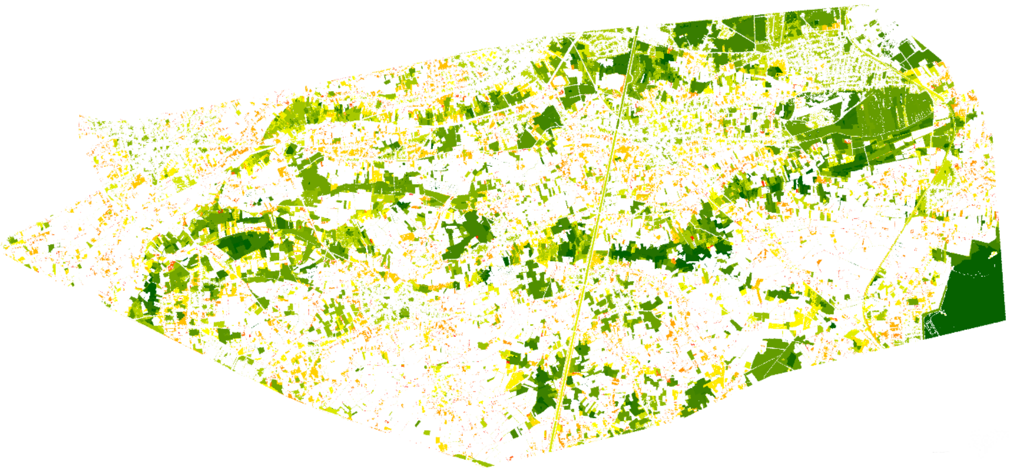
“COOKBOOK” SERIES N° 2

Suškevičs, M. and Roche, P.K. (Editors)

Assessing Green Infrastructure vulnerability to ecosystem degradation at the landscape scale



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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 (this cookbook)**
3. Assessing detailed GI habitat quality for biodiversity and ecosystem services
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

Recommended **citation** format for **this cookbook**:

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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* concerning 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.

In this IMAGINE Cookbook n° 2 '***Assessing GI vulnerability to ecosystem degradation at the landscape scale***' (Heremans and De Blust 2020 – this report) we present a methodology to calculate the vulnerability of landscape patches to disturbances caused by external pressures. For this, we use landscape metrics because they can be assessed at the landscape scale and they are related to a general potential of a habitat patch to sustain biodiversity and ensure sustained delivery of desired ecosystem services.

In the IMAGINE Cookbook n° 3 '***Assessing detailed GI habitat quality for biodiversity and ecosystem services***' (De Blust and Heremans 2020a) we build further on this, by presenting a methodology for assessing the detailed habitat quality of the land cover patches.

In the IMAGINE Cookbook n° 4, '***Green infrastructure management for ecosystem services***' (De Blust and Heremans 2020b) we analyze the functioning of a GI patch as a service providing unit based on required ecosystem attributes and the factors which may influence 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 the first phase, they can identify the patches most prone to degradation using the landscape-scale vulnerability values from this cookbook, while in the second phase they can identify the most appropriate management for safeguarding the quality of these patches using the other two cookbooks (n° 3 and 4).

3. Landscape-scale vulnerability to disturbances

The suitability and quality of green infrastructure (GI) is critical to its functioning. Poor-quality GI can adversely affect open space use (Greenspace 2007; Coombes *et al.* 2010), biodiversity objectives, and ecosystem service provision (Felson, Oldfield, en Bradford 2013). The delivery of desired ES highly depends on the location, the spatial configuration, the constituents, and the overall quality of the GI.

Therefore, information on how to evaluate the quality of green infrastructure is critical for bridging the gap between theoretical GI concepts and the GI management practice (Sinnett *et al.* 2018). Long-term management in particular has been identified as a great challenge for delivering sustainable and multifunctional landscapes (Jerome 2017; Jerome *et al.* 2017). The body of work on the advancements in environmental planning has uncovered a need for landscape-scale conservation. Taking a **landscape-scale focus** for conservation management is the foundation for GI. Planning for an area's "green infrastructure" provides a landscape-scale framework for evaluating conservation priorities. Moreover, it provides communities with a broad, unifying vision of the future and helps focus conservation efforts for regions facing severe land cover changes (McDonald *et al.* 2005).

Landscape structure, heterogeneity, and configuration determine to a large extent the occurrence of species (see, for instance, Dauber *et al.* 2003) and the delivery of ecosystem services (Syrbe & Walz 2012). The analysis and description of landscape structure are often done with landscape metrics (Girvetz *et al.* 2008; Jaeger *et al.* 2008; Kuttner *et al.* 2013; Minor and Urban 2008; Uuemaa *et al.* 2009, Vogt *et al.* 2009). The landscape metrics express different aspects of GI quality. Therefore, it is wise to apply them on a landscape level and assess the metrics individually to create strong explanatory power (see, for instance, Schindler *et al.* 2013).

Note that an unequivocal habitat quality that holds for all the different ecosystem services does not exist. The habitat properties required to deliver a particular service differ between ecosystem services and can even be opposing. What is good for one ecosystem service may be bad for another. So, habitat quality assessment in the context of ecosystem services and disservices is a relative and restrictive exercise.

With this cookbook, we present a landscape metrics-based framework for assessing habitat quality at the landscape level. It depends on a broadly applicable, efficient approach that can be applied across large study sites and does not depend on extensive field campaigns. This framework is built around an assessment of 'vulnerability to disturbances', a proxy for the chance of ecological degradation. A landscape's vulnerability to disturbances can be considered as a proxy for the chance of (future) ecosystem degradation. In patches with a high degradation risk, the actual degradation status can be assessed in more detail through field assessments, to select the appropriate conservation or restoration measures. The methodology for this can be consulted in the IMAGINE Cookbook n° 3, '*Assessing detailed GI habitat quality for biodiversity and ecosystem services*' (De Blust and Heremans 2020a).

3.1 Calculation formula

We have decided to derive the vulnerability to disturbances from the spatio-thematic composition of the GI. Spatial metrics take into account the broader spatial patterns, beyond the individual pixel or patch. This is especially important in highly fragmented landscapes with mainly small habitat patches where the surrounding landscape pattern and land use have a determining effect on the functioning of the remaining biotopes.

Weißhuhn (2019) created a 'biotope vulnerability index' based on spatial landscape metrics (spatial pattern). it is computed as:

$$v_i = E_i \times S_i \div (1 + A_i) \quad \text{eq.1}$$

where v_i is the vulnerability of a pixel i, as a function of its exposure to disturbances (E_i), its sensitivity to disturbances (S_i) and its adaptive capacity to recover from disturbances (A_i).

According to the methodology of Weißhuhn (2019), several indicators for disturbance, sensitivity, and adaptive capacity have to be preselected according to expert knowledge. Correlations between these indicators are then used to prune this initial set, where the variance weights from PCA are used to express the explanatory power of each indicator. We retain from each strongly correlated pair the indicator with the highest variance weight. The final indices for exposure, sensitivity, and adaptive capacity are averages of the retained indicators, weighed by their variance weights. The vulnerability index, a proxy for the ecological degradation risk, is then computed with eq. 1. **Figure 1** contains an overview of the approach.

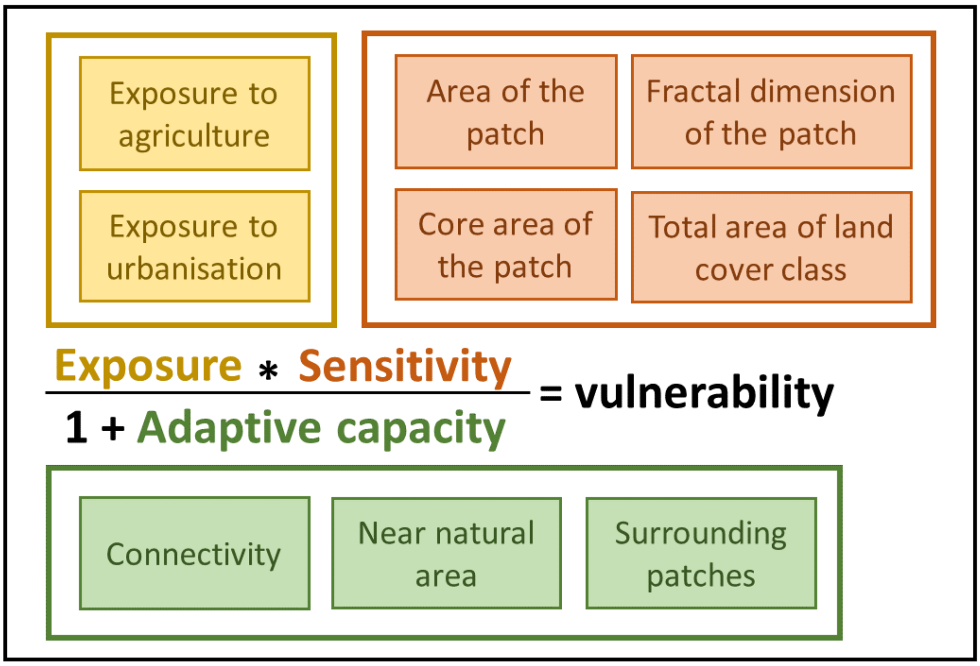

Figure 1. *Calculation scheme of the vulnerability to degradation.*

3.2 Input data: Land cover map

Landscape metrics are calculated per patch. To assemble these patches, a land cover classification is needed. The exact land cover classification used for the calculation of the vulnerability may depend on the characteristics of the study site. Take into account that classes should be as homogeneous as possible concerning their ecological value and their ecosystem service delivery; and that two classes that are similar in these respects are best dissolved to a single class. If you need to compare the vulnerability of different study sites, as is often the case in ecological studies, a single common classification scheme is needed. **Table 1** displays the hierarchical common land cover classification of the IMAGINE project; the basis of all spatial metrics in this cookbook.

Table 1. *The common land cover classification of the IMAGINE project.*

Level 1	Explanation	Level 2	Explanation
1	Freshwater	1.1	Running water
		1.2	Standing water
2	Wetland		
3	Urban paved (not part of GI)		
4	Urban green		
5	Cropland (not part of GI)		
6	Managed grassland	6.1	Intensive (not part of GI)
		6.2	Extensive
7	Natural grassland		
8	Shrubland[(2)]		
9	Forest[(1)]	9.1	Deciduous
		9.2	Coniferous
		9.3	Mixed
10	Rocky and bare areas	10.1	Dunes[(3)]
		10.2	Other
11	Marine	11.1	Sea (not part of GI)
		11.2	Estuaries
		11.3	Tidal areas

[(1)] Forest: tree dominated vegetation, dense and rather uniform in structure

[(2)] Shrubland: vegetation dominated by low or tall bushes, such as heathland, garrigues, maquis, thicket

[(3)] Dunes: includes inland shifting sand included

Our advice is that you use the most recent and appropriate land cover map available with a resolution that is high enough to allow the identification of the GI habitat types listed in table 1.

3.3 Calculating the sub-indices

As described in section 3.1, the vulnerability index is composed of three sub-indices: exposure (to external pressures), sensitivity and adaptive capacity.

3.3.1. Sensitivity

For calculating sensitivity, a Spatial Pattern Analysis (SPA) needs to be executed. In the case of multiple study sites, this is best done separately for each of the study sites. Detailed land cover datasets for each study site are first translated into the simplified common land cover typology displayed in Table 1. We recommend using level 2 classes, when available.

In Fragstats (McGarigal 1995), land cover patches are extracted from a land cover raster at 10 meters spatial resolution. At the patch level, four spatial metrics were then calculated:

(1) **area** = the total area of the patch.
(2) **core area** = the area in the inner core of the patch, further from the boundaries than the edge distance. Calculating the core area requires the specification of an edge depth, which was set at 5 meters for freshwater, 10 meters for urban green, 20 meters for wet-, grass- and shrublands and 50 meters for all types of forests.
(3) **fractal dimension** = a patch-level measure of shape complexity that is independent of scale.
(4) **class area** = the summed area of all patches that belong to the same land cover class as the current patch.

Thus, we assume that ‘sensitivity’ of a land cover (habitat) patch is a function of the combined effects of its patch size (the larger the patch, the lower the sensitivity), of the size of its core area (the larger the core area the higher the quality of the habitat and the lower the sensitivity to a decrease of the overall quality in the entire patch), the total area of all similar land cover patches in a region (the larger the total area in the vicinity, the lower the impact of a local quality degradation on the functioning of the land cover type), and of the complexity of the patch shape (complex and irregular shapes may increase ecological interactions and environmental heterogeneity and hence may result in reduced sensitivity). The fractal dimension is thus directly proportional to the sensitivity while the other three metrics are inversely proportional to the sensitivity.

3.3.2. Exposure

The ecological functioning of Green Infrastructure (GI) is threatened by external influences, mainly eutrophication, acidification, and urban sprawl. The magnitude of these influences is directly proportional to the proximity of agriculture and urbanization. We only account for proximate influences of nearby land use, long-distance impacts (e.g. background nitrogen depositions) are not considered. We have selected the following exposure indices:

(1) **Exposure to agricultural land cover** = kernel-based sum of surrounding agricultural pixels/patch area.

(2) **Exposure to urban land cover** = kernel-based sum of surrounding urban pixels/patch area.

The former includes cropland and extensively managed grasslands, the latter includes the urban paved areas.

We used a distance-weighted Euclidean kernel, where each pixel within the 0-100m range receives a weight equal to

$$w_i = (10 - d_i) * 0.1$$

with $d_i$the Euclidean distance in pixels to the center pixel. This will be declining until a distance of 10 pixels, with 0.1 per pixel. The center pixel receives a weight = 0, the pixel right next to it a weight = 0.9. Diagonal pixels are weighted by their Euclidean distance to the center pixel (measured in the number of pixels).

These pixel-based values are then summed over each GI patch (from the SPA in section 3.3.1 and divided by the total patch area. This ensures a homogeneous value at the intra-patch level.

3.3.3. Adaptive capacity

The adaptive capacity refers to the potential of a patch's natural capital to be remedied by the surrounding landscape. Three metrics are used to calculate the adaptive capacity:

(1) **connectivity** = degree to which the landscape facilitates or impedes the movement of species. We propose to use the average over a collection of 'focal species' – species of specific conservation importance – in each of the study sites, each with its own characteristics regarding landscape type preference and home range. CircuitScape, the software that can be used for calculating the connectivity, is based on algorithms from electrical circuit theory (for more details, see Anantharaman *et al.* 2019).
(2) **surrounding patches** = number of centroids of patches of the same GI class within a circular buffer of 10km. As we don't have detailed land cover information for the area surrounding the study sites, this was calculated at classification level 1, based on the CORINE land cover dataset of 2018.
(3) **near-natural area** = total area of GI within a distance of 100 meters around the edge of a patch.

Again the values are summed over each GI patch (from the SPA in section 3.3.1) and divided by the total patch area.

3.4. The final output: vulnerability

To calculate the final vulnerability, we need to combine all nine metrics that constitute sensitivity, exposure, and adaptive capacity. Because their scales cannot simply be combined, we obtain their relative importance from principal component analysis. This means that we weigh the metrics concerning the proportion of the total variability in the dataset they explain. To avoid double-counting, we first prune the metrics set based on intercorrelations.

Thus, *once all spatial metrics have been calculated for the three sub-indices, their intercorrelations are calculated using Kendall's rank correlation.* When the absolute value of the correlation between two metrics is larger than or equal to 0.30, one of the indicators is to be removed from the analysis. From a principal component analysis, we assess the relative importance, and per set of highly intercorrelated metrics we keep the one with the highest PC loadings. Once we have cut our set to the final composition, we normalize each remaining metric so their values range between 0 and 1. Fractal dimension is inversely normalized as it is inversely proportional to the sensitivity.

The three sub-indices – sensitivity, exposure, and adaptive capacity – are then calculated as the weighted average of the normalized metrics that remain after pruning, with the weights summing to 1 and directly proportional to their PC loadings. The sub-indices are then combined with the final vulnerability output by applying eq. 1.

4. Intended outputs and outcomes

This cookbook contains a methodology for calculating the vulnerability of green infrastructure patches to environmental degradation that can affect both their ability to serve as habitat for plant and animal species and their capacity to serve as a source of ecosystem services.

Note that this vulnerability is a relative index, thus the absolute values have no physical or ecological meaning. This index can be used to compare the probability that certain areas have already been affected by degradation or will be affected in the future. This can be a prerogative for monitoring the vulnerable areas more closely and adapting their management, but these aspects will be described in detail in Cookbook n° 3 (De Blust and Heremans 2020a) and Cookbook n° 4 (De Blust and Heremans 2020b).

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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 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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and supported by

biodiversa

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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.