"COOKBOOK" SERIES N° 3

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Assessing detailed GI habitat quality for biodiversity and ecosystem services

Photo: Joke Maes, Regionaal Landschap Kleine en Grote Nete.

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Table of Contents

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 (this cookbook)**
4. GI management for ecosystem services
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^{o} 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 signaling 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 this IMAGINE cookbook n° 3 '***Assessing detailed GI habitat quality for biodiversity and ecosystem services***' (De Blust and Heremans – **this report**) 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 the IMAGINE Cookbook n° 4, '***Green infrastructure management for ecosystem services***' (De Blust and Heremans 2020) 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 **this Cookbook**, and Cookbook n° 4.

2.1 Habitat quality assessment objectives

In IMAGINE, a detailed description and assessment of GI habitat quality are needed in order to better understand

- ✓ the actual state of the GI habitats;
- ✓ the relation between this state and the use & management of the GI habitats and the landscape matrix they are part of;
- ✓ the current and potential delivery of ecosystem services by the GI;
- ✓ the appropriate strategies to maintain or improve GI habitat quality while at the same time optimizing the delivery of selected ecosystem services, including the habitat and corridor function for biodiversity.

Understanding the GI as a system is a prerequisite. Here we confine to the biophysical (ecological) part of that system.

Habitat quality assessment not only relates to the actual state of the GI, but also to its management, and hence serves the IMAGINE WP3 task 3.1 '***Development of a harmonized methodology for the assessment and description of use and management of GI habitat and of the landscape matrix***'. This task is not an objective on its own, but is a condition to realize IMAGINE WP3 Task 3.2 '***Definition of suitable options for management and restoration of functions and connectivity and for maintenance of enhanced ecosystem services delivery***'. Tasks 3.1 and 3.2 have to culminate in the WP3 deliverable '***A 'catalogue' of guidelines and building blocks to construct a functional GI network for biodiversity and multiple ecosystem services***' which is the subject of IMAGINE Cookbook n° 4.

In IMAGINE we assess the instrumental quality of the GI network and its composing habitats. Consequently, habitat quality should ideally be defined with respect to a particular purpose. Interpreted in a narrow sense, the quality of a habitat type or a habitat patch to deliver a particular service or function is traditionally seen as the result of its characteristics (ecological structures and processes, species composition, environmental conditions) and how these influence the habitat properties and processes required to effectuate the different services and functions. However, when interpreted in a systemic and more integrative way, it becomes clear that the performance of GI to deliver ecosystem services not only depends on the habitat variables itself, but also on spatial, economic and socio-cultural aspects. This makes it very difficult to develop a comprehensive and integrative framework to assess GI quality across all types of GI and ecosystem services (Pakzad *et al*. 2017). In the IMAGINE project we try to assess ecosystem services provision by combining ecological, spatial and socio-cultural knowledge and analyses of CSS. In this Cookbook we focus on spatial and ecological aspects.

In IMAGINE the detailed analysis of ecosystem services and related GI types was conducted in a selection of smaller case studies in some of the CSS and in the WP2 field study plots. The objective was to establish a strong link between the biophysical analysis and the total socio-ecological processes in terms of the division of responsibility, the joys and the burdens, etc. and the associated local governance issue, which all are most tangible and concrete on this local level. Finally, by combining habitat quality assessment of GI with existing optimization potentials and restoration needs for ecosystem service delivery, we ensure that IMAGINE work starts from the real world and will yield meaningful and useful results.

As it is the objective to explore options for a variety of ecosystem services in each of the CSS, information about a series of habitat characteristics must be available. On the level of an entire CSS, this information will often be missing as a consistent valuation of the quality of the GI habitat types is not readily available for each CSS. That means that it is hard to distinguish habitat suitability and performance for each of the selected services and functions individually or in detail and that the assessment of the capacity to supply ecosystem services will remain a best guess. To tackle this problem, a variety of models and methods are developed (see, for instance, Van der Biest 2018; Vihervaara *et al*. 2018). To some extent, information can be gained from expert panels that may assess performance of ecosystem service delivery based on experience and local knowledge. Building a *capacity matrix* has become well known in this respect (Burkhard *et al*. 2009) and is also central in IMAGINE. In a capacity matrix, the suitability in general of a habitat type, often presented as land cover type, to deliver a service is assessed without explicitly referring to their actual habitat characteristics, environmental conditions or spatial context. The liability of the scores obtained, very much depends on the number of experts contributing and on their knowledge of the mechanisms and conditions that determine a habitat's performance to provide ecosystem services (Campagne *et al*. 2017). An alternative is to start from biophysical modeling of the interrelations between relevant components of the spatial unit which are thought to generate an ecosystem service. The starting point are then the processes that determine the potential to deliver particular ecosystem services (see for instance Remme *et al*. 2014). Both approaches however depend on land use or land cover maps of which the effectiveness to 'predict' ecosystem service delivery is inappropriate, whatever the detail of the land use classification system (Van der Biest *et al*. 2015). In IMAGINE we thus propose to carry out an analysis of habitat attributes that determine habitat quality, apart from the assessment through capacity matrices, to complete the valuation of ecosystem services delivery of habitats.

Ideally, the detailed recording of GI habitat quality should be done on a landscape scale, in plots with size 500*500 m. Species composition and associated ecological functioning and hence ecosystem services performance, largely depend on the interplay between land use, habitat management and landscape configuration or the size, shape and distribution of habitats in the surrounding landscape. Therefore, the survey procedure should allow the analysis of the spatial interrelations of the GI elements.

2.2 Criteria for GI habitat quality assessment

The general habitat quality assessment clarifies the overall state of GI in a region and may be used, together with an equally general analysis of the GI ecosystem services demands and delivery potentials (the 'capacity matrix'), to define priorities for conservation, management and/or restoration of GI. For the detailed quality assessment a targeted description of the actual state is necessary. From an ecological point of view this includes information about various aspects of community structure that influence the function, information about the key environmental factors that have an influence on the supply of services, and about the spatio-temporal configuration and dynamics in which service providers and service beneficiaries operate (Kremen 2005). As we concentrate on the biophysical (ecological) part of that system, the criteria for GI habitat assessment relate to biotic, environmental and spatial characteristics of the habitat. For an overview, see for instance Harrison *et al*. (2014). In general the following criteria can be used to describe a habitat's quality:

Biotic variables

- *species composition*: number, abundance, diversity, demographic rates, indicator species, keystone species, red list species, non-native invasive species, …
- *'functionality' of species*: nectar producing, food resource, productivity, ecosystem engineer species, functional and behavioral treats, pests, diseases, …
- *structure of habitat, community, population*: dominance, complexity, number of vegetation layers, trophic levels, functional micro- habitats, age classes, …
- *succession stage*

Environmental variables

- *soil characteristics*: texture, undisturbed profile, nutrient content, acidification & mineral leaching, contamination, compaction, soil moisture, …
- *water characteristics*: natural dynamics of quantity (levels, flow velocity, discharge, …) and quality (chemical composition, sediment load, …) of surface water and groundwater, hydraulic head, erosion and sedimentation dynamics, …
- *micro- climate characteristics*: exposure, temperature, air humidity, …
- *atmospheric characteristics*: nitrogen deposition, aeolian activity (erosion and sedimentation dynamics), …

Spatial variables

- patch size, shape, spatial configuration, connectedness, barriers, core/edge ratio, boundary type, …

Part of these characteristics can be derived from detailed maps or databases, others have to be collected in the field. In IMAGINE, it is impossible and also not the objective, to conduct a complete habitat quality assessment based on all these variables. On the contrary, we restrict to a selection that is suitable to describe habitat quality in relation to particular ecosystem services. Data collection on the terrain however remains necessary as far as possible.

2.3 Landscape metrics for GI habitat quality assessment

To assess the *generic habitat quality* for a whole region or CSS, we couldn't rely on existing systematic surveys and descriptions of habitat attributes. As a targeted field survey was not feasible as well, we prefer to base the generalized description of habitat quality for a whole CSS on a set of landscape metrics. Indeed, landscape structure, heterogeneity and configuration determine to a large extent the occurrence of species (see, for instance, Dauber *et al*. 2003; Walz and Syrbe 2013) and the delivery of ecosystem services (Syrbe and Walz 2012; Termorshuizen and Opdam 2009; Verhagen *et al*. 2016). The analysis and description of landscape structure itself is often done with landscape metrics (Uuemaa *et al*. 2009; Walz 2011).

As the landscape metrics express different aspects of GI quality, different metrics do not necessarily agree with each other regarding their indicator value for various species and ecosystem services. Landscape metrics are thus supposed not to be integrated into a single index to express a generalized habitat or GI quality for an entire CSS. They should be applied on a landscape level and the metrics should be assessed individually in order to create the strongest explanatory power (see, for instance, Schindler *et al*. 2013). Exception is the analysis of vulnerability to disturbances as elaborated in IMAGINE Cookbook n° 4 where landscape metrics are combined in sub-indices (Heremans and De Blust 2020).

In literature tens of landscape metrics have been proposed and tested (see for instance Farina, 2000; Schindler *et al*. 2008). Several are very useful indicators of biodiversity, although their general application as a proxy for biodiversity cannot be taken for granted (Sowińska-Świerkosz 2020). Metrics related to patch shape, patch size, proximity, texture and diversity for instance are often significant predictors for species richness (Schindler *et al*. 2013). In general, metrics that quantify composition (diversity), configuration (texture, patch shape) and edge density are valuable indicators of plant species richness (see, for instance, Honnay *et al*. 2003).

Seven indices were selected which are quite suitable to assess GI habitat quality in general in the IMAGINE case study sites, and that use input data that can easily be retrieved from land cover maps.

1) *Area of total GI*
2) *Area of individual GI patches*
3) *Total area of each GI habitat type*
4) *Area of individual patches of GI habitat types*
5) *Edge / area ratio per GI patch*
    a. for mosaic patches as a whole
    b. for homogeneous patches (consisting of 1 GI habitat type)
6) *Landscape configuration*
    a. nearest-neighbour distance (of the same patch type)
    b. proximity index
7) *Amount of disturbance induced by neighboring land use* on GI patch.

2.4 Interpretation of the indices

The landscape metrics relate to a number of ecological characteristics of the GI in the CSS. Therefore, they can – to a certain extent – be used to assess the current overall quality of GI and the potential overall quality after restoration, adapted management and/or implementation of new and agreed land use plans. To interpret the importance of GI of the whole CSS for biodiversity, for the provisioning of ecosystem services and for the prevalence of ecosystem disservices, these landscape metrics have to be considered together with results of morphological spatial pattern and connectivity analyses. The latter may yield information about the land use matrix the GI is placed in. In the IMAGINE CSS, the landscape matrix is mostly composed of intensively used agricultural land and urbanized areas which may have a considerable impact on the ecological functioning of the whole CSS.

To assess place-based ecosystem service provision of a GI habitat patch, landscape metrics are often useful (Syrbe and Walz 2012). However, the effectiveness of the service delivery equally depends, apart from the habitat quality, on the unhindered spatial and temporal connection between the GI habitat patch as the service providing unit and the place where the service is benefited. Thus, ample attention should be drawn to the flow between the service providing area through the surrounding landscape which is the connecting area towards the service benefiting area (see, for instance, Burkhard *et al*. 2014; Serna-Chavez *et al*. 2014; Syrbe and Walz 2012).

The landscape metrics that are proposed, inform about different aspects that have an influence on habitat quality related to ecosystem services provision and biodiversity support.

1) ***Area of total GI as % of total area of the CSS*** is an index that represents the total potential GI habitat area of the CSS.
For biodiversity this means the area where suitable habitat of any kind exists or where habitat can be improved by management or restoration in order to sustain biodiversity.
For the ecosystem services that are supported by the GI habitat types concerned, the index gives the total area available to design and manage GI in favor of these ecosystem services.

2) ***Area of individual GI patches*** presented as the distribution of patches per size class.
For biodiversity, this index allows reflection on species numbers and the potentials for 'viable' populations with the assumption 'the bigger the patches the better'. Furthermore, large areas can be more diverse with a variety of environmental conditions or management types and

hence different (micro) habitat types that may sustain a rich biodiversity. Internal heterogeneity of patches that are big enough may increase resilience of the total patch by providing a range of resources and refugia and by increasing total species richness.
For the ecosystem services that are supported by the GI habitat types concerned, larger areas will mostly perform better, especially for those services that are delivered in the habitat patch itself (such as many of the provisioning services). Spatial heterogeneity which will be higher in bigger patches, enhances the resistance of ecosystem functions and the associated services by improved resilience of the species communities (Oliver *et al*. 2015).

3) ***Total area of each GI habitat type*** is a further detailing of the first index. It represents the area of the CSS covered by a particular GI habitat type, not taking into account its actual habitat quality. Whether the habitat patch is part of a larger mosaic patch composed of different habitat types, is not taken into account as well.

For biodiversity it is the total area of each GI habitat type, regardless condition. As such, it only gives an indication of the potential importance of a CSS for each of the different GI habitat types.
For the ecosystem services that are supported by the GI habitat types concerned it is the total area available for each habitat type that can be further designed and managed in favor of these ecosystem services. On the scale of the CSS as a whole, it allows accounting of the contribution of the different GI habitat types to ecosystem services delivery.

4) ***Area of individual patches of GI habitat types*** represents the number of patches per size class of each of the different GI habitat types, and thus allows comparison with standards for size as a condition for habitat quality (if they exist). The patch of a specific habitat type can be part of a larger mosaic patch.

For biodiversity the number of patches that exceeds a threshold size, informs about the potential viability of that particular habitat type. This relates to the higher chance of key resources to be present and abundant and to the structure or complexity of the habitat as a key feature. For forest the 'balanced structure area' (BSA) has been defined (Koop, 1989). It is the minimum contiguous area that includes all tree development stages and thus represents the different structural phases of a forest. As habitat structure determines to a great extent total biodiversity (see, for instance, MacArthur and MacArther 1961), BSA can be a good predictor for species numbers. The BSA of broad-leaved forest in Atlantic Europe for instance equals appr. 50 ha (Vandekerkhove 1989). GI forest habitat patches of this size can be considered of good quality. Standards for the general classes of other GI habitat types still have to be defined and compiled. For habitat types that relate to the Natura 2000 habitat types, the criteria which define favourable conservation status provide some figures.
For the ecosystem services that are supported specifically by particular GI habitat types, larger areas will mostly perform better, especially for those services that are delivered in the habitat patch itself (for instance, many of the provisioning services) (see for instance Bastian *et al*., 2012). Also the extent of potential disservices associated with particular GI habitat types, will become clear.

5) ***Edge / area ratio per GI patch*** informs about the compactness of habitat patches and hence the robustness of the core habitat, or the other way around, it sheds light on the complexity of the edge habitat. For this index an 'edge area' with a certain width in the outer boundary of the patch must be defined.

Two approaches can be used:

a. ***Edge / area ratio for GI patch as a whole***. This index includes patches that contain different GI component types and hence are heterogeneous.
b. ***Edge / area ratio for homogeneous patches*** that consist of 1 GI habitat type. This index Informs about the viability and performance of particular GI component types.

The meaning of this index is not unequivocal, although it determines to a great extent the functioning and performance of the patches.
For biodiversity, edge effects are crucial to understand species occurrence and performance in fragmented landscapes (see, for instance, Ries *et al*. 2004). The more a patch has a compact shape, close to a circle, the less edge effect is generated while with increasing size, the bigger the core area becomes. This may increase the suitability of a habitat patch for particular core area species. However, complex edge shape coincides with species richness (see for instance Miller *et al*. 1996) while more boundary area also allows for more species exchange and thus increases colonization but also extinction rates. Higher potential for fluxes facilitates species exchange and dispersion. Furthermore, the roughness of an edge with for example a variation of exposure and microclimate, may create conditions that give rise to new habitat types. Finally, a habitat patch with only a small core area that is prone to increased edge effect, can be affected negatively over its whole area resulting in a considerable loss of habitat quality and species.
Regarding ecosystem services, compact habitat patches with large core areas will probably perform better than smaller ones which experience more edge effects, especially for ecosystem services delivery that needs optimal and unaffected habitat conditions. However, this does not hold for ecosystem services that depend on exchange between habitat patches. For instance, pollination and biological pest control are more successful in heterogeneous landscapes with ample 'contact zone' between the GI habitat patch that sustains the functional biodiversity and the land cover classes, mainly outside the GI network that benefit from the ecosystem services (see for instance Betts *et al*. 2019). Also the effectiveness of air quality control depends to a high degree on the structural complexity of contact zones and boundaries (see, for instance, Baldauf 2017).

6) ***Landscape configuration*** informs about the distribution of habitat patches relative to each other. It clarifies the degree of isolation, the coherence of a network, the proximity of similar habitat types.

Two approaches can be used:
a. ***Nearest-neighbour distance (of the same patch type)*** which describes the average edge-to-edge distance between two nearest habitat patches of the same type.
b. ***Proximity index*** which describes the distance of a patch to all other habitat patches of the same type that are situated within a specified zone. The width of that zone relates to a threshold value that can be associated with particular species and their 'critical dispersal distance' or with a gradient of performance of a particular ecosystem service.

In order to understand how ecological coherence on the landscape level may affect the functioning of individual habitat patches and the ecosystem services they deliver, this index should be interpreted together with the results of functional connectivity analyses. In IMAGINE this was dealt with in WP1 (see Le Louarn *et al*. 2018).

For biodiversity, the index informs about the potential isolation of suitable habitat patches and about landscape connectivity and hence the need of habitat restoration or adapted management of land use in the landscape matrix, in order to facilitate species movements between suitable areas. This relates to variation in population demographic rates, dispersal patterns and survival rates (see, for instance, Hanski 1999; Royle *et al*. 2018; Verboom *et al*. 2001). Thus, it sheds light on the chance that local populations can function as a meta-population in a network of accessible habitat patches, which increases the overall viability of species concerned. For large enough core areas (key patches) that may support core populations with a high viability that produce a regular flux of individuals (offsprings), it accounts for the chance that small and vulnerable populations in low quality habitat patches in the vicinity may be colonized or supplemented.
For ecosystem services the degree of pure physical connectedness between similar habitat types can be important depending on the ecosystem services concerned. However, increased movements of functional species between nearby habitat patches may also improve performance of particular ecosystem services. Populations can be more viable and species are more frequently present. Landscape configuration in the broad sense however, which takes the degree of fragmentation and connectedness, plus distribution, area, size and number of habitat patches into account, certainly affects ecosystem services delivery (Martin *et al*. 2019; Verhagen *et al*. 2016). The same is true for eventually disservices, as species involved may easily move through the landscape exerting negative or unwanted impact in a wider area.

7) ***Amount of disturbance induced by adjacent land use on GI patch***. This index represents the potential negative impact of adjacent land use on a habitat patch. The impact is relative to the specific land use type and the area occupied by that land use within a predefined buffer around the habitat polygon. The index is based on a unidirectional matrix with values that express the degree of compatibility between a land use type, including 'grey infrastructure', and the adjacent GI component. It indicates whether land use has a potential negative effect on the quality of the habitat patch. The index does not specify what type of land use causes the effects, nor what kind of disturbance or stress is induced.

For biodiversity the index gives more information on potential edge effects induced by land use in the vicinity of a habitat and the deterioration of the habitat's quality that is caused by it. As such, it completes the edge/area ratio index that only informs about the amount of edge relative to the core of a habitat, and so the vulnerability of a habitat patch to disturbances from outside the patch. However, particular spatial combinations of GI habitat and types of land use may also provide advantages for species living in the GI habitat. This is the case when the land use patch serves as a resource (for instance a temporary foraging area) or functions as a buffer zone that prevents major disturbances coming from land use and activities further away.
Ecosystem services provided by the GI habitat can be negatively impacted by adjacent land use. Disturbance of the environmental conditions of the habitat is quite often the cause. Particular ecosystem services however, will only become significant when the land use that benefit from these services is in their vicinity or when the processes that affect a particular land use and that should be controlled by the ecosystem services, operate in the vicinity of that area. Pollination and biological pest control are examples of the first situation, water flow regulation and erosion control are examples of the latter. The spatial relationships between the service providing areas (SPAs) and the service benefiting areas (SBAs), together with

eventually connecting areas (SCAs) thus should always be taken into account when assessing a habitat's importance for ecosystem services (Syrbe and Walz 2012).

2.5 Landscape metrics as predictors for ecosystem services provision

It is obvious that the effectiveness of the different landscape metrics to inform about the potential value of GI and its habitat patches to sustain biodiversity or to deliver ecosystem services and to avoid disservices, differs quite a lot and is not always unambiguous. In **Table 1** we relate the selected landscape metrics with the ecosystem services concerned and categorize them according to the expected performance and interrelationship. We distinguish landscape characteristics indicated by the landscape metrics that

- have a strong impact on an ecosystem service or disservice delivery (dark green, ++);
- have a lower impact on an ecosystem service or disservice delivery (light green, +);
- have positive as well as negative impacts on an ecosystem service or disservice delivery (yellow, +/-).

Table 1. *Assessment of landscape metrics relative impact on ecosystem services & disservices delivery and biodiversity maintenance.*

CORE SET ECOSYSTEM SERVICES & DISSERVICES SUSTAINING BIODIVERSITY	Area of total GI as % of total area of the CSS	Area of individual GI patches	Total area of each GI habitat type	Area of individual patches of GI habitat types	Edge / area ratio per GI patch	Landscape configuration	Amount of disturbance induced by neighbouring land use on GI patch
Habitat value for biodiversity	++	++	+	++	+/-	++	+/-
Aesthetic value	++	++	+	+	++	++	+
Knowledge, scientific and educational	++	++	++	++	++	++	++
Physical and experiential interactions (recreation)	++	++	+	+	+	+	+
Wild plants, algae, fungi and their outputs	++	+	++	++	++	+	+
Wild animals and their outputs	++	++	+	++	++	++	+
Materials and fibres	++	++	++	++	++	+	+
Climate regulation (local?)	++	++	+	+	++	+	+/-
Pest control	++	+	+	+	++	++	++
Pollination and Seed dispersal	++	+	+	+	++	++	++
Maintenance water quality	++	+	++	++	+	+	++
Mass stabilisation and control of erosion rates	++	+	+	+	++	+	++
Hydrological cycle and water flow maintenance	++	++	++	+	+	+	++
Wild animals attacks (incl. insects)	++	++	++	+	+	+	+
Plants and their pollens can cause allergies or poisoning	++	+	++	+	+	++	+
Pest damages to agriculture (incl.invasive species)	++	+	+	+	++	++	++
DS cause negative feelings (anxiety and dis-comfort)amongthe affected people, another aspect of human quality of life	++	++	+	+	++	+	++

Metrics 1 and 3 concern an area as a whole. All the others are spatially explicit and can be interpreted on an individual GI patch level.

Table 2 provides more details about the potential meaning of the scores of individual landscape metrics for the ecosystem services and disservices. We emphasize that the ideas expressed in the table are a generalization. For particular areas, with a particular composition of the GI network and a particular stakeholder population, appreciations of the importance for ecosystem services and disservices of GI habitat types and their characteristics as expressed by the landscape metrics, may differ (see also the results of the IMAGINE Capacity Matrices analyses). **Table 2** *s*hould be seen as a first step to relate landscape metrics as a proxy for habitat quality with ecosystem services and disservices and the habitat types of the GI.

Table 2. *Significance of landscape metrics for ecosystem services and disservices.*

	Area of individual GI patches	*Area of individual patches of GI habitat types*	*Edge / area ratio for GI patch as a whole*	*Edge / area ratio for homogeneous patches*	*Landscape configuration*	*disturbance induced by neighbouring land use*
	large ------ small	large ------ small	large (complex) -- small (circle)	large (complex) -- small (circle)	connected / dense -- isolated /scarce	high ------ low
Aesthetic Value	not distinctive (n.d.)	n.d.	complexity = higher value	complexity = higher value	connected & dense = high value	n.d.
	does apply to all GI habitat types					
Knowledge and education	not distinctive (n.d.)	n.d.	n.d.	n.d.	n.d.	n.d.
	does apply to all GI habitat types					
Physical interaction	large = best opportunity	no generalization, depends on habitat type large = best oppertunity	n.d.	n.d.	connected = best opportunity	n.d.
	does apply to all GI habitat types					
Wild plants, algae, fungi and their outputs	no generalization large = high value	for habitat types of concern large = highest value	complexity = higher value	n.d.	connected = best opportunity	n.d.
	tall herbs and pioneer vegetation; thicket, orchard, broadleaved & conifer forest; dry heath					
Wild animals and their outputs	large = high value	large = highest value	complexity = higher value	n.d.	connected = best opportunity	low disturbance = highest value
	tall herbs and pioneer vegetation; thicket; broadleaved & conifer forest; nutrient-poor, nutrient-rich grassland; arable land; marshes; stagnant water; running water					
Materials and fibres	n.d.	large = highest value	n.d.	n.d.	n.d.	n.d.
	broadleaved & conifer forest; reed; alluvial forest					
Local climate regulation	large = highest value	large = highest value	complexity = highest value	complexity = higher value	connected = best opportunity	n.d.
	thicket; orchard; broadleaved & conifer forest; marches; reed; alluvial forest; stagnant water; running water					
Pest control (incl. invasive species)	large = best opportunity	no generalization, depends on habitat type large = best oppertunity	complexity = highest value, because of increased interactions	complexity = highest value, because of increased interactions	connected = best opportunity	low disturbance = higher value
	tall herbs and pioneer vegetation; nutrient-poor grassland;					
Pollination and seed dispersal	large = best opportunity	no generalization, depends on habitat type large = best oppertunity	complexity = highest value, because of increased interactions	complexity = highest value, because of increased interactions	connected = best opportunity	low disturbance = higher value
	tall herbs and pioneer vegetation; thicket; orchards; broadleaved forest; nutrient-poor grassland; dry heath; wet heath; running water					
Maintenance of water quality	large = best opportunity	no generalization, depends on habitat type large = best oppertunity	n.d.	n.d.	n.d.	low disturbance = higher value
	marshes, reed, alluvial forest, stagnant water, running water					
Erosion control	large = best opportunity	large = best opportunity	complexity = higher value	complexity = higher value	connected = best opportunity	
	tall herb; thicket; broadleaved forest; conifer forest; nutrient-poor grassland; nutrient-rich grassland; dry heath; wet heath; reed; alluvial forest					
Water flow regulation	large = best opportunity	large = best opportunity	n.d.	n.d.	connected = best opportunity	low disturbance = higher value
	???					
Wild animals attacks (incl. insects)	small = least incidence	small = least incidence	low complexity = low incidence	low complexity = low incidence	no generalization: low connectedness = less contact = least incidence, but also less opporunity to avoid	n.d.
	does apply to all GI habitat types					
Plants & fungi: allergies and poisoning	small = least incidence	small = least incidence	n.d.	n.d.	connected = more contact = increased incidence (depending habitat type)	n.d.
	tall herbs; thicket; broadleaved forest; conifer forest; nutrient-poor grassland; nutrient-rich grassland;					
Pest damages to agriculture (incl. invasive species)	small = least incidence	small = least incidence	low complexity = low incidence	low complexity = low incidence	low connectedness = least spread	n.d.
	tall herbs; thicket; broadleaved forest; conifer forest; nutrient-poor grassland; nutrient-rich grassland; marshes; alluvial forest;					
Safety and risk	small = least incidence	small = least incidence	low complexity = low incidence	low complexity = low incidence	no generalization: low connectedness = less contact = least incidence, but also less opporunity to avoid	n.d.
	does apply to all GI habitat types					
Agricultural production (outside GI)	small = least competition	small = least competition	no generalization: large = more competition = negative; but large = positive pest control & pollination	no generalization: large = more competition = negative; but large = positive pest control & pollination	no generalization: low connectedness = less contact = less competition (negative); but low = less regulating services	n.d.
	does apply to all GI habitat types					

For some ecosystem services or disservices, the scores of landscape metrics may not be distinctive at all. That means that the features themselves where the landscape metrics are based on, are important for the delivery of the service or disservice, but that their proper score is not distinctive. For instance, whether or not a habitat edge zone is complex or not (landscape metric 'Edge / area ratio for GI patch', with score 'large' versus 'small'), does not determine its importance for the ecosystem service 'physical interaction'. But on the contrary, a large GI patch (landscape metric 'Area of individual GI patches') or well-connected GI patches (landscape metric 'Landscape configuration') do have a positive effect on the delivery of the ecosystem service 'physical interaction', and so the scores are distinctive. For some of the ecosystem services and disservices, the significance of a landscape metric relates to particular

GI habitat types, for others, it doesn't. Therefore, when the significance of a landscape metric for an ecosystem service or disservice refers to particular GI habitat types, these types are added in **Table 2**. Otherwise 'does apply to all GI habitat types' is noted.

2.6 A detailed GI habitat typology

The typology of GI focuses on the elements that together form the GI network. The typology makes it possible to identify and describe in a consistent and harmonized way the different components of a GI network in a CSS. Unequivocal identification should allow comparison and aggregation of GI data within as well as between CSS. The criteria used to characterize the actual state of a GI element should be relevant to the assessment of (potential) ecosystem services delivery, the management and restoration for ecosystem services and the governance regarding ecosystem services.

GI can be characterized by different aspects of the GI elements. By referring to a GI element as *land cover*, the specific use, function, meaning or value of the element for people is neglected. Only the biophysical or morphological characteristics are used to classify the GI habitats. When GI elements are interpreted as *land use*, their function becomes differential. Comparable with land use is a typology based on formal *policy categories* as laid down in for instance zoning plans. In all cases, clear definitions are needed to avoid misinterpretation.

To achieve a consistent and unequivocal typology, land cover and land use should not be mixed. Therefore, we suggest that the IMAGINE typology of GI habitat consists of different tiers that can be combined to identify a GI element. The tiers do not form a hierarchy, suggesting that one aspect is more important than another. So, the morphological, functional and formal policy categories can be applied separately, although they become more meaningful and suitable for ecosystem services assessment when they are combined.

Bartesaghi Koc *et al*. (2016) point out that a GI typology should be generic and testable at different spatial scales and settings and should not be dependent on land-uses. Furthermore, the typology should be sufficiently flexible to allow the optimum number of typologies and the aggregation of additional types in the future. Both engineered and natural elements should be included to capture the whole grey-to-green spectrum of GI.

2.6.1. Detailed IMAGINE morphological / land cover GI habitat typology

For IMAGINE we base the morphological or land cover typology of GI habitats on the dominant plant life forms of a patch or on the nature of the substrate when vegetation is absent. Plant life-form refers to Raunkiær's original approach (1904-1907) and the modifications made afterwards (for instance Ellenberg & Mueller-Dombois, 1967) (see *Fig. 1*). In this approach, plants are classified according to the place where their growth point is located during the less favorable seasons. For the phanerophytes height categories are added to distinguish between different types of shrub and forest. For the trees and shrubs, also seasonality of the leaves or photosynthetic parts is taken into account.

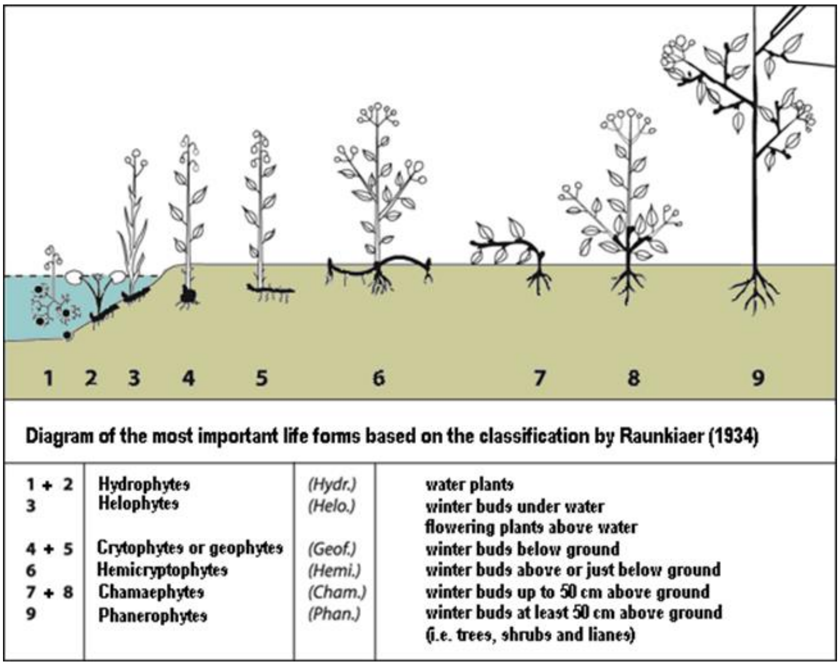

Figure 1. *Main plant life forms categories.*

The advantages to use plant life-forms are that no expert knowledge of local flora is required to typify a habitat category and that they reflect structural features of the habitat.Habitat category recording based on plant life-forms proved to be successful in the FP7-project EBONE (https://www.wur.nl/en/Research-Results/Research-Institutes/Environmental-Research/Projects/EBONE/Products.htm). (see for instance Bunce *et al*., 2008).

The detailed morphological / land cover GI habitat list consists of 23 general habitat types (*Table 3*).

Table 3. *IMAGINE Morphological / land cover GI habitat types - detailed typology.*

Land cover type	Definition	Remark
Cultivated herbaceous crops	Arable land, cultivated with annual and perennial herbaceous crops	including temporary cultivated bare ground (plowed, tilled)
Woody crops	Arable land, cultivated with trees or shrubs	including temporary cultivated bare ground (plowed, tilled)
Sea	Sea	
Tidal	Estuary; tidal zone between mean low water and mean high water	
Aquatic stagnant	Lakes, oxbow lake, moorland pool, etc.	
Aquatic running	River, brook, etc.	
Aquatic temporal / seasonal	Water bodies that run dry regularly	
Permanent ice and snow	Substrate covered permanently by ice or snow	
Bare rocks	Substrate covered permanently by bare rock, including crevices, gullies, etc.	
Boulders	Substrate covered by elements of rock that are above 20 cm	

Land cover type	Definition	Remark
Rock and Stones	Substrate covered by elements of rock that are between 5 - 20 cm	
Gravel	Substrate covered by gravel, elements between 0,5 - 5 cm	this goes beyond the standard which is between 0,2 - 6,3 cm
Earth	Substrate covered by mineral elements, less than 0,5 cm	sand - loam - clay/mud
Peat	Substrate covered by accumulated organic material; partially decayed vegetation	
Hydrophytes	Aquatic and wetland vegetation of aquatic or waterlogged conditions	including submerged and/or emergent hydrophytes (water conditions) and helophytes (of waterlogged conditions)
Leafy hemicryptophytes	Vegetation of forbs; broad leaved herbaceous species	'herbs', including 'tall herbs'
Caespitose hemicryptophytes	Grassland; grassy vegetation	perennial monocotyledonous grasses, sedges and rushes
Cryptogams	Vegetation dominated by mosses, liverworts and/or lichens	carpets of bryophytes (including Sphagnum sp.) and lichens
Shrubby chamaephytes	Shrubland; vegetation dominated by dwarf shrubs	< 0.3 m = under shrubs, including dwarf shrubs
Low phanerophytes	Shrubland, heathland, dominated by low shrubs	0.3 - 0.6 m = low shrubs
Mid phanerophytes	Shrubland, thicket, heathland, maquis, garrigues	0.6 - 2.0 m = mid shrubs
Tall phanerophytes	Tall shrub vegetation	2.0 - 5.0 m = tall shrubs
Forest phanerophytes	Woodland or forest dominated by trees	> 5.0 m = trees

2.6.2. Detailed IMAGINE functional / land use GI habitat typology

GI habitat types can also be characterized by the particular function or role they have for society. This is obvious for urbanized zones with different types of green space and green elements, for cultivated land, for water bodies that are designed and controlled for specific purposes, for managed forests, for the man-made semi-natural linear and point-like elements in our landscapes. These habitats are managed in a target-oriented manner and thus are culturally determined. Quite often, general terms are used to identify individual habitats or semi-natural landscape types with characteristic habitats or geophysical features. Also these common names, such as 'shrubland', 'marshland', 'coastal dunes', etc. are included in the list of land use / functional GI habitat types. The use of local names should be avoided as they make comparison or integration between regions more difficult, although they may have a clear meaning at a regional scale.

The detailed functional or land use GI habitat list consists of 59 general habitat types (*Table 4*).

Table 4. *IMAGINE Functional / land use GI habitat types - detailed typology.*

FUNCTIONAL CATEGORIES	Land use type	Definition	Remarks
PARKS AND GARDENS	Park *	A large green space (> 1 ha) mainly composed of a mosaic of open (lawns) and closed (shrubs and trees) vegetation, flower beds and ponds, used for leisure or recreation	* including botanical garden, arboretum, 'English landscape garden', etc.

FUNCTIONAL CATEGORIES	Land use type	Definition	Remarks
	Cemetery and churchyard		
	Domestic garden	Private gardens, fenced and belonging to a house	
	Allotments	Piece of land in or just outside town, individually rented for growing vegetables etc.	
	CommunIty garden	A single piece of land gardened collectively for growing vegetables etc.	
AMENITY GREEN SPACE	Housing green space	Small green area in an urban environment, associated with buildings and public spaces, designed and managed to improve scenic value and quality of city life; flower beds	
	Greenway	A long vegetated, linear piece of land, often used for recreation and pedestrian and bicycle traffic.	
	Informal recreation space	A green area without facilities, unofficially used for recreational activities	
	Sport fields *	Outdoor sports facilities with associated green areas	* including golf courses
	Playgrounds	Designed children's playground with associated green areas	
	Windbreaks *	Plantation to provide shelter from the wind	* only vegetation breaks
	Noise barriers *	Plantation to reduce noise pollution	* only vegetation barriers
WATER BODIES	Navigable river	River wide and deep enough for a boat to travel along safely	
	Unnavigable river	River not wide and deep enough for vessels, at most suitable for rowing boats, canoes, etc.	
	Canal		
	Ditch *		* including swales
	Lake *		* including reservoirs on dammed rivers
	Recreation pool	(Semi-)natural waterbody used as a recreation site	
	Fish pond	(Semi-)natural pond used for fishing and fish farming	
	Fish ladder	An artificial structure usually consisting of a series of relatively low steps, that allows fish to pass around a barrier; a fishway, fish pass or fish steps	
	Ornamental waterbody *		* including fountains with associated basin
	Water treatment wetland	An artificial wetland with marsh plants to purify wastewater	

FUNCTIONAL CATEGORIES	Land use type	Definition	Remarks
	Runoff water retention pools*		* including storm water retention basins
	Water supply basins		
	Salinas		
BROWNFIELDS *	Landfills	Site used for the disposal of waste materials by burial.	* only for those parts that are (locally) included in the GI
	Derelict land	Abandoned land, vacant land	
	Reclamation ground	Land, originally of very poor conditions, that is being improved for more intensive use (agricultural or construction purposes)	
	Quarries	Excavation or pit from which stone or other materials are or have been extracted	
AGRICULTURAL LAND *	Arable land		* only for those parts that are actually used and are (locally) included in the GI
	Meadows		
	Pasture		
	Green fuel production	Area for intensive biomass production	
	Historical orchard	Low density, large mature tree plantation for fruit and nut production, usually on grassland, eventually pasture	
	Modern high density orchard	High density tree plantation on low stocks for fruit production	
	Berry farm	Berry nursery	
	Vineyard		
	Tree and plant nursery		
FOREST	Planted monoculture		
	Intensively managed forest *		* with age, pattern and species composition controlled by management
	(Semi-)natural forest *		* with high structural and species diversity
SEMI-NATURAL AREAS *	Unfertilized grassland	Acid grassland, limestone grassland, etc., eventually used for grazing	* except forest and woodland
	Shrubland	Heathland, maquis, garrigues, etc.	
	Marshland	Reedbeds, mires, swamps, etc.	
	Thicket	Area dominated by dense high shrubs and low trees	
	Inland dunes	Inland bare sand and associated pioneer vegetations	
	Coastal dunes	Coastal bare sand and associated pioneer vegetations	
	Coastal beach *		* sand or pebbles

FUNCTIONAL CATEGORIES	Land use type	Definition	Remarks
	Fire breaks		
	Abandoned agricultural land		
SEMI-NATURAL LINEAR AND POINT-LIKE ELEMENTS (MAN-MADE) *	Open line of trees	A simple line of trees without or with very few shrubs, high transparency; a lane	* linear and point-like elements in the countryside
	Closed line of trees	"Hedgerow", a complex linear element composed of a line of trees and dense shrubs; low or no transparency	
	Low hedge	A linear element dominated by shrub species, regularly trimmed or cut; height < 2 m	
	Tall hedge	A linear element dominated by shrub species, regularly trimmed or cut; height > 2 m	
	Sunken road *	Traditional road excavated or eroded below general ground level	* add dominant Morphological Habitat Type for each side
	Levee / dykes	Natural or artificial raised (river) bank, height > 0,5m	* add dominant Morphological Habitat Type
	(Road)Verge *	Edge or margin vegetation, sometimes a stand-alone vegetation strip	* including narrow strips of riparian vegetation and belts of shrub + add dominant Morphological Habitat Type
	Pond *	Artificial small water body with natural substrate and banks	* add dominant Morphological Habitat Type of open water and banks
	Wall *	Very steep to vertical artificial stone or earth wall	* only when vegetated + add dominant Morphological Habitat Type

2.6.3. *Detailed IMAGINE formal policy GI habitat typology*

The third tier is a typology based on formal *policy categories* as presented in zoning plans or decided in other sectorial policy documents. They define the policy objectives related to particular areas and regulate to varying extents their use, management and development. This typology will show far less comparability between CSS, as the underlying policy that defines the categories can be quite different in the different countries. So, the short list presented in *table 5* is not complete for sure. According to the country’s legislation and policy instruments, categories can be divided, aggregated, or added. As a means of survey, this policy related typology is meant to complete the description of the GI network and to understand its institutional foundation.

Table 5. *IMAGINE Policy GI habitat types - detailed typology.*

FORMAL CATEGORIES	Remarks
Designated corridor	
Designated buffer zone	
Designated protected site for nature conservation *	* including regional nature reserves, N2000 protected sites
Protected landscape *	*scenic, historical, cultural value
Protected landscape elements	
Formal categories of (local) zoning plans *	* land use category as defined and imposed in the spatial planning zoning plan; may coincide with functional categories
Specific (local) protection sites *	* protected site, other than nature protection; e.g. drinking water protection sites, buffer zone, erosion control zone, etc.

2.6.4. Detailed habitat quality attributes

To fully characterize a GI network, the elements of the GI should be identified by combining at least land cover (morphological types) and land use (functional types). However, the GI habitat types listed in the three typologies, do not directly inform about their quality or suitability to deliver a particular ecosystem service or to sustain biodiversity. This depends on the spatial context, on their actual habitat quality and on management. Therefore, qualifiers or attributes are added that may shed light on their performance. These attributes give indications about the above mentioned environmental, biotic and spatial characteristics, together with information about management, design and use of the habitat patch.

The habitat quality that is thought to be assessed with the qualifiers or attributes relates in the first place to the ability of a habitat patch to sustain biodiversity. Besides that, the habitat's suitability to deliver particular ecosystem services can also be addressed to some extent. To assess this, an analysis of the GI habitat features required to deliver ecosystem services is needed. This will yield the relevant ecosystem attributes that must be surveyed in order to assess the GI habitat's potential to deliver particular ecosystem services. The key habitat characteristics for ecosystem services delivery and the management options to maintain and optimize them are elaborated in IMAGINE WP3 Cookbook n°3.

For most of the morphological and functional GI habitat types, the attributes that determine a habitat's quality are identified. Often they relate to the presence or abundance of particular species (functional groups), the horizontal and vertical structure and complexity of the vegetation (*Table 6*), the nature of the substrate and the morphology or dynamics of the physical environment, the evidence of management and the type of management (*Table 7*). Management-related attributes are based on the EBONE methodology (Bunce *et al.*, 2011). At least two aspects should be recorded: the 'evidence of management' points out whether or not a site is managed and if so, when that has taken place; the 'type of management' describes the specific techniques that are applied.

For the morphological and functional habitat types together, 88 attributes are selected.

Table 6. *IMAGINE GI habitat quality - biotic attributes*

Attributes regarding species composition	Attributes regarding vegetation characteristics
% algae	% transparency of shrub layer
annoying, disturbing plants	age structure trees
% emergent hydrophytes	average height (m)
% Ericoids	average stem diameter (cm)
% Fabaceae	average width of crowns (m)
% forbs + 'grass like' species	average width of hedge (m)
% forbs + tall herbs	Calluna developmental stages
% FPH species	complexity of forest edge
% 'grass like' species	nr. of distinct vegetation layers
% helophytes	orchard type
% invasive species	presence of gaps > 2 trees adjacent missing
% lichens	presence of gaps > 2 trees missing
% LPH + MPH species	presence of gaps, > 2x shrub height
% mosses + lichens on gravestones	presence of nesting holes
% mosses and liverworts	presence of old trees
% mosses, liverworts & lichens	presence of peatforming vegetation
% MPH + TPH species	structural heterogeneity
% nectar-producing plants	% lying deadwood
% nitrophilous plants	% standing deadwood
% nonnative trees and shrubs	
% of planted or sown vegetation	
% other shrubs	
% plants with edible parts	
% reed beds	
% salt water vascular plant species	
% scattered trees	
% submerged hydrophytes	
% tall herb species	
% TPH species	
% vascular plants	
% weeds graminoids	
% weeds herbaceous	
% wet heath shrubs	
broadleaf & conifers mixed?	
dominant tree type	
dominant understory type	
most common invasive species	

Attributes regarding species composition	Attributes regarding vegetation characteristics
nr. of shrub + tree species	

Table 7. *IMAGINE GI habitat quality - abiotic & management attributes*

Substrate and characteristics of the physical environment	Management and potential for recreation
% bare ground	active exploitation?
% unvegetated	bank management
% vegetated	evidence of forest management
bank type	evidence of management
presence of flood marks?	field management (techniques)
substrate	forest management (techniques)
type of material (construction)	orchard management (techniques)
	presence of artificial barriers
active erosion and sedimentation?	presence of game feeding place
height of the banks	presence of water level control device
hydro- and morphodynamics	tree and shrub management (techniques)
origin of water	vegetation management (techniques)
temporarily flooded?	water body management (techniques)
	accessibility for biking
	accessibility for walking
	accessible for collecting edible plants
	presence of limited access areas
	public domain?
	suitability as children's playground

Recording of the attributes is done binary, by scoring an integer, or by choosing from a predefined or a free list. *Table 8* shows examples for attributes regarding management.

Table 8. *IMAGINE GI habitat quality attributes - example management*

Evidence of management	Active - now	Recent - < 3 years	Neglected - no evidence of management for 3 to 10 years	Abandoned – 10 to 50 years, colonisation by shrubs	No evidence of any management	
Vegetation management	Mowing	Cutting	Grazing	Controlled burning	Sod cutting	No management
Forest management	Clear-cut	Group selection	Thinning	Coppicing	Pollarding	
	Controlled shrub burning	Scrub clearence	Planting native trees	Planting exotic trees	No management	

2.7 An app for collecting GI habitat types and GI habitat quality

To facilitate field surveys, a data collection device is developed. The above mentioned morphological and functional GI habitat types and the attributes that indicate their quality are built into the Esri-app Collector. This app makes it possible to map GI polygons and collect the descriptive data with the help of a smartphone. As the first step, ortho-photographs and/or thematic maps are uploaded to serve as the basic layer to digitize the GI polygons (see *Figure 2*).

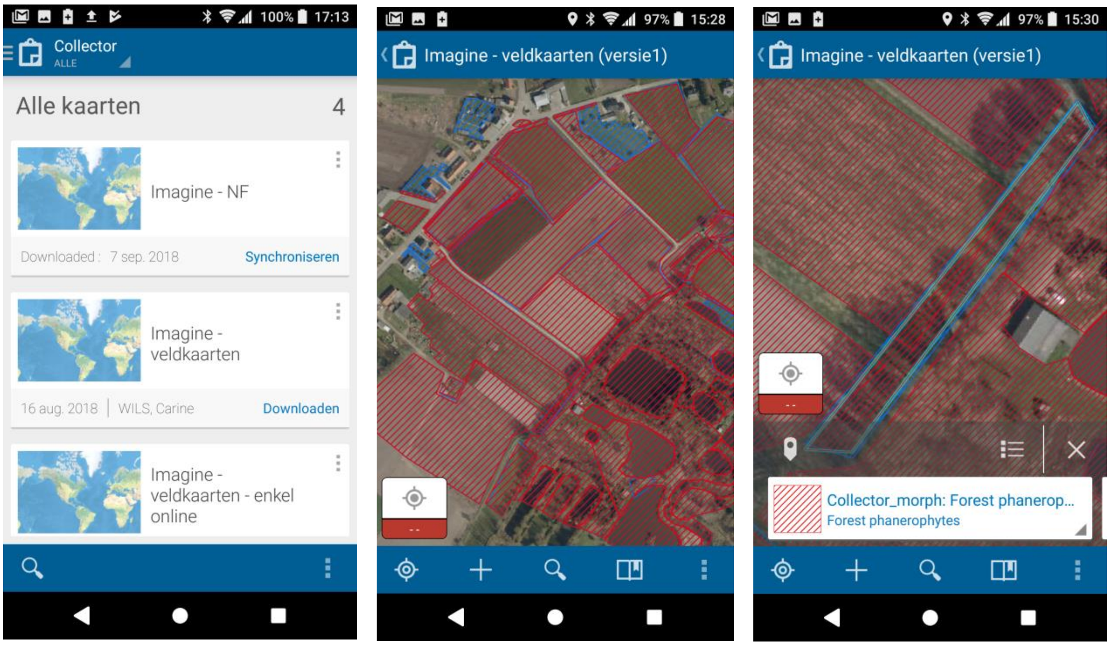

Figure 2. *Choose a base map and digitize the GI habitat patch that has to be described; from left to right: base map library, polygons, polygon selection for detailed description*

In the next step, for each polygon the corresponding morphological and functional habitat type are selected from predefined typologies and attributes lists (see *Figure 3*).

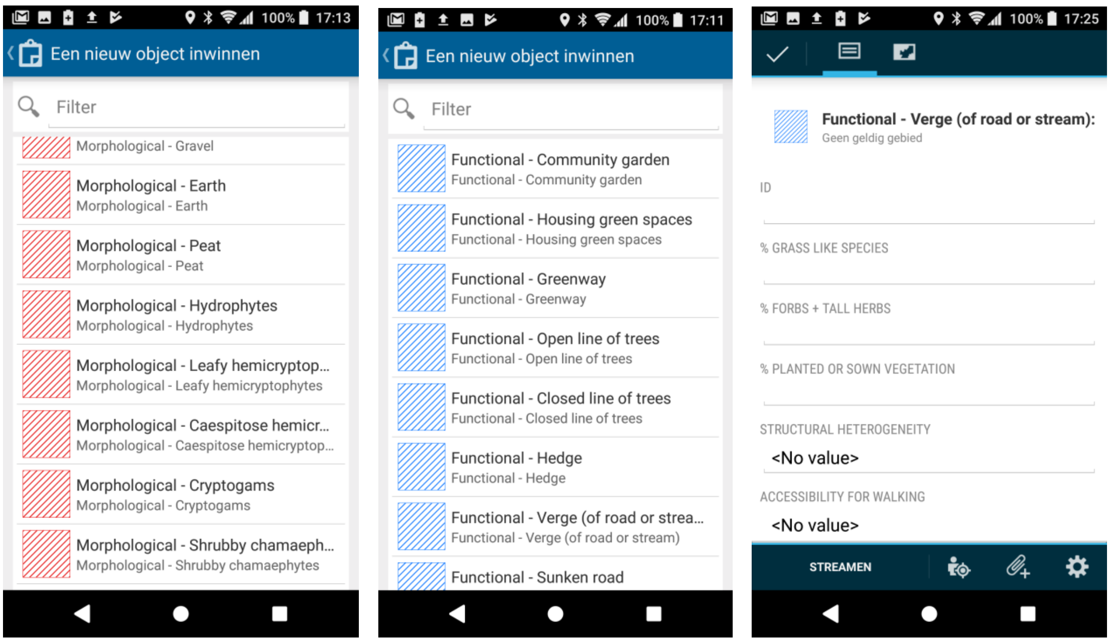

Figure 3. *Select the corresponding morphological and functional GI habitat type from the dropdown list and start completing the associated attributes; from left to right: morphological (plant life-forms) - land cover types, functional - land use typology, attributes of functional - land use types.*

Once this is done, in the next step the features that determine the quality of a selected habitat type appear. Scoring is done with the help of drop down menus, integers or binary codes (see *Figure 4*). The results are then stored in a database and can be uploaded in GIS.

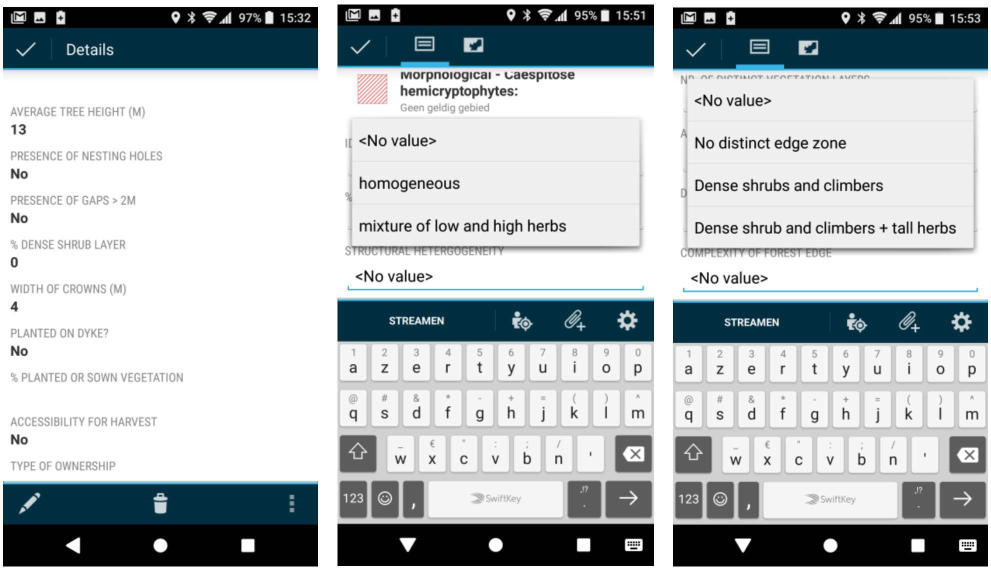

Figure 4. *Score the different attributes and store the polygon in the database; from left to right: scoring quality features of a row of trees, describing the pattern (quality feature) of grassy vegetation, describing composition (quality feature) of a forest edge.*

3. Intended outputs and outcomes

The approach and survey methodology proposed in this cookbook allow a consistent and unequivocal description of the type and the actual state of GI habitat patches and the assessment of their quality regarding the potential to deliver selected ecosystem services and support a habitat type specific biodiversity. Applying the landscape metrics yields a quick scan of the potential general habitat qualities in an area together with the identification of restoration issues. With the survey of additional qualifiers and attributes, insight can be gained about the relation between the characteristics of a habitat and its actual and potential importance for ecosystem services and biodiversity. Understanding this relationship may help to define strategies to improve, maintain or strengthen the existing situation and select appropriate management or restoration techniques. Because the quality assessment is based on an extent number of specific habitat attributes, conclusions can be drawn regarding ecosystem services provision as well as regarding habitat and corridor functioning for biodiversity. This is important when the objective is to create and implement multifunctional GI networks, designed to respond effectively to societal needs and interests leading to active engagement of as many stakeholders as possible.

The lists of functional categories, habitat quality and management attributes are not fixed. That means that they should be adapted according to the broad geographical region and the ecosystem services concerned. The files that are compiled in this cookbook however include typologies and attributes which are applicable in the whole geographical range covered by IMAGINE and the case study sites and thus are likely to be useful for GI and habitat surveys in most of Europe.

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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 multi-functionality and bio-capacity 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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« 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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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.