IMAGINE COOKBOOK SERIES N°4 Green Infrastructure management for ecosystem services

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Green Infrastructure management for ecosystem services

Photo: Geert de Blust (INBO).

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Table of Contents

Foreword 3

1. Background and objective of the cookbook 4

2. Main phases 6

3. GI ecosystem functioning: a base for sustained and optimized provision of ecosystem services.. 7

3.1. Framework: functioning, condition and management of service providing units for ecosystem services 11

3.1.1. Ecosystem service Local climate regulation 11

3.1.2. Ecosystem service Air quality regulation 13

3.1.3. Ecosystem service Pest control 14

3.1.4. Ecosystem service Pollination and Seed dispersal 15

3.1.5. Ecosystem service Maintenance of water quality 16

3.1.6. Ecosystem service Mass stabilization and control of erosion rates 17

3.1.7. Ecosystem service Protection against floods 18

3.1.8. Ecosystem service Wild plants, algae, fungi and their outputs 19

3.1.9. Ecosystem service Wild animals and their outputs 20

4. Assessing GI management and restoration needs for the sustained provision of ecosystem services 21

5. Management measures for the sustained provision of ecosystem services 26

5.1. Rivers and lakes management for ecosystem services 26

5.2. Wetland management for ecosystem services 32

5.3. Grassland management for ecosystem services 36

5.4. Forest management for ecosystem services 40

6. Planning management for ecosystem services 46

6.1. Steps in the development of a GI management plan for ecosystem services 46

Step 1: Define management area and process 47

Step 2: Identify demand for ecosystem services 47

Step 3: Determine current and desired ecosystem services supply 47

Step 4: Determine ecosystem functioning for ecosystem services 48

Step 5: Take into account ecosystem resilience to drivers of change 48

Step 6: Specify management for ecosystem services 48

6.2. Key decisions to be made when preparing a GI management plan for ecosystem services 49

6.2.1. Are bundles of goals always achievable? 49

6.2.2. Individual GI habitats or entire GI patches as spatial unit of management? 51
6.2.3. Is the GI element always the most appropriate unit for biodiversity management? ... 51
6.2.4. Is ecosystem services provision ensured by only managing the SPAs? 52
6.2.5. When is managing the landscape matrix of GI a prerequisite? 52
6.2.6. Are the ecosystem services provisioning areas accessible? 60
7. Intended outputs and outcomes 61
References 62
Appendices 68
IMAGINE project summary 71

Foreword

Often the methodological side in (applied) biodiversity projects remains unelaborated as "tacit" expert knowledge, and after the project's end, is scattered across different guidelines, or is elaborated in the method's sections in respective scientific publications. This might hinder the effective use of such knowledge and experiences.

The IMAGINE "cookbooks" is a series of guidelines intended to provide guidelines and support for scientists and practitioners working on Green Infrastructure (GI) issues. Our intention with this series is to make such methodological knowledge ("how to?") more readily available for two main potential user groups:

- other scientists working on Green Infrastructure ecological or socio-political aspects;
- national, regional, or local policy-makers and GI managers, who need some advice on practical aspects of GI governance.

This series consists of nine guidelines, with the following topical focuses for:

1. Evaluating ecosystem services capacity
2. Assessing GI vulnerability to ecosystem degradation at the landscape scale
3. Assessing detailed GI habitat quality for biodiversity and ecosystem services
4. **GI management for ecosystem services (this cookbook)**
5. Analysing coherence between different policies affecting GI
6. Analysing GI stakeholders, social frictions and opportunities
7. Adaptive planning tools for the allocation of GI
8. Quantifying GI structure and connectivity in GI elements
9. Defining and evaluating ecosystem condition

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1. Background and objective of the cookbook

Green infrastructure (GI) is an important source of ecological habitat and ecosystem services. The potential of the GI in an area to deliver ecosystem services not only depends on the land cover and the habitat types present but also the quality and the localization of the habitats, the so-called 'service providing unit' (sensu: Fisher *et al.* 2009). Environmental and spatial conditions, species composition, use, and management of a particular habitat will determine its performance. However, seldom habitat typologies or land cover classifications are detailed enough to describe the variation in the quality of a particular habitat or land cover type. This not only reduces the feasibility to assess the effectiveness of ecosystem service provision in an area but also yields only limited information about what to do to achieve the required habitat quality to provide the functions and services. For landscape and spatial planning that focuses on defining general development potentials and goals, the lack of a clear GI quality indication may not yet be a constraint. For local landscape design and management plans that seek to realize set objectives regarding ecosystem services and optimize their provision, the lack of detailed knowledge about habitat performance will hinder the proper implementation of the agreed policy.

In **three closely topic-related cookbooks (n° 2, 3, and 4)**, we describe the approach used in the IMAGINE project to assess the vulnerability of Green infrastructure to ecosystem degradation, to describe the quality of GI, and to facilitate stakeholders to decide about the management of GI, all concerning the potential of this network to deliver ecosystem services and to sustain biodiversity. The rationale and the methodology may equally inspire and guide other projects where information is needed about the composition and quality of GI networks.

When evaluating the quality of a subject, often a distinction is made between *intrinsic value* and *instrumental value.* Concerning GI and nature, intrinsic value refers to the perspective that nature has value in its own right (*ecocentric values*), independent of direct or indirect benefits to man (see e.g. Piccolo, 2017). Instrumental value, on the other hand, refers to the desired end (*anthropocentric values*), for instance, the delivery of an ecosystem service by a habitat (see, e.g., Kaufman 1980; Maguire and Justus 2008). In IMAGINE, we foremost focus on the instrumental value; the value the GI has to deliver desired ecosystem services. Also, connectedness and habitat suitability of the green-blue network can be interpreted as instrumental as it is a prerequisite to support viable populations.

There are many criteria and indicators that can be applied to assess the quality or even 'health' of habitats and their networks (see, e.g., Machado 2004; Lu *et al.* 2015; BISE, Biodiversity Information System for Europe, https://biodiversity.europa.eu/). The selection of appropriate indicators and assessment methodologies very much depends on the level of detail needed for the purpose. More general indicators inform about essential conditions, or about the capacity to resist degradation. Often this approach is applied for region-wide assessments and serves the policy and management decisions taken at a higher level. On the local level indicators will be much more detailed and relate to very specific purposes such as the valuation of habitats concerning the species they sustain, the evolution of habitat quality, or the potential to provide particular ecosystem services.

In the IMAGINE project, we adhere to a hierarchical approach to assess the quality of green infrastructure (elements) for delivering ecosystem services and ecological functions. This hierarchy is related to both the spatial and thematic level of detail. At the most general level, the landscape (patch) level, the vulnerability of green infrastructure to degradation is assessed from area-covering land cover data. This vulnerability mainly has a signalling function, as it allows for the identification of areas that require a more up-close quality monitoring. At the detailed level, some landscape metrics can already indicate the potential quality of a GI habitat patch, but the actual quality should be assessed using a targeted field survey. The detailed GI habitat quality description yields the information needed to decide about the proper restoration and management measures that should be taken to realize desired ecosystem services and sustain biodiversity.

2. Main phases

In two cookbooks approaches to assess habitat quality of GI are described for two spatial levels:

1. a *landscape-scale vulnerability to external disturbances*; in IMAGINE applied on the level of entire land cover patches within the case study sites (CSS)
2. a *detailed habitat quality* in relation to particular local projects, objectives or problems; in IMAGINE applied on the level of some detailed studies of habitat quality related to selected ecosystem services.

The first is a **core set activity** of IMAGINE, carried out in each CSS. It yields a key indicator used in other work packages of IMAGINE. The second is an **in depth activity** of IMAGINE, that provides key information useful to interpret the results of the field experiment of work package 2, and yields basic data for the analysis of management and restoration requirements which are needed to improve ecosystem service delivery, an issue dealt with in cookbook n° 4 of IMAGINE work package 3.

In IMAGINE Cookbook n° 2 '***Assessing GI vulnerability to ecosystem degradation at the landscape scale***' (Heremans and De Blust 2020) the methodology to assess a landscape-scale vulnerability to external disturbances is described.

In IMAGINE cookbook n° 3 '***Assessing detailed GI habitat quality for biodiversity and ecosystem services***' (De Blust and Heremans) useful landscape metrics are proposed and a GI habitat typology and related attributes are described that may be used for an assessment of habitat quality. By avoiding regional nomenclature or unclear definitions, we've tried to present a methodology that can be broadly applied, regardless the specific geographical context.

In this IMAGINE Cookbook n° 4, '***Green infrastructure management for ecosystem services***' (De Blust and Heremans – **this report**) we analyze the functioning of a GI patch as a service providing unit based on required ecosystem attributes and the factors which may have an influence on this. The information can then be used to determine the most appropriate management measures for different GI habitat types and desired ecosystem services.

In practice, landscape managers can combine both spatial levels to optimize their management choices. In a first phase, they can identify the patches most prone to degradation using the landscape-scale vulnerability values as described in Cookbook n° 2, while in a second phase they can identify the most appropriate management for safeguarding the quality of these patches using the approaches elaborated in Cookbook n° 3, and this Cookbook n° 4.

3. GI ecosystem functioning: a base for sustained and optimized provision of ecosystem services

To determine the need for management or restoration of GI in order to provide desired ecosystem services, the GI properties have to be assessed. This can be done in general for a particular area, starting from a spatial analysis of GI in the landscape (see Cookbooks n° 2 and n° 3; Heremans and De Blust 2020; De Blust and Heremans 2020, respectively). The assumption is that spatial characteristics of GI reflect the potentials for ecosystem service provision (Syrbe and Walz 2012). In IMAGINE we work with a general vulnerability index of GI based on landscape metrics (Heremans and De Blust 2020). Combined with the estimated ecosystem service capacity, this index is used to determine and prioritize the need for preservation, conservation or restoration of GI. However, although the GI are spatially explicitly identified, no information is provided regarding the exact GI components that should be improved nor about the most appropriate management strategies to achieve this. To this end, a more detailed analysis and assessment of the actual state of the GI is needed, which implies a targeted survey (De Blust and Heremans 2020).

To select the management strategies that support a GI's sustained provision of ecosystem services, the functionality of **the key ecosystem components and processes** which determine this provision have to be assessed. The state of these components and processes inform about the need for management or restoration. This state is influenced by drivers that either improve or disturb their functionality to supply the services. Controlling the factors that affect the key attributes of the ecosystem is the main concern of management. Management can be site-specific, only targeting the GI habitat patch itself (the 'service providing area', SPA or 'service providing unit', SPU). In that case the goal is to maintain, improve or complete the ecosystem properties that facilitate the ecosystem service. When the SPUs are spatially disconnected from the places where the ESs are used, the area in between, the 'service connecting area' (SCA), comes into focus (Serna-Chavez *et al*. 2014). Management of the broader landscape surrounding the area that benefits from the ecosystem service (the 'service benefiting area', SBA) aims (i) to control the quality of the SPUs and (ii) to preserve or improve the effectiveness of the SCAs.

The functioning of the ecosystem processes can be assessed with indicators. Some of these indicators are landscape metrics that can be calculated from available maps or RS data (Syrbe and Walz 2012), others need original and detailed field surveys.

In order to select

- the indicators that inform about the quality and potential performance of GI to provide desired ecosystem services and
- the management or restoration strategies that may support sustained and optimized provision of ecosystem services,

a clear framework should be defined that sheds light on the pathways and links between the ecosystem properties and functioning required to provide ecosystem services, the driving forces that affect these properties and functioning, and the appropriate management to maintain or improve the services provision (see for instance: Bubb *et al*. 2017; Hansen and Pauleit 2014; van Oudenhoven *et al*. 2012).

For the ecosystem services core set of IMAGINE we elaborate the nexus **'key ecosystem structures and processes' – 'effective functional components and processes' – 'facilitating and disturbing factors' – 'management subject' – 'GI quality assessment criteria'** to analyse the determining factors that affect ecosystem services performance and that are thus the subjects for GI habitat management. The '*facilitating and disturbing factors*' (drivers of change), are the focus of attention. Specific objectives can be attached to them in order to achieve appropriate conditions required for the provision of the ecosystem services. In turn, appropriate conditions and objectives determine the specific interventions (management, development, restoration, protection, etc.) and the targets in order to maintain, improve, restore or re-create the supply of the ecosystem services. The '*subject of management*' can concern the habitat patch itself, i.e. the 'service provisioning area' (SPA), or the landscape as the 'connecting area' (SCA) in which a functional connection between providing area and 'service benefiting area' (SBA) should be guaranteed (the spatial flow of ecosystem services), or in which a system of individual habitat elements performs in a network that sustains the crucial ecosystem processes. Finally, criteria to evaluate the condition or state of GI can be deduced. These '*quality assessment criteria*' can be general or detailed. The IUCN manual 'Planning management for ecosystem services – An operations manual' (Bubb *et al*. 2017) illustrates in a clear way how reasoning according such a framework leads to appropriate management decisions; management which is key to ensure a sustained flow of ecosystem services (**Figure 1**).

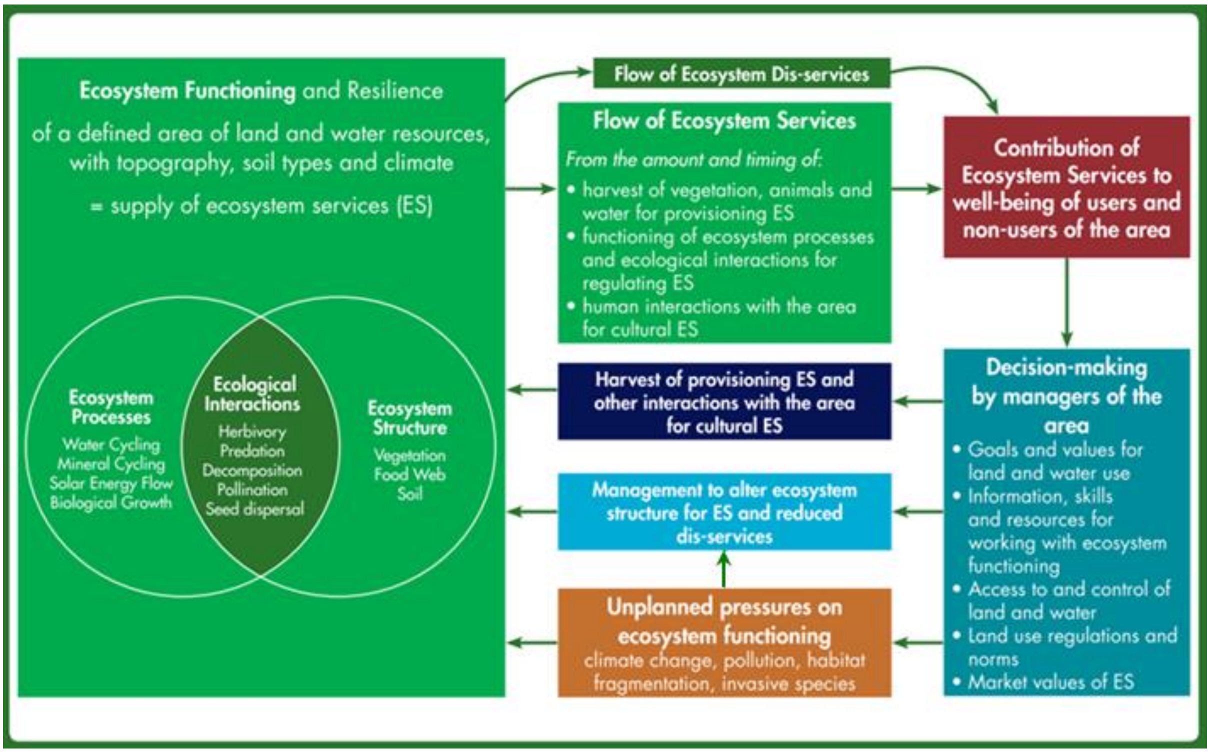


Figure 1. *Conceptual framework to guide working with ecosystem functioning for ecosystem services (Bubb et al. 2017 – partially adapted).*

We elaborated the nexus 'key ecosystem structures and processes' – 'effective functional components and processes' – 'facilitating and disturbing factors' – 'management subject' – 'GI quality assessment criteria' for 9 ecosystem services: local climate regulation; air quality regulation; pest control; pollination and seed dispersal; maintenance of water quality; mass stabilization and control of erosion rates; protection against floods; wild plants, algae, fungi and their outputs; wild animals and their outputs. This framework can be a tool to decide about the most important features of a GI habitat for which the quality has to be assessed with regard to a particular ecosystem service and to formulate the related management priorities and targets. In this respect the framework is an important building block to implement effective management of GI habitat in relation to ecosystem services provision.

The framework is based on a limited literature review and expert knowledge. Syrbe and Walz (2012) give examples of landscape metrics indicators, Albert *et al*. (2016) present ecosystem services indicators from a nature conservation policy perspective, Harrison *et al*. (2014) and Meiresonne and Turkelboom (2014) compiled biodiversity indicators for ecosystem services. When relevant, more specific literature is cited with the ecosystem service concerned.

3.1. Framework: functioning, condition and management of service providing units for ecosystem services

3.1.1. *Ecosystem service* *Local climate regulation*

Key ecosystem structures & processes	Effective functional components & processes	Facilitating & Disturbing factors (management issues)	Subject of management (Patch / Landscape)	Quality assessment criteria (General & Detail)
Air flow	Cool air producing GI habitat types Evapotranspiration	F: Cooling GI uphill; Large GI patch; Sufficient groundwater supply D: Land cover change; Objects in SCA that block free air movement; Desiccation	L: SCA open, facilitating air movement P: Maintenance or restoration of habitat types; Preventing of desiccation	G: Slope length; Land cover
Air renewal / ventilation	Turbulence boundary layer; Vegetation structure; Edge density; GI habitat types (incl. water bodies)	F: Heterogeneous vegetation structure and boundary layer D: Closing of edge	P: Maintenance or restoration of habitat types; Vegetation density control	G: Edge contrast; roughness D: GI habitat type; optical edge density
Carbon sink	Organic matter stock above and below ground; Peat formation; Hydrology; Longevity and growth of plants	F: Forest development; Old grown forest; No-till or minimal soil disturbance; Accumulation of litter D: Desiccation; Short rotation wood biomass harvesting; Total biomass harvesting; Soil erosion; Mineralization of organic matter;	L: Restoration of hydrology P: Forest management: tree species adapted to original site conditions, slow growing species, long term harvesting, dead wood accumulation, minimal soil disturbance; Allowing peat formation	D: Tree species composition; Harvesting infrastructure; Amount of dead wood; Removal of drainage ditches and groundwater extraction; Indicators of peat growth and of peat degradation or desiccation; Surface and groundwater fluctuation; Thickness of litter and organic matter layer

		Emission of greenhouse gasses (CH_4, N_2O, CO_2)		
Albedo effect; Aerosol emission	Reflection and absorption of solar radiation; Colour of land cover or vegetation species composition	F: Light surfaces D: Land cover change to dark surfaces	P: Tree and vegetation selection	D: Share of evergreen vegetation
Microclimate temperature regulation	Vegetation structure; Evapotranspiration	F: Shading vegetation, trees and forest D: Land cover change; Decrease of tree cover	P: Maintaining or improving tree cover	D: GI habitat type; Tree cover

See also: Smith *et al*. (2013)

3.1.2. Ecosystem service *Air quality regulation*

Key ecosystem structures & processes	Effective functional components & processes	Facilitating & Disturbing factors (management issues)	Subject of management (Patch / Landscape)	Quality assessment criteria (General & Detail)
Wind speed reduction. Dry deposition (interception, sedimentation capture); Gaseous absorption; Atmospheric dispersion	Properties of tree trunks, stems, branches, needles, leaves; Height of vegetation; Leave surface feature; Number of stomata per area; Foliage longevity; Vegetation structure and density; Species environmental tolerance	F: Plant species diversity; Complex vegetation structure; Development of vegetation layers; Width of vegetation belts D: Low environmental tolerance (conifers more sensitive to air pollution compared to broad leaved species); Presence of large numbers of biogenic volatile organic compounds (BVOC) emitting species (pollutant precursors); Land use change and management that release pollutants to the atmosphere	L: Total area and spatial position relative to pollution source; Distance between GI and pollution source P: Selection of species; Share of conifers and evergreen species; Share of hairy or rough leaf surfaces; Maintenance of optimal density (optical density: 40-50%)	G: Land cover in the SCA; Share and localization of air quality regulating habitats D: GI habitat types; Share of particular species traits (evergreen, leaf properties, pollution tolerance); Optical vegetation density; Vegetation height

See also: Barwise and Kumar (2020), Cellier *et al*. (2011), Wesseling *et al*. (2004)

3.1.3. Ecosystem service Pest control

Key ecosystem structures & processes	Effective functional components & processes	Facilitating & Disturbing factors (management issues)	Subject of management (Patch / Landscape)	Quality assessment criteria (General & Detail)
Predation; competition; parasitism Animal movements	Mosaic of functional micro-habitats for pest control species: Wintering and hibernation habitat; Alternative food sources; Alternative prey and hosts.	F: Plant species diversity; Habitat complexity; Wintering sites, nest sites, shelter places; Large local species pool of pest controlling species; GI fringe habitats allowing early season field colonization by natural enemies; Connectivity to crop fields D: Excessive fertilization and N-input that promote dominance of potentially unsuitable plant species; Land cover change and decrease of (semi-) natural habitats	P: Food web (re)construction with alternative sources; Selection of appropriate plant species (nectar and pollen); Development of species rich hedgerows, flower strips, field margins; Increase of tussock-forming vegetation and accumulation of litter to support high densities of hibernating predators; Decrease of broad spectrum pesticides in SBA and SCA; Management to avoid spread of unwanted plant species; Minimal or no-tillage of field margins; Avoiding species that accidently increase pest or pathogen populations or enhance weed pressure; Increase of wooded habitats with moderate microclimate to extend the lifespans of parasitoids L: Facilitation of SPA - SBA contact; Increase of crop non-crop interfaces by increasing temporary within-field strips and field margins: resource close to the crop, attracting and supporting natural enemies that provide immediate and annual control of pests; Creation of permanent landscape features; Completing grass strips under lines of trees with beneficial plant mixtures; Improvement of habitat connectivity.	G: Land cover; Habitat density; Species-based connectivity D: Share of pollen and nectar producing plant species; Share of shelter and hibernation micro-habitats (litter, dead wood, tussocks); Field margins with permanent vegetation; Measures concerning soil management (no-tillage); Sowing of annual within-field and margin elements

See also: Bianchi *et al*. (2006), Jeanneret *et al*. (2016)

3.1.4. *Ecosystem service* *Pollination and Seed dispersal*

Key ecosystem structures & processes	**Effective functional components & processes**	**Facilitating & Disturbing factors (management issues)**	**Subject of management (Patch / Landscape)**	**Quality assessment criteria (General & Detail)**
Pollinating insects Animal movements	Pollination Mosaic of functional micro-habitats for pollinating insects: wintering and hibernation habitat. Sufficient supply of pollen and nectar producing plants during the activity period of pollinators	F: Vegetation with ample pollen and nectar producing plant species; Wide variety of nesting and hibernation habitats; Large local species pool of pollinators and food plants; Orchards and fields within reach of the pollinating insects D: Fertilizer and N-input causing decline of species richness; Land cover change and decrease of (semi-) natural habitats	L: Improvement of habitat connectivity, facilitating contact between SPA and SBA; Creation of flower strips and field margins; Application of 'green manure crops' after harvest of main crop; Decrease of broad spectrum pesticides in SBA and SCA. P: Managing for bee nest sites (patches of bare ground, standing dead trees and fallen branches); No soil disturbance; Spatial and temporal distribution of resources to make diverse pollinator populations more persistent	G: Land cover; Share of flower strips; Connectivity D: Share of pollinators attracting plants; Presence of micro-habitats for hibernation and nesting. Bare ground; Dead wood

See also: Kremen *et al*. (2007)

3.1.5. *Ecosystem service Maintenance of water quality*

Key ecosystem structures & processes	Effective functional components & processes	Facilitating & Disturbing factors (management issues)	Subject of management (Patch / Landscape)	Quality assessment criteria (General & Detail)
Self purification capacity (sedimentation and re-suspension, filtration, gas transfer); Mineralization; Denitrification; Microbial activity; Chemical oxidation Soil texture; Water content (seepage water) Standing water and stream hydro-morphological properties Vegetation type and productivity	Wetlands; Riparian vegetation; Aquatic vegetation; Stream community species feeding traits (river continuum concept) Seepage areas; Infiltration rates; Inundation regime Primary production; Carbon provision and denitrification Water depth; Transparency and light; Retention time; Stream velocity; Stream bed texture	F: High groundwater level; Near-natural hydro-morphological regime; Stream-alluvial plane connectivity; Wetland Community development; Temporary inundation D: Permanent and temporary pollution; High suspension rates; High stock of fish species that grub through bottom sediments for food; Frequent mud and vegetation clearing; Invasive species; Stream canalization, compartments, weirs, barriers; O_2 depletion.	P: Increase of in-stream habitat diversity (stream deflectors); Restoration and maintenance of river bank; Assurance of free stream flow by shadowing riparian vegetation; Restoration of stream meanders (increase of water residence time); Phasing and zoning of vegetation clearing; Mowing of wetland vegetation; Varied bank profile with varied inundation regime; Promotion of helophytes; Avoidance of fertilizer and mud enrichment near drains by provision of helophytes; Control of mud grubbing fish species; Restoration of food web (predator fish species) L: Restoration of stream continuum; Management of weirs. Improvement of transversal connectivity of watercourse – riparian zone –alluvial plane including free fish movement; Functional links between habitats (ponds, ditches, wetland patches) in SCA with regard to transformation and transfer of nitrogen in both surface and groundwater	G: Stream hydro-morphological characteristics; Land cover; Connectivity D: Presence and share of reed beds, wetland vegetation, helophytes, temporary inundated vegetation; River profile, structure and texture of bank and shore; Variation of streambed texture, water depth, flow velocity; Seepage force, (ground) water height; Presence of invasive species; Presence of barriers affecting water flow and movement of aquatic animal; Presence of drains, outlets, pollution points; Mud and vegetation clearance regime

See also: Cellier *et al*. (2011), Garnier *et al*. (2014), Swanson *et al*. (2017)

3.1.6. Ecosystem service *Mass stabilization and control of erosion rates*

Key ecosystem structures & processes	Effective functional components & processes	Facilitating & Disturbing factors (management issues)	Subject of management (Patch / Landscape)	Quality assessment criteria (General & Detail)
Sediment movement: aeolean erosion, water erosion, runoff Wind and water retarding; Water interception; Infiltration Soil texture; Slope; Permanent vegetation and land cover	Vegetation type: Forest, grassland, hedgerows, lines of trees; Height, structure and density Density and depth of roots; Organic matter content of soil Orientation and configuration of habitats	F: Closed, uniform and permanent near ground vegetation (to reduce fluvial erosion); Dense rooting of fine (< 1 mm) roots in upper soil layer (50 cm); Mixed forest with a variety of tree and shrub species and different age classes, herb and litter layer present; Windbreaks hedgerows with density 40-60%; Tree species for short rotation cultivation with shallow rooting system (willow, poplar); Non-inversion tillage D: Windbreaks with density > 80% (= excessive leeward turbulence which reduces effectiveness beyond 8H); Absence of network of habitats and landscape elements that reduce wind speed and fluvial erosion (runoff)	P: Maintenance of closed swart: mowing; Control of hedge density: cutting and planting; Complementing lines of trees with understory and species rich grass layer; No-tillage practice; Increase of organic matter content of soils; Avoidance of soil damage during management; Control of burrowing animals L: Implementation of a network of erosion prevention habitats and landscape elements; Position and orientation of erosion preventing habitats	G: Slope length; Mesh size, Edge density and contrast D: Presence of grass buffer strips, vegetated walls and banks, erosion pools, hedgerows; Vegetation density (optical density); Species composition; Share of bare soil; Position and orientation of erosion reducing elements with regard to topography, prevailing wind direction and location of SBA

3.1.7. Ecosystem service Protection against floods

Key ecosystem structures & processes	**Effective functional components & processes**	**Facilitating & Disturbing factors (management issues)**	**Subject of management (Patch / Landscape)**	**Quality assessment criteria (General & Detail)**
Hydrology and runoff; Retarding; Retention; Infiltration; Discharge	Spatial relation in the watershed: infiltration area, seepage area, river inundation area; Soil texture, ground water height; Stream characteristics; Vegetation roughness	F: Vegetation supports infiltration during heavy rain; Complex forest with dense herb layer, litter and diverse soil biota (increasing soil perturbation) optimizes infiltration; Reed beds, wetlands, alluvial forest to retain ground and surface water in upstream areas; Reappraisal of open ditches; Flood retention areas; Controlled connection of stream and flood control area; River discharge control measures: meanders, riparian vegetation and aquatic vegetation development that reduce flow velocity, sediment transport and increase residence time, storage and denitrification D: Soil compaction surface sealing; Shrub and forest development in retention areas; Input of sediment and fertilizers, causing decline of storage capacity and rapid vegetation development vegetation.	P: Restoration of sealed surfaces; Avoidance of soil compaction; Cutting and mowing of wetland vegetation; Phasing of aquatic vegetation clearing; Avoiding direct input of sediment and fertilizers; Installation of helophyte filters to purify nutrient loaded inlet water and to trap sediment; Allocation of sufficient room to buffer floods L: Diminishing of sealed surfaces; Concerted implementation of interrelated discharge diminishing measures on the scale of the catchment	G: Roughness; Stream characteristics; Land cover D: Vegetation types; Share of unvegetated patches; Presence and area of sealed surface; Inlet of potentially polluted water; Storage capacity

3.1.8. Ecosystem service Wild plants, algae, fungi and their outputs

Key ecosystem structures & processes	Effective functional components & processes	Facilitating & Disturbing factors (management issues)	Subject of management (Patch / Landscape)	Quality assessment criteria (General & Detail)
Viable populations of edible plants, algae and fungi	Sufficiently large populations of edible species; Fruits, leaves, roots, flowers, whole body of plants, algae and fungi; Vegetation type	F: Favorable growing conditions D: Contaminated environment (water, soil, air, radiation); Plants or fungi polluted by fox tapeworm; Presence of poisonous or toxic species that can be mistaken as edible; Excessive harvest reducing plant productivity and population viability; Unnatural manipulation of environmental conditions by irrigation and/or fertilizing	P: Promoting favorable growing conditions of target species by reducing competition	Presence and amount of edible species

3.1.9. Ecosystem service Wild animals and their outputs

Key ecosystem structures & processes	Effective functional components & processes	Facilitating & Disturbing factors (management issues)	Subject of management (Patch / Landscape)	Quality assessment criteria (General & Detail)
Viable populations of wild game and fish Functional habitats in a complex landscape	Sufficiently large game and fish populations Sufficient food, shelter, reproduction and wintering habitat	F: Woodland with a variety of vegetation patches, forest edge; Complex landscape with a mosaic of shelter, foraging and reproduction habitat for specific game; Corridors and habitat networks that facilitate animal movements through the landscape D: overhunting and selective hunting that threaten populations; Introductions that threaten local gene pools	P: Development and preservation of suitable habitat L: Improvement of connectivity	G: Land cover; Habitat complexity; Connectivity D: Presence of specific functional habitat for target species; Presence of accessible drinking water; Presence of shelter and foraging habitat such as complex forest edges, shrubs, hedgerows, grassland, fields

4. Assessing GI management and restoration needs for the sustained provision of ecosystem services

To ensure a sustainable provision of ecosystem services and to improve the performance of the different habitat types with respect to this, the need for appropriate management of the GI habitats or effective restoration measures has to be assessed. The ecosystem services capacity assessment for each Case Study Site (the 'CSS capacity matrix') which is performed by stakeholders, local experts and the IMAGINE scientific partners associated with a CSS. It informs about the average suitability of different land cover classes within the site to deliver locally important ecosystem services. This is not sufficient for management purposes, as it is not spatially explicit and does not take into account the local state of the GI elements and their crucial attributes.

In IMAGINE we assessed the **necessity of management or restoration** interventions by combining three sources of information:

1) A landscape-scale assessment of vulnerability to ecosystem degradation assessment
2) Stakeholder questionnaires
3) Analysis of GI habitat functioning for ecosystem services provision

1) A general assessment of GI vulnerability to ecosystem degradation at the landscape scale (an entire CSS) yields information about the probability that GI patches are and remain in good condition, given the presence of environmental pressures in their vicinity (exposure); their internal configuration (sensitivity) and the way they are embedded in the broader GI matrix (adaptive capacity) (see: Heremans *et al*. in prep.; Weißhuhn 2019). The vulnerability index can be used to identify GI patches that are prone to degradation and call for (management) interventions. From a visual interpretation of the resulting maps the importance of landscape structure, land use pattern, and GI spatial configuration become apparent (**Figure 2**). These maps can thus be used as a first attempt to localize – on a regional or landscape level - the areas that may be eligible for conservation and/or restoration efforts, while a closer look reveals more clues about which what can be done to reduce the vulnerability.

Figure 2. *Map of GI vulnerability to ecological degradation for CSS Grote Nete (white = on-GI).*

Vulnerability alone however, does not inform yet about the importance of these GI patches. Prioritizing efforts to maintain or improve GI performance regarding ecosystem services provision must be based on a more elaborated rationale. With respect to this, Hobbs *et al*. (2003) suggest to combine (i) the degree of threat to a GI patch with (ii) the relative value of that habitat and (iii) the likelihood of successful management interventions. We followed this approach and combined (i) vulnerability with (ii) the importance for the delivery of locally desired ecosystem services. The latter is obtained by combining the capacity matrix with a stakeholder-based ecosystem services importance (Burkhard *et al*. 2009; REF to Cookbook WP2).

With three degrees of GI habitat patch vulnerability and of ecosystem services capacity, a number of different responses in terms of intervention types can be distinguished (see **Figure 3**).

- When a GI patch has a high capacity for delivering important ecosystem services, the main objective will be to safeguard this and to focus on the patch's quality. Combined with low patch vulnerability, passive *preservation* should be the goal. The habitat should be kept in its original state as its functioning is supposed to be optimal and active management interventions are not required. When vulnerability is medium, a more active *conservation* is appropriate. Targeted management measures that support and steer the development of populations, the structure and the availability of resources in the habitats should be implemented in order to strengthen ecosystem functioning and the associated ecosystem services provision. If vulnerability is high, active *restoration* is required. Crucial ecosystem attributes are likely to be altered or lost to such an extent that the habitat will no longer provide ecosystem services. Then measures should be taken to restore these attributes directly or to create conditions that allow their spontaneous recovery. Depending on the local situation, these measures can be executed either inside or outside the GI patch.
- For a patch with a medium capacity for delivering important ecosystem services, the objective will be to safeguard this element mainly by controlling external disturbing factors. When the patch vulnerability is low, mere *protection* can be the goal. This can be achieved by regulations that ensure that it is shielded from any threats. When the vulnerability is medium, disturbing factors should effectively be controlled in order to reduce the negative impact they (may) have on the habitat. This can be considered as *reclamation*. Measures are taken to decrease the negative influence of activities outside the habitat without removing activities altogether. When patch vulnerability is high, reversing or stopping the external disturbance and hence *remediation*, is the logical option. A change of land use in the surroundings of the patch can be the consequence.
- For a habitat type with a low capacity for delivering important ecosystem services, the required interventions are usually limited. In combination with low patch vulnerability, business as usual can continue and *no action* is needed. The habitat seems to be 'strong' enough to function in a proper way, even if the provision of ecosystem services is low. If vulnerability is medium, *maintenance* is required. The disturbing factors make some management measures necessary in order to maintain the habitat, however without raising the level of ambition regarding the provision of ecosystem services. When patch vulnerability is high, *transformation* can be considered. The chance that the habitat continues the already limited provision of ecosystem services will drop anyway, and thus transforming it to a 'novel ecosystem' (Hobbs *et al*., 2009) can be a reasonable alternative.

		Vulnerability		
		Low	**Medium**	**High**
Capacity for delivering important ES	**High**	*Preservation* (passive)	*Conservation* (active)	*Restoration* (proactive)
	Medium	*Protection* (threat avoidance)	*Reclamation* (threat reduction)	*Remediation* (threat reversal)
	Low	*No action*	*Maintenance*	*Transformation*

Figure 3. *Policy and management responses to maintain or improve ES provision by GI, given their actual vulnerability to ecosystem degradation (credits: Roel May, NINA).*

The third criterion, the foreseen effectiveness / efficiency of measures to be taken, cannot be retrieved from the general spatial analysis and the ecosystem services capacity matrix. Explicit data are needed about the type of disturbance acting on a habitat patch and about the actual state of the habitat's attributes that support the provision of the ecosystem services. The combination of vulnerability and capacity for delivering important ecosystem services thus informs *where to intervene,* potentially leading to a certain type of strategy (Fig. 3). Extra information about threats and detailed habitat quality shed light on *what to do* effectively. In this phase, appropriate measures can be selected based on the desired ecosystem services, the type and quality of the GI habitat and its spatial setting, taking into account the performance, required conditions, costs, etc. of alternative measures (see chapter Management measures for the sustained provision of ecosystem services).

Davies *et al*. (2006; cited in Hansen & Pauleit, 2014) presented a similar decision support matrix to select objectives and approaches to maintain and strengthen GI networks. This framework very much resembles the one presented above. However, ecosystem services capacity as such is not mentioned; instead it is the integrity (assessment of the vitality of key ecosystem functions) of individual GI elements and of the entire GI network that determine the potential measures (Fig. 4).

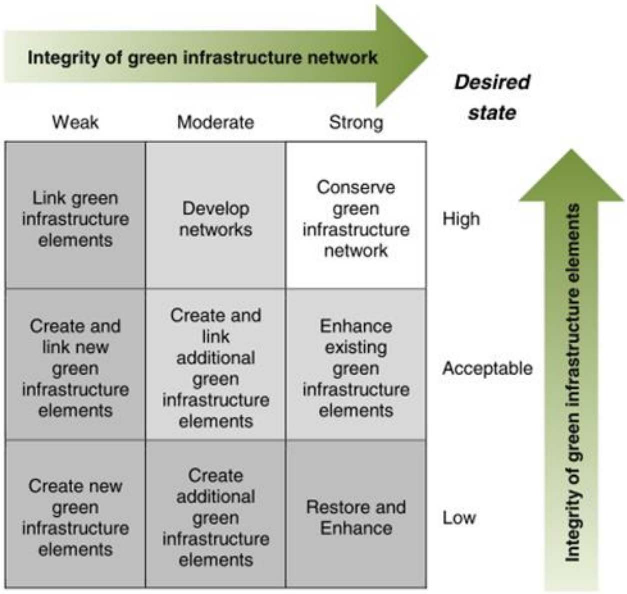


Figure 4. *Decision support matrix regarding general strategies and measures to manage or restore GI based on the integrity ('quality') of the GI elements and the GI network (Davies et al., 2006; cited in Hansen & Pauleit, 2014).*

2) A short questionnaire discussed with stakeholders and a targeted survey in some of the CSS inform about local GI use and management approaches, the opportunities present and the problems met. In order to increase comparability between sites and to ensure that all relevant aspects are included, we advise the use of a structured questionnaire (see ***Appendix 1*** for an example from the Imagine project).

In this structured questionnaire, the following topics can be included (non-exhaustive):

- ***The GI habitat types relevant to the area***. GI habitat quality and management are assessed with regard to particular objectives in terms of ecosystem services. Therefore it is important to achieve a common understanding of GI habitat types that support these services (a local ecosystem services capacity matrix).
- ***The current quality of these GI habitat types***. This involves an assessment of the potential to deliver desired ecosystem services. If the quality is rated as insufficient, the causes of weak performance and the measures to be taken to reverse the situation have to be explored.
- ***The current management of GI habitat elements***. Information has to be collected about the management techniques currently used for each of the habitat types, extended with details about frequency and timing; organization and regulations; and (grey) literature that substantiates the former aspects.
- ***Potential for improving management and restoration efforts***. Requirements regarding organization and local acceptance, technical details, availability of and access to information to improve effectiveness and efficiency of management have to be discussed.
- ***Demand and opportunities for multipurpose management***. As most GI habitats can support several ecosystem services, the potential and demand for multi-purpose management has to be assessed separately. Also determine whether this can be achieved with simple adaptations or if it implies a rethinking of the design and spatial configuration of the GI elements.

Discussions with stakeholders/managers not only yield valuable information about practical management issues, but also shed light on how GI management and policy relate to the broader societal context. This is important because this context will determine to large extent the support for GI related goals and the willingness to invest in their realization. Without a thorough understanding of how management and restoration objectives and measures might be received by the people in charge, it is difficult to predict their effective implementation and thus their probable impact. Discussions and inquiries must thus link the technical aspects of GI management and restoration with the societal reality. Ideally, these discussions should be completed by an analysis of socio-ecological interactions with regard to management, delivery remuneration, governance issues, etc. which are most tangible and concrete on the local level. Provided with this knowledge of the broader socio-ecological context, active local collaboration may succeed to find the most appropriate GI management and restoration measures to realize GI. After all, ite-specific tailoring of restoration and management will only be successful if embedded in a strong partnership with local stakeholders that identify with the land and the ecosystem services it provides.

3) An analysis of GI habitat functioning for ecosystem services provision identifies the ecosystem components and processes and their required state that lie at the basis of this delivery. As explained in framework of chapter3, this analysis yields the ecosystem attributes and the environmental conditions of which the quality has to be assessed in relation to the different ecosystem services. With management interventions, the attributes and conditions can be manipulated to maintain or improve ecosystem functioning and associated services provision. With this knowledge, an 'optimal' design and localization of a GI in the landscape can be proposed and adequate measures and techniques can be selected for its practical implementation.

5. Management measures for the sustained provision of ecosystem services

In this chapter, the main management and restoration measures and strategies are summarized per ecosystem service and disservice for four broad habitat categories: rivers and lakes, wetlands, grasslands and forests. Habitat can refer to extensive GI areas as or to a GI that is composed of small linear and point-like habitat elements.

Appropriate management measures can be derived from the analysis of the functioning of required ecosystem attributes and processes that determine the provision of ecosystem services (see chapter 3.1). Publications referred to in the next overview give scientific evidence or technical details with respect to the management strategies and measures that are proposed.

5.1. Rivers and lakes management for ecosystem services

Rivers including aquatic, river bank and riparian vegetation **Lakes including aquatic and shore vegetation** Linear and point-like landscape elements: ***Ponds and ditches***	
Local climate regulation	In general, rivers and lakes will be effective to provide ecosystem services including local climate regulation, when unrestricted ecological functioning is assured. Strategies to achieve this and management measures to improve performance of specific processes, therefore should take the total functioning into account (von Schiller *et al*., 2017; Ward *et al*., 2001). **Cooling effect**: Increase area of open water. Apply management techniques that sustain the determining factors of ecological river functioning. Different measures have to be considered (the River Restoration Centre, 1999). Ensure free water flow in rivers: remove barriers or establish bypasses, create in-stream flow velocity variation by maintenance or installation of stream deflectors (boulders, tree stems and logs). Maximize retention capacity and duration of standing waters, adapt outlet level and dimension, consider mud clearing. Facilitate internal water circulation through wind action which implies in case of small standing pools the absence of wind blocking constructions and forest near the windward side and low vegetation along the shores. Consider (temporary) installation of an aeration pump. Ensure free movement of cooling air (ventilation) from the water body to SBA: remove air flow barriers, increase and maintain low growing vegetation (grassland, herbs, low shrub) in the riparian zone and the SCA by grazing, mowing and cutting with a density (large herbivore stock rate) and periodicity according the productivity and growing rate of the respective vegetation types. Prevent expansion of trees and high growing shrubs by cutting. In case of woodland determine the preferred zone to create an effective ventilation corridor through clear cutting followed by mowing. Adapt forest management by making more use of coppicing.

	In general: the cooling effect of small water bodies, especially in cities, seems to be small, although water surface temperature may be considerably lower than the surrounding urban fabric (Jacobs *et al*., 2020; Völker *et al*., 2013). In urban and rural areas the cooling effect depends on the density, structure and material of the surroundings. Hence planning, design and management are crucial. **C-storage** (of less importance for local climate regulation): To allow transport of carbon to the ocean, management should ensure free water flow and sediment transport. To allow carbon storage in vegetation and sequestration of organic material in sediment and mud, vegetation and sediment clearance should be of relative low frequency. Frequent clearing of estuaries may release carbon and other greenhouse gasses to the atmosphere and increase turbidity what hinders vegetation development and hence carbon storage. Measures taken to improve the cooling effect of waters (such as mud and sediment clearing) and those taken to increase carbon storage (such as avoiding mud clearing because of increased emission of greenhouse gases and increasing turbidity of the water which hinders carbon storage) may oppose each other on the local scale.
Air quality regulation	Apart from the interception, sedimentation, capture of pollutants and the atmospheric dispersion brought about by riparian vegetation, rivers and standing waters do not contribute considerably to the regulation of air quality. No specific management measures are proposed.
Pest control	Rivers and lakes do not directly support the ecosystem service pest control. However, riparian vegetation may sustain populations of natural enemies when they provide alternative food sources, prey and hosts or when they contain suitable microhabitat for shelter, hibernation and/or reproduction. In this respect, riparian vegetation along ditches, rivulets and ponds in agricultural areas can be managed to optimize these functions. This implies cutting and mowing to prevent a few plant species to become dominant at the expense of species rich vegetation. Management measures should allow local accumulation of litter, dead wood, etc. as suitable shelter and hibernation microhabitat. Application of broad spectrum pesticides should be banned. Aquatic habitats themselves are often invaded by alien plant species, molluscs, crustaceans, fishes, which may cause far-reaching changes in their biotic communities and attributes. As a consequence also their ecosystem services provisioning capacity can diminish dramatically. The underlying ecological processes of invasions of aquatic species and the disturbance they bring about are very divers and call for targeted research and management (Havel *et al*., 2015). Decisions about control measures should always be based on a thorough understanding of the local situation.
Pollination and seed dispersal	Rivers and lakes do not directly support the ecosystem service pollination and seed dispersal. However, riparian vegetation may sustain pollinators when they provide alternative food sources or when they contain suitable microhabitat for shelter, hibernation and/or reproduction. Riparian vegetation along ditches, rivulets and ponds in agricultural areas can be managed to optimize the functional habitats for pollinators and seed dispersers. This implies cutting and mowing to prevent a few plant species to

	become dominant at the expense of species rich vegetation. In thicket and soft wood vegetation, a very important early season pollen (and some nectar) source such as willow (*Salix* sp.) may be favoured by planting pre-dominantly male willows that are coppiced or pollarded non-simultaneously for the whole habitat patch after flowering (see for instance Ostaff *et al*. 2015; Tumminello et al., 2018). Furthermore, management measures should allow local accumulation of litter, dead wood, etc. as suitable shelter and hibernation microhabitat. Application of broad spectrum pesticides should be banned.
Maintenance of water quality	Self-purification is a key to improve and maintain water quality. Management can optimize this complex ecological process. Physicochemical processes are supported by management measures that have a positive impact on the hydro-morphological dynamics of rivers. This includes among others the increase of variation in flow velocity, water depth, water residence time, sediment transport, deposition and erosion rate. Suitable measures are restoring longitudinal in-stream connectivity by removing all kinds of barriers, restoring meanders, installing stream deflectors. Varied hydro-morphological dynamics generate in-stream and river bank habitat diversity and associated species communities that all together contribute to the self-purification capacity of the watercourse. Aquatic plant and benthic communities, helophytes, riparian vegetation and soil biota assimilate and decompose organic matter and facilitate oxidation, reduction, nitrification, denitrification and many other chemical processes involved in self-purification of water. In agricultural land, functional links between ponds, ditches and wetland patches contribute to remove nitrogen through transformation and transfer in both surface and ground water. To be efficient, a sufficient number of habitat patches, logically arranged according the pollution source, has to be in place (Cellier *et al*., 2011; Garnier *et al*., 2014). Through cutting and mowing of vegetation nutrients are removed. Phasing and zoning of this vegetation clearing should avoid the total destruction of habitat and hence steep decline of species populations. Mowing for nutrient removal should be done before nutrients are translocated in the plants, thus summer mowing should be considered. Periodic mud clearance of ditches should equally be spatially varied, keeping a number of vegetation patches untouched. In standing waters, lakes and ponds, excessive plant growth, especially of alien invasive species may deplete oxygen and reduce decomposition rates accordingly. Eradication of the invasive species should be considered. To avoid rivers, ponds and ditches to become very eutrophic and exceed the self-purification capacity, direct input of fertilizers and nutrients should be prevented. Apart from banning drainage of polluted and heavily nutrient loaded water, the development and maintenance of productive riparian vegetation may be effective in this respect. Also connecting species rich meadows that can be inundated during periods of high discharge, can add to the decrease of nutrients in the main watercourse. To allow a reasonable water residence time and stimulate sedimentation and precipitation, a system of shallow lagoons or an adapted bank and shore profile with a zone that is temporary inundated, can be installed. Planting helophytes near drain outlets may further contribute to the purification of water. Vegetation has to be grazed, cut or mown at regular times. Apart from

	estuaries and downstream stretches of rivers, a very high turbidity of the water is often an indication of high nutrient concentration and an incomplete food web. Mud grubbing fish species, such as carp (*Cyprinus* sp.) should be controlled by re-introduction of predator fish species such as pike (*Esox lucius*).
Mass stabilization and control of erosion rates	Hydro-morphological dynamics of rivers induce erosion of the river bed and the riverbanks. This can be considered a disservice as it can hinder navigability and discharge and my affect land use in the river valley and alluvial plane. Measures to control the dynamics such as channelization of the river bed and replacement of natural banks and shores by artificial banks and dykes may indeed prevent in-situ erosion of the river bed and banks, but quite often induce erosion and inundation problems downstream and dramatically decrease the capacity of the river to provide other ecosystem services. Therefore, achieving equilibrium of erosion and sedimentation based on the natural hydro-morphological processes of the river, are to be preferred (the River Restoration Centre, 1999). Creating more space for the river to naturally flow and restoring total stretches of rivers are then the strategies and goals. High population densities of species that excavate burrow systems in riverbanks and dykes, such as muskrat (Ondatra zibethicus), may lead to serious erosion problems in the watercourses themselves and cause inundation risks in the adjacent alluvial plains. Trapping to control population density seems to be an effective measure (Bos *et al*., 2019). Watercourses, ditches and ponds can contribute to control soil degradation of adjacent land when they function as water and mud retention basins within a network of erosion preventing habitats. Their localization in the landscape must be effective, taking contour lines and runoff direction into account. Regular vegetation and mud clearing is the appropriate management to maintain sufficient buffer and storage capacity.
Protection against floods	Rivers should be given sufficient room to buffer and store flood discharge. Depending on the river system, different measures can be taken (the River Restoration Centre, 1999). It may imply the widening of the river bed and the construction of winter dykes at the outer side of the river valley or alluvial plane, allowing temporary inundation of parts of the valley or plane. By increasing the storage capacity of ditches through widening of the profile together with the construction of terraced banks, inundation prone areas can be protected. To maintain the storage capacity of the water bodies, vegetation and mud should be cleared when necessary. Disturbance of the water ecosystem should be as low as possible, which means low frequency of site specific measures. Productivity and hence plant growth that may hinder water flow and storage, can be controlled by avoiding direct input of sediments and fertilizers and by installing helophytes filters to purify inlet water and trap sediment. Excessive growth of aquatic plants that hinder water flow and storage can be decreased by planting and maintaining high growing vegetation on the south bank of rivulets and ditches. Beaver (Castor fiber) as well as invasive alien aquatic weeds may have a huge impact on discharge and hence can increase flood risk by impeding river flow. For beaver, a protected species in Europe, population control measures are currently assessed in accordance with legislation in force. To facilitate long-term coexistence between beavers and humans, raising awareness and

	creating possibilities to solve conflicts through allowed methods seems to be a necessity (see for instance Wróbel & Krysztofiak-Kaniewska, 2020). Control of excessive growth of alien aquatic plants is necessary to avoid serious ecological and economic impacts. A range of management options is available, each more or less suitable for the different habitat attributes and invasive species of concern (Hussner *et al*., 2017). Mechanical harvesting, cutting, excavation, dredging, hand-weeding are regularly used. If legally allowed, also different methods of biological control are applied, for instance with the herbivore grass carp (Ctenopharyngodon idella). However, great caution is required given potential unforeseen negative impacts on the aquatic communities. The most important strategy however is the prevention of invasive alien species to establish, followed by early detection (when the former failed) and rapid response (EU Regulation 1143/2014 on Invasive Alien Species). Wetland vegetation in the river valley and alluvial plane has to be grazed, mown and/or cut to maintain storage capacity.
Wild plants, algae, fungi and their outputs	Riparian vegetation may contain edible plants. Targeted management for these species can include maintenance of favourable growing conditions by cutting and/or mowing species that otherwise may become dominant. Appropriate measures have to be taken to prevent pollution of water and soil.
Wild animals and their outputs	In rivers and lakes, fish is the main subject of this ecosystem service. Management with the objective to ensure abundant fish stock implies control, maintenance and amelioration of water quality, preserving the essential functional habitats and improving longitudinal and transversal connectivity of the watercourse in the landscape (see for instance SEPA, 2002). Good water quality is achieved when pollution sources are removed or purified. Restoring or creating spawning habitat is a first prerequisite to maintain viable fish populations. In most cases this requires the modification of the sedimentation rate and the distribution of different sized sediments in the river bed and thus the implementation of measures that induce variation in flow velocity. Maintaining river and bank vegetation and keeping tree trunks and boulders increase habitat complexity and create microhabitat for food and shelter. Finally, removing artificial barriers that hinder migration and restoring connection with pools adjacent to the watercourse are essential management measures to allow fish to migrate and reach different habitats. Functional habitats for shelter, foraging and reproduction of specific game can be present in riparian vegetation. Targeted management may help these species. Precautionary measures, such as spatial and temporal restricted access, permanent fences and cover, can be taken to avoid disturbance during critical periods.
Aesthetics	Remove artificial material and infrastructure and replace it by natural elements. Restore the natural morphodynamic characteristics. Manage vegetation in such a way that monotony is avoided. Maintain vistas and realize infrastructure to experience the beauty of rivers, lakes and ponds.
Wild animals attacks	Inform visitors of potential encounters with wild animals. Warn visitors not to approach or feed wild animals. Remove infrastructure that may attract wild animals, such as garbage bins.

Plants and their pollens causing allergies or poisoning	Inform visitors of plants that irritate or may cause health problems. Move paths and trails away from populations of irritating plants. Keep the vegetation of path and trail verges low by mowing.
Disease transmission	Warn visitors of the existence of potential disease vectors and encourage them to stay on walking trails and paths. Advise visitors to wear appropriate clothing. Keep the vegetation of paths and verges low by mowing.
Damage on infrastructures	Inspect infrastructure regularly and take measures to protect infrastructure. This may include installation of wires, fences, covers, etc. Identify the species that cause problems and carry out species specific control measures.

5.2. Wetland management for ecosystem services

Marsh, reed land, bogs and moors **'Wetland' (excl. open water)** Linear and point-like landscape elements: ***wadies, temporary dry ditches***	
Local climate regulation	**Cooling effect**: Ensure free movement of cooling air (ventilation) from the wetland to SBA: remove air flow barriers, increase and maintain low growing vegetation (marsh, reed, bogs and moor) in wetland and the SCA by grazing, mowing and cutting with a density (large herbivore stock rate) and periodicity according the productivity and growing rate of the respective vegetation types; prevent expansion of trees and high growing shrubs by cutting. In case of woodland in the SCA determine the preferred zone to create an effective ventilation corridor through clear cutting followed by mowing. Adapt forest management by making more use of coppicing. **C-storage** (of less importance for local climate regulation): Freshwater wetlands can be both sources and sinks of carbon (Kayranli *et al.*, 2010). To allow carbon storage in vegetation, maintain or restore favourable conditions for wetland plant growth, i.e. establish the characteristic hydrology with a high ground water table, temporary submerged soils and appropriate seepage pressure. Depending the location and type of wetland habitat, restore connection with rivers to allow seasonal and temporary inundations. Avoid inlet of polluted water and decrease nutrient loads by filtering and buffering water in a cascade of retention pools. Sequestration of organic material in the soil should be maximized by establishing hydrological conditions that favour peat formation: permanent water saturation and hence anaerobic conditions which prevent decomposition of dead plant material. Prevent desiccation of peat by blocking drainage ditches and maintaining high water levels. In case of superficially desiccation of peat, gradually raise the water table to stimulate regrowth of peat forming vegetation and cut trees to reduce evapotranspiration. Keep quack mires and floating bog vegetation free of trees to continue the floating and prevent the vegetation mat to become anchored in the sediment. Ban any form of peat cutting.
Air quality regulation	Due to their low height, wetland vegetation does not contribute considerably to the regulation of air quality. No specific management measures are proposed.
Pest control	Wetlands adjacent to and networks of small march and reed habitats intersecting SBA, mainly agricultural land and gardens, may sustain populations of natural enemies when they provide alternative food sources, prey and hosts or when they contain suitable microhabitat for shelter, hibernation and/or reproduction. These habitats can be managed to optimize these functions. This implies cutting and mowing to prevent a few plant

	species to become dominant at the expense of species rich vegetation. Management measures should allow local accumulation of litter, dead wood, etc. as suitable shelter and hibernation microhabitat. Application of broad spectrum pesticides should be banned. As is the case for rivers and lakes, wetlands are prone to aquatic alien species invasions. Careful and complete removal is a necessity. Isolation of infested habitat patches can be an option, but contradict the general need to decrease fragmentation.
Pollination and seed dispersal	Marshes may sustain pollinators when they provide alternative food sources or when they contain suitable microhabitat for shelter, hibernation and/or reproduction. In this respect, marsh vegetation adjacent to or dissecting SBA can be managed to optimize these functions. This implies cutting and mowing to prevent a few plant species to become dominant at the expense of species rich vegetation. In marshland with thicket, Willow (*Salix* sp.) is a very important early season pollen (and some nectar) source. Coppicing willow bushes and pollarding trees, non-simultaneously for the whole habitat patch and after flowering, are the main management measures (see for instance Ostaff *et al*. 2015; Tumminello et al., 2018). Furthermore, management measures should allow local accumulation of litter, dead wood, etc. to provide suitable shelter and hibernation microhabitat. Application of broad spectrum pesticides should be banned.
Maintenance water quality	Wetlands play a very important role in maintaining good water quality (Vymaza, 2016). Helophytes, mire and marsh vegetation and soil biota of wetlands assimilate and decompose organic matter and facilitate oxidation, reduction, nitrification, denitrification and many other chemical processes involved in the decomposition of organic material. All this helps to maintain a good surface and ground water quality. In agricultural land, functional links between ponds, ditches and wetland patches contribute to remove nitrogen through transformation and transfer in both surface and ground water. To be efficient, a sufficient number of habitat patches, logically arranged according the pollution source, has to be in place (Cellier *et al.*, 2011; Garnier *et al.*, 2014). Cutting and mowing of wetland vegetation are most applied to remove nutrients. Locally burning of reed beds and grazing are alternatives. Mowing for nutrient removal should be done before nutrients are translocated in the plants, thus summer mowing should be considered. Phasing and zoning of management should avoid the total destruction of habitat and hence steep decline of species populations. Guidelines to prepare management plans are available (see for instance Hammerl-Resch *et al*., 2004). In eutrophic marsh patches of helophyte vegetation and reed beds can be enlarged and managed as natural purification beds for nutrient rich surface water. To allow a reasonable water residence time and stimulate sedimentation and precipitation, these helophyte filters could be arranged as a series of shallow lagoons. When they are designed as part of a ditch and canal network, these filters will be developed on the upper zone of constructed two-stage banks or shores which are temporary inundated. Planting helophytes near sub-terrain drain outlets may further contribute to the purification of water before it flows into the watercourse or percolates in the soil. Also this purifying vegetation has to be cut or mown at regular times.

Mass stabilization and control of erosion rates	Fluvial erosion energy decreases when shallow surface water flows through a marsh, reed bed or willow and alder (*Alnus* sp.) ticket. Wetland vegetation that functions as a flow buffer to prevent erosion downstream has to be heterogeneous with high growing species that reduce flow speed. Grazing and irregular mowing can be appropriate management measures. A closed vegetation swart however is necessary to protect the soil from erosion. In agricultural land, wetland patches can contribute to control soil erosion when they function as water and mud retention basins in a network of erosion preventing habitats. Their localization in the landscape must be effective, taking contour lines and runoff direction into account. Regular vegetation and mud clearing is the appropriate management to maintain sufficient buffer and storage capacity.
Protection against floods	Wetlands are extremely important to prevent floods. They function as a sponge, as they store huge quantities of water that is only slowly released. As a result, peak discharges in the main stream become smaller. Trapping sediment reduces the sediment load in the river which in turn increases discharge capacity. Along rivers and streams, wetlands are specifically designed and developed to function as controlled storm water retention basins (see for instance Van den Bergh *et al*. 2005). To maintain the storage capacity of the water bodies, vegetation and mud should be cleared when necessary. Disturbance of the wetland ecosystem should be as low as possible, which means low frequency of site specific measures. Productivity and hence plant growth that may hinder water flow and storage, can be controlled by avoiding direct input of sediments and fertilizers and by installing helophytes filters to purify inlet water and trap sediment. In general, wetland vegetation in the river valley and alluvial plane has to be grazed, mown, cut and sometimes burned to maintain storage capacity.
Wild plants, algae, fungi and their outputs	Wetland vegetation may contain plants with edible fruits. Targeted management for these species can include maintenance of favourable hydrological growing conditions and control of potential dominant plant species by cutting and/or mowing. To avoid overexploitation, it can be necessary to regulate berry picking etc. Eventually, appropriate measures have to be taken to prevent pollution of water and soil.
Wild animals and their outputs	Functional habitats for shelter, foraging and reproduction of specific game can be present in wetland vegetation. Targeted management may help these species. Precautionary measures, such as spatial and temporal restricted access, permanent fences and cover, can be taken to avoid disturbance during critical periods.
Aesthetics	Remove artificial material and infrastructure and replace it by natural elements. Manage vegetation in such a way that monotony is avoided. Maintain vistas and realize infrastructure to experience the beauty of marshes, bogs and moors.
Wild animals attacks	Inform visitors of potential encounters with wild animals. Warn visitors not to approach or feed wild animals. Remove infrastructure that may attract wild animals, such as garbage bins.

Plants and their pollens causing allergies or poisoning	Inform visitors of plants that irritate or may cause health problems. Move paths and trails away from populations of irritating plants. Keep the vegetation of path and trail verges low by mowing.
Disease transmission	Mosquitoes may be a burden and may call for appropriate management. Different management strategies may be applied, depending on the extent of the problem, the type of wetland and the desired functions and services they provide (see for instance Dale & Knight, 2008; Society of Wetland Scientists, 2009). Ecologically-sound management includes favouring of mosquito larvae predators, vegetation control and water level control. Warn visitors of the existence of potential disease vectors and encourage them to stay on walking trails and paths. Advise visitors to wear appropriate clothing. Keep the vegetation of paths and verges low by mowing.
Damage on infrastructures	Inspect infrastructure regularly and take measures to protect infrastructure. This may include installation of wires, fences, covers, etc. Identify the species that cause problems and carry out species specific control measures.

5.3. Grassland management for ecosystem services

Nutrient poor grassland, dry

Nutrient poor grassland, wet

Nutrient rich improved grassland

Sparsely vegetated areas, unpaved roads

Linear and point-like landscape elements: ***Grass strips, flower strips, field borders, tall herbs; temporary fallow and set-aside land***

Local climate regulation	**Cooling effect**: During day and night, the temperature above grass is lower than above sand or asphalt. Compared to water, the temperature is higher during the day and lower during the night. Lawns and grass vegetation may thus cool the air and can to some extent and depending on its localization and the openness of the landscape, contribute to climate regulation of adjacent land. To be effective, emphasis must be placed on free movement of cooling air (ventilation); air flow barriers have to be removed or re-oriented. The grassland has to be maintained by grazing, mowing and cutting with a density (large herbivore stock rate) and periodicity according the productivity and growing rate of the vegetation. **C-storage** (of less importance for local climate regulation): Depending on the species composition and management, perennial grasslands can be net C sinks (Bengtsson *et al*., 2019; Sollenberger *et al*., 2019). Carbon accumulation in grassland soils increases with increasing productivity of the vegetation which can be induced by management, the share of *Fabaceae* and the number of functional groups. The latter counts especially for the soil biota. Furthermore, low or moderate stocking rates in grazed grassland favor carbon accumulation. However, intensification that implies plowing and re-sowing induces the adverse effect as organic bound carbon is decomposed and released as CO_2. Through grazing and heavy fertilization to enhance productivity, grassland can also become a source of greenhouse gasses when considerable amounts of methane, CH_4 and N_2O are emitted. The balance between C-sequestration and greenhouse gas emission is thus not unequivocal and depends on the intensity of the management and the species composition of the grassland. To allow ample carbon storage in soil grazing seems to be more effective than mowing (Mestdagh *et al*., 2006). Intermediately managed grassland (stocking rate up to 1LU/ha and fertilization 25-50kg N/ha/yr) and especially extensively managed grassland (< 1LU/ha and fertilization < 25kg N/ha/yr) have significantly higher total carbon percentage in soil than intensively managed grassland (Ward *et al*., 2016). In wet semi-natural grasslands, sequestration of organic material in the soil can be maximized by establishing the original hydrological conditions.
Air quality regulation	Due to their low height, grasslands do not contribute considerably to the regulation of air quality. No specific management measures are proposed.

Pest control	Species rich permanent grassland near arable land and networks of grass strips, flower strips, field borders and tall herb vegetation intersecting SBA, may sustain populations of natural enemies when they provide alternative food sources, prey and hosts or when they contain suitable microhabitat for shelter, hibernation and/or reproduction. Because of this, species rich grass strips significantly contribute to natural pest control (Van Vooren *et al*., 2017). Management can optimize the quality of the habitat for the natural enemies. Cutting, mowing and controlled grazing with a shepherd prevent a few plant species to become dominant at the expense of species rich vegetation. Management measures should allow local accumulation of litter, dead wood, bare soil, etc. as suitable shelter and hibernation microhabitat. Cutting of non-crop plants that are used by natural enemies should be done at the right moment to encourage dispersal of the natural enemies into the crop. To achieve a habitat network with a mesh size that allows effective dispersal into entire crop parcels, restoration and well thought out creation of species rich grassland and other functional habitats should be implemented at the landscape scale (Bianchi *et al*., 2006). Application of broad spectrum pesticides should be banned.
Pollination and seed dispersal	Semi-natural grasslands, species rich field margins, grass and flower strips, fallow land and tall herb vegetation may sustain pollinators when they provide alternative food sources or when they contain suitable microhabitat for shelter, hibernation and/or reproduction. Appropriate management of habitat quality may enhance provision of pollination. This implies cutting, mowing and grazing to prevent a few plant species to become dominant at the expense of species rich vegetation. Considering the support of pollinators, attention should be paid to the timing and the spatial heterogeneity of the management as this has a direct influence on the availability of abundant nectar and pollen throughout the season and has a positive impact on the pollinator functional diversity. Equally important as providing alternative food supply, management should also create suitable microhabitat for shelter and hibernation and allow local accumulation of litter, dead wood, etc. to provide. Because of the increased fragmentation of grasslands, it is very important that management strategies are implemented on a landscape level too and not only on-farm (Sutter *et al*., 2018; Kremen *et al*., 2007). This must enhance connectivity and availability of suitable pollinator habitat. To optimize the pollination capacity, the design of the network should start from the traits and requirements of the different pollinators. Application of broad spectrum pesticides should be banned.
Maintenance water quality	The contribution of grassland to maintain good water quality very much depends on the management. Grasslands however, can also be a source of nutrients to the ground water and nearby water bodies if percolation or runoff occurs. This implies that excessive fertilization and drainage should be avoided and that a permanent dense vegetation cover is ensured. The latter is important to prevent sediment discharge. Some removal of nutrients can be achieved by cutting and mowing. The impact of grazing depends on the stocking rate. High density grazing should be avoided as this makes the soil more prone to erosion and increases nutrient loads. Due to the absence of elements that prevent runoff or infiltration and capture pollutants, nutrients

	and sediments, sparsely and unvegetated strips and verges do not support the ecosystem service. Planting and sowing can then be an option. In temporary inundated or waterlogged grassland denitrification helps to decrease total N loads. Maintaining a high ground water table is therefore an appropriate measure. However, when soils have high phosphorus concentrations, (re)wetting may lead to the release of this macro nutrient and adverse effects in ditches and watercourses. Grass swales and filter strips along roads may remove pollutants; however a lot of uncertainties remain (Gavric *et al*., 2019).
Mass stabilization and control of erosion rates	Grassland adds to control of soil erosion in various ways. Contour grass strips are often used to slow down runoff velocity and reduce sheet and rill erosion. The vegetative barriers promote infiltration and deposition of sediment. Combined with a ditch at the downhill side, runoff water can be diverted towards the main drain. Broad enough grassed waterways following the slope concentrates runoff and discharges it without further soil erosion further downhill. The width of contour buffer strip is determined by slope, soil type, field conditions, erosion potential of the regular crops and climate. Mowing outside the critical period of erosion is the general management measure.
Protection against floods	Grassland can be part of storm water basins. As they need to keep sufficient storage capacity, management should prevent succession towards shrub or forest. Therefore mowing or grazing can be implemented. Because a quick rise of water is likely to occur, escape to safe sites should be possible.
Wild plants, algae, fungi and their outputs	Grassland may contain edible plants and fungi. Targeted management for these species can include maintenance of favorable growing conditions and control of potential dominant plant species by mowing and grazing. To avoid overexploitation for instance of mushrooms, it can be necessary to regulate collection. Eventually, appropriate measures have to be taken to prevent pollution of the soil.
Wild animals and their outputs	Most of popular game finds functional habitats for shelter, foraging or reproduction in grassland and the grass and flower strips, fallow land and tall herb vegetation in agricultural landscapes. Targeted management may improve and maintain these habitats for the species. Precautionary measures, such as spatial and temporal restricted access, permanent fences and cover, can be taken to avoid disturbance during critical periods.
Aesthetics	In many regions, permanent grassland determines the identity of the open landscapes. Undisturbed wide views add to the aesthetics of the landscapes. Maintaining this quality may require that artificial material and infrastructure are removed and eventually replaced by natural elements. The mixture of open grassland, networks of low and tall linear landscape elements and scattered woodland is often appreciated for its beauty and aesthetics. Maintaining these heterogeneous and small scale landscapes calls for a variety of management measures, often originating from or referring to the traditional landscape of the past.
Wild animals attacks	Inform visitors of potential encounters with wild animals. Warn visitors not to approach or feed wild animals. Remove infrastructure that may attract wild animals, such as garbage bins.

Plants and their pollens causing allergies or poisoning	Inform visitors of grasses that may cause allergy. Move paths and trails away from populations of irritating plants. Keep the vegetation of path and trail verges low by mowing.
Disease transmission	Warn visitors of the existence of potential disease vectors and encourage them to stay on walking trails and paths. Advise visitors to wear appropriate clothing. Keep the vegetation of paths and verges low by mowing.
Damage on infrastructures	Inspect infrastructure regularly and take measures to protect infrastructure. This may include installation of wires, fences, covers, etc. Identify the species that cause problems and carry out species specific control measures.

5.4. Forest management for ecosystem services

Deciduous forests (natural and planted) **Mixed forest (natural and planted)** **Coniferous forest (natural and planted)** **Thicket** Linear and point-like landscape elements: ***Hedgerow, raised hedge (bank), hedge, row of trees, orchards***	
Local climate regulation	**Cooling effect**: Forests have a considerable effect on surface and air temperature. Increasing forested area may moderate the climate in the surrounding area. To ensure that the cooling effect air of forests can reach the SBA, land use planning should implement ventilation corridors in the SCA. Management of forest and parks can optimize the cooling effect. Species composition determines the cooling capacity as tree species differ in evapotranspiration rates (Moss *et al.*, 2019). Maintaining and restoring hydrological conditions through ending drainage and increasing water infiltration are preconditions to further improve cooling effect. **C-storage** (of less importance for local climate regulation): To enhance forest carbon stores, forests and trees should be able to grow for a long time. High stocking levels equally increase carbon stores. The latter however generally decreases the stand-level structural and compositional complexity what results in a reduced adaptation potential. To find a balance, management systems that seek to establish multi-aged forest stands are promising. Then, selection and cutting regimes that maintain a large proportion of carbon stores in retained mature trees while using thinning to create spatial heterogeneity that promotes higher sequestration rates in smaller, younger trees, can be applied. Simultaneously structural and compositional complexity is improved (D'Amato *et al.*, 2011). Increasing the amount of lying deadwood has a positive effect on carbon storage in the soil and add to replenish minerals and thus to the improvement of the buffer capacity of the soil (Dhiedt *et al.*, 2019). During harvest, it must be ensured that direct and indirect disturbance of the soil is kept to the minimum. Management strategies that enhance the viability and resilience of forests simultaneously support the regulation capacity of forests. They include the promotion of natural and/or site-adapted tree species and the increase of species and structural diversity, the maintenance and increase of genetic variation within tree species, the promotion of mixed forests in accordance with the assumed potential natural vegetation, the promotion of natural regeneration, the establishment of long regeneration periods, the maintenance of seed trees, the avoidance of clear cuts and the replacement of high-risk stands. Appropriate cutting regimes from 'close-to-nature silviculture' that can be applied are single-tree selection system, group selection system and shelterwood system (Brang *et al.*, 2014).
Air quality regulation	Because of the complex vegetation structure and the height, forest and clusters of trees and shrub can be effective for the regulation of air quality. With an appropriate selection of species and specific design and management

	measures, performance will be enhanced, especially for the woody vegetation barriers (Barwise & Kumar, 2020). Regarding the species, attention should be paid to foliage longevity and leaf phenology, leaf size and complexity, leaf surface characteristics and species environmental tolerance. Conifers generally offer higher deposition velocities than broadleaf species. Trees and shrubs with smaller leaves or with rough leaf surfaces are more effective than those with larger or smooth surface leaves. Leaf morphology may thus be decisive for species selection. In very polluted and stressful environments such as road sites, plant's tolerance should be given priority over all other functionalities as an indicator of its suitability (Tiwary *et al*., 2016). To avoid a strongly reduced performance of a GI habitat due to high susceptibility of the main tree species, managers should promote a high species diversity and complexity in order to strengthen forest and vegetation barrier resilience. Maintaining a plant's health is a precondition for its functioning as air quality regulator. When choosing species, native species are recommended and invasive or poisonous species should be avoided. The latter may always cause unintended problems. Vegetation complexity and structure have also a direct influence on the filtering capacity of the air stream. The characteristics of the vegetation barrier can be manipulated according its desired function and recommendations can be formulated (see for instance Baldauf, 2017). The design and management of forest edge and woody GI (hedgerows etc.) should be such that optical porosity is 20-50% what means that air can flow through the vegetation. Full coverage from the ground to the top of the canopy, which can be achieved by multiple rows and types of vegetation, is another prerequisite. The coverage should be maintained as much as possible throughout all seasons and thus a mixture of evergreen and deciduous shrubs and trees has to be considered. Also the thickness is important; optimal removal is achieved when vegetation barriers are 10 m thick or more. The barrier should extend sufficiently beyond the area of concern to prevent polluted air reaching the area from aside. To be effective, a height of 5 m minimum is required to trap emissions from nearby vehicles; 10 m and more will further reduce background pollution, at least in a zone of 15 to 20 times the height of the barrier. However, placing the barrier next to or around the pollution source, for instance a main road or an ammonia emitting farm, is much more effective than locating it near the target area, such as a vulnerable habitat, that has to be protected (Dragosits *et al*., 2006). As air pollutant removal is effectuated mainly at their outer fringe, forests should be large enough to maintain an unaffected inner forest core. This is important when it is the objective to achieve air quality regulation and biodiversity maintenance simultaneously. An edge zone with poorer environmental quality due to atmospheric deposition can be up to 200m wide (De Schrijver *et al*., 1998). That means that a broad-leaved forest in Atlantic Europe should not be less than 100 ha, given that the core area or 'balanced structure area', which is the minimum contiguous area that includes all tree development stages (Koop, 1989), equals approx. 50 ha (Vandekerkhove, 1989).
Pest control	Forest edges near arable land and networks of hedgerows and woody field margins intersecting SBA, may sustain populations of natural enemies when they provide alternative food sources, prey and hosts or when they contain suitable microhabitat for shelter, hibernation and/or reproduction.

	Management can optimize the quality of the habitat for the natural enemies. Cutting and mowing prevent a few plant species to become dominant at the expense of species rich vegetation. Management measures should allow local accumulation of litter, dead wood, bare soil, etc. as suitable shelter and hibernation microhabitat. Cutting of non-crop plants that are used by natural enemies should be done at the right moment to encourage dispersal of the natural enemies into the crop. To achieve a habitat network with a mesh size that allows effective dispersal into entire crop parcels, restoration and well thought creation of species rich hedgerows and other functional habitats should be implemented at the landscape scale (Bianchi *et al*., 2006). Silvo-arable agroforestry with trees aligned inside the fields may provide a perennial habitat directly in contact with the crop. The uncultivated line along the trees can then be sown with beneficial plant mixtures. Application of broad spectrum pesticides should be banned.
Pollination and seed dispersal	Forest edges and networks of hedgerows and woody field margins may sustain pollinators when they provide alternative food sources or when they contain suitable microhabitat for shelter, hibernation and/or reproduction. Appropriate management of habitat quality may enhance provision of pollination. This implies cutting and mowing to prevent a few plant species to become dominant at the expense of species rich vegetation. Considering the support of pollinators, attention should be paid to the timing and the spatial heterogeneity of the management as this has a direct influence on the availability of abundant nectar and pollen throughout the season and has a positive impact on the pollinator functional diversity. In forest edges and hedgerows Willow (*Salix* sp.) is a very important early season pollen (and some nectar) source. Coppicing willow bushes and pollarding willow trees, non-simultaneously for the whole habitat patch and only after flowering, are the main management measures (see for instance Ostaff *et al*. 2015; Tumminello et al., 2018). Equally important as providing alternative food supply, management should also create suitable microhabitat for shelter and hibernation and allow local accumulation of litter, dead wood, etc. to provide. Because of the homogenization of agricultural landscapes, it is very important that management strategies to increase pollinators habitat are implemented on a landscape level too and not only on-farm (Sutter *et al*., 2018; Kremen *et al*., 2007). This must enhance connectivity and availability of suitable pollinator habitat. To optimize the pollination capacity, the design of the network should start from the traits and requirements of the different pollinators. Application of broad spectrum pesticides should be banned.
Maintenance water quality	Forest and especially riparian forest are important to maintain good water quality. They retain inputs of nutrients in soils and biomass through filtering sediments, nutrients and other contaminants from runoff. All this helps to maintain a good surface and ground water quality. In riparian forests biogeochemical processes include the transformation and cycling of elements and retention and removal of dissolved substances and thereby the improvement of the surface, subsurface, and groundwater quality. Woody riparian vegetation with for instance alder (*Alnus* sp.) on the upper bank of a river or in a drainage channel with a constructed floodplain bench

	(two-stage ditch) catch sediment from the watercourse and surface runoff and contribute to remove nutrients through transformation and transfer. Management for this ecosystem service will focus on the maintenance of a healthy forest: promoting species composition in balance with the environmental conditions, achieving structural complexity and a heterogeneous age structure, avoiding disturbance by compaction or tillage of soil processes, increasing the organic matter content of the soils. Above all should forest cover be maintained or enhanced. Management methods and especially harvesting have effects on stream water run-off in the catchments. An increase of nitrate concentrations in run-off three to five years after clearcut and patchcut of coniferous and deciduous monocultures is obvious (Mupepele & Dormann, 2017). Selective harvest at low intensities is recommended to avoid this problem. Apart of the effect of harvesting methods, forests can also add to the pollution of groundwater by capturing atmospheric deposition. Leaching of high amounts of nitrate can then make forests less suitable as sources of drinking water supply (Van Breemen, 1988).
Mass stabilization and control of erosion rates	Forest land cover is most effective to prevent and control erosion and thus forest conservation and reforestation should be priority strategies in erosion prevention policy. In the forest itself, soil and substrate are stabilized, eroded sediment precipitates and aeolian and fluvial energy are dropped. Management may improve performance by promoting heterogeneity of species composition, forest complexity and age structure. Attention should be paid to maintain or develop a closed herb and litter layer. Forest management and harvesting should always avoid soil destruction. Cutting systems that create large gaps and corridors which may increase vulnerability of the forest to storm damage should be avoided. Wooded vegetation strips, hedgerows and hedges slow down runoff velocity, induce infiltration and deposition of sediment and thus reduce sheet and rill erosion in agricultural land. They are also very effective windbreaks and shelterbelts that reduce wind speed considerably (Brandle *et al*. 2009). Windshields with a vegetation density of 40-60% are preferable for maximum downwind area protection. When the density exceeds 80%, then excessive leeward turbulence may reduce the windbreak effectiveness beyond a distance of 8 times the height of the windshield vegetation (Nottawasaga Valley Conservation Authority. 2012). When planting trees along river banks to prevent erosion and improve stabilization, one should select species with a deep rooting system that are adapted to waterlogged soils.
Protection against floods	Forests are very important to prevent floods. In the catchment, they enhance infiltration and replenishment of ground water which in turn is only slowly released to the alluvial plane and the river. Although increased tree and shrub biomass goes at the expense of total storage capacity, riparian forest and forest in the river valley or alluvial plane still mitigate floods downstream by short-term surface water storage. Management which enhances these functions implies all measures that increase infiltration and that prevent forest soil erosion. If not yet the case, tree species composition should be changed to in favour of native species, well adapted to a temporary waterlogged environment. To control the balance between biomass increase, slowing down

	the storm water discharge and keeping sufficient storage capacity, periodical thinning of the forest and coppicing of trees and shrubs can be necessary. Dense rows of trees and shrub along the south facing border of small watercourses and ditches may, because of the shadow, prevent excessive water plant growth that can block discharge which may cause inundations. To be effective, the height of tree and shrub species must be in accordance with the width of the adjacent water.
Wild plants, algae, fungi and their outputs	In forests and woody landscape elements, many trees and shrubs with edible nuts and fruits as well as edible fungi can be found. Targeted management for these species can include maintenance of favourable growing conditions and control of potential dominant plant species by selective cutting and mowing. In case of reforestation or rejuvenation species with edible fruits can be planted. To avoid overexploitation for instance of mushrooms, it can be necessary to regulate collection.
Wild animals and their outputs	Many popular game find functional habitats for shelter, foraging or reproduction in forests an woody landscape elements such as hedgerows and hedges. Targeted management may improve and maintain these habitats for the species. Precautionary measures, such as spatial and temporal restricted access, permanent fences and cover, can be taken to avoid disturbance during critical periods.
Aesthetics	In many regions, dense forests and woodland determine the identity of the landscape. Traditional cultural landscapes are often characterized by networks of hedgerows, hedges, raised hedges, sunken roads with woody banks, rows of trees, etc. Their beauty and aesthetics are appreciated by many people. Maintaining these heterogeneous and small scale landscapes calls for a variety of management measures, often originating from or referring to the traditional use and function these landscape elements had in the past. Pollarding, coppicing, pruning, hedge laying, are typical techniques. The species concerned and the techniques applied, differ according to the region (Baudry *et al*., 2000). Given the cultural origin, special attention should go to 'heritage' species. Aesthetics, as well as biodiversity, benefit from management that encourages a range of shrubs and trees, creates structural diversity and keeps a dense shrub layer. Timing of the management should be such that shrubs can flower and set fruit. At the base of hedges should consist of a strip of herbs and flower-rich grassland. Biodiversity is especially benefited when cutting frequencies are reduced, the vegetation at the base of the hedge is mown, gaps are filled and when the traditional structure of hedges is restored (Dicks *et al*., 2019; Hedgelink, s.d.).
Wild animals attacks	Inform visitors of potential encounters with wild animals. Warn visitors not to approach or feed wild animals. Forbid access of shelter and breeding areas temporary or permanently, also during winter when there is shortage of food. Remove infrastructure that may attract wild animals, such as garbage bins.
Plants and their pollens causing allergies or poisoning	Inform visitors of poisonous mushrooms and plants that may cause allergy. Move paths and trails away from populations of irritating plants. Keep the vegetation of path and trail verges low by mowing.

Disease transmission	Warn visitors of the existence of potential disease vectors and encourage them to stay on walking trails and paths. Advise visitors to wear appropriate clothing. Keep the vegetation of paths and verges low by mowing.
Damage on infrastructures	Inspect infrastructure regularly and take measures to protect infrastructure. This may include installation of wires, fences, covers, etc. Identify the species that cause problems and carry out species specific control measures.

6. Planning management for ecosystem services

In the previous chapters the rationale to determine the attributes and ecosystem functioning that determine the provision of ecosystem services was analysed and appropriate management measures to optimize service supply selected. This yields the basic information needed to draw up an effective GI management plans, as by itself this information is not yet a management plan.

6.1. Steps in the development of a GI management plan for ecosystem services

In this chapter we discuss the content of a GI management plan in general and go into more details for some aspects related to ecosystem services provision. The effective planning of GI management for ecosystem services is a process with multiple steps. Bubb *et al*. (2017) distinguish 6 steps (**Figure 5**) which we use as guidance here.

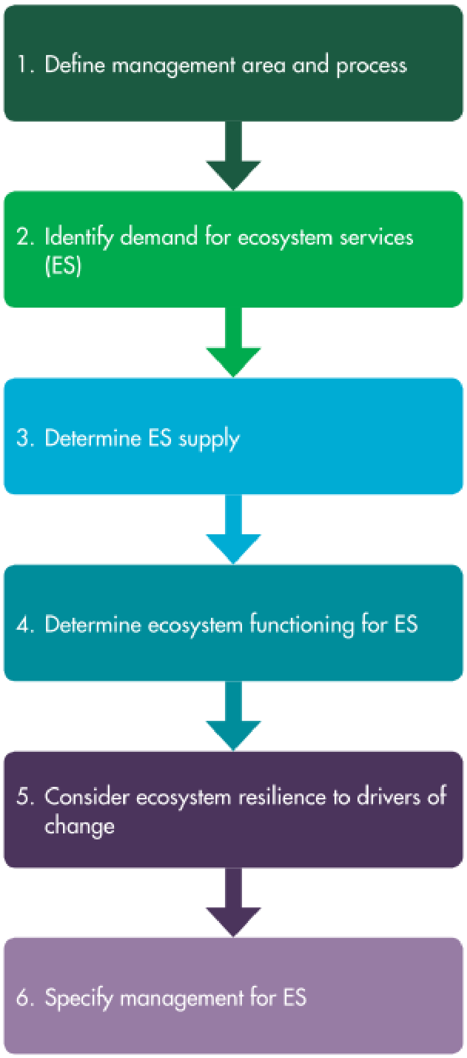


Figure 5. *Steps in planning management for ecosystem services (Bubb et al. 2017).*

Step 1: Define management area and process

Management is carried out in the context of a project. This step consist of the drawing of a general context for that project. This includes the identification and description of (i) the area, (ii) the ecosystem services beneficiary groups, (iii) the general objectives pursued, and (iv) the typology and localization of (targeted) GI elements. Furthermore the process that will be followed to prepare and implement the management plan is determined and the stakeholders and parties that should be involved (users, managers, facilitators) are identified.

Step 2: Identify demand for ecosystem services

In this step the ecosystem services preference of the beneficiary group and thus the prioritization of the ecosystem services are identified. In order to select the most appropriate management measures, a clear view on the expectations of the supply is necessary. Also the area where the provision is required, the service benefiting area (SBA) has to be identified. Finally, it is also important to consider if there are potential ecosystem dis-services that may occur and which management may need to reduce.

Important for fulfilling this demand are the GI habitat types that may supply the ecosystem services. These can be identified by means of an ecosystem capacity assessment which is done in this step. The result is a list of GI habitat types with their expected performance with respect to the provision of the desired services. The spatial distribution of these GI types has to be determined and mapped, yielding the service provisioning areas (SPA).

Regarding the selected GI types that may supply the desired and especially the priority ecosystem services, ‘single purpose’ and ‘multiple purpose’ GI types can be distinguished. The implications for management are obvious. Management of the first category is entirely targeted to control and establish ecosystem functioning to the benefit of a single ecosystem service. Optimization will be the objective. In theory, a choice for a single ecosystem service can be made (for instance ‘100% food production’), in reality however this will seldom be the case as taking ecosystem services as the starting point for planning means that it is a prerequisite to take various services into account in order to achieve sustainability and support biodiversity. Management of multiple purpose GI has multi-functionality as the objective and hence has to consider maintenance or improvement of individual service-related ecosystem attributes without mortgaging the provision of other ecosystem services.

Step 3: Determine current and desired ecosystem services supply

The previous phases identified which GI habitat types are associated with desired ecosystem services; this step takes –in one way or another– stock of actual levels and trends of the supply of ecosystem services, supplemented with information about the current management. Levels and trends of ecosystem service supply can be assessed in quantitative terms of stock and harvest (most of the provisioning ecosystem services), in semi-quantitative terms of flow rates, damage assessment, vulnerability (many regulating services) or in qualitative terms as general ecosystem and landscape structures, etc. (especially for cultural ecosystem services that depend on interactions of people with the natural environment).

In this step, also preliminary goals for the future provision of ecosystem services are set and allocated to specific SPA. At the same time, potential trade-offs between different services in certain (types of) SPAs may become apparent. Understanding the origin of these trade-offs is a prerequisite for developing balanced management that takes into account the full range of ecosystem services and beneficiaries.

Step 4: Determine ecosystem functioning for ecosystem services

Assessing the ecosystem functioning that supports the supply of desired ecosystem services in each of the SPAs, is the main objective of this step. The outcome can inform decisions about the type of intervention needed to maintain, improve or establish a sufficient level of ecosystem services provision in the different areas and GI types. The rationale behind this has been presented into more detail in section 3.1.

The selection of the core ecosystem processes, the ecosystem structure and composition, and the ecological interactions which effectuate the provision of the desired ecosystem services, plus the comparison between their observed state and the 'optimal' state, can be based on the *functioning, condition, and management of service providing units framework* (see chapter 3). Data to describe and assess the current state can partly be retrieved from land cover maps and / or remote sensing. In this respect, IMAGINE Cookbook n° 5 (De Blust and Heremans 2020) and n° 4 (Heremans and De Blust 2020) discusses resp. approaches based on landscape metrics and the calculation of a GI habitat patch vulnerability index. However, documenting the actual state of many of the attributes of the ecosystems requires a targeted field survey. This can be done following the methodology developed in Cookbook n° 5 (De Blust and Heremans 2020). Also the analysis of the current use and management of the SPA with regard to the supply of desired ecosystem services is part of this step. Suitable data can be obtained through field observations and / or inquiries of managers, land owners and land users.

Through a dialogue with the main stakeholders, potentially supported with GIS- or fieldwork-based maps, widely supported goals can finally be set and specific management actions that take into account multifunctionality and trade-offs can be proposed.

Step 5: Take into account ecosystem resilience to drivers of change

GI is exposed to different disturbances which may affect its ecological functioning and thus also the supply of ecosystem services. In this step, the drivers of change and the impact they have on GI elements are analysed in order to assess the system's resistance and / or resilience to external pressures. This is necessary to identify the specific targets of management and to select the appropriate measures. The local context is thus taken into account to adjust more general management goals and to target management effectively.

Step 6: Specify management for ecosystem services

This is the final step before moving on to putting the management into practice. GI patch related goals and actions are defined, and their implementation is organized as an agreed management plan. This whole process is supported by the data and knowledge gained during the previous steps. However, scientifically sound and quantitative data alone do not suffice to elaborate a widely supported management plan. Decision making and the drawing of the plan are social processes in which preferences, interests, moral and cultural values and standards play an important role, and hence collaboration of all key stakeholders is a prerequisite for effective planning.

6.2. Key decisions to be made when preparing a GI management plan for ecosystem services

Managing for ecosystem services implies that well-informed decisions regarding GI and ecosystem services particularities are taken. Hereafter, we discuss some of the aspects that might pop up when preparing a management plan for ecosystem services. Although making decisions in the frame of a management plan is always a social process with active stakeholder involvement, we concentrate here on the technical issues only. They can be inputs for the transdisciplinary planning process.

6.2.1. Are bundles of goals always achievable?

Most GI patches can supply a variety of ecosystem services. This is specifically important when the target includes the provision of multiple ecosystem services. However, this may lead to trade-offs between multiple, equally desired services. Trade-offs often occur among provisioning and regulating & cultural ecosystem services (Elmqvist *et al*. 2011; Raudsepp-Hearne *et al*. 2010). The challenge is to determine how to manage for multiple ecosystem services in such a way that trade-offs are avoided, but synergies arise (Raudsepp-Hearne *et al*. 2010).

In this respect, it is important that the **compatibility of these functions is** assessed beforehand. A way to do that is to define the ecological foundation behind each individual ecosystem service, to identify the key requirements and to translate them into specific design and management criteria (Dosskey *et al*. 2012) (**Figure 6**). In cases where different ecosystem services are co)delivered in time and space, by a single GI element, targeted management can reduce or remove trade-offs by adapting the extent, frequency and timing of the management measures applied. When on the other hand multiple services are supplied by a complex of different GI elements a spatial zoning can be implemented. The aim is to adapt the spatial layout of a GI in such a way that suitable conditions for the ecological functioning related to multiple ecosystem services are met in separate but adjacent parts of the GI while minimizing mutual trade-offs. The final management plan is adjusted to environmental conditions, to species composition and habitat structure, to intensity of use and disturbance, also taking into account the timing of management (**Figure 7**). The provision of suites of ecosystem services in agricultural and suburban areas will mainly rely on these GI complexes, designed and implemented at the landscape scale.

Table 1

Example of a function-criteria matrix for designing a vegetative buffer that would perform three different conservation functions. Only a few design criteria are shown in this simplified matrix in order to clearly illustrate the process of comparing criteria to determine compatibility.

Criterion type	Design criteria			Compatibility
	Function A: Provide shaded aquatic habitat	**Function B: Stabilize eroding stream bank**	**Function C: Provide pollinator habitat**	
Location	Near the water's edge. On west and south sides of stream.	Both sides of stream. As close to the toe of the bank as possible.	Near water and moist soil. Within 300 m of cropland.	Compatible, but Function B has the most stringent criterion for the final design.
Dimensions	Minimum width 10 m.	Minimum width 5 m.	Minimum width unknown.	Compatible, but Function A has the most stringent criterion for the final design.
Vegetation	Trees, mature height > 30 m. Fast growing. Dense foliage.	Trees and shrubs, mature height < 10 m with open crowns. Moderate herbaceous ground cover.	Nectar and pollen producing plants. Trees and shrubs for shelter. Retain snag trees.	Conflict: tall shade trees on high banks may topple and increase bank erosion. Compromise: select tall species having open crowns and low weight, avoid placing tall species on high banks, maintain snag trees away from bank.
Management	Weed control through year 3.	Weed control through year 3.	Protect from pesticides.	Compatible, but need to ensure weed control does not adversely impact Function C.

Figure 6. *Example of an ecosystem services bundle compatibility analysis related to design criteria (Dosskey et al. 2012).*

Figure 2

Conceptual diagram of a vegetative buffer designed to provide three ecosystem services: provide shaded aquatic habitat, stabilize eroding stream bank, and provide pollinator habitat.

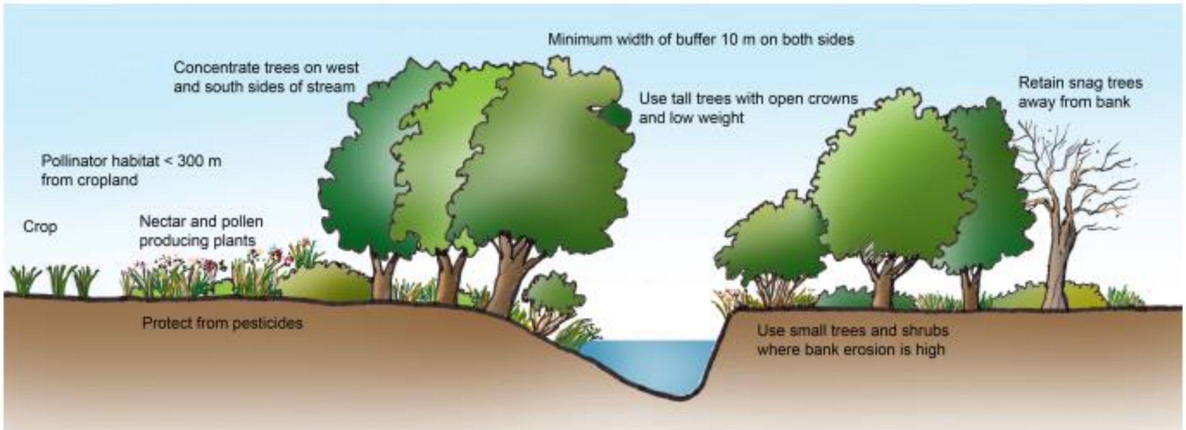


Figure 7. *Example of the spatial design of an ecosystem services bundle (Dosskey et al. 2012).*

No matter how good the scientific underpinning, some level of uncertainty will remain about system response to spatial interactions and management. Therefore it is recommended to monitor habitat development and the dynamics of key structure and processes once a GI design and management plan is being implemented. An effective realization of multifunctional GI networks will depend on the ability to revise the objectives to ongoing developments and to adapt the management accordingly (**Figure 8**). This calls for a dynamic process of **adaptive management** that enables informed decision making based on targeted data monitoring (Martinez-Harms *et al*. 2015). Monitoring should focus on the key structures and processes that underlie the provision of each of the ecosystem services. With the knowledge gained by this monitoring, adaptive management for ecosystem services will become possible and hence the realization of multifunctional GI networks (Birgé *et al*. 2016).

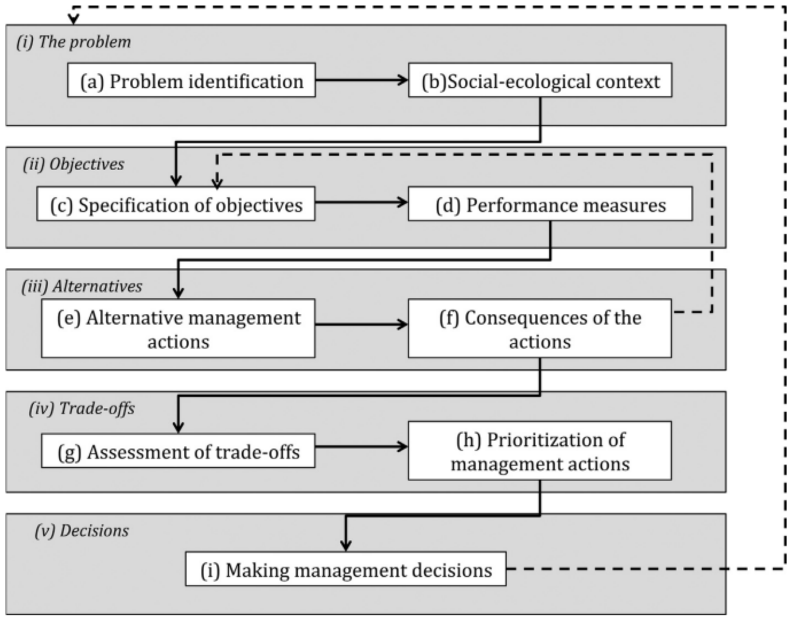


Fig. 2. Core steps in a decision making process for ecosystem services. The connection between the consequences of alternatives with the objectives represents the evaluation of the outcomes of the alternatives against the objectives with the possibility to update the objectives. The connection between the implementation of actions with the identification of the problem represents the monitoring and adaptive management loop.

Figure 8. *Decision making with feedback loops enables adaptive management (Martinez-Harms et al., 2015).*

6.2.2. Individual GI habitats or entire GI patches as spatial unit of management?

In a management plan for ecosystem services, the spatial units of management need to be specified. This is closely related to the former issue: should the supply units consist of individual GI element or complexes of different elements and habitat types. This raises questions whether an individual habitat type of a GI patch or the entire GI patch itself is the spatial unit of management.

Although in chapter 5 we discussed GI management per habitat type, GI patches in reality often consist of different habitat types and hence, management should be aimed at the mosaic rather than at the individual elements. In general, management decisions regarding the mosaic will take into account the area fractions of the habitat types and the spatial transition between these habitats. The variation in habitat characteristics may reflect an underlying variation in environmental site conditions (abiotics), or differences in land use and management. In the latter case, adaptation of management can affect the proportion of habitat types as well as the transition between habitat patches. Often, the goal in nature conservation is to reduce the impact of management in favour of the underlying abiotics and to increase the range of successional stages. This can be achieved either by reducing the frequency and extent of management or by adopting different management schemes for different parts of a habitat complex. Eligible techniques in this respect however do not differ much from those applied in the management of the 'pure' and single habitat patches. Therefore the proposed management measures per habitat type can still be the starting point for the drawing of a management plan that focusses on GI patches that consist of multiple habitats.

6.2.3. Is the GI element always the most appropriate unit for biodiversity management?

A considerable part of the importance of GI for biodiversity is linked to its spatial configuration within the landscape, as many of the ecosystem services supplied by GI rely on specific spatial interactions between patches at different scales. This poses a challenge for management; **how should management interventions be adjusted to the spatial functioning of the ecosystems** concerned.

Transitions between habitat patches as well as complexes of different habitat types benefit species richness and viability of populations. Spatial transitions often induce environmental gradients and in that way increase the variation of micro-habitats. An increase of species numbers relates to that. For a lot of animal species, a mosaic or network of different (micro-)habitat patches means a greater chance that necessary resources (food, shelter, breeding sites, wintering sites, etc.) are sufficiently accessible and available to complete their life cycle. From this perspective, when defining the spatial unit for management aimed at sustaining these species, it seems more appropriate to start from a so-called **resource-based habitat description** that takes composition, configuration and availability of resources into account (Turlure *et al*. 2019), then from a management unit based on land cover or vegetation (as used for instance in the EU Habitats Directive). The functional area of species described in terms of resources, might not coincide with the area occupied by the GI habitat that is subject of management. Targeted management of GI for biodiversity should thus take the combination of resources into account in order to be effective.

6.2.4. Is ecosystem services provision ensured by only managing the SPAs?

In order to decide about proper management, the need to analyse the spatial relations of ecosystem services is evident. The service provisioning area (SPA) and the areas where the services are benefited (SBA) may be disconnected. However, the ecosystem service flows between these two are often poorly understood or are in any case hardly managed (Serna-Chavez *et al*. 2014). Water-related ecosystem services such as maintenance of water quality, or mass stabilization and control of erosion rates, result from landscape and biophysical patterns at catchment scales, far beyond the individual GI patches. Dedicated ecosystem service management with an exclusive focus on the service providing GI elements only will then not be effective. As described earlier, the ecosystem services flow through the intermediate connecting landscape (SCA). Thus, the landscape elements that contribute to or influence these fluxes can also be subject of management intervention, even if they are not considered part of the GI. Therefore, when optimization of these ecosystem services is considered, it is important to evaluate the **type and scales of functional landscapes for each ecosystem service** (Jones *et al*. 2013). Planning and management of the surrounding area (landscape matrix) so that ecosystem services can reach the location of their delivery, is as important as proper management of the provisioning GI itself (Serna-Chavez *et al*. 2014).

6.2.5. When is managing the landscape matrix of GI a prerequisite?

Benefiting from ecosystem services provision will often depend on a landscape scale approach of planning and management. Two scenarios can be distinguished.

<u>Ensuring unaffected flow</u>: Benefiting from high quality groundwater that is ‘produced’ in areas where optimal recharge and purity of water is ensured, means that groundwater quantity and quality are not negatively affected by extraction or polluting land use in the basin area of the groundwater flow. Regulations of environmental management and land use have to be implemented in this respect.

Local climate regulation may benefit from air that originates from areas where temperature fluctuations are tempered. Effectiveness of this ecosystem service depends on free air flow in the area in between SPA and SBA which can be near each other or wide apart. Flow obstructing land cover or constructions should therefore be avoided (**Figures 9, 10**).

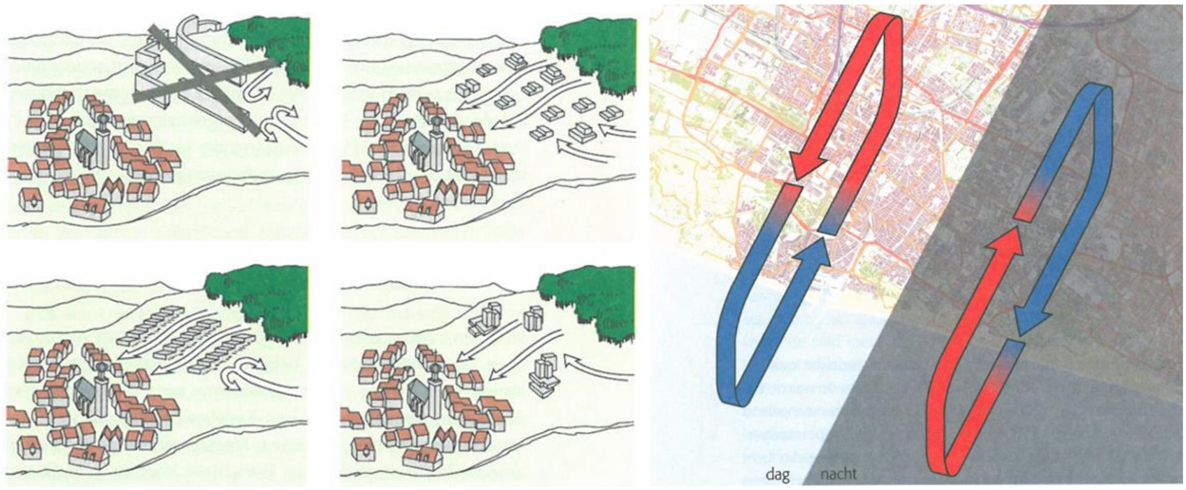
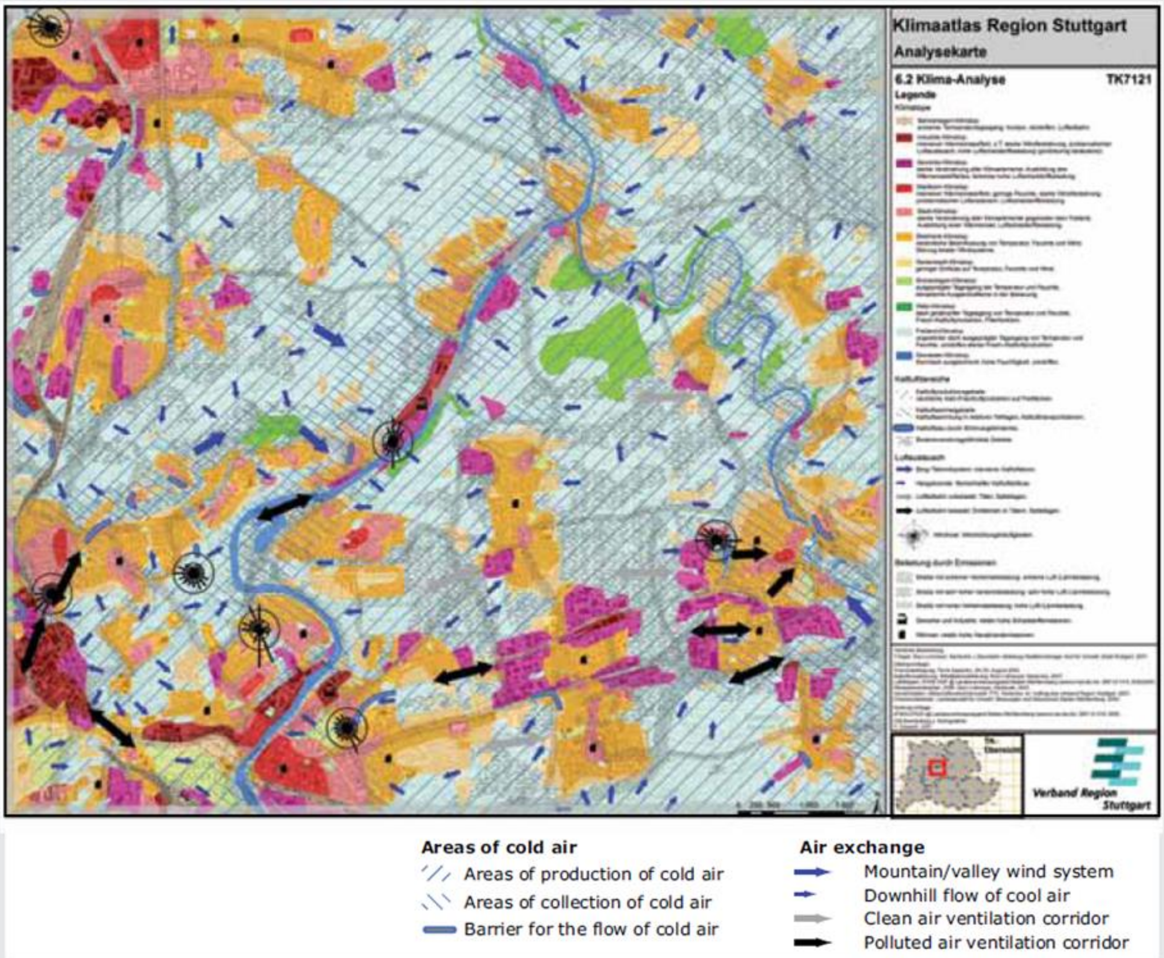


Figure 9. *SPA for local climate (temperature) regulation and realted SBA; left: SPA uphill of SBA and building design in the connecting area; right: the sea as SPA for air temperature regulation, day and night (Lenzholzer A. 2013).*

Box 2.5 Stuttgart managing urban heat island effects

Stuttgart's climate planning strategy is an excellent example of urban heat island management. The city of Stuttgart has been designed to not only respect and protect nature, but to exploit how natural wind patterns and dense vegetation can actively help the city to reduce its problems of overheating and air pollution. At night cool air sweeps down from the surrounding hills and runs through a series of 'ventilation-corridors' which have been kept open as wide, tree-flanked arteries within the city's street infrastructure.

Map 2.3 Climate analysis map for the Stuttgart region, also showing so-called ventilation paths along with other climate related features



Source: Baumüller and Verband Region Stuttgart, 2008; Klimaatlas Region Stuttgart; http://www.stadtklima-stuttgart.de/index.php?klima_klimaatlas_region.

Figure 10. *Local climate regulation SPA, SBA and SCA ('ventilation paths) in an urban context, Stuttgart (Reuter and Kapp, 2012).*

Targeted and spatially coherent interventions: Some ecosystem services only emerge when a sufficient amount of GI is arranged in well-thought-out patterns related to the processes which should be controlled. In this case, targeted design and management of the flow area is crucial. Some examples are given below.

Example 1: Mass stabilization and control of erosion rates

Although most hedgerows or grass strips have the capacity to halt erosion, the ecosystem service 'mass stabilization and control of erosion rates' will only provide a benefit when these GI elements together form a structure, strategically placed in the area prone to erosion (**Figure 11**). A landscape plan of the area where the ecosystem service can be delivered, based on micro-topography, runoff patterns, soil types and land cover which altogether determine the spatiotemporal pattern of the erosion process, is the starting point to decide about principles of erosion prevention and sediment control, the type and location of suitable landscape elements and interventions, and the management of the land in between. Potential measures are very diverse and comprise for instance principles of conservation agriculture such as minimum soil disturbance (no-till management), application of organic manures and green cover after harvest, agroforestry, construction of terraces and graded ditches, etc. Recent guidelines give extent overviews of strategies and useful measures (see, for instance, Clean Water Services 2020; Vandekerckhove 2010).

Figure 11. *Grass strips strategically placed around fields.*

Example 2: Flood protection

Effective protection against floods (storm water control) equally depends on the coherent functioning of GI elements in the whole watercourse system of a river basin plus an adapted land use in the catchment. Integrated river basin management plans define spatially explicit targets and potential measures regarding water storage in soil, canopy and wetlands, and in the floodplain and waterbodies. The locations of different types of GI, their size, performance criteria and management requirements can be derived from the plan. The flow of the water, the residence time, storage capacity and discharge characteristics of individual parts of the catchment, define the logics of a GI management plan for this ecosystem service (see for instance: European Commission 2009).

Example 3: Pest control and pollination and seed dispersal

Pollination and seed dispersal, and pest control are two prototypes for ecosystem services that only become effective when a network of supporting GI is well spread over the benefiting area. The extent of the area where the ecosystem services can be delivered is relative to the home and foraging range of the species that provide the services. A way to expand this area is by creating a network of suitable habitat throughout the potential benefiting area. In arable land this network will, dependent on the geographical region, consist of semi-natural landscape elements such as field margins, road verges, ditch banks, dikes etc. These habitats provide resources that support species which can for instance, suppress pests. Steingröver *et al*. (2010) present an example where this approach was put into practice, together with the stakeholders. The authors distinguish between fine linear elements which are at least 3.5 m width and robust line elements that are more than 25 m width. In both type of elements the pest controlling species move actively between the semi-natural elements and the crops where they predate the pest species. Robust elements however also support population development and passive dispersal by wind during seasonal movements and so provide influx of natural enemies over large areas (**Figure 12**). Based on average distances covered by active and passive movement, spatial norms for the GI network were drawn. In turn, this was translated into norms for the distance between the landscape elements and thus the width of the crops (see **Figure 13**). With these norms and a detailed mapping of the actual distribution of the fine and robust landscape elements in the area, the potentials for natural pest control could be assessed and places that needed a completion of the network identified (**Figure 14**). This network then forms the core of the local landscape management plan. Although science-based evidence is available and models produce valuable designs for (re-)structuring the landscape, efficient implementation of biological pest control requires a wide range of knowledge and skills. Stakeholder involvement, especially of farmers is essential to co-create the landscape plan, to adopt and realize it and manage the GI network according the set objectives (Jeanneret *et al*. 2016).

Fig. 2 Illustration of the norm for the distance between fine elements when robust elements are present (*top panel*) or absent (*central panel*). Due to the presence of robust elements as a source for passive movement, the norm for maximum distance between fine elements is higher when robust element are present, than when they are absent

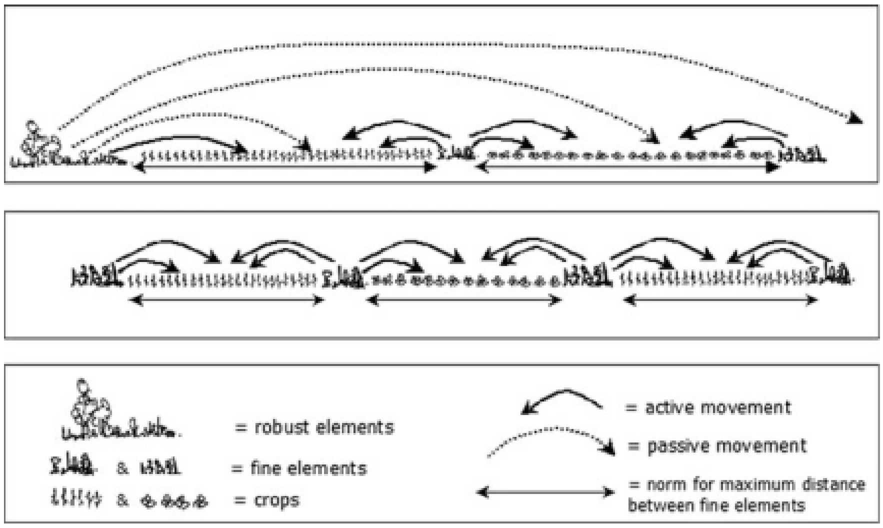


Figure 12. *Passive and active movement of pest control species linked to fine and robust landscape elements (Steingröver et al. 2010).*

Table 1 Summary of the spatial norms for the density of fine elements, dependent on the presence or absence of robust elements in the landscape and also indicating the source (*E* expert knowledge, *M* simulation model, *F* published field data)

	Robust elements present	Robust elements present	Robust elements absent
Distance from robust element	0–75 m (E)	75–1,000 m (F)	>1,000 m (F)
Influence	Active movement	Passive movement	No influence
Additional fine elements needed?	No	Yes (every 150 m) (M)	Yes (every 100 m) (F)

Figure 13. *Design norms for density of landscape elements supporting natural pest control (Steingröver et al. 2010).*

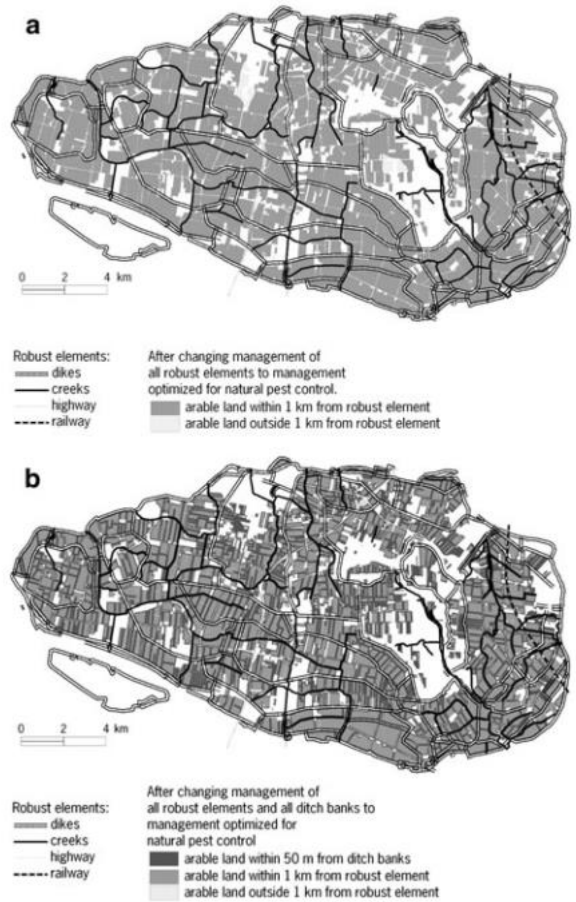


Fig. 3 Potential of Hoeksche Waard area for natural pest control, depending on which existing landscape elements are managed. **a** all robust elements managed for natural pest control (the arable land within 75 m from robust elements is not shown because not clear at this scale); **b** all robust elements and ditch banks managed for natural pest control

Figure 14. *Potentials for natural pest control, landscape plan (Steingröver et al., 2010).*

Example 4: Water, air and noise quality control

When it is expected that regulating ecosystem services can be used to control problems caused by water and air pollution or by noise, a good insight of the spatiotemporal relationship between the source of the problem and the affected area is required. This implies knowledge of the processes and the flows brought about, to foresee how ecosystem functioning of GI elements can alter them in such a way that the negative impacts are alleviated. That knowledge then enables the selection of suitable GI types and their optimal position with respect to the source and the affected area. Between emission and effect, chemical reactions take place and pollutants may change. Often, this relates to the ecosystem compartments the substances travel through. Recognition of the 'corridors' along which the pollutant's transport and transform, of the environmental conditions, the associated ecosystems such as wetlands and riparian vegetation, and their specific functioning with regard to the chemical transformations, helps to select appropriate measures and GI elements to counteract the pollution (see, for instance, **Figures 15, 16**).

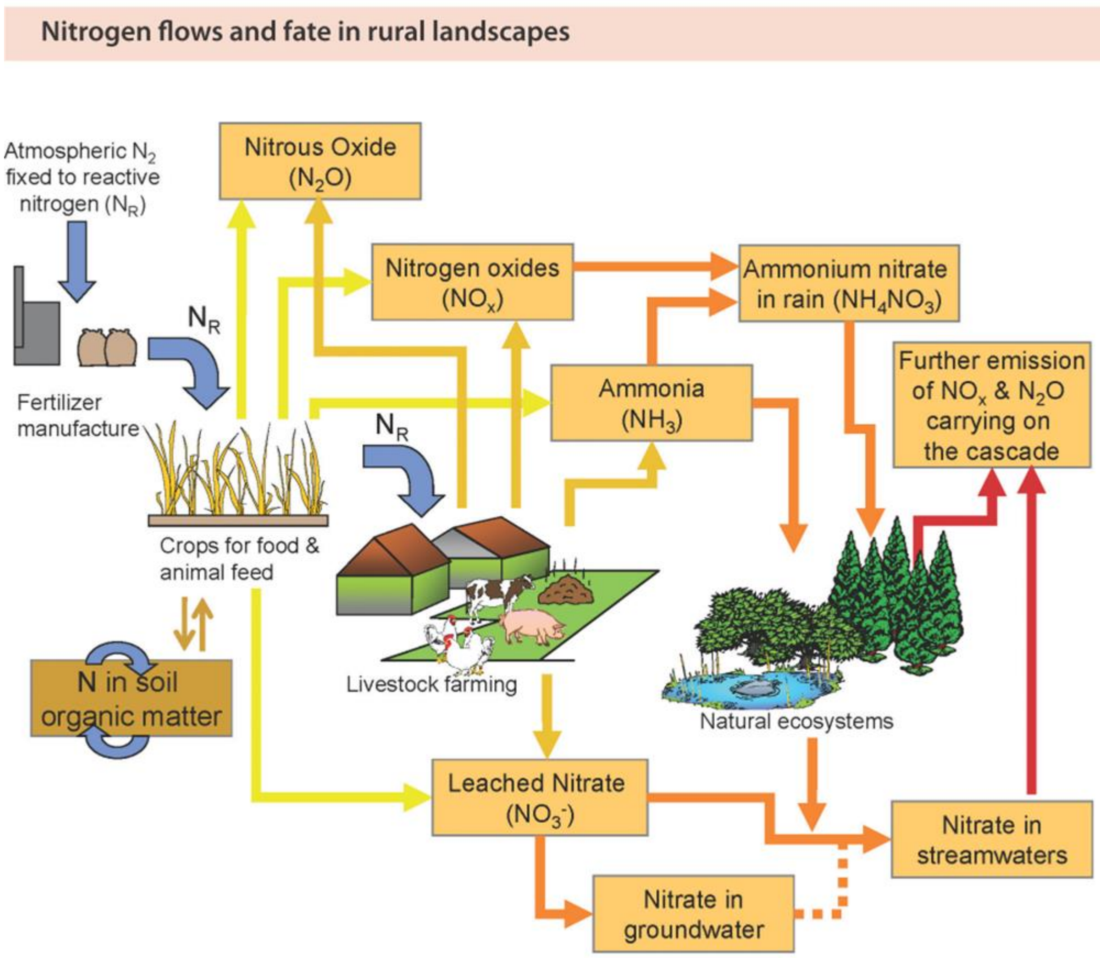


Figure 15. *Nitrogen flow and fate in rural landscapes (Cellier et al. 2011, after Sutton et al. 2011).*

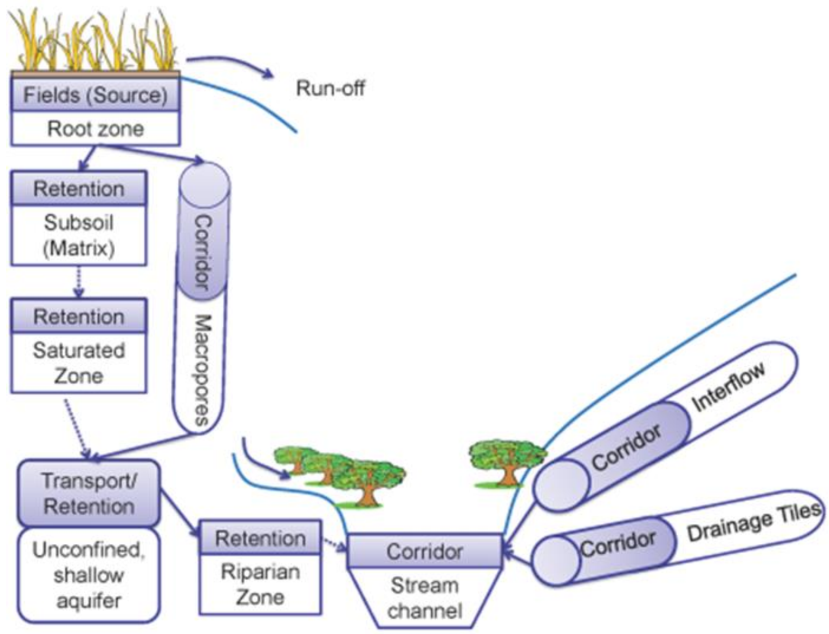


Figure 16. *Scheme of corridors and retention compartments. The sequence of compartments depends upon the specific hydrological setting and is spatiotemporally variable (Cellier et al. 2011).*

Modelling the changes of flows generated with alternative landscapes designs, can be used to inform about the effectiveness of different scenarios, for instance with regard to the position of service provisioning GI elements (**Figure 17**). The results of this kind of analyses are presented in landscape plans with guidelines for the design and management of the required GI network.

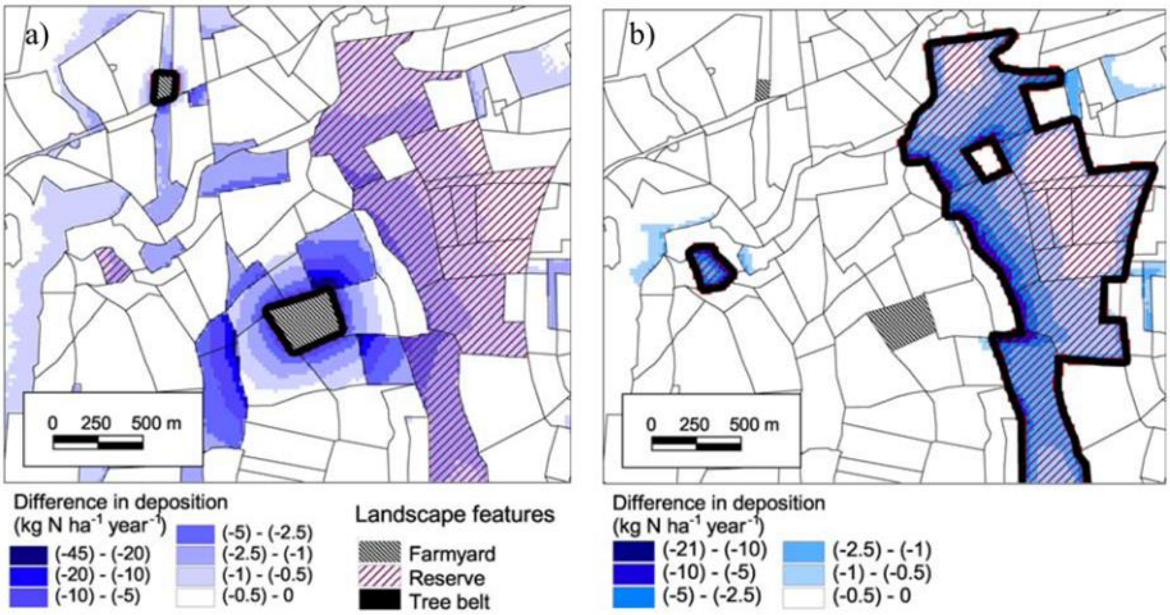
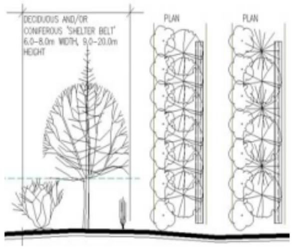


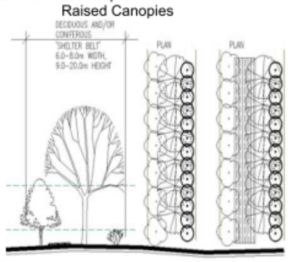
Figure 17. *Effect of two scenarios of landscape planning using trees to reduce the impacts of ammonia deposition on two hypothetical Special Areas of Conservation (hSAC). Reductions in deposition in neighbouring areas resulting from planting 50 m wide belts of trees a) around two farms, and b) around two hSACs. (Sutton et al. 2004; Dragosits et al. 2006).*

Example 5: Multifunctional hedgerows and tree belts

Other applications of GI where a landscape scale approach is needed are related to the role of small landscape elements such as row of trees and hedgerows to simultaneously act as windbreaks, noise barriers and filters to improve local, near-road air quality. Simultaneously realizing these multiple services requires a thorough understanding of the factors that affect the performance of these landscape elements, including physical characteristics such as height, thickness, length and porosity; vegetation characteristics such as seasonality, leaf surface, pollution and drought tolerance (see chapter 3.1). The required GI attributes for the different objectives pursued, the thresholds that must be taken into account to ensure proper ecological functioning, and the desired combination of ecosystem services provision, can be translated into design principles (**Figure 18**) (see for instance Baldauf 2017; Brandle *et al*. 2009; Nottawasaga Valley Conservation Authority 2012). When the provision of yet some other ecosystem services is aimed for, such as hedgerow habitat function for biodiversity and biomass production for fuel (see, for instance, Crossland *et al*. 2015), the data obtained through targeted surveys should be combined with the physical principles underlying the other services.

Figure 5: NVCA Multi-functional windbreaks generic designs- field protection: double or multiple rows.





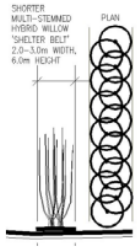


	Fig. 5.1 Double or Multiple Row Deciduous - One Raised Canopy	Fig. 5.2 Double or Multiple Row Deciduous - Two Raised Canopies	Fig. 5.3 Fast-growing Shrub or Hybrid Willow Shelterbelt
Description	Double or Multiple Row Deciduous - One Raised Canopy	Double or Multiple Row Deciduous - Two Raised Canopies	Shrub or Hybrid Willow Shelterbelt - Double rows, offset
Purpose	Field Protection, limited biomass harvest	Field Protection, limited biomass harvest	Field or farmstead protection, and biomass harvest
Working Width	6.0 - 8.0 m	6.0 - 8.0 m	2.0 - 3.0 m
Mature Height	9.0 - 20 m	9.0 - 20 m	6.0 m
Spacing In-row	3.0 m o/c standard, up to 4.0 m o/c 1.5 m - 2.0 m shrubs	3.0 - 4.0 m o/c	0.25m down alternate rows or 0.50m down each row
Harvestable Components and Timing	Fruit in ~5 years, wood in 40 + years	Limited wood at maturity; 40 + years	willow biomass in 10 - 3-year rotations
Maintenance Needs:	Shrub pruning for fruit production	Standard for coniferous, some lower branch pruning	Virtually none after establishment
Target Porosity	70% winter, 40% - 50% summer	70% winter, 40% - 50% summer	70% winter, 40% - 50% summer
Advantages	Greater diversity, potential for fruit harvest, v. good porosity	Greater diversity, potential for fruit harvest, v. good porosity	Produces biomass for fuel, fiber or livestock litter
Disadvantages	Higher maintenance (pruning) and production harvest costs	Higher maintenance (pruning) and production harvest costs	Requires bio-harvester and biomass market
Typical Species	Oaks, maples, currants, blackberries, raspberries, etc	Oaks, maples, currants, blackberries, raspberries, etc	Fast-growing shrub willow or hybrid willow
Economic Comparison	Payback 9 years based on crop yield increases, fruit harvest vs. implementation, maintenance costs	Payback 9 years based on crop yield increases, fruit harvest vs. implementation, maintenance costs	Payback varies based on crop yield increases, biomass harvest vs. implementation, maintenance costs
Notes	Excellent porosity for field protection year round including longer snow accumulation zone. Centre tree row can alternate with conifers or more shrubs, see 4.3 through 4.6 above. Naturalization shrubs can eliminate pruning costs. Between-row spacing 3.0m takes up more space than single row.	Excellent porosity for field protection year round including longer snow accumulation zone. See 5.1 Notes. Between-row spacing may be widened up to 6.2 m to permit row cultivation or mechanical berry harvesting.	Excellent porosity and short 3-year harvest rotations for 30 years. This design may be used as field or farmstead and laneway protection windbreaks (payback periods may be reduced to 1 or 2 years), or used solely for biomass harvest.

Multi-functional Windbreaks: Design Options and Economic Evaluation 25

Figure 18. *Example of design principles for multifunctional wind breaks (Nottawasaga Valley Conservation Authority, 2012).*

6.2.6. Are the ecosystem services provisioning areas accessible?

Part of the ecosystem services is only provided when the provisioning element can be accessed. 'Accessibility' can relate to visibility from a distance, possibilities for walking along and through the area, harvesting, etc. Maintaining, improving or restoring accessibility, developing appropriate infrastructure and agreeing on regulations with landowners and users, should be dealt with in a landscape plan. Just focussing on the management of GI as a provisioning unit, cannot ensure that services will be benefited.

7. Intended outputs and outcomes

This Cookbook focusses on GI management for ecosystem services and thus can be of use to those who want to bring the process of assessing GI capacity to supply ecosystem services one step further and create appropriate conditions for GI to effectively provide desired ecosystem services. Therefore, background information is given and approaches described that may be relevant to

- decide about the necessity of management or restoration of GI elements and networks in order to deliver desired ecosystem services;
- decide about the biophysical and technical basis to draw up integrated GI management plans for ecosystem services.

With this Cookbook we want to raise awareness of the different aspects that have to be taken into account when goals are formulated regarding the provision of ecosystem services by GI and GI management plans have to be prepared. Background information about suitable management techniques for different GI types and different ecosystem services, and conclusions and suggestions regarding management and restoration issues, are not meant to be copy-pasted into management plans. The local context is indeed too precise and decisive to simply adopt guidelines. However, we are convinced that the rationale and the discussions may feed the decision processes that are an inherent part of the preparation of management plans.

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Appendices

Template for management questionnaire

Selection of relevant habitat types (German CSS challenge)

- hedgerows (an alignment of low trees and shrubs only cut every >5 years)
- flower strips
- field edges
- forest
- riparian strips
- line of trees
- permanent pasture

Current management

Collect information about the actual management of these GI elements

hedgerow	Cutting	Coppicing	Pollarding	No management							Others
flower strips	Mowing	Cutting	Grazing	Controlled burning	Sod cutting	No management					Others
field edges	Mowing	Cutting	Grazing	Controlled burning	Sod cutting	No management					Others (e.g. herbicides)
forest	Clear-cut	Group selection	Thinning	Coppicing	Pollarding	Controlled shrub burning	Scrub clearing	Planting native trees	Planting exotic trees	No management	Others
riparian strips	Cutting	Mowing	No management								Others
line of trees	Pollarding	Mowing	Cutting	Grazing	Controlled burning	Sod cutting	No management				Others
permanent pasture	Mowing	Cutting	Grazing	Controlled burning	Sod cutting						Others

What is the ***purpose or objective of the management for each of the GI elements*** (in terms of ESS delivery or other, more familiar terms)? Are all objectives equal or are there priorities?

Who is responsible for the management?

Which are the ***techniques used***, what is the ***frequency of management***, when is the management done (***time of the year***)?

Are there ***particular regulation*** regarding the management of the GI elements? Is the management organized according ***management plans*** or ***official guidelines***?

Are there guidelines, websites, handbooks, leaflets, fact sheets, reports, which give ***technical advice or information about best practice***? (collect references, libraries, websites, contact persons, organizations, etc. where these publications and information (in English, French, German) can be obtained)

Has ***scientific research*** being done to increase the ***evidence base***? Are results available?

GI elements quality

How do stakeholders ***assess the actual quality*** of the different GI elements regarding the potential to deliver the required ESS.

In general: insufficient, sufficient, good, excellent

If insufficient: what are the ***causes of this malfunctioning***? What is lacking; ***what should be done to improve*** the performance?

Opportunities or requirements to improve management

Are there ***requirements to improve GI management***?

Why and for which GI elements? Lack of management, less effective techniques, unsuitable techniques regarding some of the objectives pursued, efficiency of management organization, etc.

Lack of knowledge?

Is there a ***need to restore*** GI elements? ***Why and for which GI elements***?

What should be done to restore particular GI elements?

Multipurpose management

Are there potentials and needs to ***combine ESS or functions***? Which combination of ESS or functions?

How can ***management contribute to that***?

Does ***combining different ESS*** or functions ‘only’ imply ***adaptation of management*** or is ***design or spatial arrangement*** of GI elements also an issue?

IMAGINE project summary

The IMAGINE project ran between 2017–2020, between five countries and 6 partner institutions:

- INRAE (FR);
- Institute for Social-Ecological Research (ISOE, DE);
- Kiel University (UniKiel, DE);
- Norwegian Institute for Nature Research (NINA, NO);
- Estonian University of Life Sciences (EMU, EE), and
- Research Institute for Nature & Forest (INBO, BE).

The project aimed at quantifying the multiple functions, ecosystem services, and benefits provided by Green Infrastructures (GI) in different contexts from rural to urban. It used a multidisciplinary approach across six case study territories spanning a European north-south gradient from the Boreal zone to the Mediterranean.

IMAGINE aimed to demonstrate an integrative assessment of GI multifunctionality and biocapacity to deliver ES and to propose options to manage and design GI from patch to landscape. The project contributed to developing an innovative approach to support ecosystem resilience, sustainable essential ecosystem services flow, and contributing to human wellbeing to meet EU policy targets.

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biodiversa

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« Understanding and managing biodiversity dynamics to improve ecosystem functioning and delivery of ecosystem services in a global change context: the cases of soils and sediments, and land- river and sea-scapes »

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AGENCE NATIONALE DE LA RECHERCHE ANR

Bundesministerium für Bildung und Forschung

Belgian Science Policy Office belspo

Forskningsrådet The Research Council of Norway

ALTER-Net

IMAGINE is an Alternet Project. The idea of proposing this project and the initial consortium members was initiated during the Alternet Conference session on Biodiversa Calls.