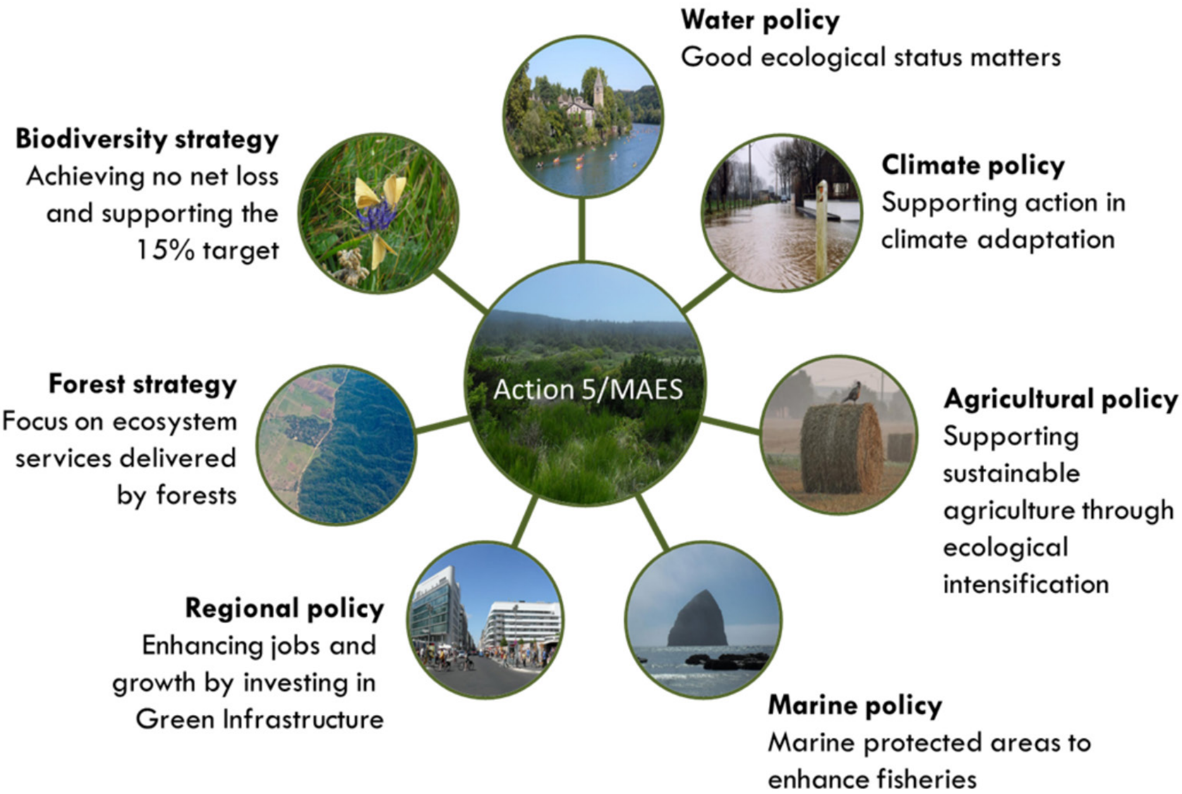

Figure 4.1 Inputs of Biodiversity Strategy, Action 5 'Mapping and Assessing ES' into other policies (© European Union, European Commission 2014).

Outputs from the European Mapping and Assessment of Ecosystems and their Services (MAES) can contribute to policy decisions affecting the environment (European Commission 2014). The starting point is Target 2 of the Biodiversity Strategy 2020. Target 2 aims to maintain and restore ecosystems and their services by including green infrastructure in spatial planning and restoring at least 15 % of degraded ecosystems. EU Member States, with the assistance of the European Commission, fulfilled Action 5 of Target 2 by mapping and assessing (to different degrees) the state of ecosystems and their services in their national territories (Figure 4.1).

A coherent analytical framework, common typologies of ecosystems, and an initial set of indicators has been proposed that could be used at the European- and Member State-level to map and assess biodiversity, ecosystem conditions and ES. Such a framework would ensure consistent approaches between member states. A number of projects that assessed freshwater-related ES took place on a smaller scale (river basins) in all European countries.

The new Biodiversity Strategy for 2030 also aims to restore EU biodiversity, reduce pressures on EU ecosystems, and ensure sustainable management of biodiversity (European Commission 2021).

4.3. Added value of IDES

Several EU projects have been focusing on developing methods to evaluate ES and to foster their integration into planning processes (e.g. OPERAs, MAES, OpenNESS, ESMERALDA, ECO KARST and AlpES). However, none of these projects have focused on floodplains. The results from national and bi-national floodplain projects (e.g. RESI and Eco Wet), and EU projects on rivers (HyMoCARES, SPARE and AQUACROSS), were adopted and complemented in IDES for application to the Danube and its tributaries, including their floodplains. In contrast to other Danube Transnational Programmes (DTP) like Danube Floodplain, MEASURES, JOINTISZA and SEE River which focused on detecting synergies between flood risk, nature conservation and drought prevention, IDES added the ES approach to water management and focused on the water quality issue.

The IDES Project aimed at improving water quality along the Danube and its tributaries by integrative floodplain management based on ecosystem services. The IDES approach enabled the identification of efficient and feasible local water management measures to improve water quality. The Project did this by using detailed data, especially in the pilot areas, for an indicator-based assessment of ES along the active floodplain of the Danube, and by implementing a co-creation approach with the local stakeholders from each pilot area. During the co-creation process, stakeholders' opinions were noted and added to a Fuzzy Cognitive Model (Chapters 2.3 and 3.2) that enabled the visualisation of the effects of the discussed measures on human pressures, and thus ultimately on the ES availability. This also facilitated demonstrating a) the effects of measures on human pressure levels, b) the impacts of pressures on ES, and c) the mapping of the synergies and trade-offs between ES. Gaining an improved understanding of stakeholders and raising their awareness leads to an improved and accelerated implementation of water quality management. Thus, the outcomes of the IDES Project facilitate the implementation of spatially discrete, specific actions for improving water quality from the local to national level while creating synergies with other ES.

Consequently, IDES can be used as a decision-making tool for the management of Danube floodplains that considers the interests and goals of a large number of stakeholders; including local, regional and national stakeholders as e.g., water administration agencies, forest and natural park administrations, energy providers, and farmers. The acceptance of decisions is also dependent on how they are communicated; hence, the consequences of those management decisions are made visible and understandable to most of the stakeholders. The effects of those management decisions on ES are visualised in maps that were created for the Danube floodplain and for the IDES pilot areas Chapter 3.1).

In order to present the project results both in a Danube-wide and local context (Figure 4.2), Interactive Story Maps were created using GIS for each of the five pilot areas: Donau-Auen National Park - Austria, Tisza River near Szolnok - Hungary, Mura River Kučnica Mura Petajnci – Gibina - Slovenia, Koviljsko-Petrovaradinski Rit Special Nature Reserve - Serbia, and the Brăila Islands - Romania. Detailed information on the pilot areas, the main pressures they experience, and the related ecosystem services and can be found at:

Donau-Auen National Park, Austria
https://storymaps.arcgis.com/stories/47d2b67054a34463bb0ace66baa465d8

Tisza River, Hungary
https://storymaps.arcgis.com/stories/a582152c6a4f40358a959d809f2323e7

Mura River Kučnica Mura Petajnci, Slovenia
https://storymaps.arcgis.com/stories/81e156190f454766aa2a1015b794c65c

Koviljsko-Petrovaradinski Rit Special Nature Reserve, Serbia
https://storymaps.arcgis.com/stories/b60a158d7a5c455abe2671500f159eee

Brăila Islands, Romania
https://storymaps.arcgis.com/stories/3552e8e8bbb14cbdb05d132b874002b4

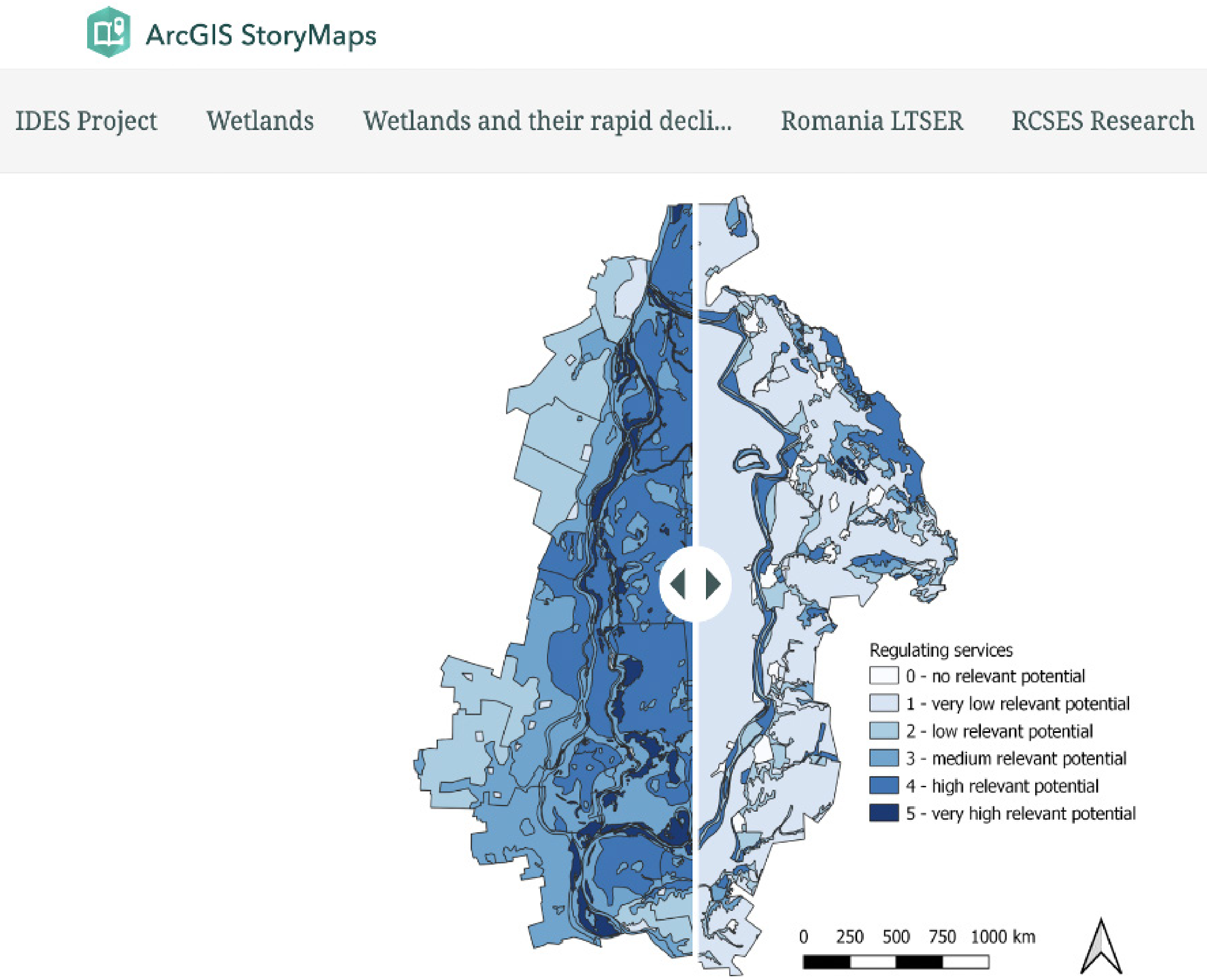

Figure 4.2 ArcGIS Story Map for the Brăila Islands IDES pilot area in Romania.

Another thing that sets IDES apart from other projects are the co-created (in collaboration with the stakeholders) national roadmaps to be included in the transnational *IDES Strategy* (available online at https://www.interreg-danube.eu/approved-projects/ides/outputs). The national roadmaps detail the high priority areas and measures needed to improve water quality management for all involved stakeholders with the aim to reduce the eutrophication of the Danube and the Black Sea.

4.4. Future perspectives

Finding a way to reduce the nutrient load of the Danube, and improve water quality through NBS, is only possible with the involvement of a wide range of stakeholders from different sectors and at different levels (local, regional and national). An upscaling of the water management concepts developed together with the local stakeholders is also necessary to further demonstrate the efficiency of the IDES approach. A ready-to-use tool (the IDES Tool) is provided within the IDES Manual to assist decision-makers to identify the most effective options to improve water quality. Furthermore, to make the next step from policy to the operationalisation of the ecosystem-based approach, the IDES Tool is designed to be used by experts in different areas of expertise; such as integrated environmental impact assessment, landscape planning or biodiversity conservation. Upgrading the IDES Tool to an online user-friendly application would make it more accessible to a larger number of users.

The implementation of NBS in the floodplains for flood mitigation, climate change adaptation or the improvement of water quality is also encouraged by the European Green Deal and will hopefully be supported by the National Recovery and Resilience Plans. The NBS proposed in those frameworks can then be tested using the IDES Tool. Different scenarios can be compared by highlighting their ES pros and cons, and facilitate the identification of the most optimal solutions.

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