Project

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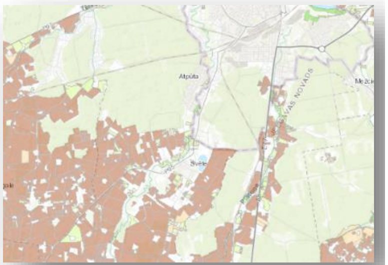
Methodology for Regional and Local Landscape and Green Infrastructure Planning in Lowland Areas

Deliverable T1.2.1



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Methodology for Regional and Local Landscape and Green Infrastructure Planning in Lowland Areas

ENGRAVE Deliverable T1.2

Authors: Anda Ruskule, Kristīna Veidemane, Dana Pričavoite (PP2 Baltic Environmental Forum-Latvia)

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Introduction

The river landscapes in lowland areas have been substantially altered over the last centuries by human activities such as conversion of the fertile floodplains into intensive agriculture fields or settlement areas, straitening of rivers or construction of dams for flood protection etc., leading several challenges to society, including diminishing water quality, intensifying floods as well as loss of biodiversity and various ecosystem services essential for human well-being[1]. This is also the case in the Latvian-Lithuanian cross border region, located within the Lielupe river basin, characterised by intensive, large scale farming.

Landscape and green infrastructure planning as well as applying nature-based solutions can significantly contribute to improving of environmental quality, ecosystem conditions and related services, essential for human well-being. The Green Infrastructure (GI) is an emerging concept with great potential for enhancing ecosystem-based approach in land-use planning. It allows to identify ecological hot-spot areas, essential for ensuring ecosystem functions and delivery of wide range of ecosystem services, as well as encourage a smarter and more integrated approach to development and efficient use of the space.

The ENGRAVE project aims to enhance river-based green infrastructure by integrating ecosystem and landscape concepts in to the planning and integrated management of the lowland rivers at local and regional scale. This includes development of a methodology for landscape and green infrastructure planning as well as testing it within four planning ceases representing different planning levels: i) Zemgale Regional Landscape and Green Infrastructure Plan (LV); ii) Plan for enhancing the river Svete catchment (LV); iii) Local plan on landscape and green infrastructure for Bauska Local Municipality (LV); and iv) Special Plan for Preservation, Landscaping and Development of Green Infrastructure along the Rivers Apščia and Agluona in Biržai Town, and the Lake Širvena in Biržai district (LT).

This document gives an overview on integrated approaches for ecosystem and landscape management, with particular focus on river ecosystems within lowland landscape – the special character of the ERNGRAVE project area. We introduce to the concept of green infrastructure and nature-based solutions, applicability of these concepts for the river ecosystem and landscape management as well as explore examples of the GI assessment and planning at different scales. Further on we propose the **methodology for integrated GI and landscape planning** at regional and local scale applicable to lowland areas and river valley landscapes. The methodology describes the key steps in development of the integrated GI and landscape plan, as well as available tools/methods and data for implementation of each step. It also suggests how to handle different scale issues in order to ensure coherence between the planning levels.

Although the methodology primary is targeted to the ENGRAVE project partners and planning cases, it offers a flexible planning framework, which can be applied at different scales for integrating ecosystem approach and GI elements into the spatial planning process.

[1] Albert C., et al.2019. Addressing societal challenges through nature-based solutions: How can landscape planning and governance research contribute? Landscape and Urban Planning 182: 12–21

1. Background

Green infrastructure and nature-based solutions are relatively new concepts, developed within the recent decades, although the same principles have been applied already before in landscape-ecology and analysis of ecological networks. The theories behind the ecological networks dates back to 19th century, while the present concept has been elaborated by various scientists since 1970s, defining the main components of the network: core areas (i.e. central nodes in the network), ecological corridors (i.e. continuous connections between the nodes), stepping stones (i.e. non-continuous corridors), buffer zones (i.e. barriers between natural and anthropogenic areas), and restoration areas (i.e. anthropogenic areas that are being managed to make them more natural).[2][3] The ecological networks are supposed to be designed and managed for preserving biological diversity through the interconnectivity among the network's physical elements within the landscape[4]. Lithuania and Estonia were among the first countries in Europe, which have elaborated the principles of ecological network and introduced those in the spatial planning practice. In Lithuania this concept was applied for development of so called 'nature frame', which has served as basis for the network of protected areas[5]. In Estonia the proposal of green network was included in the long-term strategy "Estonia vision 2010" as well as considered in other policy documents related to nature conservation, land use and spatial planning. In Latvia the planning of ecological networks has tested conceptually at nation scale, as well as in few case studies at municipality level, however this approach has not been integrated in official land use policies.

The present European environmental policy is focusing on the Green Infrastructure concept, which integrates the biodiversity targets from the above described concept of ecological networks, but also emphasizing the multifunctionality of the ecosystems, i.e. their capacity to supply the ecosystem services and contribution to human well-being.

Green Infrastructure

Traditionally, infrastructure was understood as human-made "*elements of interrelated system that provides goods and services essential for enabling or enhancing societal living conditions"*[6]. However, since 1980s scientists have suggested that ecosystems should also be considered as type of infrastructure. The basis for such assumption is that healthy ecosystem, besides maintaining biodiversity, can provide goods and services to humans, some of which are consumed directly, while others bring benefits to society only after interreacting with human-made infrastructure[7]. Thus, the Green Infrastructure (GI) is directly related to the concept of **ecosystem services**, which are defined as

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[2] Sepp, K., Kaasik, A. (Eds.), 2002. Development of National Ecological Networks in the Baltic Countries in the Framework of Pan-European Ecological Network. IUCN European Programme, Warsaw, Poland. International Union for Conservation of Nature (IUCN), Gland, Switzerland. 183 pp.

[3] Mander et al., 2018. Green and brown infrastructures support a landscape-level implementation of ecological engineering. Ecological Engineering 120: 23–35

[4] Jongman et al., 2011. The pan European ecological network: "PEEN". Landscape Ecology, 26: 311–326.

[5] Kavaliauskas, P., 1995. The nature frame: Lithuanian experience. Landschap 12 (3), 17–26.

[6] Fulmer, J.E. (2009). What in the world is infrastructure? Infrastructure Investor 9, 30–32.

[7] da Silva J.M.C. & Wheeler E. (2017). Ecosystems as infrastructure. Perspectives in ecology and conservation. 15: 32-35

“*contributions of ecosystem structure and function (in combination with other inputs) to human well-being*”[8].

This perspective has been highlighted by the European Commission in 2013, defining the GI as a ***“strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services****. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas.*”[9]

The conservation and development of GI is acknowledged as one priorities of EU policies, including the EU Biodiversity Strategy to 2020[10], the roadmap to a Resource Efficient Europe [11], the Commission’s proposals for the Cohesion Fund and the European Regional Development Fund[12], the Common Agricultural Policy[13], the new EU Forest Strategy[14], etc.

The EU Biodiversity Strategy’s target 2 requires that “by 2020, ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15% of degraded ecosystems.” The action 6 of the Strategy is <u>setting priorities to restore and promote the use of green infrastructure</u>, including commitment of the Commission to develop “*a Green Infrastructure Strategy by 2012 to promote the deployment of green infrastructure in the EU in urban and rural areas, including through incentives to encourage up-front investments in green infrastructure projects and the maintenance of ecosystem services, for example through better targeted use of EU funding streams and Public Private Partnerships*”.

As one of the key steps towards implementation of the EU Biodiversity Strategy to 2020, the EC has adopted in 2013 an **EU-wide strategy promoting investments in green infrastructure**. The strategy promotes the deployment of green infrastructure across Europe as well as the development of a Trans-European Network for Green Infrastructure in Europe, a so-called TEN-G, equivalent to the existing networks for transport, energy and ICT, which should enhance the health and wellbeing of EU citizens, provide jobs, and boost the economy. The EC Communication on GI strategy highlights the main tasks for encouraging the development of GI, including:

- **integration of GI into the key policy areas** and ensuring that it becomes a standard part of spatial planning and territorial development;
- **improving the information, knowledge base and reliable data** on: the extent and conditions of ecosystems and services they provide; understanding the links between biodiversity and conditions of ecosystem (vitality, resilience and productivity) and between the condition of

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[8] Burkhard B., de Groot R., Costanza R., Seppelt R., Jørgensen S.E. & Potschin M. (2012). Solutions for sustaining natural capital and ecosystem services. Ecological Indicators, 21: 1 – 6.

[9] European Commission (2013). Green infrastructure (GI) – Enhancing Europe’s Natural Capital. COM(2013)249. In http://eur-lex.europa.eu/resource.html?uri=cellar:d41348f2-01d5-4abe-b817-4c73e6f1b2df.0014.03/DOC_1&format=PDF

[10] COM (2011) 244 final, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0244&from=EN.

[11] COM (2011) 571 final, http://ec.europa.eu/environment/resource_efficiency/pdf/com2011_571.pdf.

[12] COM (2011) 612 final/2, http://www.espa.gr/elibrary/Cohesion_Fund_2014_2020.pdf; COM (2011) 614 final, http://www.esparama.lt/es_parama_pletra/failai/fm/failai/ES_paramos_ateitis/20111018_ERDF_proposal_en.pdf.

[13] COM (2010) 672 final, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0672:FIN:en:PDF ; Regulations 1305/2013, 1306/2013, 1307/2013 and 1308/2013.

[14] COM (2013) 659 final, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2013:0659:FIN:en:PDF.

the ecosystem and its capacity to deliver ecosystem services; valuation of ecosystem services, in particular the social, health and security/resilience benefits of GI solutions;

- **providing financial support** for GI projects and setting up innovative funding mechanisms for encouraging GI development across the EU.

The GI concept has become popular in the urban context, where it refers to patchwork of green areas, providing habitats, flood protection, cleaner air, recreation or at site scale to specific nature-based solutions (e.g. bio-infiltration of stormwater, green roofs etc.). At the same time, it is gaining importance for rural development and assessing the network of natural or semi-natural areas at regional, national and even Pan-European scale.

River valleys are crucial elements of the GI (and ecological networks), providing core areas and migration corridors for maintenance of biodiversity as well as various ecosystem services, including flood regulation, water retention, filtration and accumulation of nutrients, regulation of water quality, climate regulation as well as various cultural services, e.g. recreation and aesthetic value, educational and scientific value, symbolic value etc.

Nature-based solutions

The term 'nature-based solutions' (NBS) was relatively recently introduced in environmental policy and science communication. The word 'nature' indicates that it refers to natural or self-regulating ecosystem processes, while 'solutions' implies that a particular challenge or problem shall be solved[15]. The IUCN defines the NBS as "actions to protect, sustainably manage and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits"[16]. The definition proposed by the European Commission suggestions that **NBS are "*actions which are inspired by, supported by or copied from nature***. [..] Many NBS result in co-benefits for health, the economy, society and the environment, and thus they can represent more efficient and cost-effective solutions than more traditional approaches"[17]. Thus, in addition to IUCN definition, which focus on protection, sustainable management and restoration of ecosystems, the EC suggests a border interpretation of the concept connecting it to social and economic innovation goals.

For application in landscape planning and governance research Albert et al. (2019) defines NBS as actions that i) alleviate well-defined societal challenges, ii) utilize ecosystem processes of spatial, blue and green infrastructure networks, and iii) be embedded with viable governance or business models for implementation.

[15] Albert C., et al.2019. Addressing societal challenges through nature-based solutions: How can landscape planning and governance research contribute? Landscape and Urban Planning 182: 12–21.
[16] Cohen-Shacham et al. (2016). Nature-Based Solutions to address societal challenges. http://doi.org/10.2305/IUCN.CH.2016.13.en.
[17] European Commission (2015). Towards an EU Research and Innovation policy agenda for Nature-Based Solutions & Re-Naturing Cities (Final Report of the Horizon 2020 Expert Group on Nature-Based Solutions and Re-Naturing Cities). Brussels, Belgium: European Commission Retrieved from: https://publications.europa.eu/en/publication-detail/-/publication/fb117980-d5aa-46df-8edc-af367cddc202.

Depending on the level and intensity of engineering solution the NBS can be classified in three categories[18]:

1. approaches, which involve no or minimum intervention in ecosystems to maintain or improve the delivery of ecosystem services;
2. measures that aim at establishing sustainable and multi-functional landscapes and ecosystems;
3. actions that manage ecosystems in very intensive ways or create new ecosystems.

NBS can provide a support in addressing various environmental challenges by protecting, sustainably managing, restoring or creating ecosystems in a way to enhance those ecosystem services which minimize the challenge in focus. Examples of NBS, suitable for river landscapes, and the supported ecosystem services are provided in Table1.

Table 1. Examples of NBS in river landscapes. Source: based on Albert et al., 2019

Nature-based solution	***Revitalisation of floodplains***	***Protection/establishment of wetlands***	***Site-specific land-use adaptation***
Addressed challenge	Reduction of flood risks	Mitigation of climate change	Soil erosion
Examples of co-benefits	Biodiversity protection Recreation Drinking water provision	Biodiversity protection Flood regulation Water quality protection	Biodiversity protection Recreation Water retention
Utilised ecosystem process	Natural water retention capacity Water (evapo-) transpiration	Carbon sequestration in soil and vegetation	Natural soil cover providing soil fixation
Examples of NBS actions	Reconnection rivers and floodplains Allowing of meandering	Enhance water retainment Initiate typical plant communities	Extensity of agricultural land use Transform fields into grasslands

Fore example, to reduce the flood risks an appropriate NBS would be to reconnect rivers and floodplains and to allow meandering of the rivers. Floodplains have a natural water retention capacity, which would minimize the negative impact of floods, but at the same time this NBS would provide habitats for species and increase the biodiversity as well as can support nature-based recreation or eco-tourism and drinking water provision. Similar effect can be provided by NBS - site-specific land-use adaptation, e.g. transformation of arable land into grasslands for minimising soil erosion, which at the same time is increasing biodiversity, recreation and water retention potential of the area.

Landscape planning

Various interpretation and approaches to landscape planning exist and are applied within different contexts. According to the European Landscape Convention[19] the **landscape planning is defined as "a strong forward-looking action to design, enhance or restore landscapes"**. Landscape planning can be based on landscape-ecology approach, according to which the landscape patter is described by the dominant land use type (or matrix), patches and connecting corridors. This approach is related to the above described concept of the ecological networks, and applicable for enhancing ecosystem

[18] Eggermont et al. (2015). Nature-based Solutions: New Influence for Environmental Management and Research in Europe. GAIA - Ecological Perspectives for. Science and Society, 24(4), 243–248.
[19] Council of Europe. (2000). European Landscape Convention. European Treaty Series (Vol. 176). Florence, Italy – Council of Europe. Retrieved from: http://conventions.coe.int/Treaty/en/Treaties/Html/176.htm.

functionality and resilience, conditions for species migration and maintenance of biodiversity, etc. Other approaches are based on identification of high value landscapes (including aesthetic, ecological and cultural heritage aspects) and designing of the appropriate management or landscape restoration measures. This approach is more related to landscape design and architecture.

Landscape planning and design provides great opportunities for improving of the green infrastructure as well as selection of the most suitable sites for NBS in order to address particular societal challenges. This is especially relevant in case of river landscapes within intensively used and modified lowland areas, where rivers and other water bodies provide essential GI core areas and corridors for maintaining of biodiversity as well as improving of environmental quality and human well-being.

River basin management

The concept of GI was introduced in the policy frames later than Water Framework Directive, adopted in 2000. Therefore, there is no direct requirements or links in the legislation on European water policy and setting up of the river basin management plans. GI as is an important instrument for achieving and maintaining healthy water ecosystems and offers multiple benefits to the water sector has been recognised in the studies and publications published by the European Commission in 2015[20]. The materials highlight importance of GI in providing a regulation of water flows, water retention for further use later on, water purification and water provisioning, species protection, biodiversity enhancement, climate change mitigation and adaptation and disaster reduction by the prevention and mitigation of floods.

To integrate GI aspects into water and river basin management has the potential to significantly contribute to the improvement or preservation of water of good quality and quantity. Such integration also has a large potential to reduce the impacts of floods and droughts and to mitigate hydro-morphological pressures. Examples of water-related functions of GI include Natural Water Retention Measures (NWRM) or also called as nature-based solutions (NBS), which are multi-functional measures that aim to safeguard water resources using natural means and processes. The main focus of NWRM is to enhance, as well as preserve the water retention capacity of aquifers, soils and ecosystems with a view to improve their status.

In 2014, United Nations Environment Programme (UNEP) produced a guide on GI and water management.[21] The guide identifies and demonstrated which GI solutions can be used to solve issues of the water management. The guide also includes an outline methodology for water management options assessment comprised of a number of steps relating to definition of development objectives, specification of investment portfolios, modelling of environmental outcomes and economic evaluation, cost-benefit analysis, as well as risk and uncertainty analysis.

[20] http://ec.europa.eu/environment/nature/ecosystems/studies/index_en.htm
[21] UNEP. 2014. Green Infrastructure Guide for Water Management: Ecosystem-based management approaches for water-related infrastructure Projects.

Table 2. Green Infrastructure solutions for water resources management (UNEP, 2014).

Water management issue (Primary service to be provided)		Green Infrastructure	Location			
Water supply regulation (incl. drought mitigation)		Re/afforestation and forest conservation				
		Reconnecting rivers to fl				
		Wetlands restoration/conservation				
		Constructing wetlands				
		Water harvesting*				
		Green spaces (bioretention and infi				
		Permeable pavements*				
Water quality regulation	Water purifi	Re/afforestation and forest conservation				
		Riparian buffers				
		Reconnecting rivers to fl				
		Wetlands restoration/conservation				
		Constructing wetlands				
		Green spaces (bioretention and infi				
		Permeable pavements*				
	Erosion control	Re/afforestation and forest conservation				
		Riparian buffers				
		Reconnecting rivers to fl				
	Biological control	Re/afforestation and forest conservation				
		Riparian buffers				
		Reconnecting rivers to fl				
		Wetlands restoration/conservation				
		Constructing wetlands				
	Water temperatur e control	Re/afforestation and forest conservation				
		Riparian buffers				
		Reconnecting rivers to fl				
		Wetlands restoration/conservation				
		Constructing wetlands				
		Green spaces (shading of water ways)				
Moderation of extreme events (fl	Riverine fl control	Re/afforestation and forest conservation				
		Riparian buffers				
		Reconnecting rivers to fl				
		Wetlands restoration/conservation				
		Constructing wetlands				
		Establishing fl bypasses				
	Urban stormwater runoff	Green roofs				
		Green spaces (bioretention and infi				
		Water harvesting*				
		Permeable pavements*				
	Coastal fl (storm) control	Protecting/restoring mangroves, coastal marshes and dunes				
		Protecting/restoring reefs (coral/oyster)				

2. Examples of Green infrastructure and landscape planning at different scales

2.1. Mapping green infrastructure based on ecosystem services and ecological networks: A Pan-European case study.

The European Environmental Agency (EEA) has developed a comprehensive methodology for mapping of multi-functional GI at EU scale, based on supply of ecosystem services as well as ecological networks formed by core habitats for target species and connectivity between these habitats (published by Liquete et al., 2015)[22]. The methodology was tested within a continental case study, covering the EU-27 territory, focusing on a landscape scale. However, it is applicable at different spatial scales for planning and policy implementation.

Following the definition of the GI proposed by the EC Communication in 2013, this approach is focusing on two crucial criteria for identification of the GI elements: i) multifunctionality linked to the provision of variety of ecosystem services and ii) the connectivity associated to the protection of ecological networks. The methodology involves the following steps (see figure 1):

- Quantification of the natural capacity to deliver ecosystem services;
- Identification of essential core habitats and their connectivity analysis;
- Normalization of original values of ecosystem service and core habitat & corridor assessment;
- Integration of obtained results into a meaningful network of GI.

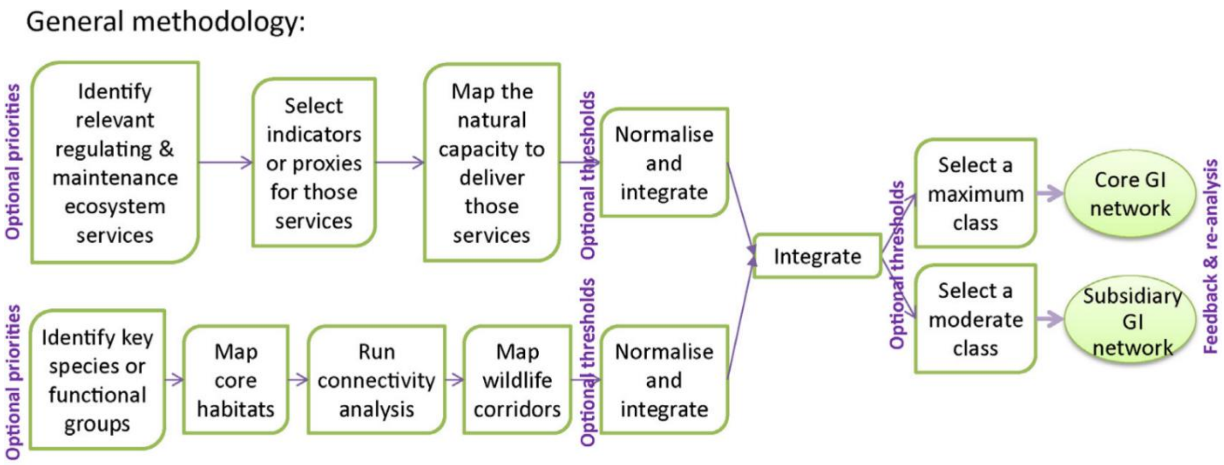

Figure 1. Methodology proposed by the EEA for mapping of GI within a Pan-European case study. Source: Liquete et al., 2015.

The first part of the assessment addresses the natural capacity of the area to deliver ecosystem services. Within the presented case study eight regulating and maintenance services were selected, including air quality regulation, erosion protection, water flow regulation, coastal protection, pollination, maintenance of soil structure and quality, water purification and climate regulation. Different methods can be applied for mapping of the ecosystem services, from direct conversion of land use/ land cover maps as proxies for ecosystem service supply, through the compilation of local

[22] Liquete et al. (2015). Mapping green infrastructure based on ecosystem services and ecological networks: A Pan-European case study. Environmental Science and Policy, 54, 268–280.

primary data or statistics, up to application of dynamic process-based models. Within the cases study proxies of biophysical process determining each ecosystem service was defined, based on published scientific models and results. The mapping results were normalised, reclassifying the ecosystem assessment data in five ranks ranging from minimum (1) to maximum capacity (5).

The second part of the cases study included identification of core and transitional habitats for key functional groups. As core habitats and functional groups are species-related, the most relevant species for the context of the study shall be identified. In this study the analysis focused on large mammals and identification of large, dense forest patches as core habitats for the species, followed by habitat connectivity analysis for section of wildlife corridors between the patches. The habitat modelling results of the cases study were qualitative (i.e. presence or absence of different kinds of habitats). However, for integration with the ecosystem service assessment, the results of habitat modelling had to be normalised using the same scale (ranks from 1 to 5). Thus, the following categories were assigned: maximum value (5) – the actual core habitats; high value (4) – wildlife corridors or transitional habitats among the core areas; moderate value (3) other potential core areas or wildlife corridors; and minimum value (2) – the rest of the territory.

The normalised results of the ecosystem service assessment and habitat modelling were finally integrated by selection of maximum values, i.e. the value of criterion with the highest score was assigned to each square kilometre. The Core GI network included the areas which were scored with maximum value (5) for the capacity to deliver ecosystem services or as actual core habits based on habitat modelling. The Subsidiary GI network included the areas scored with value 4 for the capacity to deliver ecosystem services or the wildlife corridors or transitional habitats based on habitat modelling.

The authors conclude that the proposed methodology can be applied at any other location or scale. One of its main advantages is its flexibility to adjust the selection criteria by choosing the appropriate ecosystem services or features essential for maintaining the ecological networks.

2.2. Mapping green infrastructure at national scale for supporting landscape-level planning solutions: Estonian case study

Landscape-level GI mapping was tested also in Estonia, covering the whole territory of the country[23]. Thus, the Estonian experts have developed a methodology for national-scale GI determination, which is based on analysis of spatially explicit datasets (e.g. landcover, nature conservation data, soils, topography, water courses as well as roads and other brown infrastructure elements) and expert evaluation of the different land use types. The vector layer representing a regular grid 1×1 km cell size was used for intersecting all the data sets.

Experts have assigned scores to each land use category based on its ecological value, which represents its contribution to habitat diversity as well as ability to regulate nutrients and carbon cycles. GI elements have received scores 0 to 5, while the brown infrastructure elements were scored from -1 to -5. The scores were used for calculation of greenness and brownness indices and conflict hotspots. The greenness index combined the value the expert scoring value of the green land use/land cover (LULC) type, nature conservation areas, soil taxonomic diversity, relief complexity, hedgerow density and water course density map layers. The brownness index combined the brown LULC types (e.g. areas

[23] Mander et al., 2018. Green and brown infrastructures support a landscape-level implementation of ecological engineering. Ecological Engineering 120: 23–35.

under urban fabric, industrial units, roads, mineral extraction sites, dump sites etc.), road density, traffic intensity, power line density and wind turbine density. Before combining all the input layers into the greenness index map and the brownness index map, all the variables were normalised by splitting them into quantiles and weighted, based on expert rating of their relative importance. The conflict intensity map was developed by subtracting the brownness index value of each cell from the corresponding greenness index value.

The overlapping map (Figure 2) combines the GI core and buffer areas, identified based on the greenness index values, and the conflict hotspots between Estonia's green and brown infrastructures. This map reveals the priority sites for implementation of the ecological engineering measures (i.e. NBS).

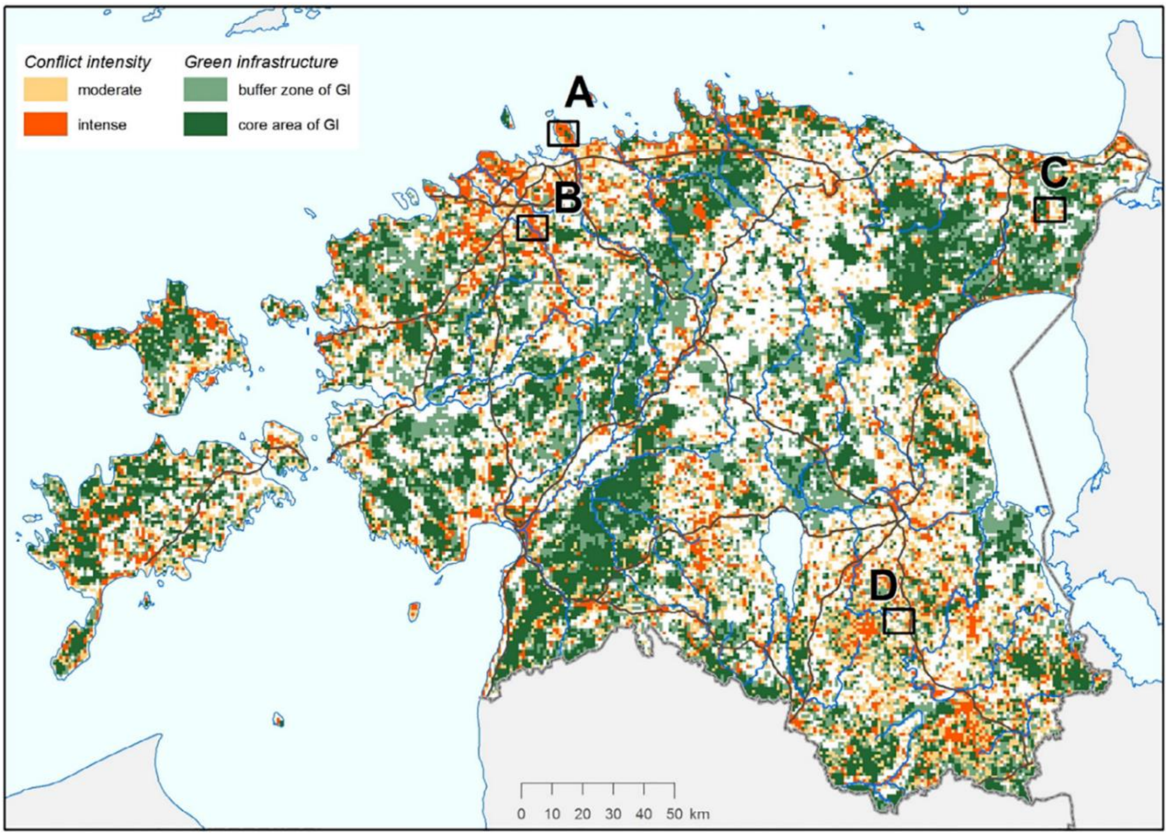

Fig. 2. Systematic map of GI in Estonia and the conflict areas between green and brown infrastructure. Source: Mander et al., 2018

The proposed spatially explicit model of conflicts between green and brown infrastructure represents a new approach in landscape planning and environmental management and provides an interlink between core-scale landscape planning and regional planning with more detailed local landscape plans, which could support site specific ecological engineering or NBS.

2.3. Regional scale case study – Great Manchester Region

Green infrastructure (GI) is defined in Manchester's Core Strategy as "a network of multi-functional greenspace. It includes open space, waterways, woodlands, green corridors, verges, green roofs and trees." [24] Within this case study the term green infrastructure includes also aquatic features in

[24] Manchester City Council. 2015. Manchester Green Infrastructure Strategy. Technical Report.

recognition of their importance to Manchester. The river valleys, including incised valleys and broad flood-plains are particularly important to the green infrastructure network in the City Region.

In Greater Manchester, green infrastructure consists of:

- **open spaces** (parks, woodlands, informal open spaces, nature reserves, lakes, historic sites and natural elements of built conservation areas, civic places and plazas, and accessible countryside) (the map below illustrates the present extent of such spaces)
- **linkages** (river corridors and canals, pathways, cycle routes and greenways).
- **networks of "urban green"** (the collective resource of private gardens, pocket parks, street trees, verges and green roofs)

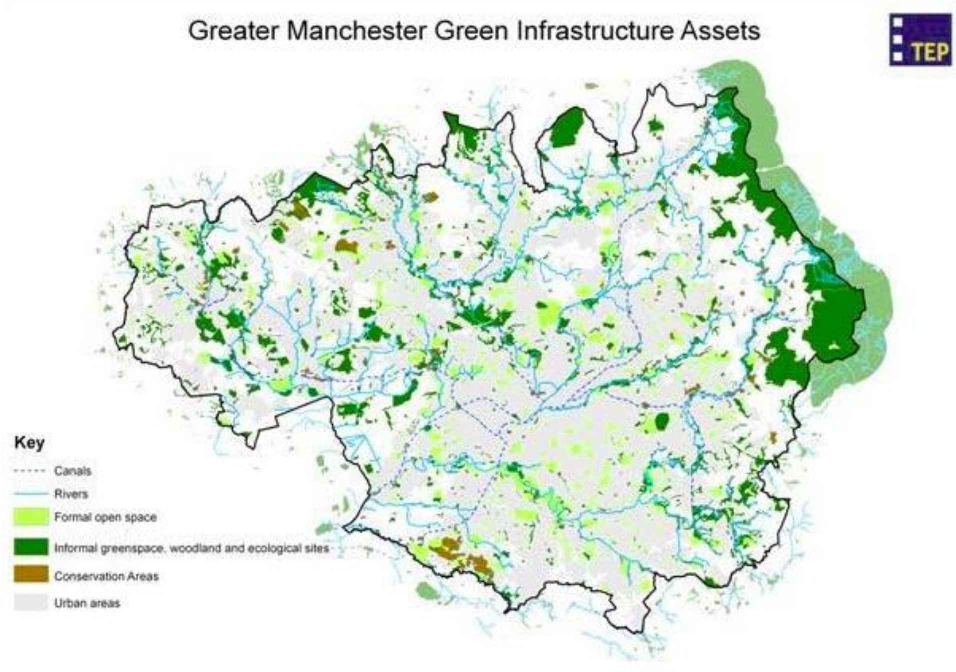

Fig.3. Greater Manchester Green Space Assets. Source: Report of Greater Manchester's Green Infrastructure, 2010

The green infrastructure of Greater Manchester is part of the city-region's life support system. The case study is generated spatial priorities as strategic green infrastructure network, economic centres and growth points, regeneration priority areas, destination parks, landmarks and trails, a sustainable movement network, greening the urban environment and civil society actions in 10 local authorities and Manchester City[25].

Spatial priorities must be derived from best available evidence about environmental conditions and socio-economic priorities. The first task of green infrastructure planning is land form evaluation and GI typology development. After that, spatial analytical techniques were used:

- Mapping of patterns of settlement and open spaces
- Mapping and characterisation of GI assets (green spaces, rivers, canals, conservation areas, sites of biodiversity value, landscapes of natural and cultural distinctiveness, wildlife corridors and greenways) (Figure 3).
- Mapping of social and demographic patterns (deprivation, economic activity, demographic trends).

[25] TEP. 2010. Greater Manchester's Green Infrastructure. Report.

- Consideration of where the GI functions are most needed for growth of the city region.

Several different measures have been carried out using the different datasets to give an insight into the patterns of different types of green infrastructure. The best analysis unit was chosen of green infrastructure social, economic or environmental problem (“needs”) analysis. The “needs” which can be reduced through GI mapped five classes of social need and environmental stress, considering factors where GI could make a difference. Datasets should be the best available because of mapping at a reasonably fine-grained scale and regional replicable. The “Needs” maps were prepared for clusters of local authorities and covered the following elements, which partly overlap:

- Most deprived neighbourhoods (using the worst 30% Super Output areas)
- Neighbourhoods suffering health deprivation (health indicators)
- Areas in the 30% worst quality band for Natural Environment (using the Natural Environment Index)
- Areas in flood zone (allowing for climate change adjustment?
- Areas most likely to suffer from urban heat stress (using the 30% most affected neighbourhoods)
- Areas of Derelict, Underused and Neglected Land

The last step in Greater Manchester GI planning case is to determine areas which have policy or market priority for Economic Growth and Transformation called as “Opportunities”. Most of this investment is being made in areas which:

- have important GI assets (rivers, parks, city-centre public realm) or
- are vulnerable to future environmental stresses (flooding, urban heat) or
- will support a growing and/or ageing population which requires access to high-quality open space
- “on the doorstep” or
- already suffer health deprivation or
- are essential drivers for the economy by virtue of their location and accessibility.

This sort of targeted investment is vital to the regeneration and economic development of the city-region, beyond the immediate boundaries of the investment area. The areas of economic activity and proposed major investment are mapped by local authority cluster.

2.4. Local scale case study: Irwell Catchment Pilot

This Irwell[26] case study[27] sets out a proposed approach to identifying opportunities for addressing issues of water management and water quality through installation of GI, or improved management of existing GI resources. The aim to identify where, in a predominantly urban environment, there is the greatest potential for GI to bring improvements to the water environment. Key to the approach was made best use of readily available data to facilitate desktop assessment across the entire catchment. Additionally, GI has the potential to modify rates of water flow over the ground, promote infiltration to ground, remove excess water through transpiration, and provide areas for water storage during high rainfall or other flood events, and thus help to reduce downstream flood risk.

General goals:

- Reducing diffuse pollution from rural and urban sources

[26] James, P. et al., 2012. The Irwell Catchment Pilot: The Rivers Return. The Environment Agency, Warrington

[27] The Mersey Forest. 2017. Green infrastructure for Water. LIFE Nature Course project report.

- Restoring the condition of riparian and aquatic habitats.

On this basis, a GIS model has been constructed, comprising individual “layers” of different landscape features, each a potential pathway for pollutants or water, and each offering the opportunity for GI. Construction of GIS model or tool, which demonstrates:

- what GI interventions to apply in particular locations
- where to implement GI solutions to get the maximum benefit.

The main steps were taken to construct GI analysis:

- Identifying water problem issues - list of common sources of contamination
- Identify likely pathways of pollution or water related problems and opportunities consisting of “layers” of different landscape features -land cover and land use characterisation. Each pathway relates to a particular type of landscape feature, e.g.: natural surface, car park, industrial yard etc. Each opportunity layer therefore answers a specific issue, and also implies specific GI interventions appropriate to that issue and feature type. A total of 18 different classes of opportunity feature have been identified and included in the model.
- GI Opportunity assessment – The GIS was used to overlay each layer of opportunity features to generate a “heat map” to be used in the targeting of interventions, or further detailed investigation. In this phase, it is possible to use datasets weighting and spatial prioritisation with or without stakeholder involvement. A map highlights those locations that have the greatest number of opportunities to disrupt pathways. An important point about the opportunities is their multifunctionality.
- Deliverability and Constraints – This additional range of features, which presently highlight locations of water protection zones, or valuable habitat types, can be brought into the assessment at any stage to indicate wither locations or particular interventions that ought to be avoided, or that would be most favourable.
- Benefit analysis - The final opportunity targeting map highlights those locations across the catchment where there is the greatest number of opportunities for GI to have a beneficial impact.

3. Conceptual framework for integrating green infrastructure and landscape planning

Following the definitions and examples provided above, **the GI is understood as a <u>strategically planned</u>, spatial network of ecologically valuable areas significant for**:

- ecosystems’ health and resilience,
- biodiversity conservation and,
- multiple delivery of ecosystem services essential for human well-being.

The ecosystems’ health and resilience as well as its capacity to supply services for human well-being directly depends on the **ecosystem condition**, which is characterized by its structure (land cover type/habitats & species composition) and underlaying ecological processes (see figure 4). While increasing the pressure on ecosystem or by changing the land use type (and thus fundamentally impacting or destroying the previous ecosystem), people influence the ecosystem structures as well as its capacity to supply ecosystem service.

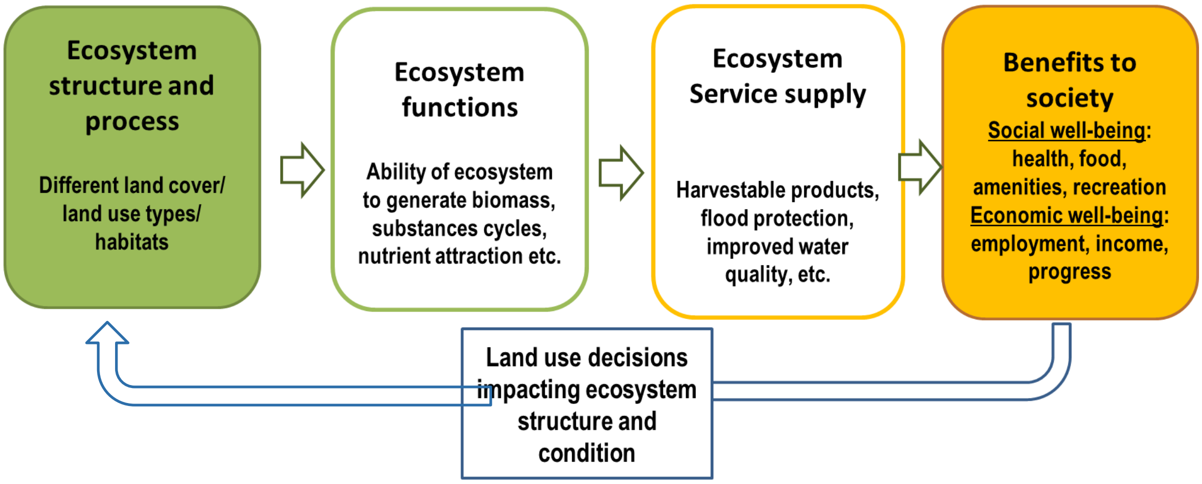

Fig. 4. ES concept describing the mutual connection between ecosystem condition and well-being of society

Therefore, **mapping and assessment of the existing GI** preferably shall be based on assessment of the ecological value, ecosystem condition and service supply of the area.

While **planning improvement of the existing GI**, the problem areas shall be identified by carrying out analysis of the threats, existing pressures or insufficient ecosystem service supply. Furthermore, the societal needs and priorities shall be discussed and agreed by involvement of local stakeholders.

The human interventions in the ecosystem, which are targeted to improvement of ecosystem condition and supply of particular ecosystem services, are referred as **nature-based solutions** (NBS). Such innervations, as described before, can include i) the change of the land use/land cover type or adjusting of management practice for improving connectivity of the network or ecosystem service supply, ii) restoration of ecosystems or even creation of ecosystem as well as iii) more sophisticated technological solution or ecological engineering, which imitates ecosystem function or particular services. The selection of the appropriate NBS for particular problem area should be based on analysis where it would be the most effective for addressing particular societal challenges and taking into account the site-specific ecological conditions (e.g. soil, relief, distance to water bodies or other habitat types etc.).

The landscape planning as an action to conserve, restore, enhance or create multifunctional landscapes, provides suitable framework for assessment of the existing GI and suggesting the land use options for achieving the environmental objectives, including improvement of green infrastructure and delivery of ecosystem services[28]. The analysis of the landscape structure and assessment of its ecological value, connectivity and ecosystem service supply of different land cover types can help in mapping of GI as well as identification of risk areas or conflict between existing land use and optimum ecosystem service supply, where particular NBS shall be applied. The conceptual frame for such approach in landscape planning is illustrated in the figure 5.

[28] Albert C., et al.2019. Addressing societal challenges through nature-based solutions: How can landscape planning and governance research contribute? Landscape and Urban Planning 182: 12–21.

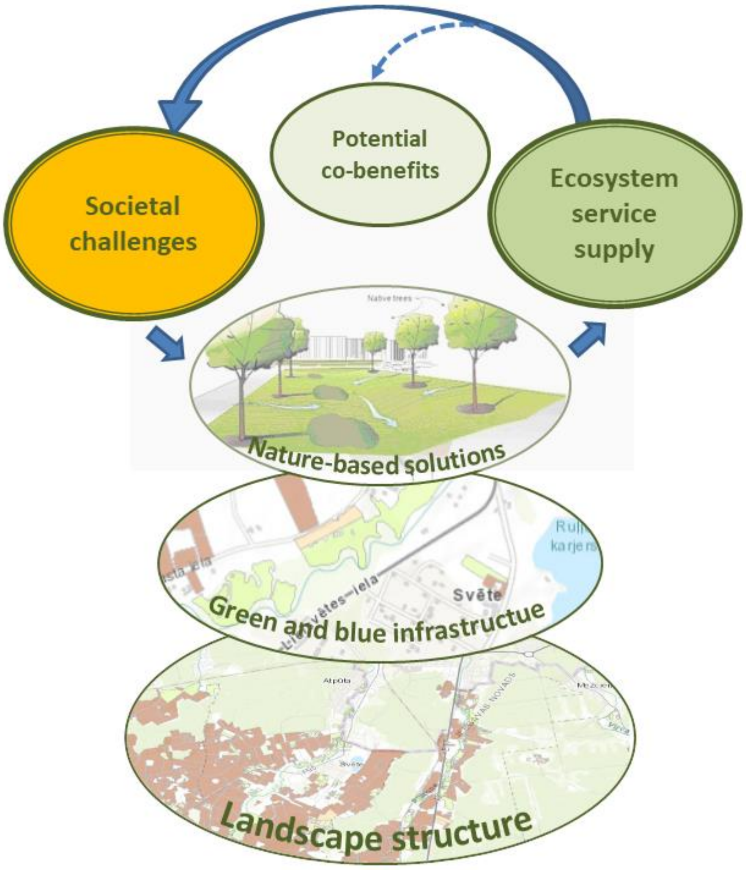

Fig.5. Conceptual framework illustrating the role of landscape planning in GI and NBS. Source: based on Albert et al., 2019

The same approach is embedded in the conceptual framework of the ENGRAVE project to be applied for the integrated landscape and GI planning (see figure 6). It entails that that landscape and its forming elements (e.g. river, river valley, floodplain and as well as surrounding land use and cultural heritage) forms the basis for the GI and ecosystem service supply and related benefits to society (e.g. healthy living conditions/environmental quality, amenities, possibilities for tourism and recreation as well as related income and economic growth). The integrated landscape and GI planning within the ENGRAVE project shall involve assessment of the landscape structure, GI and ecosystem service supply as well as the identification of the societal challenges and public needs/priorities through the participatory process. After all, it shall result in proposals for improvements in landscape and GI for enhancing the ecosystem service supply and benefits to society.

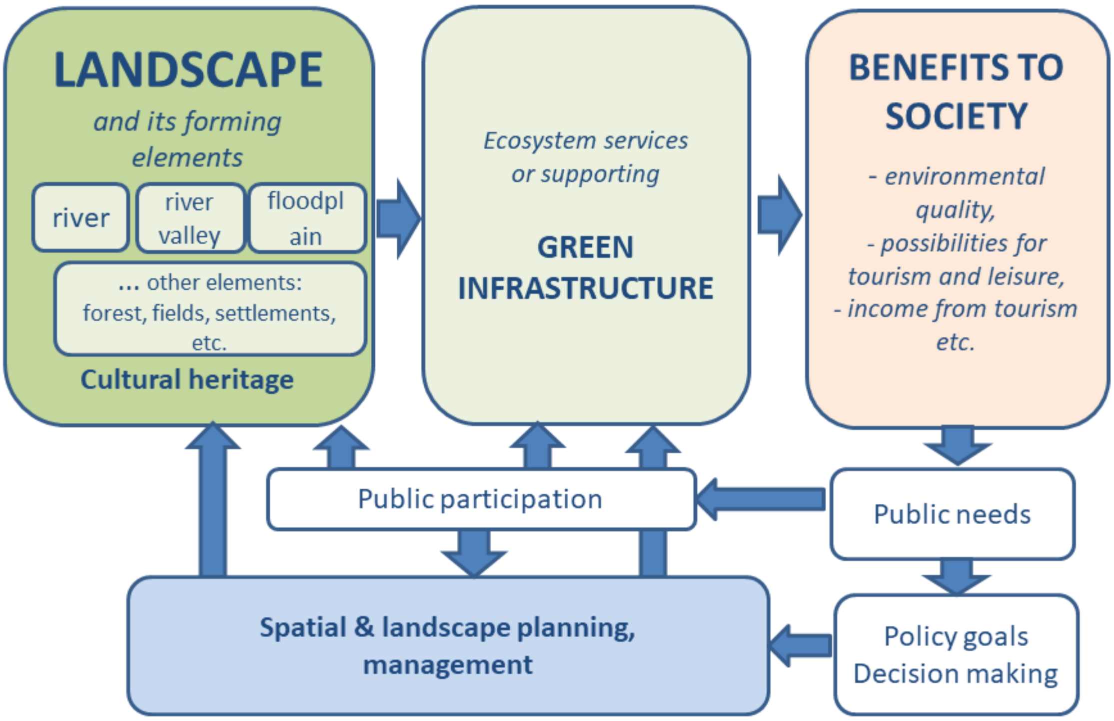

Fig.6. Conceptual framework of the ENGRAVE project

The GI mapping and planning can be applied various scales and planning levels. Depending on the scale different GI forming components can be considered (see table 3). The ENGRAVE project case studies include regional as well as river valley and local scale. The landscape planning approach described above is the most suitable for the regional, municipality scales as well as river valley scales, but at the same time it helps to identify areas, where the planning solutions would have to be elaborated at lower planning level (e.g. local scale).

Table 3. GI forming components relevant for different planning scales

GI forming components	Pan-European scale	National scale	Regional scale	Municipality scale	River valley scale	Local scale
Ecosystem service supply potential	X	X	X	X	X	X
Network of core habitats for species	X	X	X			
Connecting habitats	X	X	X			
Areas of high ecological value	X	X	X	X		
Valuable landscape elements			X	X	X	X
Natural features with specific ecological function (wetlands, rapids etc.)				X	X	X
Other (artificial) elements providing nature-based solutions				X	X	X

4. Proposal on methodology for integrated landscape and green infrastructure planning to be applied within ENGRAVE project

The following sub-chapters describe the main steps of the integrated landscape and GI planning as well as the related methods and data requirements, which can be applied within the ENGRAVE project case studies.

4.1. Mapping and assessment of existing GI

Mapping of the existing GI can include assessment of the ecological value, landscape value as well as ecosystem service supply of the study area and identification of the areas (patches and corridors), which are essential for maintaining ecological networks, biodiversity, ecosystem health, resilience and multiple services. This includes:

- selection of criteria for assessment of the ecological (and landscape) value, relevant indicators and data sets for assessment;
- selection of ecosystem services to be assessed, relevant indicators and data sets for assessment;
- data collection, assessment and producing single ecological and landscape value maps (based on the selected criteria) and single ecosystem service maps;
- producing aggregated maps, which summarize the ecological value and ecosystem service value;
- prioritisation/identification of the areas forming GI (e.g. by setting the value thresholds or applying multi-criteria analysis)

Selection of criteria for the GI assessment

Selection of the relevant criteria for assessment is the first and very important step in mapping of GI, determining which areas will qualify as GI. So far there has not been developed one standardised list of criteria for GI mapping, therefore the selection shall be based on the specifics of the area, but also following the concept of GI, which defines it as network of ecologically valuable areas maintained for multiple delivery of ecosystem services essential for human well-being.

The **ecological value** is related to maintenance of biodiversity as well as rare, unique or threatened biological or geomorphological features. The examples of criteria for assessment of the ecological value are listed in the Table 4. The assessment can include one (e.g. 'biological diversity' or 'Importance for threatened, endangered or declining species and/or habitats') or combination of several criteria depending on area specifics and data availability. The ecological value of the area can be also represented by the network of existing protected areas (or their functional zones), which are established based on the criteria listed in the table XX. However, it shall be taken into account that network of the existing protected areas depends on the level of knowledge, data availability as well as often political choice at the time of their designation and might not reflect the true ecological value of the area. This approach might be also not suitable for the local scale assessments.

Table 4. Examples of possible criteria for assessment of ecological value:

Criteria	***Explanation***
Biological diversity	Area contains comparatively higher diversity of habitats, communities, or species;

Rarity	Area contains rare species, populations or communities, and/or rare or distinct, habitats or ecosystems or unusual geomorphological features
Uniqueness	Area contains either unique ("the only one of its kind") or endemic species, populations or communities, and/or unique, distinct, habitats or ecosystems; and/or unique geomorphological features
Importance for threatened, endangered or declining species and/or habitats	Area containing habitat for the survival and recovery of endangered, threatened, declining species or area with significant assemblages of such species; e.g. HD Annex I habitats; Annex II species; BD species
Vulnerability, fragility, sensitivity, or slow recovery	Areas that contain a relatively high proportion of sensitive habitats or species that are functionally fragile
Naturalness	Area with a comparatively higher degree of naturalness as a result of the lack of or low level of human-induced disturbance or degradation

Another important aspect for the integrated landscape and GI planning is assessment of the **landscape value**. Aesthetic value of the area (or 'characteristics of living systems that enable aesthetic experiences') usually is included in ecosystem service assessment as one of the cultural services. Though, the landscape planning might require more in-depth analysis of the landscape structure, its forming elements and values. The possible criteria for assessing the landscape value are listed in the table 5.

Table 5. Examples of possible criteria for assessment of landscape value:

Criteria	***Explanation***
Diversity	Area contains comparatively higher diversity of land uses (land covers)
Rarity	Area contains rare land uses, patterns and/or landscape elements
Uniqueness	Area contains unique (one of the kind) land uses, patterns or landscape elements
Sameness	Area with repeatable, uniform land use patterns
Naturalness	Proportion between natural and cultural land uses/elements
Historical value	Presence and density of historical elements and spatial structures
Cultural value	Presence and density of acknowledged cultural heritage elements and values attributed by society as actually and potentially desirable
Recreational use value	Presence and density of touristic spots, outdoor recreation infrastructure, diversity of recreational uses
Scenic-aesthetic value	Presence and diversity of landmarks and distinctive landscape features Possibility to observe distant horizons and extensive views
Spiritual value	Knowledge of associative landscapes and places (religious, artistic, social associations): sites associated with important historical events, sites of historical scientific value, sites or landscapes associated with significant people or cultural activities, natural sites that have become associated with recreational use' and other social activities

Selection of ecosystem services relevant for the GI assessment depends on the specifics of the area as well as available knowledge and data for the assessment of particular service. Usually assessment does not include all the ecosystem services provided by the area, but ones which are the most relevant for the study context. For assessment of GI the regulation & maintenance services as well as cultural services (particularly those related to recreation potential) are considered as most appropriate. The provisioning service, like cultivated crops or other materials harvested from intensive agricultural land, usually will not be appropriate for assessment of GI. On other hand private household gardens in urban areas, used for production of vegetables and fruits might be essential part of the urban GI. Therefore, the list of ecosystem services selected for GI mapping shall depend on specific societal challenges or demand for particular services, which are can be provided by the network of natural and semi-natural areas or other environmental features.

Different classification systems of ecosystem services have been developed, however we recommend using the Common International Classification of Ecosystem Services (CICES), Version 5.1, published in 2018[29]. CICES is the most commonly used for ecosystem service studies in Europe and ensures consistency among different studies and assessment results. The list of all possible ecosystem services, which potentially could be used for GI are listed in the table 6.

Table 6. Ecosystem services relevant for GI assessment (based on CICES Version 5.1):

Ecosystem service	***Explanation/ examples of indicators***
Provisioning services	
Cultivated plants for nutrition, materials or energy	Any crops and fruits grown by humans for food; material from plants, fungi, algae or bacterial that can be harvested and used as raw material for non-nutritional purposes or as a source of biomass-based energy
Reared animals for nutrition, materials or energy	Livestock raised in housing and/or grazed outdoors for the production of food; material from animals that can be harvested and used as raw material for non-nutritional purposes
Wild animals for nutrition, materials or energy	Parts of the standing biomass of a non-cultivated plant species that can be harvested and used for the production of food, as raw material or energy source
Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Non-domesticated, wild animal species and their outputs that can be used as raw material for the production of food, for non-nutritional uses or energy source
Genetic material from plants, algae, fungi or animals	Seeds and spores and other plant materials, fungi, algae and bacteria or animals that can be used to maintain or establish a new population, develop new varieties or gene synthesis.
Regulation & Maintenance services	
Bio-remediation by micro-organisms, algae, plants, and animals	Transformation of an organic or inorganic substance by a species of plant, animal, bacteria, fungi or algae that mitigates its harmful effects and reduces the costs of disposal by other means
Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	The fixing and storage of an organic or inorganic substance by a species of plant, animal, bacteria, fungi or algae that mitigates its harmful effects and reduces the costs of disposal by other means
Smell reduction	The reduction in the impact of odours on people that mitigates its harmful or stressful effect, or the cost of the nuisance
Noise attenuation	The reduction in the impact of noise on people that mitigates its harmful or stressful effect, or the cost of the nuisance
Visual screening	The reduction in the visual impact of human structures on people that mitigates its harmful or stressful effect, or the cost of the nuisance
Control of erosion rates	The reduction in the loss of material by virtue of the stabilising effects of the presence of plants and animals that mitigates or prevents potential damage to human use of the environment or human health and safety
Buffering and attenuation of mass movement	The reduction in the speed of movement of solid material by virtue of the stabilising effects of the presence of plants and animals that mitigates or prevents potential damage to human use of the environment or human health and safety
Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	The regulation of water flows by virtue of the chemical and physical properties or characteristics of ecosystems that assists

[29] https://cices.eu/

	people in managing and using hydrological systems, and mitigates or prevents potential damage to human use, health or safety
Wind protection	The reduction in the speed of movement of air by virtue of the presence of plants and animals that mitigates or prevents potential damage to human use of the environment or human health and safety
Pollination	The fertilisation of crops by plants or animals that maintains or increases the abundance and/or diversity of other species that people use or enjoy
Seed dispersal	The dispersal of seeds an spores of plants and other organisms that are important to people in use and non-use terms
Maintaining nursery populations and habitats (Including gene pool protection)	The presence of ecological conditions (usually habitats) necessary for sustaining populations of species that people use or enjoy
Pest control (including invasive species)	The reduction by biological interactions of the incidence of species that prevent or reduce the output of food, material or energy from ecosystems, or their cultural importance, by consumption of biomass or competition
Disease control	The reduction by biological interactions of the incidence of species that otherwise could prevent or reduce the output of food, material or energy from ecosystems, or their cultural importance, by hindering or damaging the ecological functioning of useful species
Regulation of soil quality by weathering processes	Biological decomposition of minerals that maintain fertility or conditions necessary for human use
Regulation of soil quality by decomposition and fixing processes	Decomposition of biological materials and their incorporation in soils that maintains their characteristics necessary for human use
Regulation of the chemical condition of fresh waters by living processes	Maintenance of the chemical condition of fresh waters by plant or animal species that enable human use or health
Regulation of chemical composition of atmosphere and oceans	Regulation of the concentrations of gases in the atmosphere that impact on global climate or oceans
Regulation of temperature and humidity, including ventilation and transpiration	Mediation of ambient atmospheric conditions (including micro- and mesoscale climates) by virtue of presence of plants that improves living conditions for people
Cultural services	
Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	Using the environment for sport and recreation; using nature to help stay fit
Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions	Watching plants and animals where they live; using nature to destress
Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	The biophysical characteristics or qualities of species or ecosystems (settings/cultural spaces) that are the subject matter for *insitu* research
Characteristics of living systems that enable education and training	The biophysical characteristics or qualities of species or ecosystems (settings/cultural spaces) that are the subject matter for *insitu* teaching or skill development
Characteristics of living systems that are resonant in terms of culture or heritage	The things in nature that help people identify with the history or culture of where they live or come from
Characteristics of living systems that enable aesthetic experiences	The beauty of nature
Elements of living systems that have sacred or religious meaning	The things in nature that have spiritual importance for people

The full list of the CICES V5.1. ecosystem services, examples and related explanations are available at https://cices.eu/ .

Methods for mapping ecological & landscape value and ecosystem service supply:
GI mapping can be focused particular GI forming features (specific land cover or habitat types) or by assessing the ecological value and ecosystem service supply of all land cover types in the study areas and producing aggregated value map, based on which the core and buffer areas of the GI can be identified. The first approach can be more suitable for the local case studies or urban context, where particular GI features can be well distinguished from other land cover types, while the second approach – continuous ecological value mapping of the whole area would be more suitable for agro or forest ecosystems at the municipality, regional, national or even continental scale as demonstrated above by the Pan-European and Estonian case studies (see chapter 2.1 and 2.2).

Variety of methods are available for mapping ecosystems and their status or ecological value as well as mapping of ecosystem service supply, ranging from direct measurements or field observations, indirect measurements, which relay on interpretation of available data sets, up to sophisticated modelling techniques[30]. Here are described relatively simple methods, which do not specific knowledge and skills in modelling.

- **Direct measurement methods**

The direct measurements are the most accurate method, which can be applied for mapping ecosystems, distribution of habitat types and species, assessment of the ecological or landscape value as well as for assessment of ecosystem service supply. This includes i) collection of data/samples according to defined sampling design during local scale field surveys, national scale habitat mapping, national biodiversity or environmental monitoring programmes, regular forest inventories etc., or ii) collection and processing of remote sensing data, including satellite or airborne images, LiDAR data, etc. (which usually also requires verification of the data in the field). These methods deliver a biophysical value, which is expressed is physical units (e.g. number of species per ha; amount of produced biomass tonnes per ha etc.). In order to assess the ecological value of the areas or ecosystem service supply a suitable indicator shall be selected, which determines the assessment unit. One criterion can be assessed by one indicator or combination of several indicators. For identification of the areas of high ecological value or high supply of a particular ecosystem service the quantitative biophysical value data can be expressed in assessment scale.

Direct measurement data probably are the most suitable for assessment of the ecological value, which depends on presence and abundance of particular species or habitats. The local scale cases studies can include the actual data collection in the field, while for regional or national scale case studies the available data sets from the national level surveys or monitoring programmes usually are applied. For assessment of the ecosystem service supply the collection of the field data might be too costly and time demanding, and available data sets mostly do not exist. Therefore, in this case indirect measurements or modelling are applied, which however might require some direct measurements (e.g. land cover, soil type, relief) as input data.

- **Spatial proxy methods**, including expert scoring (spreadsheet/matrix model)

[30] Vihervaara, P., Mononen, L., Nedkov S., Viinikka, A., et al. (2018). Biophysical mapping and assessment methods for ecosystem services. Deliverable D3.3 EU Horizon 2020 ESMERALDA Project, Grant agreement No. 642007.

Spatial proxy methods are derived from indirect measurements (e.g. land cover maps produced using remote sensing and Earth observation data), which deliver a biophysical value in physical units, but these values need further interpretation or data processing and rely upon certain assumptions. For example, the assessment value can be attributed to land cover type based on data from literature, expert knowledge or direct field measurements. The expert knowledge is considered as the most rapid way to collect comprehensive information about multiple ES supply [31]. Experts can assess the capacity of each selected land use or land cover (LU/LC) type to provide particular ES in a relative scale. The assessment is inserted in a matrix where LU/LC type are listed in the rows, while assessed ES – in columns (see Figure 7) [32]. When the scores of potential ecosystem service supply in each LU/LC type are obtained, the LU/LC map can be used for producing single ecosystem service supply maps.

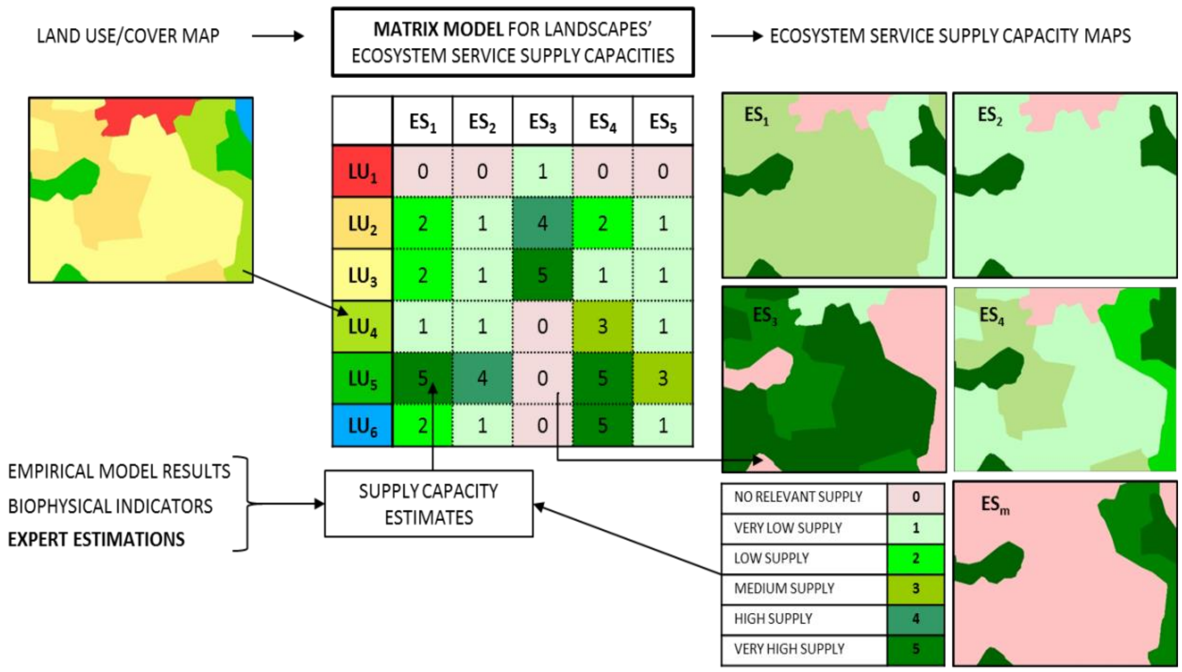

Figure 7*. The concept of the ES Matrix model developed by Burkhard et al. (2009). Based on expert estimations, biophysical quantifications or empirical model results, estimates for ES supply capacities are attributed to land use/cover (LULC) classes. Source: Jacobs et al., 2015.*

Land cover type based on satellite images can be used as a suitable proxy for ecosystem service mapping at regional and national scale. Such approach was followed also in national scale mapping of ecosystem service potential in Lithuania[33]. The publication of the study results includes the filled matrix, providing ecosystem service scores for each land cover type, wich probably can be applied for similar assessments in Lithuania and Latvia.

At more detailed scale studies (e.g. mapping of urban or river valley/catchment GI) such land cover data might be to coarse. In such case study specific typology of LU/LC, using available data sets on land use, distribution of habitat types, topography, soil type etc. For example, in a cases study of GI

[31] Helfenstein, J., Kienast F. (2014): Ecosystem service state and trends at the regional to national level: A rapid assessment. Ecological Indicators 36: 11-18.
[32] Jacobs, S., Burkhard, B., van Daele, T., Staes, J., Schneiders, A. (2015): The Matrix Reloaded – A review of expert knowledge use for mapping ecosystem services. Ecological Modelling 295:21-30
[33] Depellegrin D., Pereira P., Misiunė I. & Egarter-Vigl L. (2016). Mapping ecosystem services potential in Lithuania, International Journal of Sustainable Development & World Ecology, 23:5, 441-455

assessment in the city of Järvenpää, Finland a typology of urban GI was developed by compilation of the relevant background information and spatial data from the national and city archives and remote sensing images.[34]

Methods for producing aggregated GI maps

- **Aggregation of different assessment values**

Ares significant for maintaining of the GI can be identified by aggregating the mapping results of each single criterion of ecological value and ecosystem service supply. The most convenient approach for intersecting values from different data sets (i.e. single ecological value and ecosystem service maps) can be by applying a grid of regular cells (e.g. 1 × 1 km as demonstrated by Estonian and Pan-European example) – the values of all selected criteria are summed up per each grid cell. In order to sum up the values from different data sets, which might be expressed in different biophysical units or assessment scores, they shall be first normalised on a same scale (e.g. 0-5 or 0-1 or 0-100). The sum of all values again can be expressed in a scale 0-100, where 100 is equal to the maximum possible value, when summing up all criteria.

A threshold can be set to define the value, when a grid cell is assumed to be significant for maintaining of the GI. For example, in the Pan-European cases study, described before, the values of ecosystem service assessment and core habitat modelling were normalised on the scale 0-5. The normalised results of each criterion were integrated by selection of maximum values, i.e. the value of criterion with the highest score was assigned to each grid cell. Then the areas which were scored with maximum value (5) for the capacity to deliver ecosystem services or as actual core habits based on habitat modelling where included in the Core GI network, while areas scored with value 4 were included in the Subsidiary GI network.

- **Multi-criteria analysis for prioritisation of areas significant for GI**

Spatial multicriteria analysis is a decision-support method that helps to compare different development/land use alternatives or to prioritise areas for a particular development option by assessing them against a set of explicitly defined criteria. These criteria should account for the most relevant aspects in a given decision-making context. The method allows to assign weights to the selected criteria, indicating their relative importance for the particular decision-making question. The weights can range from 0-100%, and the sum of all percentages shall be equal to 100%. The weights can be assigned by the involved researchers, planners, experts, officials or local stakeholders, thus enabling participatory approach in a spatial planning or land use decision-making process.

The multi-criteria approach can be applied for prioritisation of the areas significant for the GI maintenance (or development) based on the above described criteria of ecological and landscape value and potential supply of ecosystem services. In such case the value of each grid cell is obtained by summing up the values of the selected criteria, which are multiplied by the assigned weight. The spatial multi-criteria approach involving local practitioners was also applied in the cases study of the

[34] Viinikka et al., (2018). Case Study Booklet: GREEN INFRASTRUCTURE AND URBAN PLANNING IN THE CITY OF JÄRVENPÄÄ. ESMERALDA EC H2020 Grant Agreement no. 642007.

city of Järvenpää, Finland for prioritisation of the areas for residential infill development and areas where the GI shall be maintained. [35]

4.2. Assessment of GI condition and identification of problem areas

The planning solutions and measures for improvement of GI shall be based on:

- analysis of the condition of the existing GI and its capacity to supply ecosystem service;
- apprising of the societal challenges related to insufficient environmental quality or risks as well as inadequate ecosystem service supply;
- identification of the problem areas were improvements of the GI are required or where application of particular nature-based solutions would be the most effective.

Methods for assessing the condition of GI and identification of problem areas

- **Analysis of 'cold' and 'hot' spots in ecosystem service supply**

'Cold' and 'hot' spot analysis is relatively simple and fast way to obtain an overview on capacity of the ecosystem to supply multiple-services in a situation when mapping of the single services has been performed. The cold spots are the spatial units where great number of ecosystem services are provided at low or very low values, while hot spots represent the units where several ecosystem services are provided at high or very high values. Thus, the cold spots indicate the areas where certain land use change or management measures could be applied for increasing the ecosystem service supply. The hot spots on other hand indicate areas with high ecosystem service supply potential and importance for GI, which should be maintained avoiding land use change or intensification.

- **Connectivity analysis of GI**

Connectivity of the GI promotes the provision of many ecosystem services, as connectivity is fundamentally linked to the ecological processes providing these services. Therefore, the connectivity analysis might be essential for assessment of the GI condition. However, such analysis can be rather complicated requiring specific GIS and modelling skills. Ecological connectivity models can be applied to evaluate the structural and/or functional degree to which the landscape facilitates or hinders movement of different ecological processes. For example, *Structural connectivity models* apply Land Use Land Cover (LULC) data as a basis to generate the geometry of the landscape elements and perform connectivity or fragmentation analyses. The latter are used to define the spatial pattern of the service providing units and their capacity to provide services. *Functional connectivity models* use data from species dispersal in addition to physical attributes of the landscape.[36]

- **Mapping of environmental risks and pressures**

Mapping of the environmental risks and pressures can be based on available data sets, e.g. data on anthropogenic landcover types (e.g. urban fabric, industrial areas, road network, dump sites, mineral extraction sites etc.), monitoring data on water pollution from diffuse and point sources, areas of flood

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[35] Tiitu, M., Viinikka, A., Kopperoinen, L., Geneletti, D., 2018. Balancing urban green space and residential infill development: A spatial multi-criteria approach based on practitioner engagement. Journal of Environmental Assessment Policy and Management 20(3): 1840004.

[36] Vihervaara, P., Mononen, L., Nedkov S., Viinikka, A., et al. (2018). Biophysical mapping and assessment methods for ecosystem services. Deliverable D3.3 EU Horizon 2020 ESMERALDA Project, Grant agreement No. 642007.

risks etc. Important source of information for planning of GI in river landscapes can be water quality assessment in water bodies performed for monitoring the implementation of the river basin management plans.

Environmental pressures can be also modelled by using sophisticated process-based models, which rely on the explicit representation of ecological and physical processes, such as carbon sequestration or nutrient cycling, that determine the functioning of ecosystems. These models can explore the impact of anthropogenic pressures on ecosystems and their biogeochemical processes.

4.3. Development and assessment of scenarios for GI improvement

Scenarios for GI improvement shall be built on results of existing GI mapping, analysis of its condition as well as identified environmental risks and pressures. The proposed solutions shall address particular societal challenges and shall be applied in the areas where particular solutions would be the most effective. Therefore, scenario development for GI improvement includes:

- Identification of the locations where GI interventions would be necessary and where the implementation of GI improvement solutions would bring the maximum benefit to society.
- Assessment of the impacts of the proposed solutions/scenario on landscape structure, connectivity of GI and ecosystem service supply;
- Involvement of local stakeholders in development/ prioritisation of the proposed solutions and discussing their likely impacts and implementation possibilities.

Methods for identification of the most suitable areas for particular NBS.

❖ **Construction of GIS models and tools** for identifying most suitable areas for specific NBS:

Example of the Irwell Catchment Pilot, UK demonstrates that GIS can be applied to overlay different layers of landscape features (each providing a potential pathway for pollutants or water) in order to assess the opportunities of GI to minimise the environmental risks. As result of this assessment so called "heat map" is generated, which is used for targeting of interventions, or further detailed investigation. A map highlights those locations that have the greatest number of opportunities to disrupt pathways.

Slightly different approach has been applied in Antwerp, Belgium, where a GIS based *Greentool* [37] was developed to support spatial planners and city officials to take smart and green measures when developing urban locations. The tool includes modelling results on distribution of several pressures (air quality, noise, urban heat, flood risks and areas with shortage of green space), which were developed using process-based models. Expert based scoring matrix was created to assess the impacts of different measures (e.g. creation of green roof) on the assessed pressures. The results of the scoring were applied in the *Greentool* to identify the areas where selected GI solution will have the most positive effect (see figure 8).

[37] https://groentool.antwerpen.be/

Figure 8. Application of GIS based tool for identification of the most suitable areas for GI solutions in the Antwerp, Belgium (Source: Liekens et al., 2018)

Methods for assessment of impact of the proposed scenarios

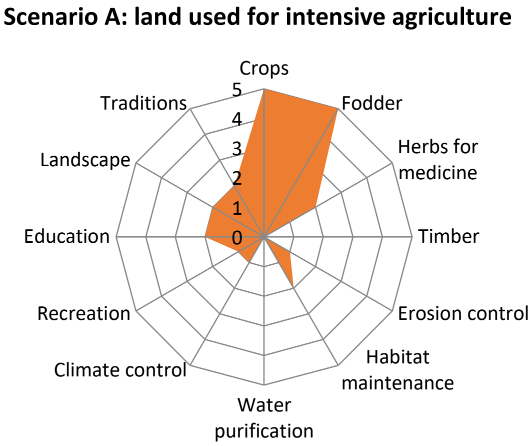
- **Analysis of landscape structure**

Impacts of the proposed GI solutions/scenarios on maintenance of the ecological networks and condition of the GI can be assessed by applying landscape-ecology approach – analysis of landscape metrics. This includes characterisation of the landscape structure forming patterns (i.e. dominant land use type or matrix, patch within the matrix and; and corridors between the patches). Furthermore, methods for GI connectivity analysis, described before, can be applied to assess the impacts on ecological processes underpinning the ecosystem service supply. This includes GIS analysis of the change in spatial patterns of landscape and impact of this change on GI connectivity.

- **Trade-off analysis of the proposed scenarios**

Trade-off analysis can be applied to compare two different scenarios or land use options with regard to potential of ecosystem service supply. This can include comparison of the current situation with proposed development scenario as well as comparison of two alternative development options. The trad-off analysis reveals which ecosystem services are increasing and which decreasing as result of the proposed change. The most convenient approach for comparing ecosystem service supply of two different development options is by using ecosystem service scoring matrix, where ecosystem service supply potential is assessed against different LU/LC types (the matrix reveals the change of ecosystem service value in the case of change of the LU/LC type). Thus, the same matrix is applied for mapping of the ecosystem service supply of the proposed scenario.

The trade-offs of between two scenarios can be visualised by calculating the weighted average of each ecosystem service within the study area depending on area covered by particular LULC types (see figure 9).



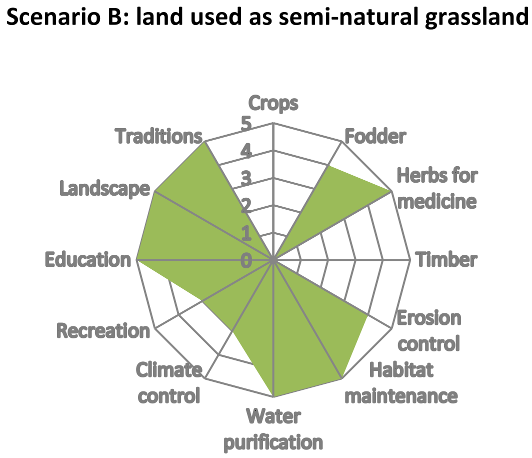


Figure 9. Hypothetical representation of the ecosystem service values in areas dominated by two different land use types – intensive agriculture and semi-natural grasslands.

Methods for stakeholder engagement

Stakeholders can be involved and contribute to different stages of the scenario development including selection of most appropriate GI interventions/NBS as well as evaluation and discussion of proposed solutions and their impacts. In order to stimulate stakeholder contribution different discussion moderation techniques can be applied including focus group discussion, “world café” method, SWOT analysis as well as questionnaires and online surveys.

Suitable method for scenario analysis can be also the above described the multi-criteria decision analysis, where stakeholders can participate in weighting of selected criteria used to assess the proposed scenarios and, in this way, contribute in selection of most desirable scenario. Application of this method was also tested in the above described cases of GI planning in Irwell Catchment Pilot, UK and city of Järvenpää, Finland.

5. Data sets suitable for green infrastructure planning

The suitable data sources for the different steps in GI planning and their applicability for the different planning levels are listed in the Table 7.

Table 7. Data sets suitable for GI planning

GI planning steps	Data sources	Applicability at different planning levels			
		Regional scale	Municipality scale	River valley scale	Local scale
1. Mapping and assessment of existing GI					
Ecological value assessment	Habitat distribution maps	X	X	X	X
	Distribution of protected/rare/endemic species	X	X	X	X
	Geomorphological/geology maps	X	X	X	X
	Land cover maps	X	X		

	Maps of protected areas	X	X	X	X
Landscape value assessment	Land cover maps	X	X		
	Topography maps	X	X	X	X
	Cultural heritage sites	X	X	X	X
	Thematic maps	X	X	X	X
	Planning documents	X	X	X	X
Ecosystem service assessment	Land cover/land use maps based on satellite images	X	X		
	Land use data from spatial plans		X	X	X
	Agriculture land use (Data of the Integrated administration and control system)	X	X	X	X
	Forest inventory data	X	X	X	X
	Habitat distribution maps	X	X	X	X
	Soil maps	X	X	X	X
	Topography maps	X	X	X	X
2. Assessment of GI condition and identification of problem areas					
Cold spot/ hotspot analysis	Ecosystem service assessment maps	X	X	X	X
Connectivity analysis	Land cover/land use maps based on satellite images	X	X		
	Species distribution/migration data	X	X	X	X
	Habitat distribution maps	X	X	X	X
Risk assessment	Flood risk assessment maps	X	X	X	X
	Monitoring data on quality of water bodies	X	X	X	X
	Monitoring data on point and diffuse pollution sources	X	X	X	X
	Land cover/land use maps based on satellite images	X	X		
	Land use data from spatial plans	X	X	X	X
	Road network and other grey infrastructure data	X	X	X	X
3. Development and assessment of scenarios for GI improvement					
Identification of the most suitable areas for GI interventions/ NBS	Results of risk and pressure assessment maps	X	X	X	X
	Existing GI	X	X	X	X
Trade-off analysis	Ecosystem service assessment maps	X	X	X	X
	Existing GI	X	X	X	X

Further reading

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