ESA DUE Innovator III

Earth Observation in support of the City Biodiversity Index

Project deliverable D2.1: Product Delivery Documentation Stockholm

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1 BACKGROUND

1.1 PROJECT DESCRIPTION

For the first time in history, there are now more people living in cities than in rural areas; cities are becoming larger, and the number of cities will continue to increase. Capturing the status and trends of biodiversity and ecosystem services in urban landscapes represents an important part of understanding whether a metropolitan area is developing along a sustainable trajectory or not.

The World Summit on Sustainable Development in 2002 assigned to the Convention on Biological Diversity (CBD) a target for 2010 of significantly reducing the rate of biodiversity loss. Since this target has been collectively missed, the new Aichi biodiversity targets aim to improve the status of biodiversity and to reduce the pressures on biodiversity by 2020.

The City Biodiversity Index (CBI) was developed as a tool to evaluate the state of biodiversity in cities and to provide insights for improving conservation efforts (CBD, 2010). In the framework of the project, it is foreseen to contribute to capturing and evaluating the state of biodiversity in cities, thereby responding to internationally defined biodiversity targets (such as the Aichi biodiversity targets set by the Convention on Biological Diversity, CBD). The CBI includes 23 indicators designed to help cities monitoring their progress in implementing conservation efforts and their success in halting the loss of biodiversity as formulated in the Aichi targets.

In preparing the project, it was recognised that many cities stated not to have sufficient data, personnel, and GIS skills to deal with and assess some of the indicators (Kohsaka et al., 2013). To overcome this situation, the project provides support for four indicators linked to spatial data and GIS:

- Indicator 1 “Proportion of natural areas in city”;
- Indicator 2 “Connectivity measures or ecological networks to counter fragmentation”;
- Indicator 11 “Regulation of quantity of water”; and
- Indicator 12 “Climate regulation: carbon storage and cooling effect of vegetation”.

We use satellite-based data and combine them with appropriate in-situ and ancillary data to produce those indicators. They are designed in a way to be directly usable by cities to assess their performance regarding their biodiversity targets.

In the past years, some cities have implemented and tested the CBI, but their number is still too low to be statistically representative. Consequently, there exists a clear need to raise awareness across cities world-wide about the short- and long-term benefits of the CBI which will also increase their readiness for using the indicators. We aim to improve this understanding by actively involving ICLEI Europe and the ICLEI City Biodiversity Centre, located in Cape Town, South Africa, as end-user organisations who as umbrella organisations of a global city network run programmes on biodiversity and ecosystem services for their member cities. ICLEI was deeply involved in the development of the CBI and is very willing to support the uptake of the CBI by cities across the globe.

In terms of practical application, the most important challenges of the CBI are (i) the lack of data; (ii) the scale, boundaries, and definitions; (iii) the scoring that needs to capture the vast bio-geographical differences among cities; and (iv) the limited number and scope of ecosystem services. We will set out to improve the situation regarding the challenges (i) and (ii) by producing the four above mentioned indicators based on satellite imagery which will, at least partly, overcome the data gaps as well as scale issues. The issues of boundaries and definitions will also be addressed.

1.2 DOCUMENT CONTENT

While this chapter provides a short project description, chapter 2 presents the City Biodiversity Index, its history and structure as well as applications.

Chapter 3 gives a detailed overview (in tabular format) of the selected CBI indicators that are the major subject of this project. Chapter 4 provides short and concise general technical specifications for each of the indicators, whereas chapter 5 goes deeper into the specifics of the portfolio and product development of each of the indicators for Stockholm. This also contains the final maps and CBI scores.

Finally, chapter 6 gives all references used in the report.

2 THE CITY BIODIVERSITY INDEX

It is commonly assumed that cities, being urban areas, are devoid of flora and fauna – the reality is that many cities have rich biodiversity, regardless of geographical location and climate. Some are even located within or near biodiversity hotspots, while others are important stopover sites for migratory species. The ecosystem services that urban biodiversity provides to the local area are innumerable and often undervalued. Beyond aesthetics, ecosystems regulate the supply and quality of water, air and soil as well as moderating ambient temperatures. Water supply to urban areas frequently comes from catchment areas within or beyond the city boundaries; these catchment areas are sustained by natural ecosystems that store and purify the water. Urban greenery replenishes oxygen, sequesters carbon, absorbs solar radiation, reduces air pollution, maintains water balance and regulates surface temperature in urban landscapes through shading and evapotranspiration. Parks and natural areas provide recreational and educational opportunities to residents and contribute towards the liveability of a city.

Actions to conserve biodiversity should start with stock-taking and identifying baselines, followed by regular monitoring of conservation initiatives. Prior to the development of the Singapore Index, existing environmental and sustainability indices for cities and local authorities covered broader environmental issues and where biodiversity was considered, it typically formed only a minor component of the composite scores. In addition, indices that focussed specifically on biodiversity were targeted at the national level, which made local application challenging.

2.1 GENERAL INFORMATION ABOUT THE INDEX

At the Ninth Conference of Parties to the Convention on Biological Diversity (CBD) in May 2008, former Minister of National Development, Mr. Mah Bow Tan proposed the development of a city biodiversity index (CBI) as a self-assessment tool for cities to evaluate their biodiversity conservation efforts over time. Subsequently, Singapore hosted three expert workshops in 2009, 2010 and 2011. The technical development of the draft CBI was led by a panel of seven experts from NParks, London School of Economics, German Institute of Housing and Environment, Stockholm Resilience Centre, ICLEI-Local Governments for Sustainability, International Union for Conservation of Nature and the Secretariat of the Convention on Biological Diversity. The Global Partnership on Local and Sub-national Action for Biodiversity promoted the CBI.

At the Tenth Meeting of the Conference of Parties to the CBD (COP-10) in October 2010, the CBI was endorsed as part of the Plan of Action for Sub-national Governments, Cities and Other Local Authorities for Biodiversity. The Plan encourages Parties to engage cities and local authorities in implementing the CBD, and includes the CBI as a tool for cities to monitor their biodiversity conservation efforts. In recognition of Singapore's leadership in the technical development of the index, it was named the Singapore Index on Cities' Biodiversity (SI). At the High-Level segment of COP-10, Mr. Mah offered the World Cities Summit (WCS) and the Mayors' Forum as platforms for sharing of best practices and as preparatory meetings for cities to report on their progress in biodiversity conservation and the application of the SI.

The term City Biodiversity Index (CBI) and Singapore Index (SI) are used interchangeably in this report.

2.2 STRUCTURE OF THE INDEX

The SI is a self-assessment tool for cities to benchmark and monitor the progress of their biodiversity conservation efforts against their own individual baselines. It comprises:

a) the “Profile of the City”, which provides comprehensive background information on the city (e.g. location, size, population, economic parameters, physical features, biodiversity features); and

b) the city’s self-assessment of the 23 indicators based on the guidelines and methodology provided.

The scoring of the Index is quantitative in nature. A maximum score of four has been allocated to each indicator, and with the current count of 23 indicators, the total possible score of the index is 92 points. The year in which a city first embarks on this scoring will be taken as the baseline year, and this will be measured against future applications of the index to chart its progress in conserving biodiversity. For seven of the indicators, a statistical treatment will be applied to sample data from cities to ensure the scoring ranges established are unbiased and fair to a broad spectrum of cities of different characteristics over a wide geographical range.

Table 1: CBI indicator list

Core components	Indicators
Native Biodiversity in the City	1. Proportion of Natural Areas in the City
	2. Connectivity Measures
	3. Native Biodiversity in Built Up Areas (Bird Species)
	4. Change in Number of Vascular Plant Species
	5. Change in Number of Bird Species
	6. Change in Number of Butterfly Species
	7. Change in Number of Species (any other taxonomic group selected by the city)
	8. Change in Number of Species (any other taxonomic group selected by the city)
	9. Proportion of Protected Natural Areas
	10. Proportion of Invasive Alien Species
Ecosystem Services provided by Biodiversity	11. Regulation of Quantity of Water
	12. Climate Regulation: Carbon Storage and Cooling Effect of Vegetation
	13. Recreation and Education: Area of Parks with Natural Areas
	14. Recreation and Education: Number of Formal Education Visits per Child Below 16 Years to Parks with Natural Areas per Year
Governance and Management of	15. Budget Allocated to Biodiversity
	16. Number of Biodiversity Projects Implemented by the City Annually

Biodiversity	17. Existence of Local Biodiversity Strategy and Action Plan
	18. Institutional Capacity: Number of Biodiversity Related Functions
	19. Institutional Capacity: Number of City or Local Government Agencies Involved in Inter-agency Cooperation Pertaining to Biodiversity Matters
	20. Participation and Partnership: Existence of Formal or Informal Public Consultation Process
	21. Participation and Partnership: Number of Agencies/Private Companies/NGOs/Academic Institutions/International Organisations with which the City is Partnering in Biodiversity Activities, Projects and Programmes
	22. Education and Awareness: Is Biodiversity or Nature Awareness Included in the School Curriculum
	23. Education and Awareness: Number of Outreach or Public Awareness Events Held in the City per Year

2.3 APPLICATION OF THE INDEX

The Singapore Index is a pioneering self-assessment tool designed to help cities better understand how they can improve their biodiversity conservation efforts over time. It is not a tool for comparing and contrasting the performance of different cities, as context is core to performance, nor is it a tool to be used only once. Cities should make an initial baseline measurement; identify policy priorities based on their measurements and then monitor again at periodic intervals.

The Singapore Index helps cities to accomplish their biodiversity goals via three interrelated mechanisms, which are vital to positive policy outcomes. First, the Index is a tool that allows cities to create baseline measurements of their current biodiversity profiles and then monitor and assess those over time. Secondly, it serves as a public platform upon which biodiversity awareness raising exercises can be launched. Finally, the Index acts as portal among various departments within city governance, academics, NGOs and the public, encouraging better communication, stronger networks and more co-operation, through data collection and sharing of mutual goals, which ultimately results in better policy outcomes. Indicators can serve as important policy tools in the measurement of economic, social and environmental variables.

The Singapore Index encourages cities to complete a baseline assessment of their biodiversity and then monitor this over time. As a tool this provides cities with valuable information that they might not otherwise have and can aid in the decision-making process as it helps to identify strengths, weaknesses and trends over time. Brussels has found the Singapore Index to be useful in identifying gaps in the local biodiversity management strategies, and it has led to an improvement in the data collection system.

The Singapore Index also serves as a valuable method of awareness raising allowing cities to mobilise their citizenry in efforts to protect and enhance locally important populations of species and ecosystems. Scientific evidence (for example, Danielsen et al. 2010, Environmental monitoring: the scale and speed of implementation varies according to the degree of people's involvement) indicates that where local people are involved in monitoring and data collection, better policy outcomes are often the case. The Index provides opportunities for citizen and city collaboration and potential media exposure which can help cities create momentum behind biodiversity conservation efforts. In a study conducted by *Corporate Knights*[1] on good sustainable development practices in Canadian cities, Edmonton and Montreal scored a perfect score for their biodiversity monitoring efforts, attributing their performance to the use of the Singapore Index.

The Singapore Index has also been instrumental in helping local, national and regional government departments to exchange information and ideas on measuring biodiversity. This creates a new network of policy actors around the issue of biodiversity and further embeds the idea into policy discourse. There has been growing participation of NGOs, universities and consultancy firms and this has benefited biodiversity policy in the cities that applied the Index by presenting new policy opportunities that might not have readily existed without the synergies created by the networks involved in data collection. For example, in Lisbon, Portugal, the application of the Singapore Index led to the development of a Local Biodiversity Strategy and Action Plan. It has also been creatively used in Singapore by city planners in the master planning of new districts and the Building and Construction Authority in their Green Mark for Districts scheme. Here the Index helped to create new networks of actors who came together to formulate policies that would not have been possible otherwise.

Although the Singapore Index was originally designed as a monitoring tool, other applications of CBI have emerged:

a) The indicators can act as guidelines on how to conserve and enhance biodiversity in cities. In Lisbon, the application of the Singapore Index led to the development of a Biodiversity Strategy and a Local Action Plan for Lisbon.

b) The index is not restricted to cities and can be applied at different scales. Singapore has used the index at the sub-city level, in the master planning of new districts. Perak, Malaysia has expressed interest to apply the Singapore Index at the state level. IUCN is also exploring how the Singapore Index indicators can be used to monitor biodiversity in the French regions.

c) The index can be incorporated as a biodiversity component of broader environmental indices. In Singapore, the index has been incorporated into the Building and Construction Authority's Green Mark for Districts, which is a certification to promote environment-friendly and sustainable development. The index has also been used as part of the scoring criteria for the European Capitals of Biodiversity Competition.

[1] *Corporate Knights* is a quarterly Canadian magazine dedicated towards advocating responsible business practices within Canada and promoting sustainable development globally

3 THE SELECTED INDICATORS

For the current assessment, we have focussed on a selection of four indicators which have been identified by the early implementers of the CBI as particularly difficult, due to a) lack of skills, b) lack of personnel and c) lack of data.

The information of the following chapters is taken from the User's manual of the Singapore Index on Cities' Biodiversity[2], indicators are presented in separate tables concerning the rationale behind, the variables and calculation required, and the thresholds for the scores.

3.1 INDICATOR 1 – PROPORTION OF NATURAL AREAS IN THE CITY

Rationale for selection of indicator Natural ecosystems harbour more species than disturbed or manmade landscapes, hence, the higher the percentage of natural areas compared to that of the total city area gives an indication of the amount of biodiversity there. However, a city by definition has a high proportion of modified land area and this is factored into the scoring. Natural ecosystems are defined as all areas that are natural and not highly disturbed or completely man-made landscapes. Some examples of natural ecosystems are forests, mangroves, freshwater swamps, natural grasslands, streams, lakes, etc. Parks, golf courses, roadside plantings are not considered as natural. However, natural ecosystems within parks where native species are dominant can be included in the computation. The definition also takes into consideration "restored ecosystems" and "naturalised areas" in order to recognise efforts made by cities to increase the natural areas of their city. Restoration helps increase natural areas in the city and cities are encouraged to restore their impacted ecosystems.
Variables and calculation How to calculate the indicator: *(Total area of natural, restored and naturalized areas) ÷ (Total area of city) × 100%* Sources of data on natural areas include government agencies in charge of biodiversity, city municipalities, urban planning agencies, biodiversity centres, nature groups, universities, publications, etc. Google maps and satellite images can also provide relevant information for calculating this indicator
Score Based on the assumption that, by definition, a city comprises mainly manmade landscapes, the maximum score will be accorded to cities with natural areas occupying more than 20% of the total

[2] https://www.cbd.int/doc/meetings/city/subws-2014-01/other/subws-2014-01-singapore-index-manual-en.pdf

city area.

- 0 points: < 1.0%
- 1 point: 1.0% – 6.9%
- 2 points: 7.0% – 13.9%
- 3 points: 14.0% – 20.0%
- 4 points: > 20.0%

3.2 INDICATOR 2 – CONNECTIVITY MEASURES OR ECOLOGICAL NETWORKS TO COUNTER FRAGMENTATION

Rationale for selection of indicator

Fragmentation of natural areas is one of the main threats to the sustainability of biodiversity in a city. It is an indicator to chart possible future trends. Some of the ways to measure fragmentation include mean patch size or distance between patches or effective mesh size etc. This indicator score can be improved when more of the fragments are connected.

Variables and calculation

How to calculate indicator?

$$IND2 = \frac{1}{A_{\text{total}}}\left(A_1^2 + A_2^2 + A_3^2 + \ldots + A_n^2\right),$$

where n is the total number of groups of connected natural areas (counting those that are connected to each other only once), A_1 to A_n represent the sizes of these groups of natural areas, and A_{total} is the total area of all natural areas together.

This measure of connectivity is called "effective mesh size" (EMS)

Source of data are satellite images

Score

EMS is based on the probability that two points chosen randomly in a region are connected (or are considered connected (< 100m between the patches with no major barrier between). Larger values of the effective mesh sizes indicate higher connectivity.

- 0 points: < 200 ha
- 1 point: 201 - 500 ha
- 2 points: 501 - 1000 ha
- 3 points: 1001 - 1500 ha
- 4 points: > 1500 ha

3.3 INDICATOR 11 – REGULATION OF QUANTITY OF WATER

Rationale for selection of indicator

Climate change is in many places predicted to result in increased variability in precipitation which in urban landscapes may translate into high peaks in water flow and damage to construction, business and transport. Vegetation has a significant effect in reducing the rate of flow of water through the urban landscape, e.g. through presence of forest, parks, lawns, roadside greenery, streams, rivers, waterbodies, etc.

Variables and calculation

How to calculate the indicator?

Proportion of all permeable areas (including areas identified in indicator 1 plus other parks, roadside, etc. but excluding artificial permeable surfaces, if applicable) to total terrestrial area of city (excluding marine areas under the city's jurisdiction).

(Total permeable area) ÷ (Total terrestrial area of the city) × 100%

Data sources include government environmental agencies, city municipalities, urban planning, water and land agencies, satellite images, etc.

Score

The following points are awarded for the respective proportions of permeable areas in the city:

- 0 points: < 33.1%
- 1 point: 33.1% - 39.7%
- 2 points: 39.8% - 64.2%
- 3 points: 64.3% - 75.0%
- 4 points: > 75.0%

3.4 INDICATOR 12 – CLIMATE REGULATION: CARBON STORAGE AND COOLING EFFECT OF VEGETATION

Rationale for selection of indicator

Carbon storage and cooling effects provided by vegetation, in particular tree canopy cover are two important aspects of climate regulation services. Climate regulation services are affected the size of trees, the different characteristics of tree species and other variables.

Plants capture carbon dioxide during photosynthesis, hence, capturing carbon that is emitted by anthropogenic activities. Canopy cover of trees, which includes those that are naturally occurring and planted in a city, is accepted as an indirect measure of the carbon sequestration and storage service. The extent of tree canopy cover can also act as a proxy measure for filtering of air and numerous other biodiversity benefits.

This indicator is optional for cities in the desert or arid zones or other ecological zones where extensive canopy cover in the city may not be feasible.

Variables and calculation

How to calculate the indicator?

Carbon storage and cooling effect of vegetation

(Tree canopy cover) + (Total terrestrial area of the city) × 100%

Data sources include city councils and satellite images

Score

The more trees there are in a city, the higher would be the carbon stock of ecosystem services value provided. Tree canopy cover is being used as a proxy measurement of the number of trees in a city.

The following points are awarded for the respective proportions of canopy cover within the city:

- 0 points: < 10.5%
- 1 point: 10.5% - 19.1%
- 2 points: 19.2% - 29.0%
- 3 points: 29.1% - 59.7%
- 4 points: > 59.7%

4 TECHNICAL PRODUCT SPECIFICATIONS

In general, the framework for the development and production of the indicators is to a large extent defined by the specifications in the CBI User Manual. However, there still exists some degree of freedom regarding the exact definition of the indicators (e.g., the definition of natural areas remains somewhat open to account for geographic, climatological or historic differences). It is therefore of utmost importance to collect these specific requirements from the end users to be able to customise the indicator production accordingly.

The following chapters provide general information about the technical specifications of each of the products.

4.1 INDICATOR 1 – PROPORTION OF NATURAL AREAS IN THE CITY

In general, we differentiate two types of products for indicator 1:

The basic product is the main product for indicator 1 and solely derived from satellite data and other publicly available ancillary data (such as OpenStreetMap). Due to the characteristics of the input data it can achieve a certain depth of information and accuracy, but is relatively inexpensive due to the large coverage and low costs of the satellite data (the new Sentinel-2 data are even free of charge). The use of satellite data also makes the product objective and repeatable which is an important factor for the implementation of monitoring activities.

On top of the basic product an advanced product can be created (if requested and feasible from a data availability perspective) to fulfil some additional needs of the users.

The following tables summarize the detailed technical specifications of the deliverable products taking into account the general as well as the specific user requirements on the one hand, and the feasibility of the products given the selected EO input data on the other.

Table 2: Technical specifications for product 1 of indicator 1 – Land cover maps

Product	**Land use/land cover maps**
Basic product	
Content	The basic product consists of land cover/use maps for one reference year for the cities derived from high resolution EO data and publicly available ancillary data: • major classes such as Agriculture, Buildings, roads, paved grounds, mining areas, Forest, Meadows, grasses and pastures and water. • Candidate natural areas
CBI indicator	Proportion of natural areas in the city [%]: This product is the share of natural areas in the city calculated as a percentage cover of the total area of the city based on the land use/cover map.

Input data	Satellite images (e.g., Sentinel-2, SPOT-5, RapidEye, Landsat) OpenStreetMaps Other publicly available ancillary data that might be useful
Temporal Requirement	Recent years (to be defined with client)
Spatial coverages	City boundary (to be provided by the end user)
Minimum Mapping Unit	No MMU, minimum mappable area determined by pixel size of the satellite images
Thematic accuracy	85 % (depending on the quality of EO data and reference data)
Geometric accuracy	< 1 pixel
Projection	Local/national projection (to be provided by the end user)
Delivery format	The final products in digital format are delivered both on-line via FTP & on media DVD • Geographic data (incl. meta-data in acc. with INSPIRE and ISO standards) in standard GIS format: ○ raster data (imagery): .geotiff ○ vector data (land cover data): shape file, (e.g. ArcGIS project) and as .kmz/.kml to enable to view the data on Google Earth • Maps (land cover/use maps) in high quality ready for printing in adequate scale and out-put size (e.g. .tiff, .pdf) • Reports, statistics and input material for brochures (images, text etc.): in MS Office (word, power point, excel) format and pdf (all annexes included into one file) Analogue paper versions of the maps will be provided on request of and in agreement with the user organisations.
Advanced product	
Content	The advanced product builds on the basic product and allows for the integration of local ancillary data to respond to specific local requirements that cannot be fulfilled by satellite data alone. However, the possibility to implement this advanced product very much depends on the availability of local ancillary data; to fulfil the requirements of the CBI, the basic product is sufficient.
Data	Thematic data layers, such as natural parks, forest or tree cadastre data, local topographic maps.

4.2 INDICATOR 2 – CONNECTIVITY MEASURES OR ECOLOGICAL NETWORKS TO COUNTER FRAGMENTATION

Indicator 2 measures the degree of connectivity of natural areas within cities. Connectivity is defined as “the degree to which the landscape facilitates or impedes movement among resources” and it can be “measured by the probability of movement between all points or resource patches in a landscape”.

Table 3: Technical specifications for indicator 2

Product	**Connectivity of natural areas**
Content	Indicator 2 represents the degree of connectivity of natural areas, or the average amount of natural area that an individual (of a certain wildlife species) is connected to from any randomly chosen starting point in a landscape/city. The indicator is computed according to the formula $$IND2 = \frac{1}{A_{\text{total}}}(A_{G1}^2 + A_{G2}^2 + A_{G3}^2 + \cdots + A_{Gn}^2)$$ where n denotes the number of groups of connected patches of natural area; A_{G1}, A_{G2}, A_{G3},... indicate the sizes of each group of connected patches of natural area; and A_{total} represents the total area of all patches of natural area in the landscape.
CBI indicator	Total connectivity [ha]
Input data	GIS data layers of indicator 1 Ancillary data about barriers and connectors (e.g., roads, built-up areas, and semi-natural areas) which are used for the delineation of the fragmentation geometry and connectors. These ancillary data sets should ideally be provided by the cities; if they are not available, public data might be used instead.
Temporal Requirement	Recent years
Spatial coverages	City boundary (to be provided by the end user)
Minimum Mapping Unit	No MMU
Thematic accuracy	NA as no quantitative validation is performed.
Geometric accuracy	< 1 pixel
Projection	Local/national projection (to be provided by the end user)
Delivery format	The final products in digital format are delivered both on-line via FTP & on media DVD • Geographic data (incl. meta-data in acc. with INSPIRE and ISO standards) in standard GIS format: ○ vector data (land cover data): shape file, (e.g. ArcGIS project) and as .kmz/.kml to enable to view the data on Google Earth • Reports, statistics and input material for brochures (images, text etc.): in MS Office (word, power point, excel) format and pdf (all annexes included into one file)

	Analogue paper versions of the maps will be provided on request of and in agreement with the user organisations.

4.3 INDICATOR 11 – REGULATION OF QUANTITY OF WATER: PROPORTION OF PERMEABLE AREAS

The following tables summarize the detailed technical specifications of the deliverable products taking into account the general as well as the specific user requirements on the one hand, and the feasibility of the products given the selected EO input data on the other.

Table 4: Technical specifications for product 1 of indicator 11 – Share of permeable areas

Product	**Degree of permeability**
Content	The service will comprise: 1. Map of predicted degree of permeable surfaces 2. Map of improved degree of permeable surfaces using open street maps (roads & buildings)
CBI indicator	Proportion of permeable areas in the city [%]: This product is the share of permeable areas in the city obtained as a percentage cover of the total area of the city.
Input data	Satellite images (e.g., Sentinel-2, SPOT-5, RapidEye, Landsat) OpenStreetMaps Other publicly available ancillary data that might be useful
Temporal Requirement	Recent years
Spatial coverage	City boundary (to be provided by the end user)
Minimum Mapping Unit	No MMU, minimum mappable area determined by pixel size of the satellite images
Thematic accuracy	85 % (depending on the quality of EO data and reference data)
Geometric accuracy	< 1 pixel
Projection	Local/national projection (to be provided by the end user)

Delivery format	The final products in digital format will be delivered both on-line via FTP & on media DVD
	• Geographic data (incl. meta-data in acc. with INSPIRE and ISO standards) in standard GIS format:
	  ○ raster data (imagery): .geotiff
	  ○ vector data (land cover data): shape file, (e.g. ArcGIS project) and as .kmz/.kml to enable to view the data on Google Earth

	• Maps (degree of imperviousness maps) in high quality ready for printing in adequate scale and out-put size (e.g. .tiff, .pdf) • Reports, statistics and input material for brochures (images, text etc.): in MS Office (word, power point, excel) format and pdf (all annexes included into one file) Analogue paper versions of the maps will be provided on request of and in agreement with the user organisations.

4.4 INDICATOR 12 – CLIMATE REGULATION: CARBON STORAGE AND COOLING EFFECT OF VEGETATION: EXTENT OF TREE CANOPY COVER

Table 5: Technical specifications for product 1 of indicator 12 – Tree canopy cover

Product	**Tree canopy cover**
Content	The service will comprise: 1. Map of predicted tree canopy cover 2. Map of improved tree canopy cover using land cover layers (agriculture, grasslands, meadows, pasture) and Open Street Maps (roads)
CBI indicator	Proportion of tree canopy cover in the city [%]: This product is the share of tree canopy cover in the city obtained as a percentage cover of the total area of the city.
Input data	Satellite images (e.g., Sentinel-2, SPOT-5, RapidEye, Landsat) OpenStreetMaps Other publicly available ancillary data that might be useful
Temporal Requirement	Recent years
Spatial coverage	City boundary (to be provided by the end user)
Minimum Mapping Unit	No MMU, minimum mappable area determined by pixel size of the satellite images
Thematic accuracy	85 % (depending on the quality of EO data and reference data)
Geometric accuracy	< 1 pixel
Projection	Local projection (to be provided by the end user)
Delivery format	The final products in digital format will be delivered both on-line via FTP & on media DVD • Geographic data (incl. meta-data in acc. with INSPIRE and ISO standards) in standard GIS format: ○ raster data (imagery): .geotiff

	◦ vector data (land cover data): shape file, (e.g. ArcGIS project) and as .kmz/.kml to enable to view the data on Google Earth • Maps (tree canopy cover maps) in high quality ready for printing in adequate scale and out-put size (e.g. .tiff, .pdf) • Reports, statistics and input material for brochures (images, text etc.): in MS Office (word, power point, excel) format and pdf (all annexes included into one file) Analogue paper versions of the maps will be provided on request of and in agreement with the user organisations.

5 SERVICE PORTFOLIO AND PRODUCT DEVELOPMENT FOR STOCKHOLM

The following chapters present the entire service and product portfolio for the city of Stockholm, including the general pre-processing steps as well as both specific technical specifications and the final results for all indicators.

5.1 PRE-PROCESSING

Prior to the production of the indicators, the Sentinel-2 images were corrected for atmospheric errors using the "sen2cor" plugin in the SNAP toolbox which converts level 1C to level 2A products (SNAP is a common architecture for Sentinel toolboxes, called the Sentinel Application Platform[3]). The corrected level 2A images were georeferenced using the free and open-source GIS software QGIS[4] and the proprietary image processing software Envi[5] to assign real-world coordinates to each pixel of the images. The time-series datasets were georeferenced to a master image (image-to-image geo-referencing) and stacked for classification using Random Forest classifiers available in the software package R 3.2.5[6].

The pre-processed Sentinel-2 images were used for the production of three indicators (indicators 1, 11 and 12), while indicator 2 uses indicator 1 as input information. For this production, temporal statistics of the image bands as well as various indices calculated from the images at different time steps were used. However, to speed-up processing not all calculated statistics were used in the land cover classification and prediction of indicators 11 and 12. Pairwise correlation was performed on the temporal statistics and the relatively less correlated were selected for the analysis.

5.2 RESULTS

5.2.1 INDICATOR 1 – PROPORTION OF NATURAL AREAS IN THE CITY

The production of indicator 1 results in a number of sub-products (which are not part of the final data delivery) that lead to the final products/indicator: first, the land cover map from which the natural areas are derived, and secondly, the percentage value representing the proportion of natural areas per city. Table 6 and Table 7 present more specific technical specifications of product 1 and product 2 of indicator 1 together with the final map and the CBI score.

Table 6: Technical specifications for product 1 of indicator 1 – Land cover maps

Product	**Land use/land cover maps**
Content	The product consists of land cover/use maps for the cities derived from high resolution EO data.

3 http://step.esa.int/main/toolboxes/snap/
4 http://www.qgis.org/en/site/
5 http://www.harrisgeospatial.com/ProductsandSolutions/GeospatialProducts/ENVI.aspx
6 https://www.r-project.org/

The service consists of land cover maps for one reference year (2016) derived from high resolution EO data. It includes

- 5 major classes such as Agriculture; Buildings, roads, paved grounds, mining areas; Forest; Meadows, grasses and pastures; and Water.
- Vegetated and not vegetated areas layer
- Candidate natural areas levels 1 and 2 layers

Based on the specific requirements, the nomenclature[7] includes the following classes:

Product	
Land cover map	
LC_ID	Class name
1	Water
2	Forest
3	Agriculture
4	Meadows, grasses and pastures
5	Buildings, roads, paved grounds, mining areas

LC_ID	Class name
1	Water
2	Vegetated
3	Not vegetated

Vegetated areas of the city
Candidate natural areas level 1
Candidate natural areas level 2

Input data	Sentinel 2 (10m resolution)
Temporal Requirement	2016

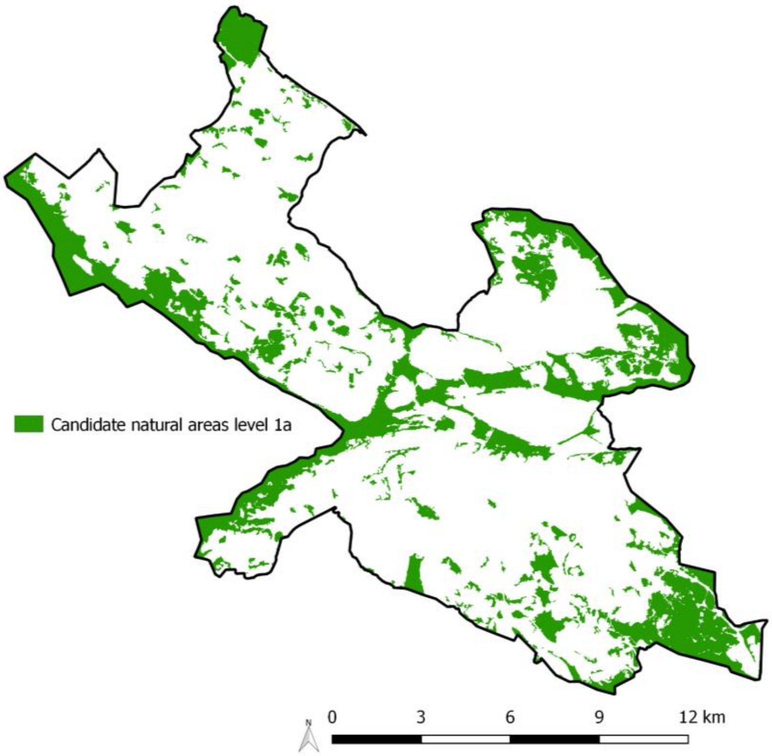
Table 7: Technical specifications for Indicator 1 (Product 2) – Proportion of natural areas

Service 2: Proportion of natural areas	
Service content	This product is the share of natural areas in the city calculated as a percentage cover of the total area of the city.
Spatial resolution	NA
Geometric accuracy	NA

[7] Further on in the project the nomenclature will be converted into an object-based LCML-compatible legend.

Thematic accuracy	NA
Temporal resolution	Stockholm: three time steps (from 2016)

Table 8: Results for indicator 1, Stockholm

Land cover map **(Natural areas)**	
CBI value/score	4 points (25.5% natural areas)

5.2.2 Indicator 2 – Connectivity Measures or Ecological Networks to Counter Fragmentation

Urban wildlife populations are negatively affected by the inability to move between fragmented habitats, resulting in reduced access to resources and mating partners as well as higher rates of extinction and the loss of genetic diversity among native species (Brook et al., 2003; Di Giulio et al., 2009; LaPoint et al., 2015; Taylor et al., 1993; Tischendorf & Fahrig, 2000). The importance of landscape connectivity for biodiversity has been discussed extensively in the literature (Brook et al., 2003; Di Giulio et al., 2009; Taylor et al., 1993). For example, enhancement of connectivity is the most often recommended measure to address the effect of climate change on biodiversity by enabling species to move to more suitable locations (Heller and Zavaleta, 2009). Therefore, higher efforts are needed to protect natural areas from destruction and fragmentation.

Indicator 2 measures the degree of connectivity of natural areas within cities. Connectivity is defined as "the degree to which the landscape facilitates or impedes movement among resources" and it can be "measured by the probability of movement between all points or resource patches in a landscape"

(Taylor et al., 1993).

Table 9 presents the detailed technical specifications of indicator 2.

Table 9: Technical specifications for indicator 2

Product	**Connectivity of natural areas**
Content	Indicator 2 represents the degree of connectivity of natural areas, or the average amount of natural area that an individual (of a certain wildlife species) is connected to from any randomly chosen starting point in a landscape/city.
Input data	GIS data layers of indicator 1 Ancillary data about barriers and connectors (e.g., roads, built-up areas, and semi-natural areas) which are used for the delineation of the fragmentation geometry and connectors. Selection of the ancillary data about the fragmentation geometry (barriers) and connectors was based on the protocol of CBI User's Manual as well as opinions of experts from the participating cities (users). The following table presents the detailed information of the input data used for the calculation of indicator 2 for Stockholm.
Methodology	$$IND2 = \frac{1}{A_{\text{total}}}(A_{G1}^2 + A_{G2}^2 + A_{G3}^2 + \cdots + A_{Gn}^2)$$ where n denotes the number of groups of connected patches of natural area; A_{G1}, A_{G2}, A_{G3},... indicate the sizes of each group of connected patches of natural area; and A_{total} represents the total area of all patches of natural area in the landscape.
Temporal Requirement	2016

City of Stockholm			
Input data class	**Input data**	**Source**	**Type of data**
Natural areas	- Product of indicator 1 (using Sentinel 2 images)	- Internal data	- Shapefile (polygon)
Barriers	- Major roads - Building footprints	- Open Street Map - Open Street Map	- Shapefile (polyline) - Shapefile (polygon)
Connectors	- Cemeteries - Parks - Forest - meadow - nature-reserve	- OSM - OSM - Combination of Sweden National Land Surveying Agency (Lantmäteriet) data and OSM - OSM - OSM	- Shapefile (polygon) - Shapefile (polygon) - Shapefile (polygon) - Shapefile (polygon)
Other	- City Boundary	- Land Surveying Agency (Lantmäteriet)	- Shapefile (polygon)

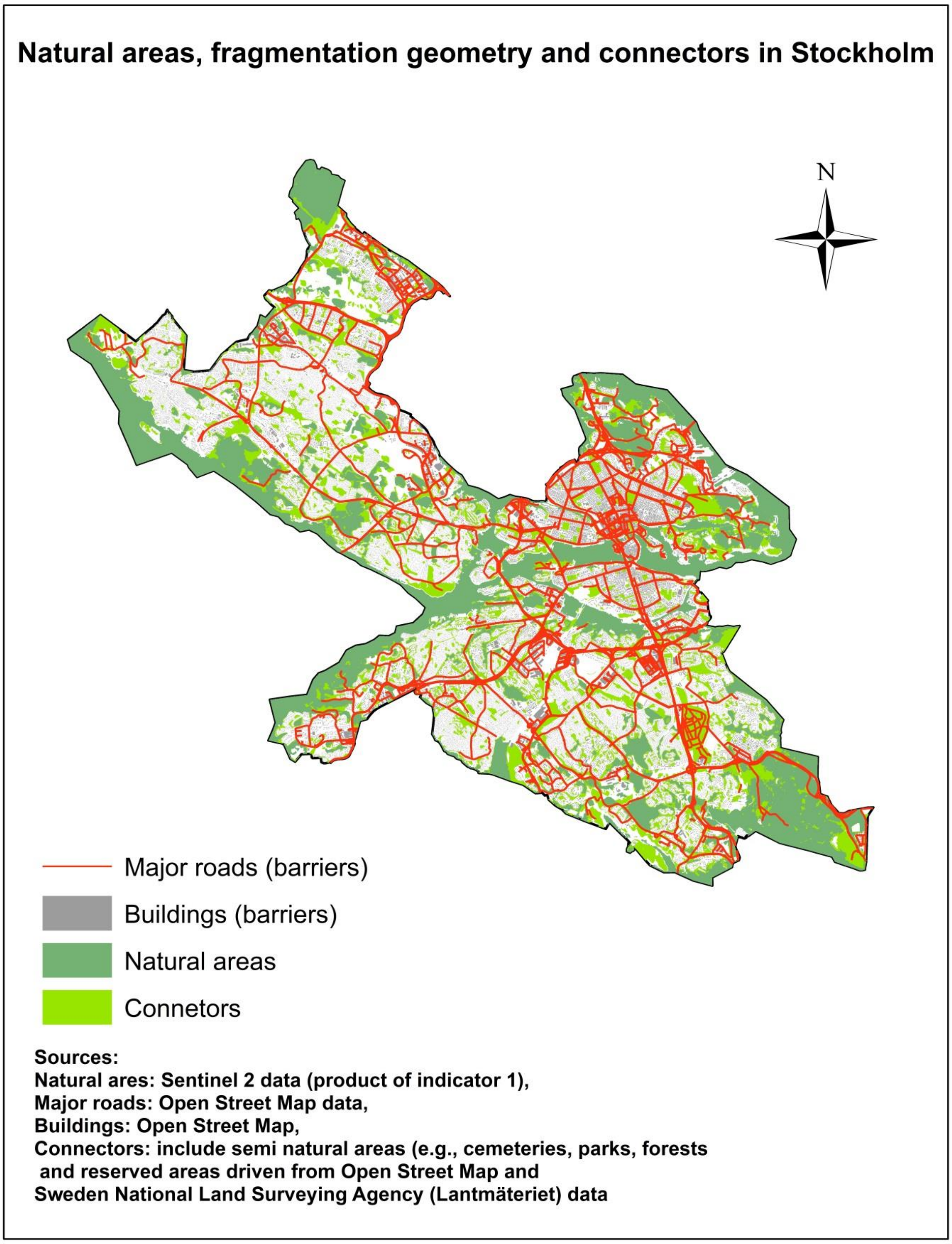


Figure 1: Natural areas, fragmentation geometry, and connectors in Stockholm

Table 10: Results for indicator 2, Stockholm

Connectivity Analysis (Indicator 2 of CBI) Stockholm	With barriers/ Without connectors	With barriers/ With connectors	Without barriers/ Without connectors	Without barriers/ With connectors
	Scenario 1	Scenario 2	Scenario 3	Scenario 4

Total Connectivity (ha)	Option A: 408.98 Option B: 412.11	Option A: 419.84 Option B: 423.06	2211.08	2320.71
Intra/Within-Patch Connectivity (ha)	Option A: 338.69 Option B: 341.28	Option A: 338.69 Option B: 341.28	408.51	408.51
Inter/Between-Patch Connectivity (ha)	Option A: 70.29 Option B: 70.83	Option A: 81.16 Option B: 81.78	1802.57	1912.20
Total area of Natural Areas (ha)	Option A: 5504.09 Option B: 5462.24	Option A: 5504.09 Option B: 5462.24	5504.09	5504.09

Note: Option A: refers to the situation in which the total area of natural areas (as calculated for indicator 1), not corrected for barriers, is used for A_{total} in the denominator of the connectivity equation. Option B refers to the situation in which the area covered by the barriers (roads and building footprints) is subtracted from the total area of the natural areas (indicator 1) and then used as A_{total} in the denominator of the connectivity equation.

CBI value/score	1 point (408.98 ha)

Some explanatory remarks provide further insight into the output tables for indicator 2. The connectivity values were compared between four scenarios. Scenario 1 represents the main value of connectivity according to the CBI User's Manual, including the effect of barriers, but without connectors. Connectivity was also calculated for three additional scenarios (scenarios 2-4), with and without consideration of barriers and connectors.

It is very important to use an appropriate denominator (total area of natural areas) in the connectivity equation in order to be able to compare connectivity values for different scenarios or points in time. We decided to use option A for reporting A_{total} for indicator 1 and for calculating connectivity to avoid potential confusion caused by using different values of A_{total} in indicator 1 and indicator 2. Another advantage of option A is that the total areas are the same for all 4 scenarios (while in option B they often differ between 1/2 and 3/4), and therefore, connectivity values for different scenarios can be compared directly (in option A). We also report the values of option B in the table as additional information that is useful for monitoring changes over time.

5.2.3 INDICATOR 11– REGULATION OF QUANTITY OF WATER: PROPORTION OF PERMEABLE AREAS

The production of the indicator 11 results in a number of sub-products that lead to the final product/indicator: first, a (binary) GIS layer showing the distribution of permeable and impermeable (impervious) areas, and secondly the proportion of permeable areas per city. Table 11 and Table 12 present technical specifications for products 1 and 2 of indicator 11 respectively.

Table 11: Technical specifications for product 1 of indicator 11 – Degree of imperviousness

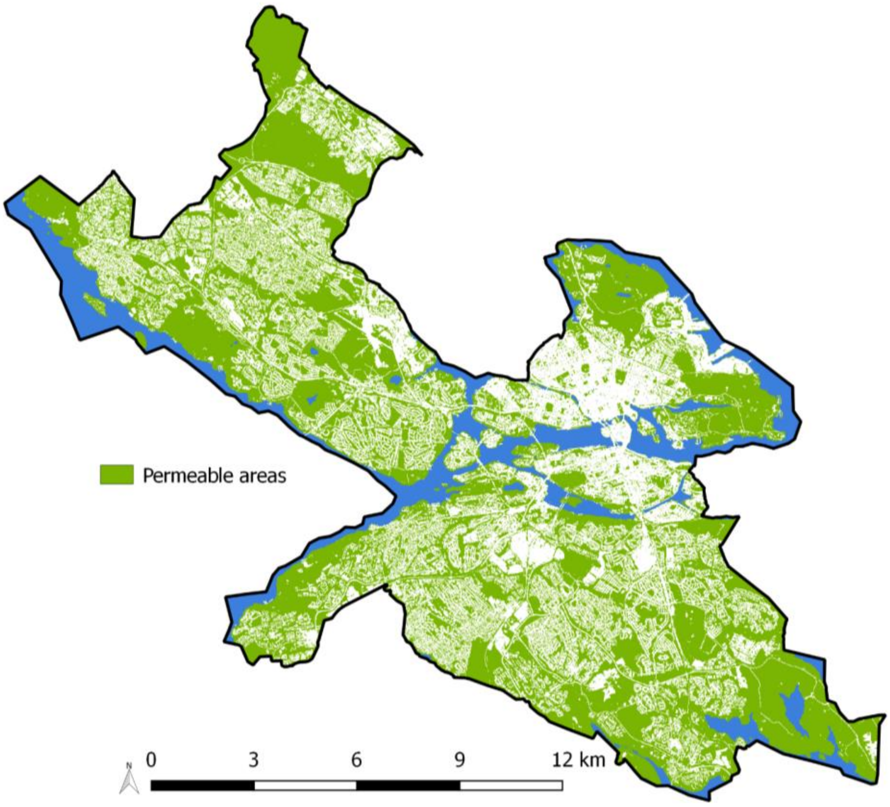
Product	**Degree of imperviousness**
Content	The service will comprise:

	1. Map of predicted degree of imperviousness 2. Map of improved degree of imperviousness using open street maps (roads & buildings) 3. Map of degree of imperviousness above 50 percent
Input data	Sentinel-2 10m resolution images
Temporal Requirement	2016

Table 12: Technical specifications for product 2 of indicator 11 – Proportion of permeable areas

Service 2: proportion of permeable areas	
Service content	This product is the share of permeable areas in the city obtained as a percentage cover of the total area of the city.
Spatial resolution	NA
Geometric accuracy	NA
Thematic accuracy	NA
Temporal resolution	Stockholm: three time steps (from 2016)

Table 13: Results for indicator 11, Stockholm

Map of permeability	
CBI value/score	2 points (52.9% permeable)

5.2.4 Indicator 12– Climate Regulation: Carbon Storage and Cooling Effect of Vegetation: extent of tree canopy cover

Table 14 and Table 15 present detailed technical specifications of product 1 and product 2 of indicator 12 respectively.

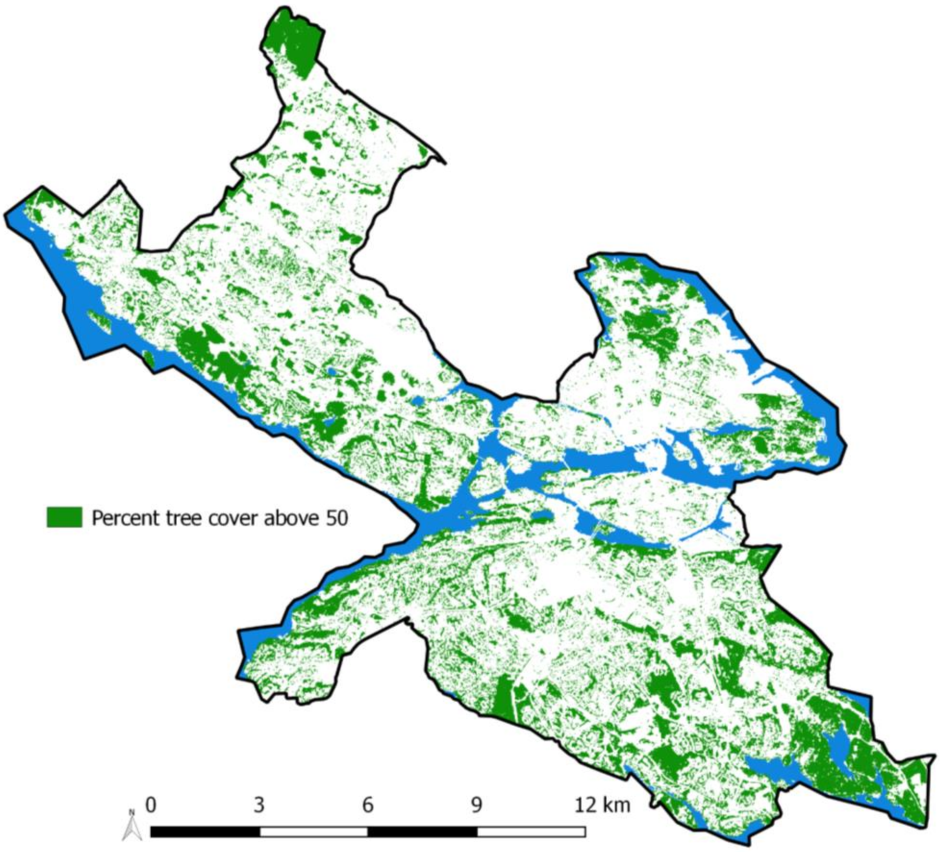
Table 14: Technical specifications for product 1 of indicator 12 – Tree canopy cover

Product	**Tree canopy cover**
Content	The service will comprise: 1. Map of predicted tree canopy cover 2. Map of improved tree canopy cover using land cover layers (agriculture, grasslands, meadows, pasture) open street maps (roads) 3. Maps of tree canopy cover above 50 percent
Input data	Sentinel-2 10m resolution
Temporal Requirement	2016

Table 15: Technical specifications for product 2 of indicator 12 – Proportion of tree canopy cover

Service 2: proportion of permeable areas	
Service content	This product is the share of tree canopy cover in the city obtained as a percentage cover of the total area of the city.
Spatial resolution	NA
Geometric accuracy	NA
Thematic accuracy	NA
Temporal resolution	Stockholm: three time steps (from 2016)

Table 16: Results for indicator 12, Stockholm

Map of the extent of tree canopy cover	
CBI value/score	2 points (24.9% tree canopy cover)

5.3 VALIDATION

The following tables present the validation statistics for the three indicators 1, 11 and 12 which have undergone a quantitative validation according to the protocol that is described in more detail in the Product Validation Plan (D1.3).

Table 17: QA parameters indicator 1, Stockholm

Natural areas	
validation code	**count of points**
incorrect points (commission)	7
correct points (commission)	93
All valid points (commission)	100
incorrect points (omission)	9
correct points (omission)	91
All valid points (omission)	100
All valid points (total)	200
Overall Accuracy [%]	**92.0**
Error of commission [%]	**7.0**

Error of omission [%]	**9.0**
Uncertainty	*+/- 1.9 %*
Mean Absolute Error	8.0
Target Error	<15%

Table 18: QA parameters indicator 11, Stockholm

Permeable areas	
validation code	**count of points**
incorrect points (commission)	13
correct points (commission)	87
All valid points (commission)	100
incorrect points (omission)	11
correct points (omission)	89
All valid points (omission)	100
All valid points (total)	200
Overall Accuracy [%]	**88.0**
Error of commission [%]	**13.0**
Error of omission [%]	**11.0**
Uncertainty	*+/- 2.3%*
Mean Absolute Error	12.0
Target Error	<15%

Table 19: QA parameters indicator 12, Stockholm

Tree cover density	
validation code	**count of points**
incorrect points (commission)	13
correct points (commission)	87
All valid points (commission)	100
incorrect points (omission)	19
correct points (omission)	81
All valid points (omission)	100
All valid points (total)	200
Overall Accuracy [%]	**84.0**
Error of commission [%]	**13.0**
Error of omission [%]	**19.0**
Uncertainty	*+/- 2.6%*
Mean Absolute Error	16.0
Target Error	<15%

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