ESA DUE Innovator III

Earth Observation in support of the City Biodiversity Index

D1.2 Technical Specifications

[PROJECT DELIVERABLE SUBMITTED FOR REVIEW]

DOCUMENT RELEASE SHEET

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1 BACKGROUND OF THE DOCUMENT

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. However, 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). It consists of 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”.

The project partners 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. More background information on the CBI and its structure is provided in the project deliverable D1.1 – Requirements Baseline.

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 organisation 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. But also boundaries and definitions will be addressed.

1.2 DOCUMENT CONTENT

While this chapter 0 provides a short project description and lists the document content as well as applicable input and output documents, chapter 2 presents the basic characteristics of the CBI indicators that are the major subject of this project in tabular format.

Chapter 3 provides detailed descriptions of each product, their specifications, production approaches together with a justification of each selected method. The subsequent chapter 4 presents the proof-of-concept results for the three phase 1 pilot cities Barcelona, Tallinn and Edmonton.

Then, chapter 5 gives the updated data procurement plan, before chapter 0 provides conclusions of the prototyping phase together with a critical analysis of the elements and recommendations for possible improvements or adaptations.

Finally, chapter 7 gives all references used in the report.

1.3 RELATED DOCUMENTS

1.3.1 INPUT

Document ID	**Descriptor**
DUE_InnovatorIII_EO4CBI_Offer_I1.pdf	Technical offer, dated 26/08/2014
Clarification_CBI_ESA.docx	Reply to RfC, dated 26/01/2015
EO4CBI_Negotiation_MOM_I1.0.docx	MOM negotiation meeting, 02/02/2015
EO4CBI_D1.1_RB_I1.0.docx	Requirements Baseline, 30/09/2015

1.3.2 OUTPUT

Document ID	**Descriptor**
EO4CBI_D1.2_TS_I1.0.docx	Technical Specifications, 01/04/2016
EO4CBI_Deliverables_Data	Data and product delivery, 01/04/2016

2 THE SELECTED CBI 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 (see the short project description in chapter 1.1) as particularly difficult, due to a) lack of skills, b) lack of personnel and c) lack of data.

The information of the following paragraphs is taken from the User's Manual of the Singapore Index on Cities' Biodiversity[1], indicators are presented in separate tables concerning the rationale behind, as well as the variables and calculation required. More detailed information, also on thresholds and scoring, can be found in the project deliverable D1.1 – Requirements Baseline; this document also contains the exact definitions of "natural areas" for each of the cities.

Indicator 1 – Proportion of Natural Areas in the City
Rationale for selection of indicator 1 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 may also take 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

Indicator 2 – Connectivity Measures or Ecological Networks to Counter Fragmentation
Rationale for selection of indicator 2 Fragmentation of natural areas is one of the main threats to the sustainability of biodiversity in a city.

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

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. 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).

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); the source data are satellite images as well as ancillary data.

Indicator 11 – Regulation of Quantity of Water: Proportion of permeable areas

Rationale for selection of indicator 11

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.

Indicator 12 – Climate Regulation: Carbon Storage and Cooling Effect of vegetation: Extent of tree canopy cover

Rationale for selection of indicator 12

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 by 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

3 SERVICE PORTFOLIO AND SERVICE PRODUCTS

Although the framework for the development and production of the indicators is to a large extent defined by the specifications in the CBI User Manual, there still exists some degree of freedom regarding the exact definition of the indicators (e.g., the definition of natural areas remains somewhat open). At the beginning of the project we have therefore systematically identified specific needs by addressing end user cities with a dedicated questionnaire (see deliverable D1.1). The following chapters present the entire service and product portfolio tested on for the three committed prototype cities Barcelona (Spain), Tallinn (Estonia) and Edmonton (Canada).

3.1 INDICATOR 1 – PROPORTION OF NATURAL AREAS IN THE CITY

The production of the 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.

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.

3.1.1 Specifications

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

<table>
<tr><th>Product</th><th>Land use/land cover maps</th></tr>
<tr><td>Content</td><td>
The product consists of land cover/use maps for the cities derived from high resolution EO data.
The service consists of land cover maps for one reference year (2015) 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
Vegetated areas layer
Candidate natural areas levels 1 and 2 layers

Based on the specific requirements, the nomenclature[2] includes the following classes:
<table>
<tr><th colspan="2">Product</th></tr>
<tr><td colspan="2">Land cover map</td></tr>
<tr><td>LC_ID</td><td>Class name</td></tr>
<tr><td>1</td><td>Water</td></tr>
<tr><td>2</td><td>Forest</td></tr>
<tr><td>3</td><td>Agriculture</td></tr>
<tr><td>4</td><td>Meadows, grasses and pastures</td></tr>
<tr><td>5</td><td>Buildings, roads, paved grounds, mining areas</td></tr>
</table>
<table>
<tr><td>LC_ID</td><td>Class name</td></tr>
<tr><td>1</td><td>Water</td></tr>
<tr><td>2</td><td>Vegetated</td></tr>
<tr><td>3</td><td>Not vegetated</td></tr>
</table>
<table>
<tr><td>Vegetated areas of the city</td></tr>
<tr><td>Candidate natural areas level 1</td></tr>
<tr><td>Candidate natural areas level 2</td></tr>
</table>
</td></tr>
<tr><td>Input data</td><td>SPOT-5 10m for the entire AOI (Barcelona)
SPOT-5 (Take-5) 10m for the entire AOI (Tallinn)
RapidEye 5m for the entire AOI (Edmonton)</td></tr>
</table>

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

Methodology	See the illustrations of the production approach in Figure 1 to Figure 3
Temporal Requirement	Recent years (2014, 2015)
Spatial coverages	Barcelona core city, Metropolitan area of Barcelona Tallinn core city City of Edmonton
Minimum Mapping Unit	No MMU, minimum mappable area determined by pixel size (10 m for SPOT-5/Take-5 and 5 m for RapidEye)
Thematic accuracy	85 % (depending on the quality of EO data and reference data)
Geometric accuracy	< 1 pixel
Projection	Barcelona: PROJCS["ETRS89 / UTM zone 31N", GEOGCS["ETRS89", DATUM["European_Terrestrial_Reference_System_1989", SPHEROID["GRS 1980",6378137,298.257222101, AUTHORITY["EPSG","7019"]], TOWGS84[0,0,0,0,0,0,0], AUTHORITY["EPSG","6258"]], PRIMEM["Greenwich",0, AUTHORITY["EPSG","8901"]], UNIT["degree",0.0174532925199433, AUTHORITY["EPSG","9122"]], AUTHORITY["EPSG","4258"]], PROJECTION["Transverse Mercator"], PARAMETER["latitude_of_origin",0], PARAMETER["central_meridian",3], PARAMETER["scale_factor",0.9996], PARAMETER["false_easting",500000], PARAMETER["false_northing",0], UNIT["metre",1, AUTHORITY["EPSG","9001"]], AXIS["Easting", EAST], AXIS["Northing", NORTH], AUTHORITY["EPSG","25831"]] Tallinn: PROJCS["Estonian Coordinate System of 1997", GEOGCS["EST97", DATUM["Estonia_1997", SPHEROID["GRS 1980",6378137,298.257222101, AUTHORITY["EPSG","7019"]], TOWGS84[0,0,0,0,0,0,0], AUTHORITY["EPSG","6180"]], PRIMEM["Greenwich",0, AUTHORITY["EPSG","8901"]], UNIT["degree",0.01745329251994328, AUTHORITY["EPSG","9122"]],

	AUTHORITY["EPSG","4180"]], UNIT["metre",1, AUTHORITY["EPSG","9001"]], PROJECTION["Lambert_Conformal_Conic_2SP"], PARAMETER["standard_parallel_1",59.33333333333334], PARAMETER["standard_parallel_2",58], PARAMETER["latitude_of_origin",57.51755393055556], PARAMETER["central_meridian",24], PARAMETER["false_easting",500000], PARAMETER["false_northing",6375000], AUTHORITY["EPSG","3301"] Edmonton: PROJCS["NAD83 / Alberta 3TM ref merid 114 W", GEOGCS["NAD83", DATUM["North_American_Datum_1983", SPHEROID["GRS 1980",6378137,298.257222101, AUTHORITY["EPSG","7019"]], AUTHORITY["EPSG","6269"]], PRIMEM["Greenwich",0, AUTHORITY["EPSG","8901"]], UNIT["degree",0.01745329251994328, AUTHORITY["EPSG","9122"]], AUTHORITY["EPSG","4269"]], UNIT["metre",1, AUTHORITY["EPSG","9001"]], PROJECTION["Transverse Mercator"], PARAMETER["latitude_of_origin",0], PARAMETER["central_meridian",-114], PARAMETER["scale_factor",0.9999], PARAMETER["false_easting",0], PARAMETER["false_northing",0], AUTHORITY["EPSG","3776"], AXIS["Easting”, EAST], AXIS["Northing”, NORTH]]

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.

Table 2: 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
Thematic accuracy	NA
Temporal resolution	Barcelona: one time step (2014) Tallinn: six time steps (from 2015) Edmonton: one time step (2015)

3.1.2 Production approach

The details of the workflow followed in the derivation of the indicators for the three prototype cities are shown in Figure 1 to Figure 3 below. The major steps are pre-processing, land cover classification and extracting the final output.

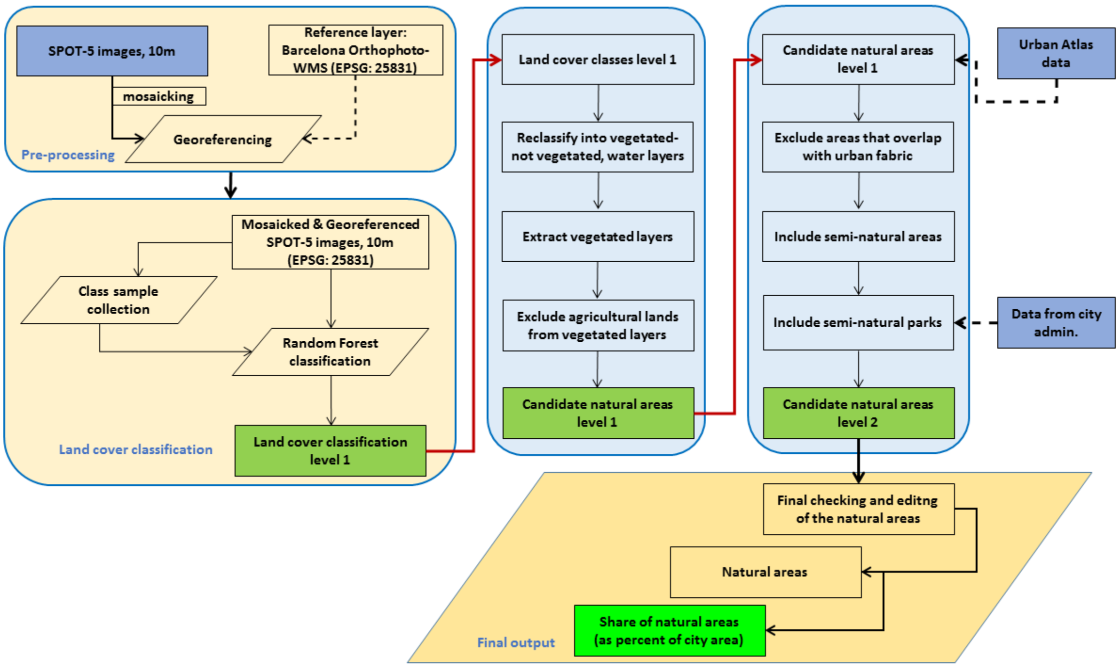


Figure 1: Details of workflow for the derivation of indicators 1, Barcelona

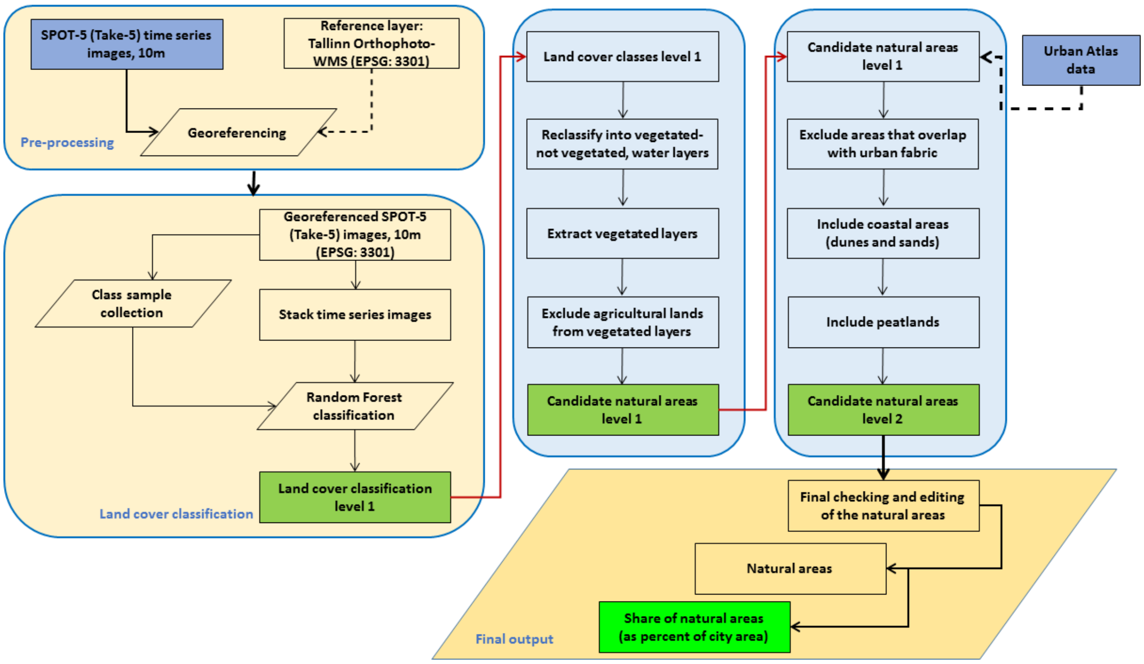


Figure 2: Details of workflow for the derivation of indicators 1, Tallinn

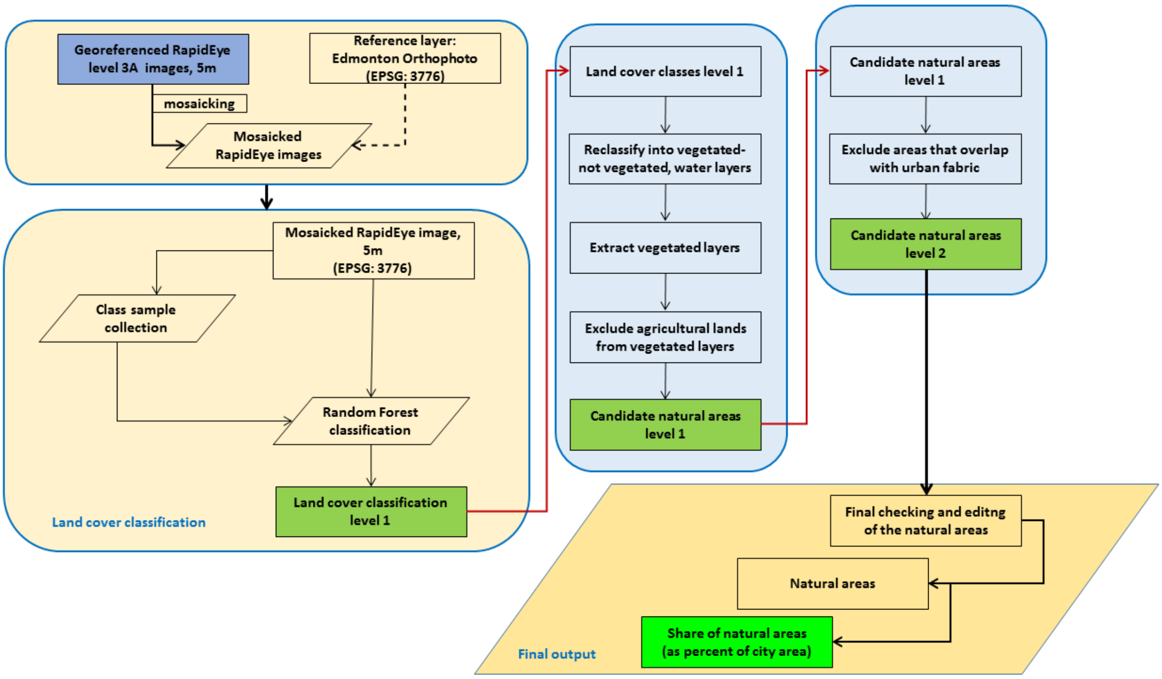


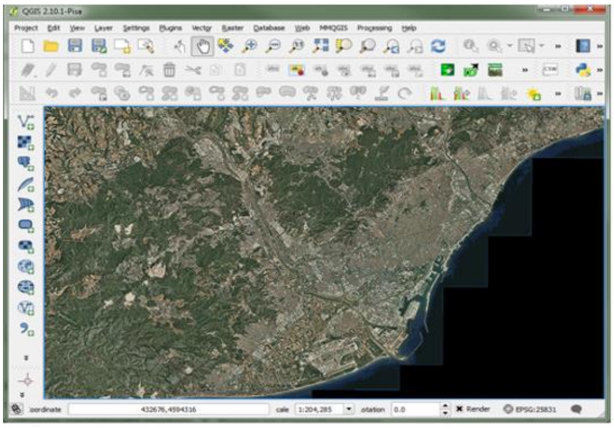
Figure 3: Details of workflow for the derivation of indicator 1, Edmonton

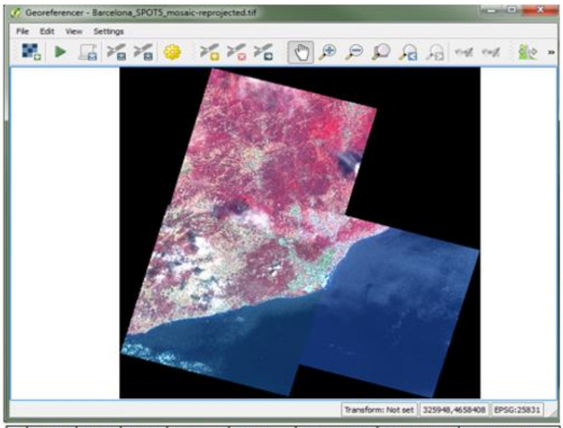
3.1.3 PRE-PROCESSING

Prior to processing, the SPOT-5 (Take-5) images were georeferenced and clipped to the Area of Interest (AOI). The time-series datasets were stacked for classification using Random Forest in the R software (see more detailed description in chapter 3.1.4). The geo-referencing steps in QGIS are shown in Figure 4 and Figure 5 below. Geo-referencing is the process of assigning real-world coordinates to each pixel of the raster. The SPOT-5 images were georeferenced using QGIS software using orthophoto of Barcelona and Tallinn as a reference layer.

For Edmonton prior to processing, the RapidEye images were checked for the correct projection using landmarks on an orthophoto provided by Edmonton City administration. For this task the images used are level 3A products and were found to be with good projection and hence additional georeferencing was not necessary.

Sample coordinate points that are clearly visible were selected by clicking both on the SPOT-5 (Take-5) image and the orthophoto. Using these sample coordinates or GCPs (Ground Control Points), the image is warped and made to fit within the chosen coordinate system. Location of the points were adjusted until the desired accuracy (< 1 pixel) was obtained (see Figure 4 and Figure 5).





ID	Enabled	Pixel X	Pixel Y	Map X	Map Y	Res X (pixels)	Res Y (pixels)	Res Total (pixels)
0	yes	429073	4572001	429075.815	4571999.309	0.199325	0.104776	0.225185
1	yes	434303	4600871	434302.917	4600871.001	-0.0644537	-0.0435594	0.0777927
2	yes	366118	4555107	366118.959	4555107.255	0.0891404	-0.00534791	0.0893006
3	yes	394213	4562921	394212.889	4562921.209	-0.0692937	-0.0316117	0.0761637
4	yes	405973	4591831	405972.985	4591831.294	-0.0375605	-0.0309422	0.0486643
5	yes	388858	4656195	388858.831	4656195.985	0.0922668	0.00847591	0.0926553
6	yes	388703	4643241	388703.059	4643241.461	0.044693	0.0301167	0.0538932
7	yes	384280	4635244	384278.734	4635245.636	-0.122475	-0.0618042	0.137185
8	yes	368523	4583611	368523.347	4583611.274	0.0296059	0.0251776	0.0388642
9	yes	374323	4570821	374322.905	4570821.256	-0.0379026	0.00604985	0.0383824
10	yes	391893	4579331	391892.824	4579331.297	-0.0545398	-0.0225182	0.0590056
11	yes	444333	4641601	444333.029	4641600.977	-0.0185005	-0.0178022	0.0256746
12	yes	435113	4628341	435113.019	4628341.167	-0.0275183	-0.0358957	0.0452301
13	yes	405636	4623850	405633.510	4623849.998	-0.198795	0.00124207	0.198799
14	yes	407323	4648321	407324.484	4648320.855	0.176008	0.0736437	0.190794

Figure 4: Geo-referencing, Barcelona

ID	Enabled	Pixel X	Pixel Y	Map X	Map Y	Res X (pixels)	Res Y (pixels)	Res Total (pixels)
0	yes	377043	6584890	547482.989	6583277.028	0.0185183	-0.0784314	0.0805879
1	yes	418572	6595539	588503.847	6595787.726	-0.221635	0.115313	0.249839
2	yes	403851	6554816	575619.659	6554429.531	0.13243	-0.28782	0.316825
3	yes	367010	6571989	538033.831	6569929.878	-0.0363237	0.0645081	0.0740318
4	yes	368934	6560745	540458.169	6558779.011	-0.21636	0.0697579	0.227328
5	yes	360739	6587995	531048.712	6585647.138	-0.210095	-0.161217	0.264823
6	yes	359453	6569985	530573.948	6567586.923	0.136133	0.0838629	0.159891
7	yes	412159	6572733	583119.327	6572705.338	0.103328	0.219229	0.24236
8	yes	377370	6602704	547014.085	6601096.311	0.252208	-0.185965	0.313356
9	yes	348115	6587153	518474.345	6584233.206	0.0417967	0.160763	0.166107

Figure 5: Geo-referencing, Tallinn

NB: satellite image pre-processing only takes place once; this means that the same geo-referenced images are used for the production of all indicators. Hence, this step is only described here and left out in the description of the production approaches for indicators 2, 11 and 12.

3.1.4 LAND COVER CLASSIFICATION

The land cover classification involves the collection of samples from the underlying satellite images and the orthophotos and a subsequent Random Forest (RF) classification.

<u>Class sample collection</u>

Samples representing the different land cover classes were collected using the SPOT-5 (Take-5)/RapidEye images and the orthophoto. The reflectance from the various surfaces was used as a guideline for selecting the class samples.

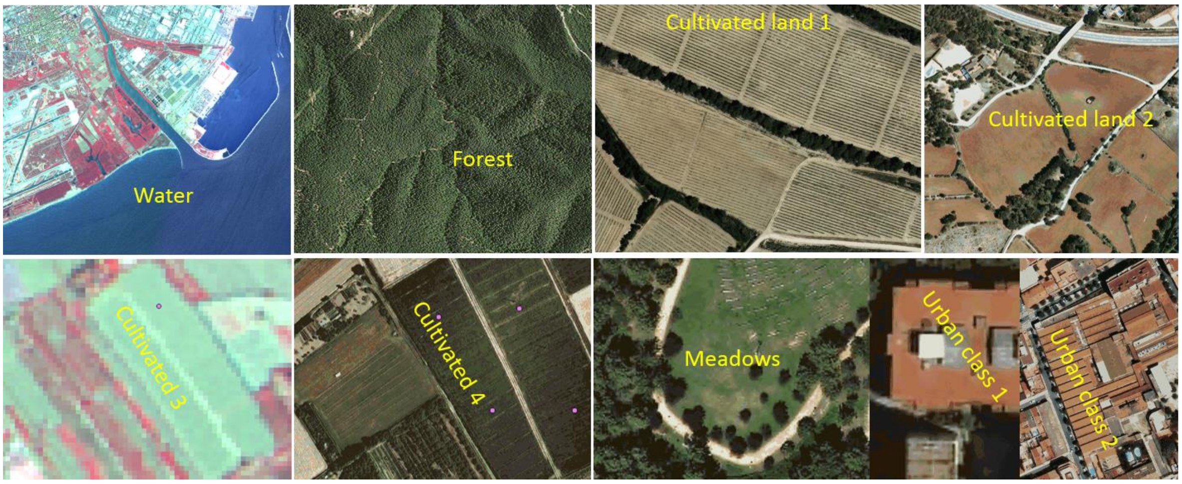


Figure 6: Identified land cover classes, Barcelona

Figure 7: Identified land cover classes, Tallinn

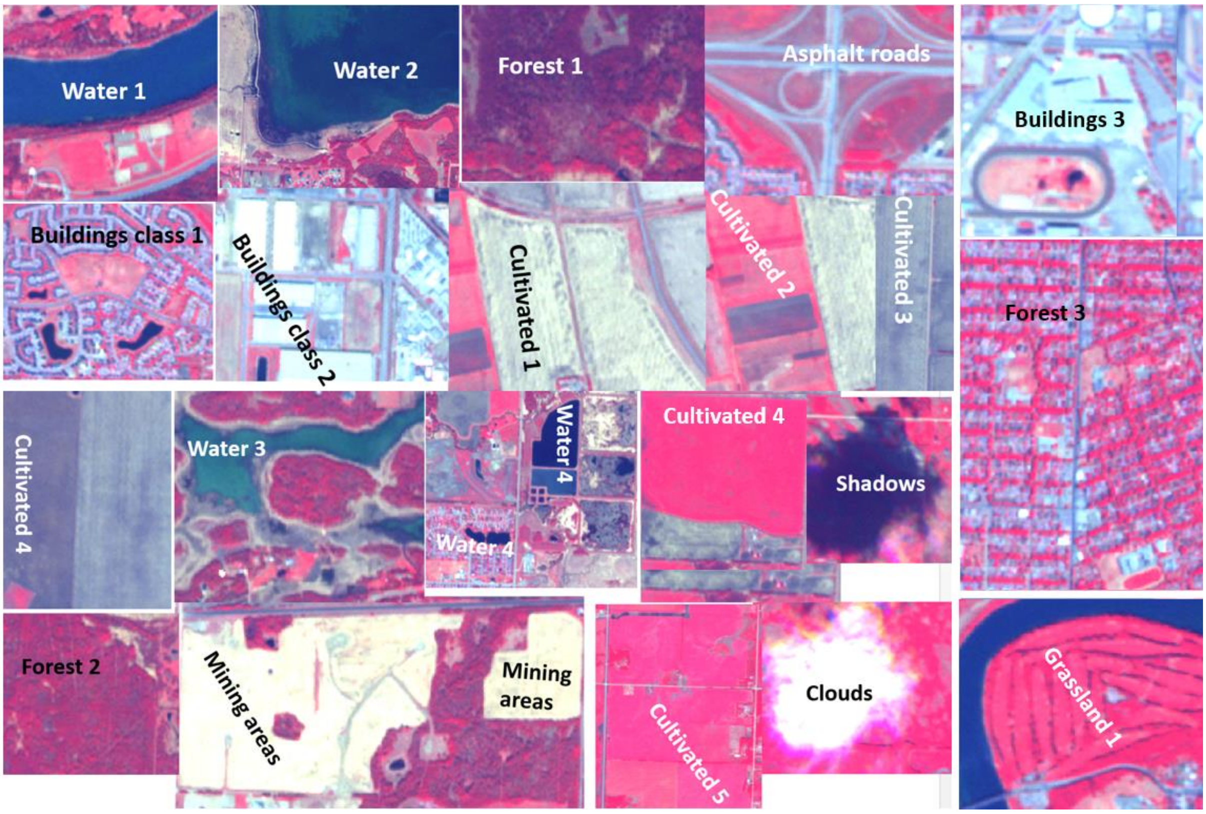


Figure 8: Identified land cover classes, Edmonton

Sample points were digitized for each of the above land cover classes and were used for supervised learning in Random Forest classification approach. At each sample point the pixel values of the layer-stacked image bands and indices calculated from the time series images were extracted to be used for Random Forest classifier.

Random Forest (RF) classification

To derive the land cover/use classes from the SPOT-5 (Take-5) images, the Random Forest (RF) classifier (Breiman 2001) was implemented in R 3.2.2 statistical software package (R Development Core Team 2008). RF is a refinement of Bagging Trees and uses an ensemble of tree-like classifiers (Breiman 1996) similar to Bagging Trees in which bootstrap samples are drawn to construct multiple trees from training samples. In the RF methodology a large number of trees (500 to 2,000) are grown with a randomized subset of predictors from which the name random forests is derived (Breiman 2001). Random Forest classifier searches a random subset of features from the total number of predictors to find the best split at each tree node in order to minimize the correlation between classifiers in the ensemble. Since the resampling is not based on weighting, the RF classification method is not sensitive to noise or overtraining and has been widely used for classification since it provides high classification accuracy (Gislason et al. 2006, Rodriguez-Galiano et al. 2012, Zhu et al. 2012, Conrad et al. 2014).

3.1.5 QUANTIFICATION OF THE INDICATORS

Share of natural areas in the city is computed as the proportion of area of natural areas to the total area of the city. Thus, it was necessary to extract the natural areas layer for the three pilot cities. Initially it was not possible to directly extract the natural areas from the satellite imagery with high accuracy, hence, here we refer to candidates for natural areas. The process involves the extraction of the candidates at different levels. Firstly, the RF classification result was reclassified into three major classes such as vegetated, not-vegetated and water. As per the definition of the natural areas for the cities (although varying to a certain degree, see chapter 0 for a discussion on this perceived issue), it is clear that from the above classes only vegetated areas are of interest for the derivation of natural areas. Agricultural areas (croplands) were excluded from the vegetated areas to obtain the first level of candidate natural areas. Secondly, for Barcelona and Tallinn the Copernicus Urban Atlas data set[3] was used to further refine the candidates for natural areas. Accordingly, areas overlapping with urban fabrics were considered managed and were excluded from the natural areas. Thirdly, for Tallinn coastal areas (dunes and sands) as well as peatlands were manually digitized and included as candidates for natural areas. However, in Barcelona all coastal and beach elements are considered to be man-made and, hence, not natural. The resulting candidate natural areas level 2 were rechecked and edited with the consultation of the city administration and experts to obtain the natural areas. Finally, the share of the natural areas was calculated by dividing the total area of natural areas with area of the city and multiplying by 100.

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

Urban wildlife populations are negatively affected by the inability to migrate 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).

[3] http://land.copernicus.eu/local/urban-atlas/view

3.2.1 SPECIFICATIONS

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.
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.

Barcelona Municipality			
Input data class	**Input data**	**Source**	**Type of data**
Natural areas	Product of indicator 1	Internal data	Shapefile (polygon)
Barriers	Major roads Building footprints	- City of Barcelona - City of Barcelona	- Shapefile (polyline) - Shapefile (polygon)
Connectors	- Golf courses - Botanical garden - Cemeteries - Semi-natural parks	- City of Barcelona - City of Barcelona - City of Barcelona - City of Barcelona	- Shapefile (polygon) - Shapefile (polygon) - Shapefile (polygon) - Shapefile (polygon)
Other	- City Boundary	- City of Barcelona	- Shapefile (polygon)
Barcelona Metropolitan			
Input data class	**Input data**	**Source**	**Type of data**
Natural areas	Product of indicator 1	Internal data	Shapefile (polygon)
Barriers	Major roads Building footprints	- City of Barcelona - City of Barcelona	- Shapefile (polyline) - Shapefile (polygon)
Connectors	- Golf courses - Botanical garden - Cemeteries	- City of Barcelona - City of Barcelona - City of Barcelona	- Shapefile (polygon) - Shapefile (polygon) - Shapefile (polygon)
Other	- Regional Boundary	- City of Barcelona	- Shapefile (polygon)
Tallinn			
Input data class	**Input data**	**Source**	**Type of data**
Natural areas	Product of indicator 1	Internal data	Shapefile (polygon)
Barriers	- Major roads - Heavily concretised canals - Building footprints	- City of Tallinn - City of Tallinn - Open Street Map	- Shapefile (polyline) - Shapefile (polyline) - Shapefile (polygon)
Connectors	- Parks - Botanical garden - Cemeteries	- City of Tallinn - City of Tallinn - City of Tallinn	- Shapefile (polygon) - Shapefile (polygon) - Shapefile (polygon)
Other	- City Boundary	- City of Tallinn	- Shapefile (polygon)
Edmonton			
Input data class	**Input data**	**Source**	**Type of data**
Natural areas	Product of indicator 1	Internal data	Shapefile (polygon)
Barriers	- Major roads - North Saskatchewan river - Building rooflines	- City of Edmonton - City of Edmonton - City of Edmonton	- Shapefile (polyline) - Shapefile (polygon) - Shapefile (polygon)
Connectors	- Cemeteries - Parks	- City of Edmonton - City of Edmonton	- Shapefile (polygon) - Shapefile (polygon)

		- Golf courses - Other open green spaces - Primary vegetation data (from PLVI)	- City of Edmonton - City of Edmonton - City of Edmonton	- Shapefile (polygon) - Shapefile (polygon) - Shapefile (polygon)
	Other	- City Boundary	- City of Edmonton	- Shapefile (polygon)

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	Recent years (2014, 2015)
Spatial coverages	Barcelona core city, Metropolitan area of Barcelona Tallinn core city City of Edmonton
Minimum Mapping Unit	No MMU, minimum mappable area determined by pixel size (10 m for SPOT-5/Take-5 and 5 m for RapidEye)
Thematic accuracy	85 % (depending on the quality of EO data and reference data)
Geometric accuracy	< 1 pixel
Projection	Barcelona: PROJCS["ETRS89 / UTM zone 31N", GEOGCS["ETRS89", DATUM["European_Terrestrial_Reference_System_1989", SPHEROID["GRS 1980",6378137,298.257222101, AUTHORITY["EPSG","7019"]], TOWGS84[0,0,0,0,0,0,0], AUTHORITY["EPSG","6258"]], PRIMEM["Greenwich",0, AUTHORITY["EPSG","8901"]], UNIT["degree",0.0174532925199433, AUTHORITY["EPSG","9122"]], AUTHORITY["EPSG","4258"]], PROJECTION["Transverse Mercator"], PARAMETER["latitude_of_origin",0], PARAMETER["central_meridian",3], PARAMETER["scale_factor",0.9996], PARAMETER["false_easting",500000], PARAMETER["false_northing",0], UNIT["metre",1, AUTHORITY["EPSG","9001"]], AXIS["Easting”, EAST],

	AXIS["Northing", NORTH], AUTHORITY["EPSG","25831"]] Tallinn: PROJCS["Estonian Coordinate System of 1997", GEOGCS["EST97", DATUM["Estonia_1997", SPHEROID["GRS 1980",6378137,298.257222101, AUTHORITY["EPSG","7019"]], TOWGS84[0,0,0,0,0,0,0], AUTHORITY["EPSG","6180"]], PRIMEM["Greenwich",0, AUTHORITY["EPSG","8901"]], UNIT["degree",0.01745329251994328, AUTHORITY["EPSG","9122"]], AUTHORITY["EPSG","4180"]], UNIT["metre",1, AUTHORITY["EPSG","9001"]], PROJECTION["Lambert_Conformal_Conic_2SP"], PARAMETER["standard_parallel_1",59.33333333333334], PARAMETER["standard_parallel_2",58], PARAMETER["latitude_of_origin",57.51755393055556], PARAMETER["central_meridian",24], PARAMETER["false_easting",500000], PARAMETER["false_northing",6375000], AUTHORITY["EPSG","3301"] Edmonton: PROJCS["NAD83 / Alberta 3TM ref merid 114 W", GEOGCS["NAD83", DATUM["North_American_Datum_1983", SPHEROID["GRS 1980",6378137,298.257222101, AUTHORITY["EPSG","7019"]], AUTHORITY["EPSG","6269"]], PRIMEM["Greenwich",0, AUTHORITY["EPSG","8901"]], UNIT["degree",0.01745329251994328, AUTHORITY["EPSG","9122"]], AUTHORITY["EPSG","4269"]], UNIT["metre",1, AUTHORITY["EPSG","9001"]], PROJECTION["Transverse Mercator"], PARAMETER["latitude_of_origin",0], PARAMETER["central_meridian",-114], PARAMETER["scale_factor",0.9999], PARAMETER["false_easting",0], PARAMETER["false_northing",0], AUTHORITY["EPSG","3776"], AXIS["Easting", EAST], AXIS["Northing", NORTH]]
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.

3.2.2 PRODUCTION APPROACH

Indicator 2 measures the degree of connectivity of natural areas in cities. It represents the average amount of natural area that an individual (of a certain wildlife species) is connected to in a landscape from any randomly selected start location. Alternatively, it can be interpreted as the probability that two individuals randomly dropped in the landscape are connected. The more barriers present in a landscape, the less natural area animals have access to, and the lower the value of connectivity.

Indicator 2 considers two patches connected if they are located 100 m or less apart with no barriers between them. The 100 meter distance is a threshold distance that is specified in the CBI User's Manual and represents a general average movement range of species between habitat patches. According to the CBI User's Manual, barriers include roads (that are 15 m or more in width; or smaller but have a high traffic volume of more than 5000 cars per day), rivers that are highly modified and other artificial barriers such as heavily concretised canals and heavily built up areas or any other artificial structures that the city would consider as a barrier. Indicator 2 is calculated as:

$$IND2 = \frac{1}{A_{\text{total}}}(A_{\text{G1}}^2 + A_{\text{G2}}^2 + A_{\text{G3}}^2 + \cdots + A_{\text{G}n}^2),$$

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 (or the previous total area of all patches of natural area at an earlier reference point in time, when monitoring temporal change).

Accordingly, IND2 is calculated as the sum of intra-patch and inter-patch connectivity. For example, for a group (G1) of three connected patches of sizes AG1.P1, AG1.P2, and AG1.P3:

Intra-patch connectivity = ($AG1.P1^2$ + $AG1.P2^2$ + $AG1.P3^2$) / Total area (for Group 1)

Inter-patch connectivity = (2·AG1.P1·AG1.P2 + 2·AG1.P1·AG1.P3 + 2·AG1.P2·AG1.P3)/ Total area (for Group 1),

Total connectivity of Group 1 = Intra-patch connectivity + Inter-patch connectivity,

where A refers to Area, G refers to Group of patches and P refers to Patch of natural area (within a certain group).

The following examples demonstrate how Indicator 2 is calculated (see Figure 9).

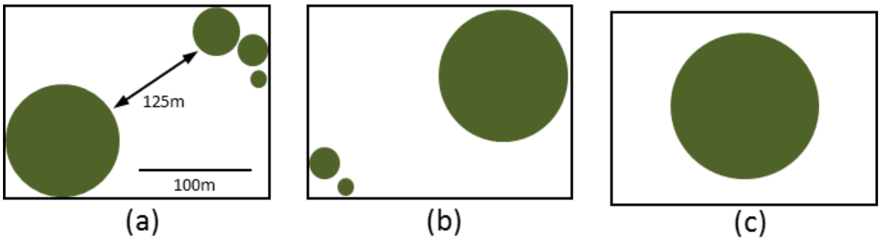


Figure 9: Three landscapes in different configurations. a) Connectivity= 83.15 ha, b) connectivity= 108.33 ha and c) connectivity= 135 ha (as explained in the text).

Example a: There are four patches in the landscape with a combined total area of 135 ha. Three patches are less than 100 m apart and, accordingly, are considered connected. The areas of these patches are 20 ha, 10 ha, and 5 ha. The fourth patch has an area of 100 ha and is not considered connected to the other three patches (see Figure 9a). According to the formula, connectivity is:

$((20\text{ ha})^2 + (10\text{ ha})^2 + (5\text{ ha})^2 + (2\cdot 20\text{ha}\cdot 10\text{ha}) + (2\cdot 20\text{ha}\cdot 5\text{ha}) + (2\cdot 10\text{ha}\cdot 5\text{ha}) + (100\text{ ha})^2) / (135\text{ ha}) =$ 83.15 ha.

Example b: There are three patches in the landscape, two of which are less than 100 m apart and considered connected. Their areas are 10 ha and 5 ha. The third patch has an area of 120 ha and is not connected to the other two patches (see Figure 9b). According to the equation, connectivity is higher than in the previous scenario. The total area of patches is the same (135 ha), but the degree of fragmentation is lower:

$((10\text{ ha})^2 + (5\text{ ha})^2 + (120\text{ ha})^2 + (2\cdot 10\text{ ha}\cdot 5\text{ ha})) / (135\text{ ha}) = 108.33\text{ ha}$.

Example c: There is one resource patch in the landscape with an area of 135 ha (see Figure 9c). According to the equation, all connectivity is intra-patch connectivity and is at its highest possible value, i.e., the total amount of natural area (whereas inter-patch connectivity is zero as the patch is not connected to any surrounding patches):

$(135\text{ ha})^2 / (135\text{ ha}) = 135\text{ ha}$.

Figure 10 presents the step by step approach for calculation of IND2. The detailed description of each phase is presented afterwards.

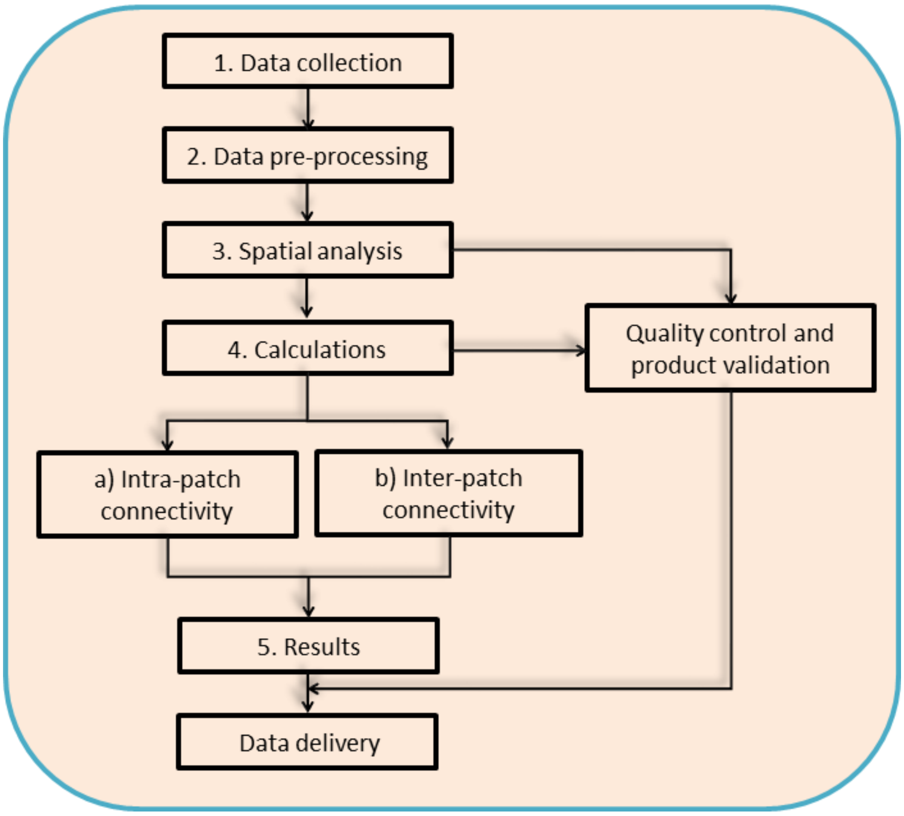


Figure 10: Workflow/step by step process for production of indicator 2

Phase 1: Data collection

Data about the natural areas (the product of indicator 1) are the main input for the calculation of indicator 2. Data needed for the specification of the fragmentation geometry and the connectors were requested from the contact person of each participating city (see the following maps in Figure 11 to Figure 14). For more detailed information on input data used in the calculation of indicator 2 please refer to Table 3 in chapter 3.2.1.

Figure 11: Natural areas, fragmentation geometry and connectors in the Barcelona Municipality

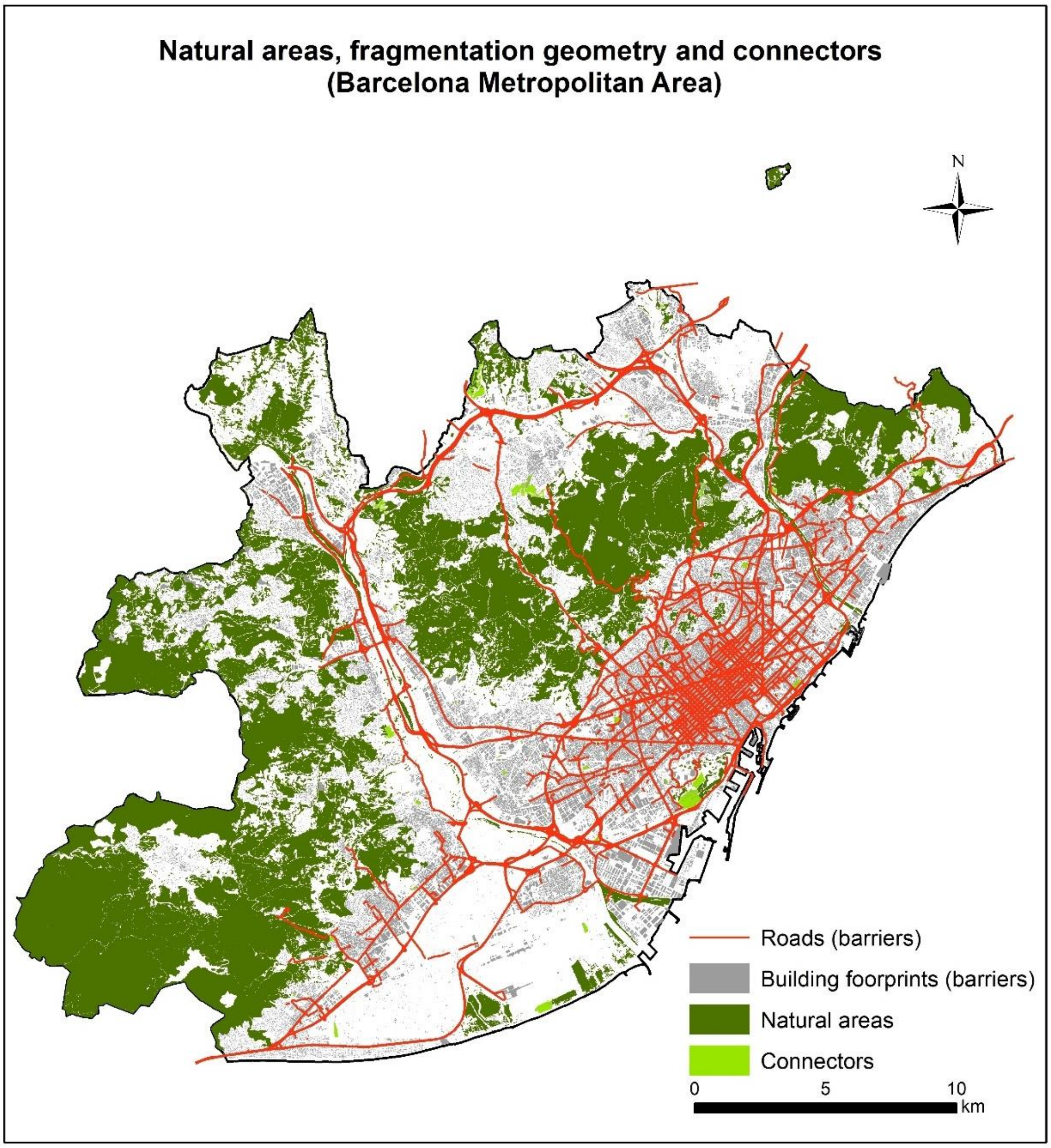


Figure 12: Natural areas, fragmentation geometry and connectors in the Barcelona Metropolitan Area

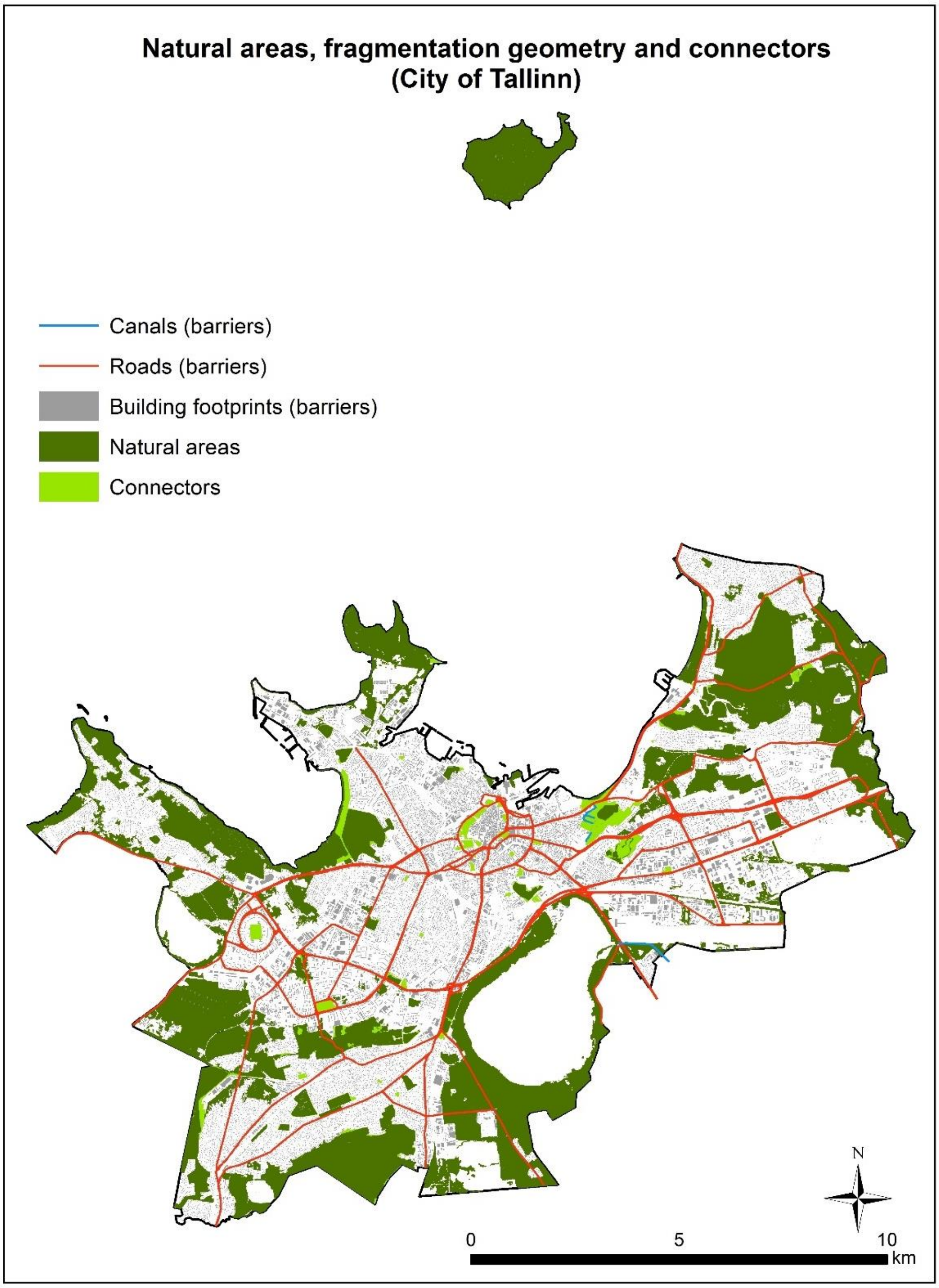


Figure 13: Natural areas, fragmentation geometry and connectors in the city of Tallinn

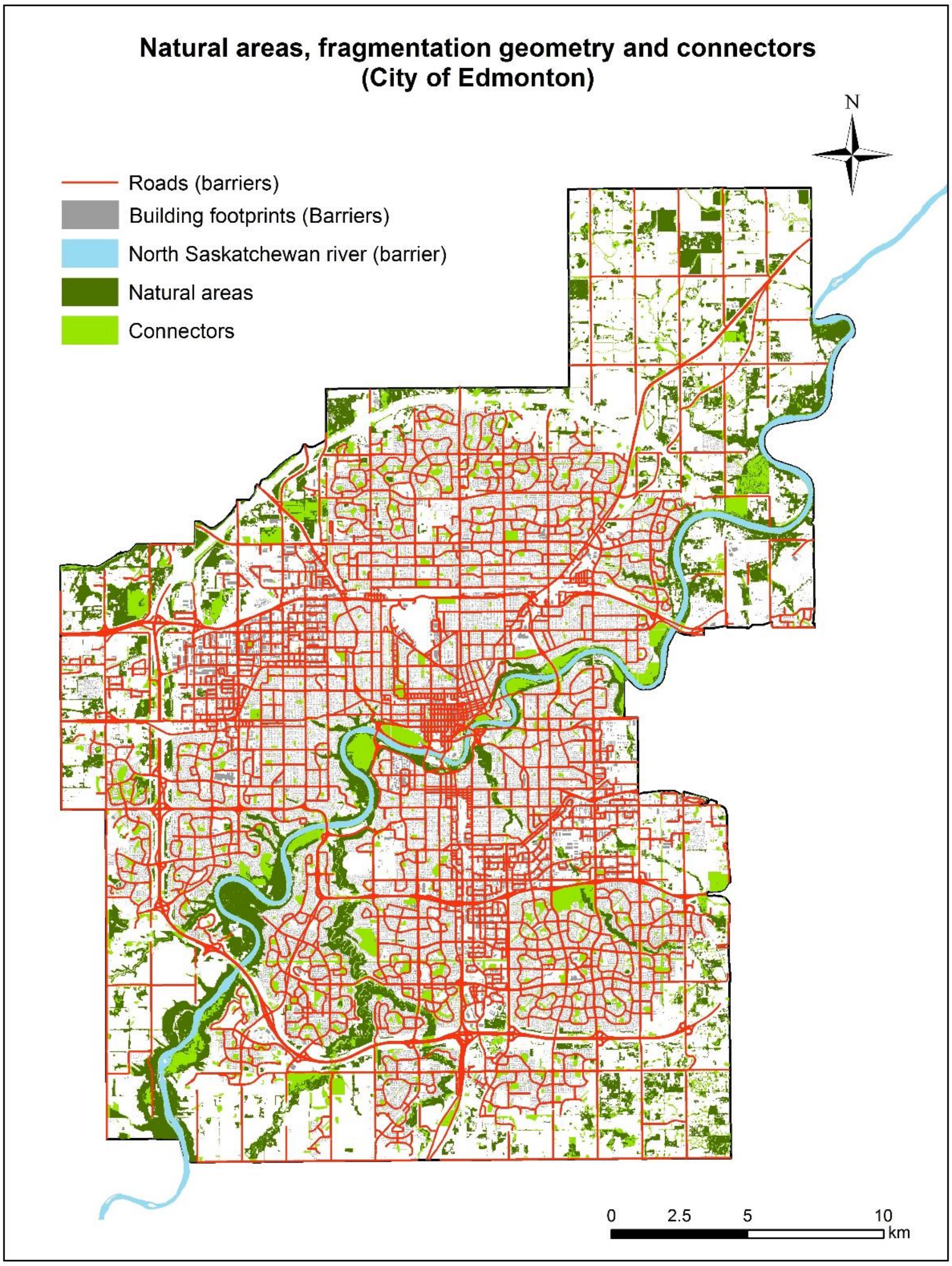


Figure 14: Natural areas, fragmentation geometry and connectors in the city of Edmonton

Phase 2: Data pre-processing

Prior to the spatial analysis, the input data were pre-processed. This includes a geometric repair of some of the ancillary data by inspecting potential geometry problems and applying relevant fixes, a verification of the ancillary data by investigating the compatibility of the data, received from each user, with initial data request which was based on CBI User's Manual. Additionally, the projections of all feature classes being used in the analysis were checked because they should be in a correct and consistent projection system. The final step was to test the layer of natural areas against the existence of overlapping patches.

Phase 3: Spatial analysis

Step 1: According to the CBI User's Manual, IND2 considers two patches connected if they are located 100 m or less apart with no barriers between them. The 100 meter distance is a threshold distance that is specified in the CBI User's Manual and is used to represent a general average movement range of species between habitat patches. In order to consider this distance, all natural areas were buffered at 50 m, representing connections between patches up to a maximum of 100 m apart.

Step 2: Barriers that were received in the form of polylines were buffered at 2x7.5 m for roads and 2x5 m for canals representing an average area that they take up in the fragmentation geometry.

Step 3: All barriers (e.g., roads, canals, and building footprints) were merged in order to create one single layer that represents the fragmentation geometry.

Step 4: The barriers in the fragmentation geometry that overlap with the buffer of natural areas were subtracted from the buffered natural areas (input: buffered natural areas (output of step 1), erase feature: fragmentation geometry (output of step 3).

Step 5: In order to identify the patches that are connected (groups of connected patches), similar feature IDs were given to those patches that were connected (input: Step 4). In practice, in this step the attribute of the input feature was maintained and a new field (ORIG_FID) was added to the attribute of the output feature class. In the ORIG_FID field patches that are apart less than 100 m and no barriers between them received repeating IDs/similar IDs.

Step 6: The output of step 5 was intersected with the original layer of natural areas/ indicator 1 (natural areas without buffer) in order to compute the correct values of the areas of the connected patches and unconnected patches of natural areas (input features: output of step 5 and the layer of natural areas (indicator 1).

Step 7 (final output): A new field was added to the attribute of the output from step 6 and the areas of the patches of natural areas were calculated.

Note: In the scenarios that account connectors for connectivity, the feature class that includes all connectors was merged with the output of step 1 to determine the groups of connected patches. All the other steps (steps 2-7) remained the same.

Phase 4: Calculations

a) Intra-patch connectivity: total sum of the squares of the areas of all patches (including both repeating IDs (connected patches, i.e., groups of two or more patches) and non-repeating IDs (unconnected patches) divided by the total area of natural areas (sum of the area of all patches). [e.g., intra-patch connectivity = ($AG1.P1^2 + AG1.P2^2 + AG1.P3^2$) / Total area].

b) Inter-patch connectivity: The difference between the total sum of the squares of the areas of groups of connected patches[4] (patches that have repeating Group IDs) and the total sum of the squares of areas of the connected patches[5], divided by the total area of natural areas (sum of the area of all patches). [e.g., inter-patch connectivity = (2·AG1.P1·AG1.P2 + 2·AG1.P1·AG1.P3 + 2·AG1.P2·AG1.P3)/ Total area].

c) Total connectivity= intra-patch connectivity + inter- patch connectivity.

3.3 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. 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.

3.3.1 SPECIFICATIONS

Table 4: 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 25 percent 4. Maps of degree of imperviousness above 50 percent
Input data	SPOT-5 10m for the entire AOI (Barcelona) SPOT-5 (Take-5) 10m for the entire AOI (Tallinn) RapidEye 5m for the entire AOI (Edmonton)
Methodology	See the illustrations of the production approach in Figure 15 to Figure 17
Temporal Requirement	Recent year (2014, 2015)

[4] i.e., squares of the sums of the areas of patches in each group of connected patches; e.g., $(AG1.P1 + AG1.P2 + AG1.P3)^2 + (AG2.P1 + AG2.P2)^2 + \ldots$.

[5] i.e., squares of all the areas of patches by themselves; e.g., $AG1.P1^2 + AG1.P2^2 + AG1.P3^2 + AG2.P1^2 + AG2.P2^2 + \ldots$.

Spatial coverage	Barcelona core city, Metropolitan area of Barcelona Tallinn core city City of Edmonton
Minimum Mapping Unit	No MMU, only a determining pixel size (10 m for SPOT-5/Take-5 and 5 m for RapidEye)
Thematic accuracy	85 % (depending on the quality of EO data and reference data)
Geometric accuracy	< 1 pixel
Projection	Barcelona: PROJCS["ETRS89 / UTM zone 31N", GEOGCS["ETRS89", DATUM["European_Terrestrial_Reference_System_1989", SPHEROID["GRS 1980",6378137,298.257222101, AUTHORITY["EPSG","7019"]], TOWGS84[0,0,0,0,0,0,0], AUTHORITY["EPSG","6258"]], PRIMEM["Greenwich",0, AUTHORITY["EPSG","8901"]], UNIT["degree",0.0174532925199433, AUTHORITY["EPSG","9122"]], AUTHORITY["EPSG","4258"]], PROJECTION["Transverse Mercator"], PARAMETER["latitude_of_origin",0], PARAMETER["central_meridian",3], PARAMETER["scale_factor",0.9996], PARAMETER["false_easting",500000], PARAMETER["false_northing",0], UNIT["metre",1, AUTHORITY["EPSG","9001"]], AXIS["Easting", EAST], AXIS["Northing", NORTH], AUTHORITY["EPSG","25831"]] Tallinn: PROJCS["Estonian Coordinate System of 1997", GEOGCS["EST97", DATUM["Estonia_1997", SPHEROID["GRS 1980",6378137,298.257222101, AUTHORITY["EPSG","7019"]], TOWGS84[0,0,0,0,0,0,0], AUTHORITY["EPSG","6180"]], PRIMEM["Greenwich",0, AUTHORITY["EPSG","8901"]], UNIT["degree",0.01745329251994328, AUTHORITY["EPSG","9122"]], AUTHORITY["EPSG","4180"]], UNIT["metre",1, AUTHORITY["EPSG","9001"]], PROJECTION["Lambert_Conformal_Conic_2SP"], PARAMETER["standard_parallel_1",59.33333333333334], PARAMETER["standard_parallel_2",58],

	PARAMETER["latitude_of_origin",57.51755393055556], PARAMETER["central_meridian",24], PARAMETER["false_easting",500000], PARAMETER["false_northing",6375000], AUTHORITY["EPSG","3301"] Edmonton: PROJCS["NAD83 / Alberta 3TM ref merid 114 W", GEOGCS["NAD83", DATUM["North_American_Datum_1983", SPHEROID["GRS 1980",6378137,298.257222101, AUTHORITY["EPSG","7019"]], AUTHORITY["EPSG","6269"]], PRIMEM["Greenwich",0, AUTHORITY["EPSG","8901"]], UNIT["degree",0.01745329251994328, AUTHORITY["EPSG","9122"]], AUTHORITY["EPSG","4269"]], UNIT["metre",1, AUTHORITY["EPSG","9001"]], PROJECTION["Transverse Mercator"], PARAMETER["latitude_of_origin",0], PARAMETER["central_meridian",-114], PARAMETER["scale_factor",0.9999], PARAMETER["false_easting",0], PARAMETER["false_northing",0], AUTHORITY["EPSG","3776"], AXIS["Easting", EAST], AXIS["Northing", NORTH]]

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.

Table 5: 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	Barcelona: one time step (2014) Tallinn: six time steps (from 2015) Edmonton: one time step (2015)

3.3.2 Production approach

Regulation of quantity of water depends on the proportion of permeable areas in the city. The proportion of permeable areas in the city was indirectly calculated from the share of impervious areas. Thus, it was necessary to map the impervious surfaces of the cities. Prediction of degree of imperviousness using SPOT-5 (Take-5)/RapidEye images involves two steps, i.e., the selection of sample degrees of imperviousness and the subsequent prediction of imperviousness.

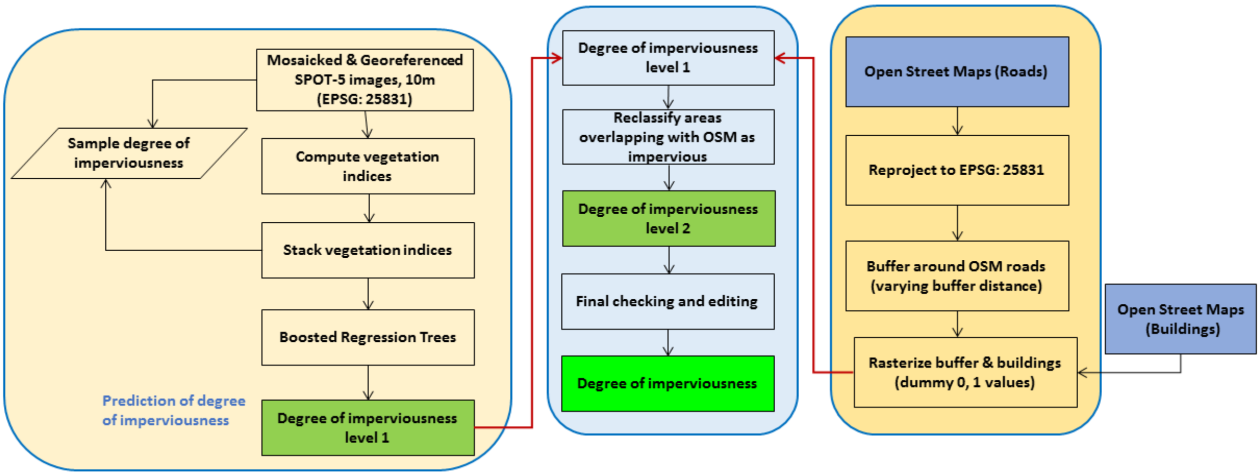


Figure 15: Details of workflow for the derivation of indicator 11, Barcelona

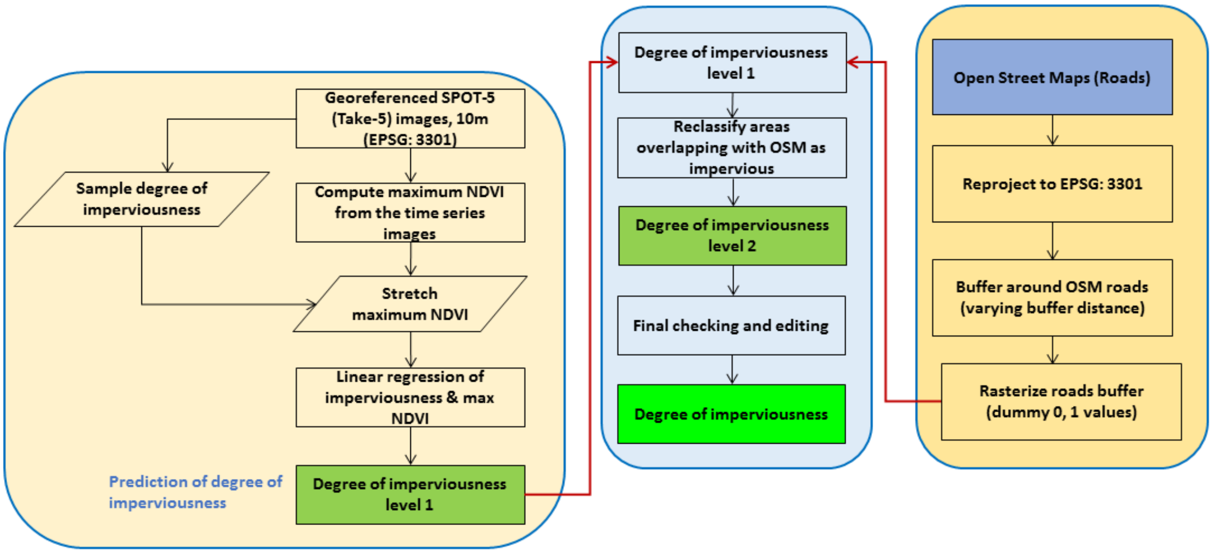


Figure 16: Details of workflow for the derivation of indicator 11, Tallinn

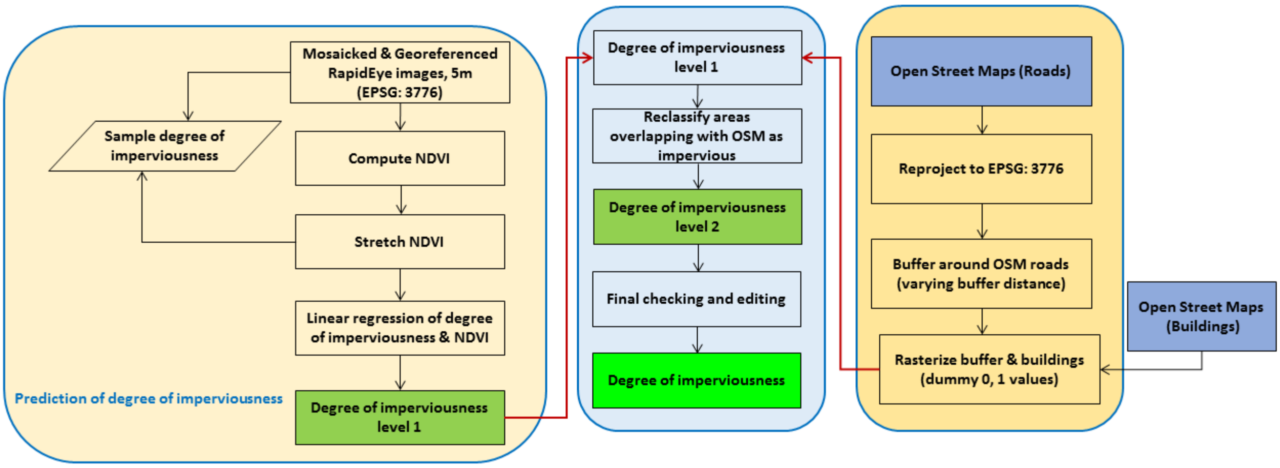


Figure 17: Details of workflow for the derivation of indicator 11, Edmonton

3.3.3 PREDICTING THE DEGREE OF IMPERVIOUSNESS

Samples for the degree of imperviousness were collected from low permeability areas such as paved grounds, roads as well as high permeability areas such as forests and grasslands. The sample points overlaid on impervious layers were assigned 100% degree of imperviousness, while sample points overlaid on permeable land were assigned 0% degree of imperviousness (Figure 18 to Figure 20). At each sample point the pixel values of vegetation indices were extracted from SPOT/RapidEye images.

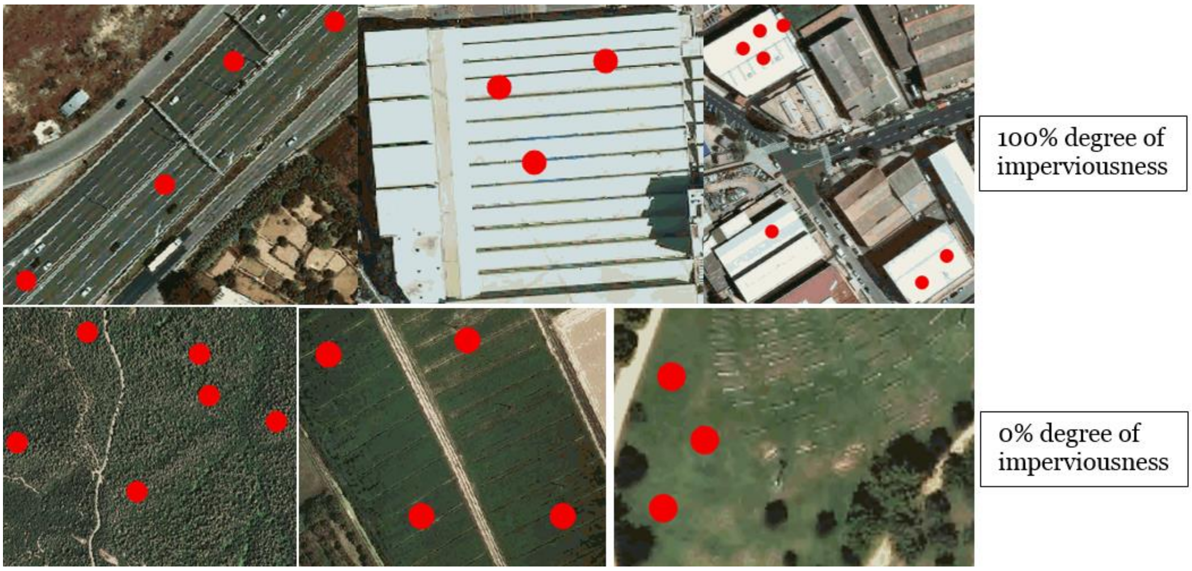


Figure 18: Sample points for degree of imperviousness, Barcelona

Figure 19: Sample points for degree of imperviousness, Tallinn

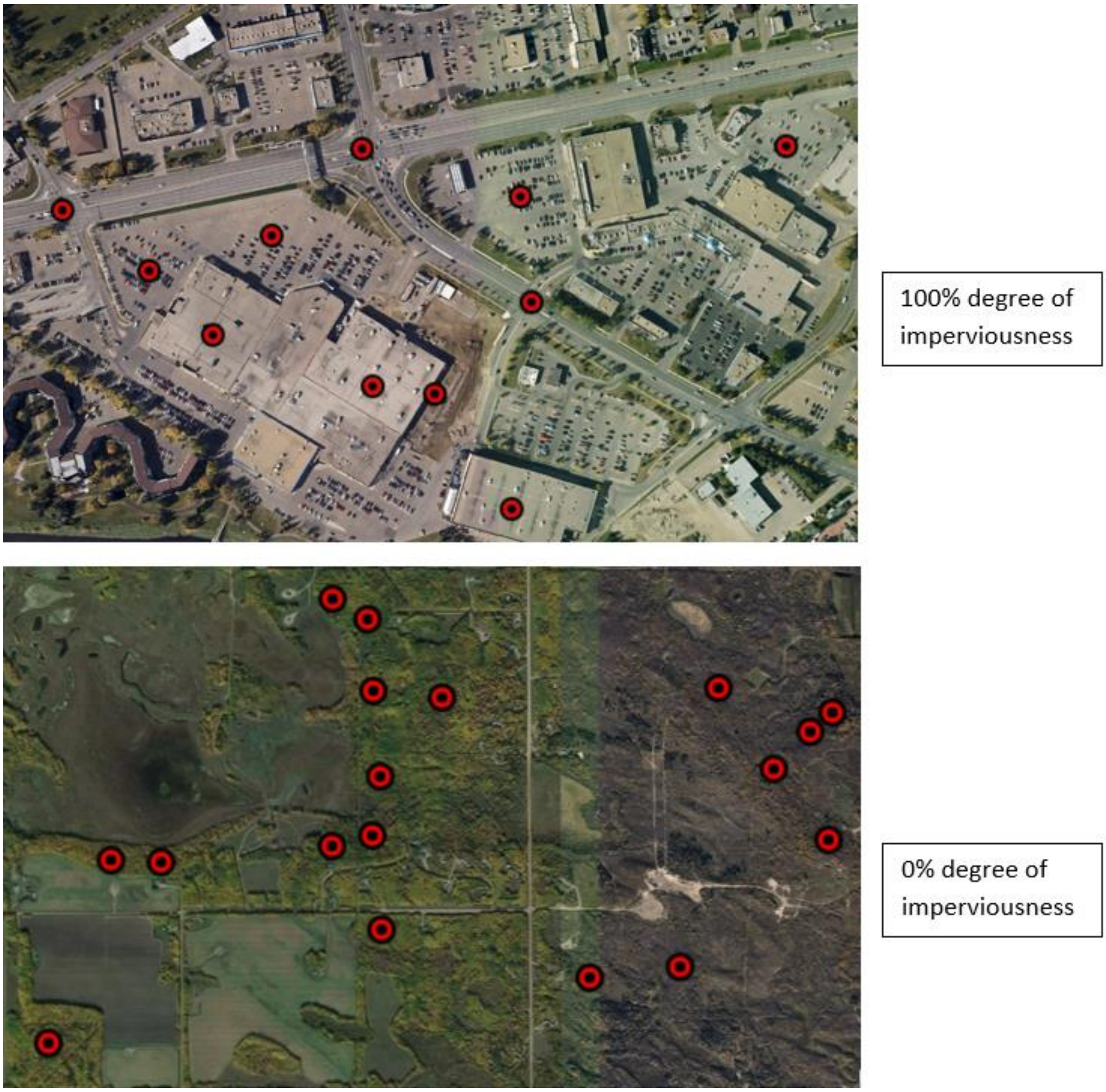


Figure 20: Sample points for degree of imperviousness, Edmonton

Two different regression methods were used to predict degree of imperviousness from SPOT and RapidEye images, i.e. Simple Linear Regression (SLR) and Boosted Regression Trees (BRTs).

Predicting degree of imperviousness using Simple Linear Regression

Simple Linear Regression models provide a simplistic approach for predicting an unknown variable from one or more explanatory variable(s). This method was used to predict the degree of imperviousness from time series of SPOT-5 (Take-5) images for Tallinn. The availability of time series SPOT images for Tallinn allows derivation of indices (e.g. maximum NDVI) that are highly correlated with the sample degree of imperviousness using SLR.

Prediction of degree of imperviousness from time series of SPOT-5 (Take-5) images involves several steps. Firstly, maximum NDVI was calculated from time series SPOT-5 (Take-5) images and stretched to extract values above 0.3. Secondly, the values were regressed against the sample degree of imperviousness using SLR. There is high correlation between degree of imperviousness and maximum NDVI which shows that simple regression can be used to predict the degree of imperviousness over the entire area of interest. Although the RapidEye images used to predict the degree of imperviousness for Edmonton are from the same period, the correlation from SLR of NDVI calculated from the images and the sample degree of imperviousness was high. Hence, SLR was used to predict degree of imperviousness from RapidEye images for the entire area of Edmonton.

Predicting degree of imperviousness using Boosted Regression Trees

Unlike Tallinn, time series data was not available for Barcelona and a prediction of the degree of imperviousness from an NDVI calculated from SPOT-5 images of the same period showed poor performance. Thus, an alternative method, Boosted Regression Trees, was used. Boosted Regression Trees (BRTs) (Elith et al. 2008), an ensemble method used for fitting statistical models was used to predict the degree of imperviousness from SPOT-5 images. BRTs combine algorithms of regression trees that use recursive binary splits to relate a response to their predictors and boosting that combines simple models to improve predictive performance (Elith et al. 2008, Leathwick et al. 2006, De'ath 2007). Moreover, BRTs are preferred since they capture complex structures that arise from spatial autocorrelation within a dataset and allow comparison of the relative importance of the predictors (Crase et al. 2012). Boosted Regression Trees was implemented in R 3.2.2 statistical software package (R Development Core Team (2008)).

Contrary to SLR that only implements predetermined linear model, BRTs provide more flexibility and capture non-linear relationships between the variable predicted and predictors using set of decision trees. Thus, for Barcelona, several indices (e.g. NDVI, band ratios, band differences, etc.) were calculated from the SPOT-5 images to predict degree of imperviousness based on samples imperviousness collected at different locations in the city. Compared with SLR, BRTs require preparation of large datasets and long processing time. Hence, SLR was preferably used for Tallinn and Edmonton because maximum NDVI calculated from SPOT-5 (Take-5) and NDVI calculated from RapidEye images were found sufficient in predicting the degree of imperviousness.

The degree of imperviousness predicted using either of the methods (SLR or BRTs) for the entire area of the cities is in percent and values range from 0 to 100. The predicted degree of imperviousness (level 1) was further improved using open street maps (roads, buildings). The OSM (roads) were re-projected to the required projections for the three cities (Barcelona: EPSG 25831, Tallinn: EPSG 3301, Edmonton: EPSG 3776) and different buffer distances (2, 3, 4 and 5m) were used depending on the width of the roads (types of roads). The buffer was rasterized to create a layer with values "0" indicating no roads and "1" indicating roads. The OSM (roads) were re-projected to the city's coordinate system and different buffer distances (2, 3, 4 and 5m) were used depending on the width of the roads (types of roads). The buffer was rasterized to create a dummy layer with a "0" value indicating no roads and a "1" indicating roads. The resulting OSM (roads) raster layer was used to update the predicted degree of imperviousness based on the fact that asphalt roads are impervious. In addition, areas overlapping with OSM buildings footprint were also assigned as impervious. Finally, the degree of imperviousness (level 2) was rechecked and edited based on feedbacks from the city administration and experts to derive the final imperviousness map.

Share of permeable areas

The percentage area of the city which is impervious was calculated from the last level of the degree of imperviousness using zonal statistics in QGIS software. The share of permeable areas is the inverse value of the imperviousness and is calculated as follows:

$$share\ of\ permeable\ areas = 100 - share\ of\ impervious\ areas$$

An important point to consider is the threshold that is applied to decide whether or not a pixel is permeable. The Copernicus HRL Imperviousness, for example, does also come with a built-up mask for which the threshold is set to 30 % sealing degree to include this cell into the built-up layer. However, in the current project it was agreed to not follow that guideline but that the majority of the cell (> 50%) should be permeable. If only the pixels below 30% degree of soil sealing would be considered as permeable, the indicator would substantially underestimate permeable surfaces. Regulation of quantity of water is thus interpreted in terms of the permeability of the soil with high values implying better conditions of this service.

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

3.4.1 SPECIFICATIONS

Table 6: 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. Map of tree canopy cover above 25 percent 4. Maps of tree canopy cover above 50 percent
Input data	SPOT-5 10m for the entire AOI (Barcelona) SPOT-5 (Take-5) 10m for the entire AOI (Tallinn) RapidEye 5m for the entire AOI (Edmonton)
Methodology	See the illustrations of the production approach in Figure 21 to Figure 23.
Temporal Requirement	Recent year (2014, 2015)
Spatial coverage	Barcelona core city, Metropolitan area of Barcelona Tallinn core city City of Edmonton
Minimum Mapping Unit	No MMU, only a determining pixel size (10 m for SPOT-5/Take-5 and 5 m for RapidEye)
Thematic accuracy	85 % (depending on the quality of EO data and reference data)
Geometric accuracy	< 1 pixel
Projection	Barcelona: PROJCS["ETRS89 / UTM zone 31N", GEOGCS["ETRS89", DATUM["European_Terrestrial_Reference_System_1989", SPHEROID["GRS 1980",6378137,298.257222101, AUTHORITY["EPSG","7019"]], TOWGS84[0,0,0,0,0,0,0], AUTHORITY["EPSG","6258"]], PRIMEM["Greenwich",0, AUTHORITY["EPSG","8901"]], UNIT["degree",0.0174532925199433, AUTHORITY["EPSG","9122"]], AUTHORITY["EPSG","4258"]], PROJECTION["Transverse Mercator"], PARAMETER["latitude_of_origin",0], PARAMETER["central_meridian",3], PARAMETER["scale_factor",0.9996],

```
    PARAMETER["false_easting",500000],
    PARAMETER["false_northing",0],
    UNIT["metre",1,
        AUTHORITY["EPSG","9001"]],
    AXIS["Easting", EAST],
    AXIS["Northing", NORTH],
    AUTHORITY["EPSG","25831"]]
```

Tallinn:

```
PROJCS["Estonian Coordinate System of 1997",
    GEOGCS["EST97",
        DATUM["Estonia_1997",
            SPHEROID["GRS 1980",6378137,298.257222101,
                AUTHORITY["EPSG","7019"]],
            TOWGS84[0,0,0,0,0,0,0],
            AUTHORITY["EPSG","6180"]],
        PRIMEM["Greenwich",0,
            AUTHORITY["EPSG","8901"]],
        UNIT["degree",0.01745329251994328,
            AUTHORITY["EPSG","9122"]],
        AUTHORITY["EPSG","4180"]],
    UNIT["metre",1,
        AUTHORITY["EPSG","9001"]],
    PROJECTION["Lambert_Conformal_Conic_2SP"],
    PARAMETER["standard_parallel_1",59.33333333333334],
    PARAMETER["standard_parallel_2",58],
    PARAMETER["latitude_of_origin",57.51755393055556],
    PARAMETER["central_meridian",24],
    PARAMETER["false_easting",500000],
    PARAMETER["false_northing",6375000],
    AUTHORITY["EPSG","3301"]
```

Edmonton:

```
PROJCS["NAD83 / Alberta 3TM ref merid 114 W",
    GEOGCS["NAD83",
        DATUM["North_American_Datum_1983",
            SPHEROID["GRS 1980",6378137,298.257222101,
                AUTHORITY["EPSG","7019"]],
            AUTHORITY["EPSG","6269"]],
        PRIMEM["Greenwich",0,
            AUTHORITY["EPSG","8901"]],
        UNIT["degree",0.01745329251994328,
            AUTHORITY["EPSG","9122"]],
        AUTHORITY["EPSG","4269"]],
    UNIT["metre",1,
        AUTHORITY["EPSG","9001"]],
    PROJECTION["Transverse Mercator"],
    PARAMETER["latitude_of_origin",0],
    PARAMETER["central_meridian",-114],
    PARAMETER["scale_factor",0.9999],
    PARAMETER["false_easting",0],
    PARAMETER["false_northing",0],
    AUTHORITY["EPSG","3776"],
    AXIS["Easting", EAST],
    AXIS["Northing", NORTH]]
```

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.

Table 7: 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	Barcelona: one time step (2014) Tallinn: six time steps (from 2015) Edmonton: one time step (2015)

3.4.2 PRODUCTION APPROACH

Tree canopy cover is an essential component of climate regulation in urban areas. In this task the cooling effect of vegetation is predicted using percent tree cover as a proxy. Prediction of percent tree cover using SPOT-5 (Take-5)/RapidEye images involves two steps i.e. selection of sample percent tree cover and prediction of the tree canopy cover.

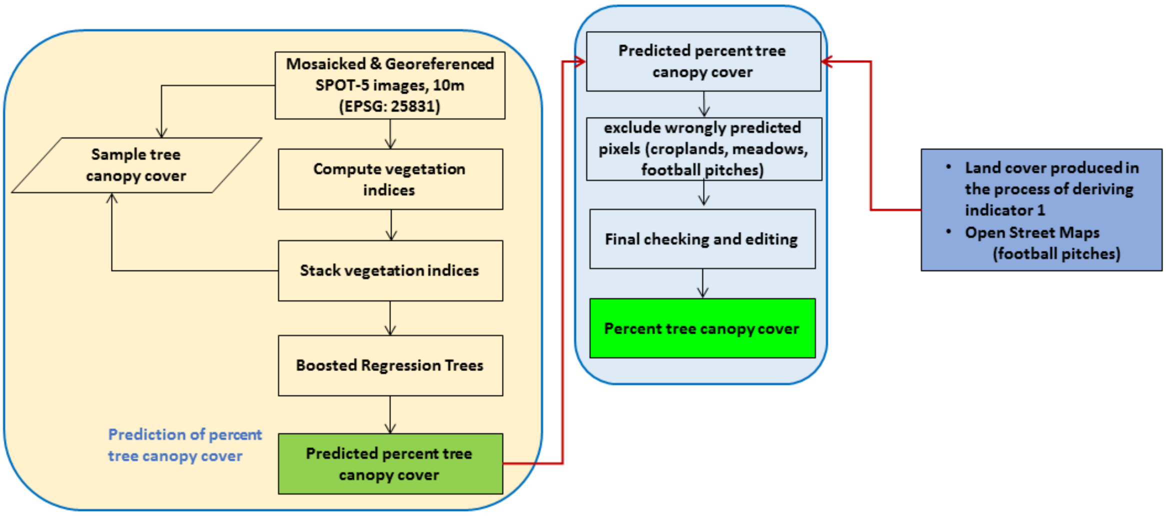


Figure 21: Details of workflow for the derivation of indicator 12, Barcelona

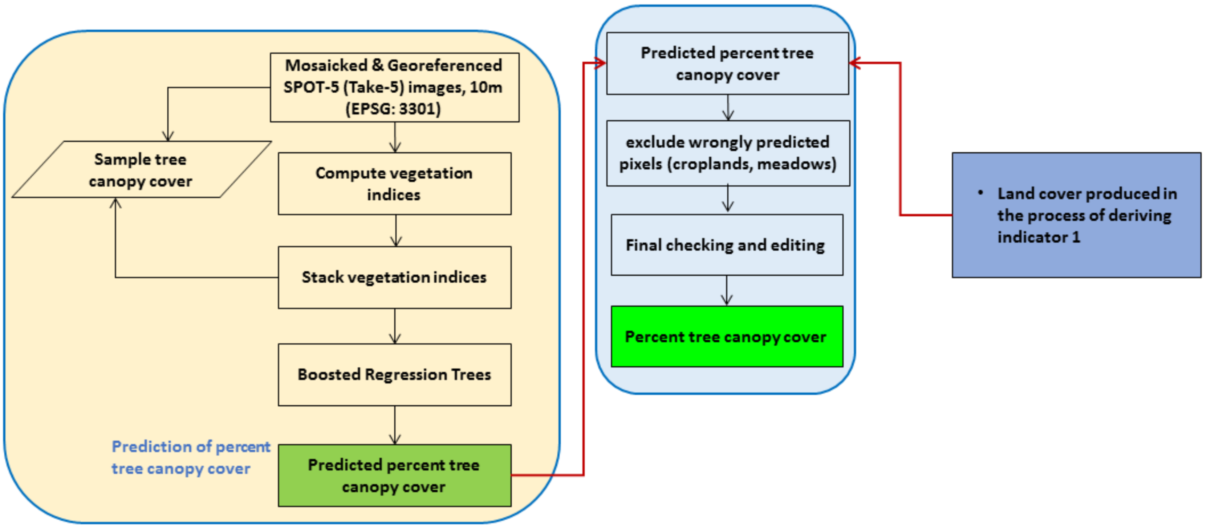


Figure 22: Details of workflow for the derivation of indicators 12, Tallinn

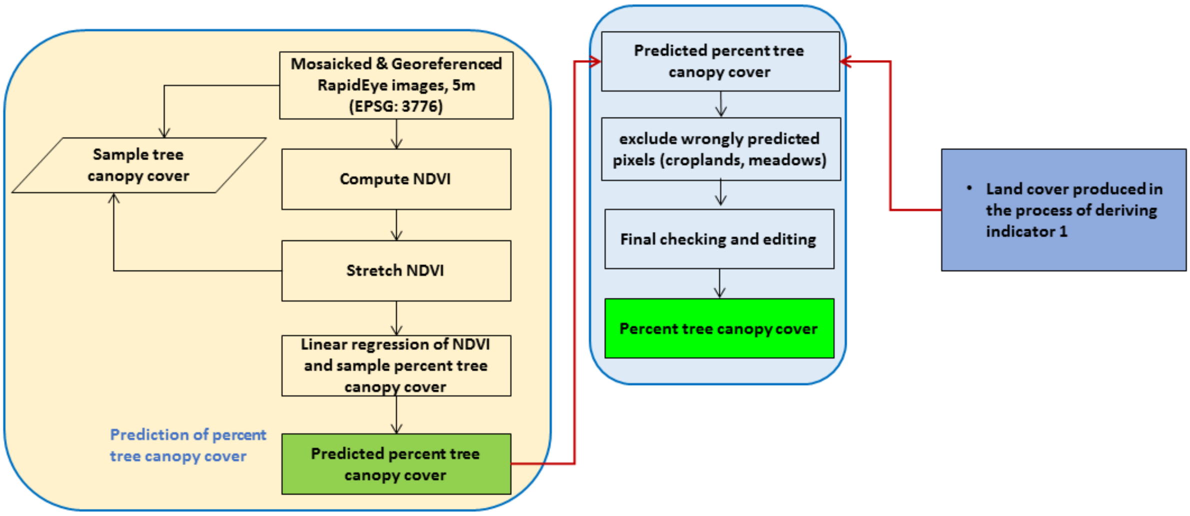


Figure 23: Details of workflow for the derivation of indicators 12, Edmonton

3.4.3 Predicting the extent of tree canopy cover

The approach used for predicting tree canopy cover is similar to that of the degree of imperviousness described in chapter 3.3.3. Samples for percent tree canopy cover were collected from areas with no tree canopy cover such as open paved grounds without trees as well as areas with dense tree canopy cover. The sample points overlapping with zero tree canopy cover areas were assigned a tree cover density value of 0% while those in the dense tree canopy areas were assigned tree cover density value of 100% (Figure 24 to Figure 26). At each sample point the pixel values of many vegetation indices (e.g. NDVI, band ratios, band differences) calculated from SPOT-5 (Take-5)/RapidEye images were extracted.

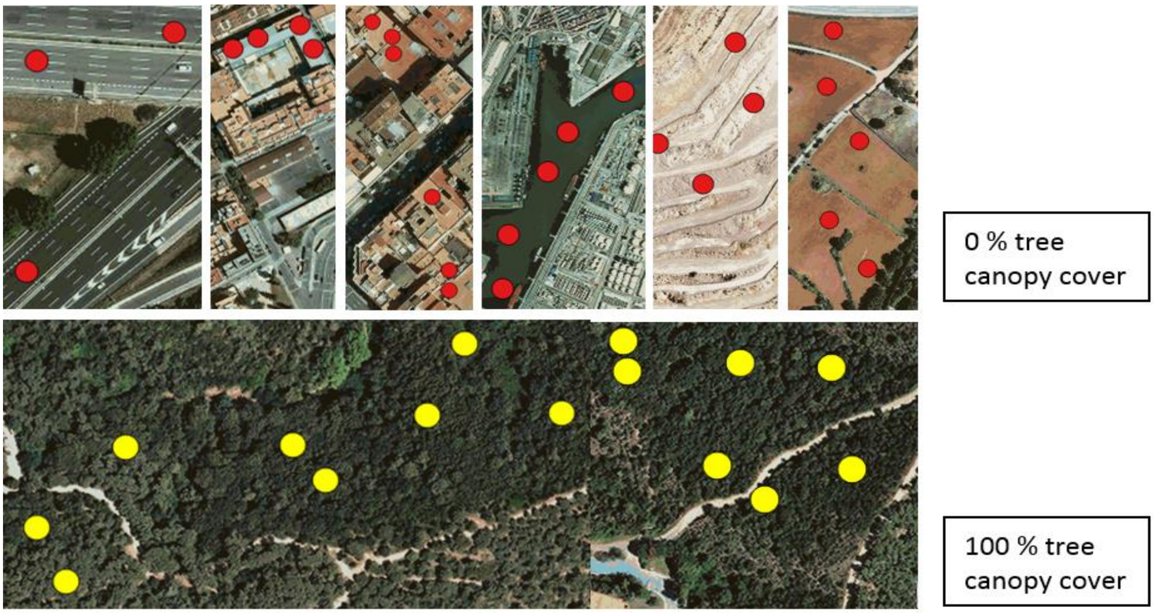


Figure 24: Examples of sample points for percent tree canopy cover, Barcelona

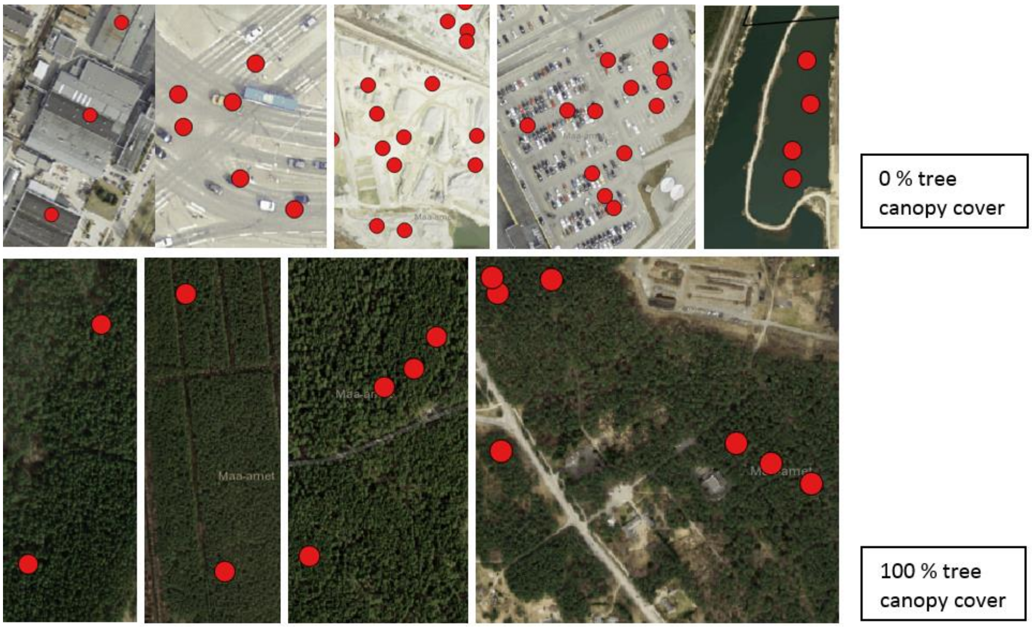


Figure 25: Examples of sample points for percent tree canopy cover, Tallinn

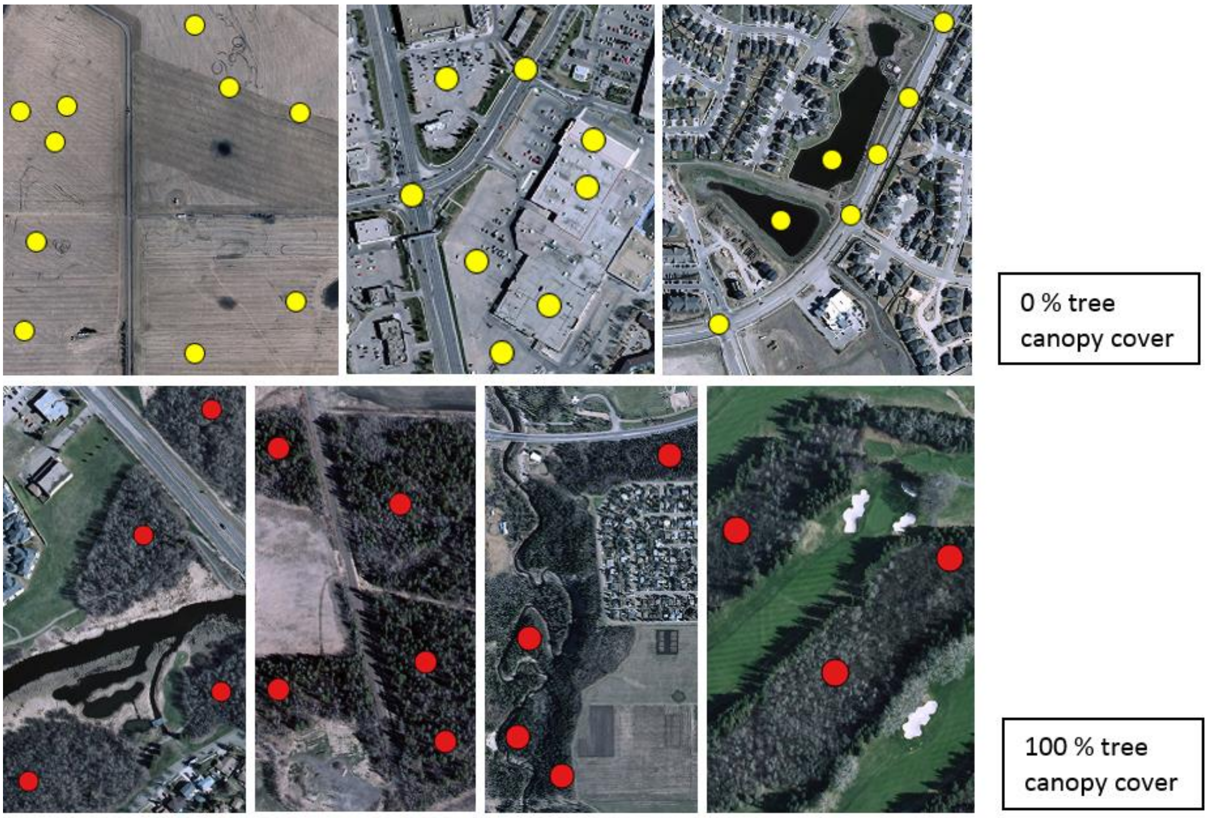


Figure 26: Examples of sample points for tree canopy cover, Edmonton

Predicting tree canopy cover using Boosted Regression Trees

Boosted Regression Trees (BRTs) described in chapter 3.3.3 were used to predict the percent tree canopy cover from SPOT-5 (Take-5) images (Tallinn) and SPOT-5 images (Barcelona). Percent tree canopy cover was predicted from vegetation indices (e.g. NDVI, band ratios, band differences, etc.) calculated from the SPOT images based on the sample tree canopy cover collected at different locations in the city (see Figure 24 and Figure 25). Boosted Regression Trees was implemented in R 3.2.2 statistical software package (R Development Core Team (2008)).

Predicting tree canopy cover using Simple Linear Regression

BRTs using high resolution images such RapidEye was found time consuming for larger cities and SLR was preferably used for Edmonton. The prediction of percent tree canopy cover involves several steps. Firstly, the NDVI was calculated from RapidEye images and stretched to extract suitable values between 0 and 1. Secondly, the relationship between the sample tree canopy and NDVI values extracted at different locations (Figure 26) was determined using Simple Linear Regression. There is a high correlation between tree canopy cover and NDVI which shows that simple regression can be used to predict percent tree canopy over the entire Edmonton city area. Since the RapidEye images were from two different dates, the prediction of tree canopy cover was done by dividing the entire Edmonton city area into two blocks (block 1 covered with two scenes from 17/05/2015 and block 2 covered with three scenes from 07/07/2015).

The tree canopy cover predicted using both methods (SLR, BRTs) is in percent and values range from 0 to 100. The result of the prediction was further corrected using forest, agriculture and grassland layers produced during the production of indicator 1. Agricultural and grassland areas that were wrongly predicted as having tree canopy cover were excluded while forest areas that were omitted in the prediction were included in the tree canopy layer. The final product of tree cover was checked and validated for its accuracy.

4 PROOF-OF-CONCEPT: PROTOTYPE

This chapter presents the final products as listed in the previous chapter, i.e. the GIS layers (maps) and the final CBI-relevant value of the different indicators together with the CBI scoring. The results are sorted per city. The maps are presented as smaller quick looks, but the final delivery (EO4CBI_Deliverables_Data) also contains the GIS data as well as graphics files with the maps in higher resolution.

4.1 BARCELONA

Indicator 1 – Proportion of Natural Areas

As per user request, maps for two reference units have been produced, the municipality (core reference unit for the CBI) as well as the metropolitan area. In the following tables it is always the municipality presented first.

Table 8: Results for indicator 1, Barcelona municipality

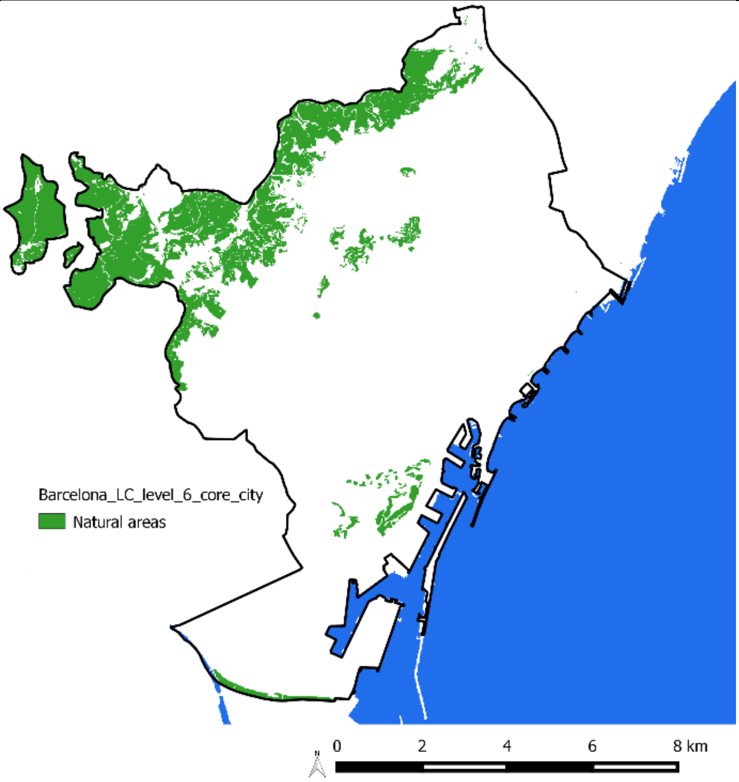
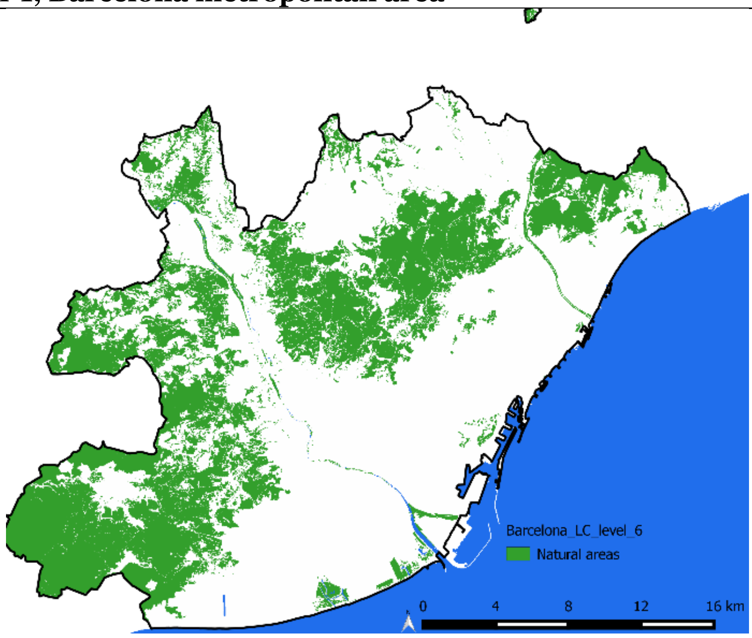
Land cover map	
CBI value/score	3 points (16%)

Table 9: Results for indicator 1, Barcelona metropolitan area

Land cover map	
CBI value/score	4 points (34.50%)

<u>Indicator 2 – Connectivity Measures or Ecological Networks to counter Fragmentation</u>

Indicator 2 does not provide any maps as final output of the process. Rather, several input GIS data layers are collected and represented in a map (see Figure 11 to Figure 13) which then serves as basis for the calculation of the connectivity measure values. Therefore, other than for the three remaining indicators only the calculation results are presented here (see the following Table 10, Table 16 and Table 20).

Table 10: Results of the connectivity analysis for the Barcelona Municipality and the Barcelona Metropolitan Area

Connectivity Analysis (Indicator 2 of CBI) <u>Barcelona Municipality</u>	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: 292.5 Option B: 294.03	Option A: 293.03 Option B: 294.6	982.6	983.3
Intra/Within-Patch Connectivity (ha)	Option A: 191.7 Option B: 192.7	Option A: 191.7 Option B: 192.7	313.5	313.5
Inter/Between-Patch Connectivity (ha)	Option A: 100.8 Option B: 101.3	Option A: 101.3 Option B: 101.8	669.1	669.9
Total area of Natural Areas (ha)	Option A: 1621.7 Option B: 1613.3	Option A: 1621.7 Option B: 1613.3	1621.7	1621.7

Connectivity Analysis (Indicator 2 of CBI) Barcelona Metropolitan Area	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: 6608.5 Option B: 6638.6	Option A: 6608.7 Option B: 6638.8	8144.2	8144.4
Intra/Within-Patch Connectivity (ha)	Option A: 3593.7 Option B: 3610.0	Option A: 3593.7 Option B: 3610.0	4592	4592
Inter/Between-Patch Connectivity (ha)	Option A: 3014.8 Option B: 3028.5	Option A: 3015.1 Option B: 3028.8	3552.2	3552.5
Total area of Natural Areas (ha)	Option A: 21937.2 Option B: 21837.7	Option A: 21937.2 Option B: 21837.7	21937.2	21937.2

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	Barcelona municipality: 1 point (292.5 ha) Barcelona Metropolitan Area: 4 points (6608.5 ha)

Some explanatory remarks have to be given, though, to further provide 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 (area of natural areas) in the connectivity equation in order to be able to compare connectivity values for different scenarios. For example, the total area of natural areas in the municipality of Barcelona is 1621.7 ha as determined from the satellite images for indicator 1. However, 8.4 ha are in fact covered by barriers, and accordingly, the A_{total} in option B is 1613.3 ha. 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. We also report the values of option B in the table as additional information that is useful for monitoring changes over time.

Scenario1 - with barriers, without connectors:

The value of connectivity for Barcelona Municipality is 292.5 ha with a total amount of 1621.7 ha. This value increases to 6608.5 ha for Barcelona Metropolitan Area which has 21937.2 ha of natural areas.

Even though, the amount of natural areas in Tallinn is three times higher than in Barcelona Municipality (4999.5 ha vs 1621.7 ha), connectivity in Tallinn is 280.1 ha, which is slightly lower than in Barcelona

Municipality. This indicates that the large amount of natural areas in a city does not always result in a higher value of connectivity. However, the existence of barriers and the spatial distribution of natural areas in the landscape have direct impacts on connectivity. Finally, there are 7456.3 ha of natural areas in Edmonton, and their connectivity is 128.1 ha.

Scenario 2 - with barriers, with connectors:

The connectivity for Barcelona Municipality in scenario 2 increases slightly to 293.03 ha. This small increase in connectivity of 0.5 ha demonstrates the degree to which connectors advance connectivity in Barcelona Municipality. Most of the connectors received from Barcelona were already detected as natural areas in indicator 1. Therefore, the effect of the remaining connectors on the value of connectivity was not huge in this city. The total connectivity in this scenario for Barcelona Metropolitan area, Tallinn and Edmonton are 6608.7 ha, 283.2 ha and 133.3 ha respectively. The strongest effect was observed in Edmonton, in which the connectors advanced connectivity value by 5.2 ha.

Scenario 3 - without barriers, without connectors:

Connectivity in Scenario 3 exhibits a strong increase compared to Scenarios 1 and 2 in all cities (19% to 70% higher). In fact, this scenario shows to what degree the barriers hinder connectivity in scenarios 1 and 2. In this scenario, total connectivity values for Barcelona Municipality, Barcelona Metropolitan Area, Tallinn and Edmonton are 982.6 ha, 8144.2 ha, 827.9 and 169.1 ha respectively.

Scenario 4 - without barriers, with connectors:

The IND2 value for this scenario represents the maximum possible level of connectivity for each city. If all barriers are ignored and connectors are considered as movement routes or stepping-stones between primary habitat patches, total connectivity values for Barcelona Municipality, Barcelona Metropolitan Area, Tallinn and Edmonton are 983.3 ha, 8144.4 ha, 828.9 ha and 320.1 ha respectively. The contribution of connectors is not large, e.g., 0.7 ha in the municipality of Barcelona and 1 ha in Tallinn.

In Barcelona Municipality, within-patch connectivity is almost two times higher than between-patch connectivity (191.7 ha vs 100.8 ha, for scenario 1). In Barcelona Metropolitan Area the degree of contribution of within-patch connectivity and between-patch connectivity in total connectivity is closer (3593.7 ha and 3014.8 ha respectively, for scenario 1). The largest difference between within-patch connectivity and between-patch connectivity was observed in Tallinn (224.99 ha vs 55.1 ha respectively, for scenario 1).

Connectors do not have any effect on the value of within-patch connectivity which measures the contribution of all patches individually, (whether connected or not connected to a group of patches) to the total connectivity. In contrast, between-patch connectivity changes depending on the existence or absence of connectors.

Indicator 11 – Regulation of Quantity of Water

Table 11: Results for indicator 11, Barcelona municipality

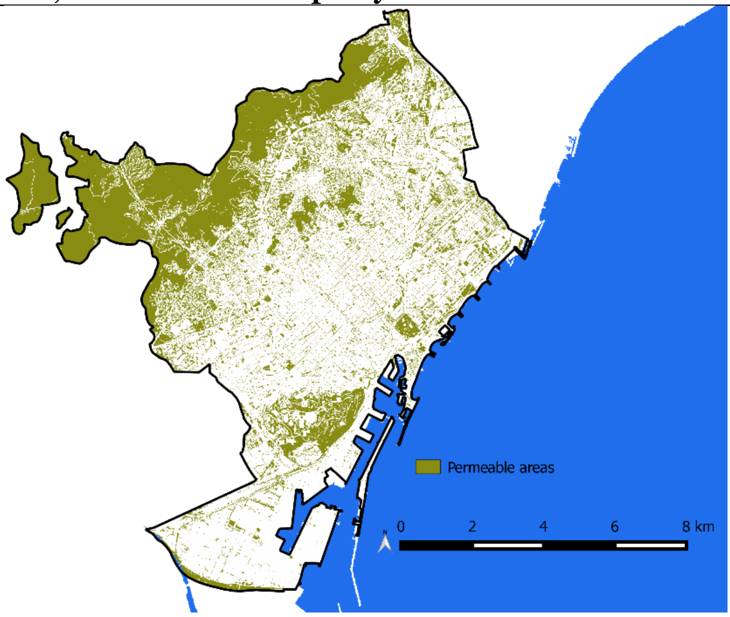
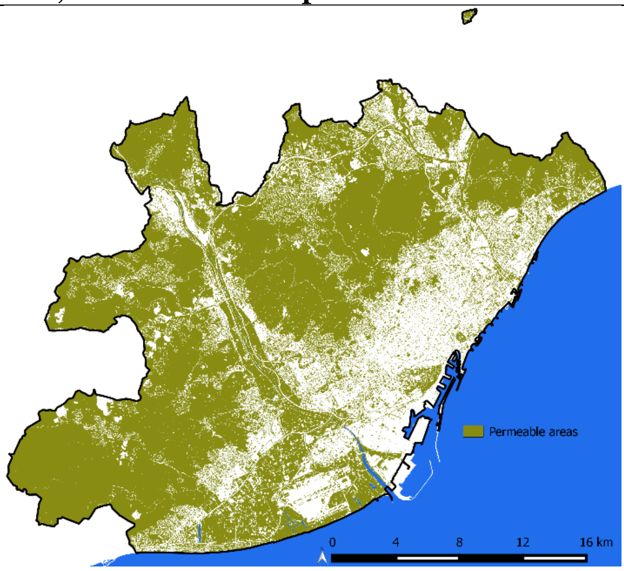
Map of permeability	
CBI value/score	1 point (38% permeable)

Table 12: Results for indicator 11, Barcelona metropolitan area

Map of permeability	
CBI value/score	3 points (70% permeable)

Indicator 12 – Climate Regulation: Carbon Storage and Cooling Effect of Vegetation

Table 13: Results for indicator 12, Barcelona municipality

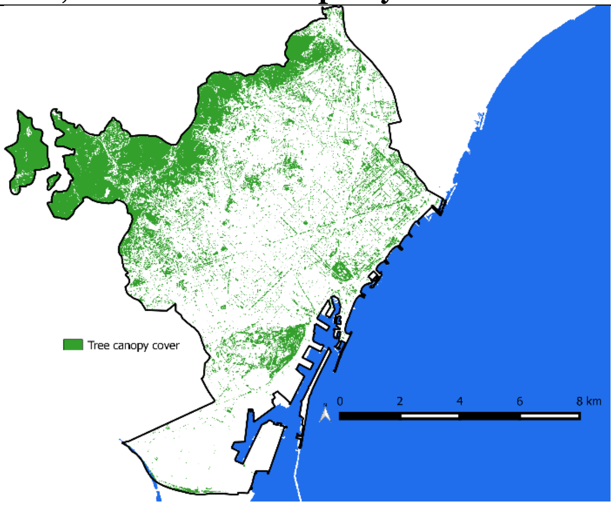
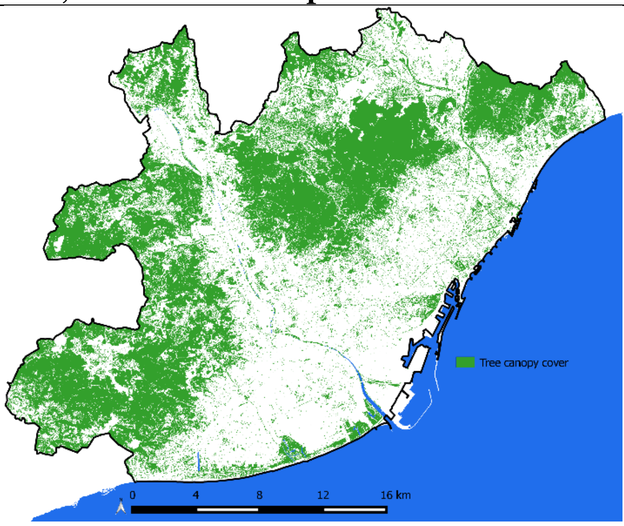
Map of the extent of tree canopy cover	
CBI value/score	2 points (20.73% tree cover)

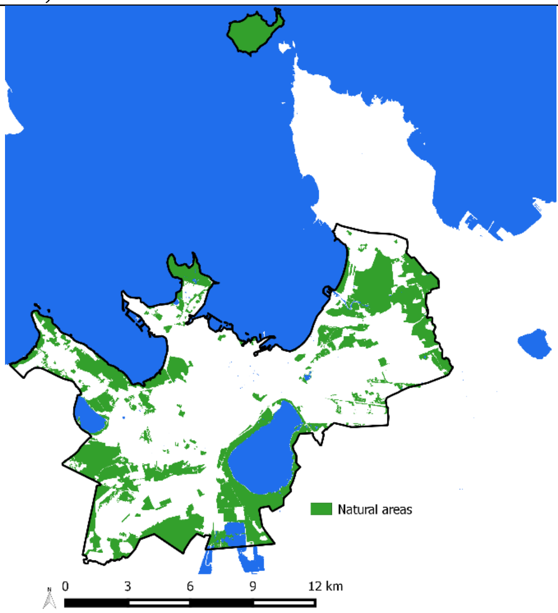
Table 14: Results for indicator 12, Barcelona metropolitan area

Map of the extent of tree canopy cover	
CBI value/score	3 points (32.44% tree cover)

4.2 TALLINN

Indicator 1 – Proportion of Natural Areas

Table 15: Results for indicator 1, Tallinn

Land cover map	
CBI value/score	4 points (31.38%)

Indicator 2 – Connectivity Measures or Ecological Networks to counter Fragmentation

Table 16: Results of the connectivity analysis for the City of Tallinn

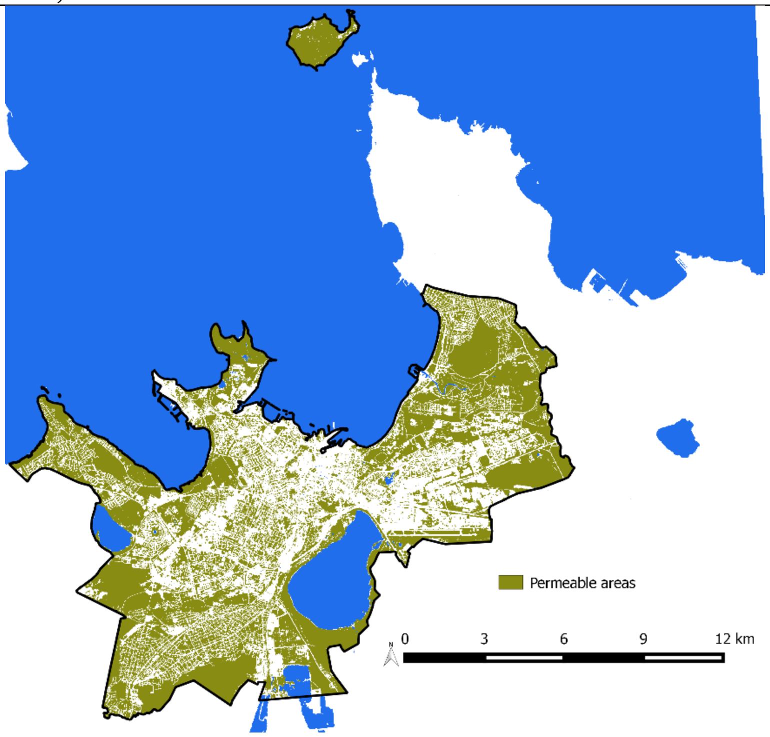
Connectivity Analysis (Indicator 2 of CBI) Tallinn	With barriers/ Without connectors	With barriers/ With connectors	Without barriers/ Without connectors	Without barriers/ With connectors
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total Connectivity (ha)	Option A: 280.1 Option B: 282.6	Option A: 283.2 Option B: 285.7	827.9	828.9
Intra/Within-Patch Connectivity (ha)	Option A: 224.99 Option B: 227.01	Option A: 224.98 Option B: 227.00	413.2	413.2
Inter/Between-Patch Connectivity (ha)	Option A: 55.1 Option B: 55.6	Option A: 58.2 Option B: 58.7	414.7	415.7
Total area of Natural Areas (ha)	Option A: 4999.5 Option B: 4954.98	Option A: 4999.5 Option B: 4954.98	4999.5	4999.5

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	280.5 ha = 1 point

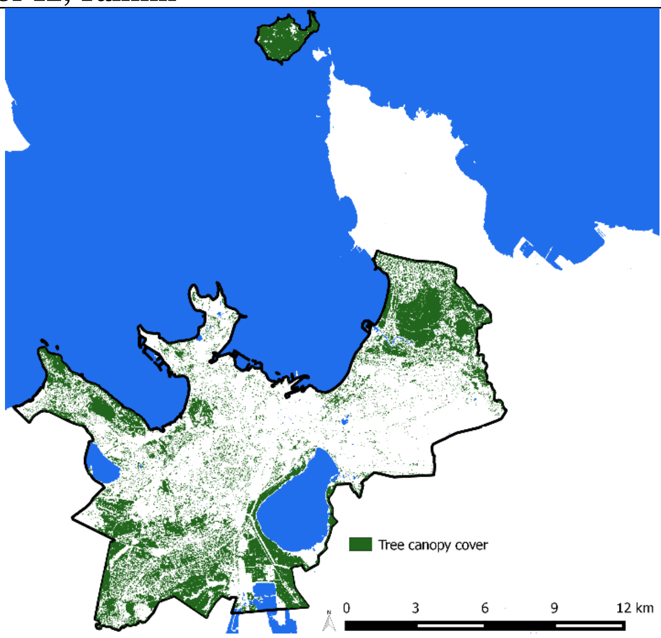
Indicator 11 – Regulation of Quantity of Water

Table 17: Results for indicator 11, Tallinn

Map of permeability	
CBI value/score	3 points (65.92% permeable)

Indicator 12 – Climate Regulation: Carbon Storage and Cooling Effect of Vegetation

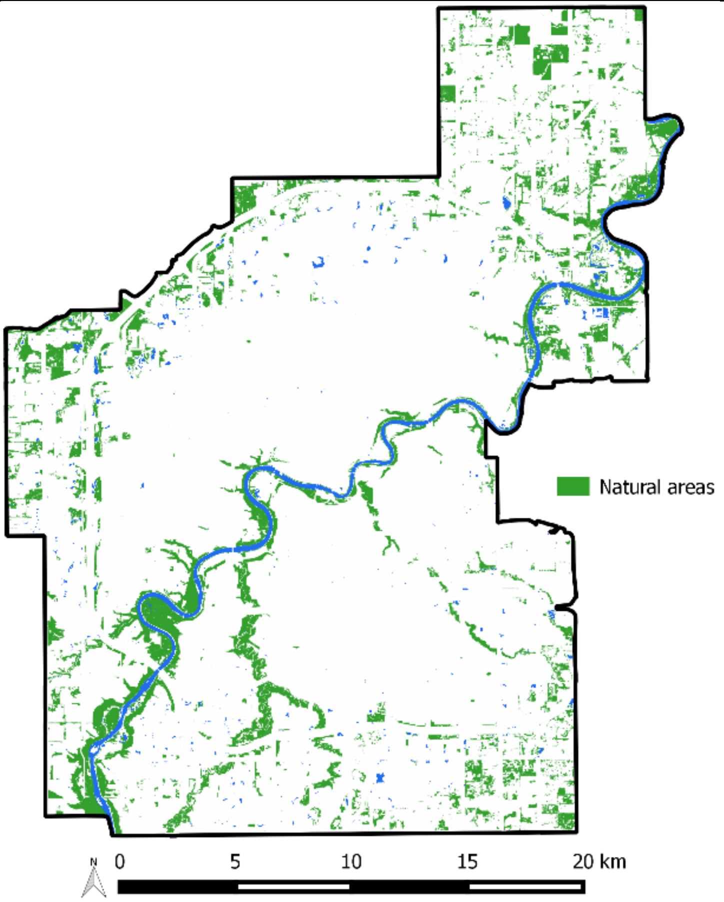
Table 18: Results for indicator 12, Tallinn

Map of the extent of tree canopy cover	
CBI value/score	2 points (22.46% tree cover)

4.3 EDMONTON

Indicator 1 – Proportion of Natural Areas

Table 19: Results for indicator 1, Edmonton

Land cover map	
CBI value/score	2 points (10.67%)

Indicator 2 – Connectivity Measures or Ecological Networks to counter Fragmentation

Table 20: Results of the connectivity analysis for the City of Edmonton

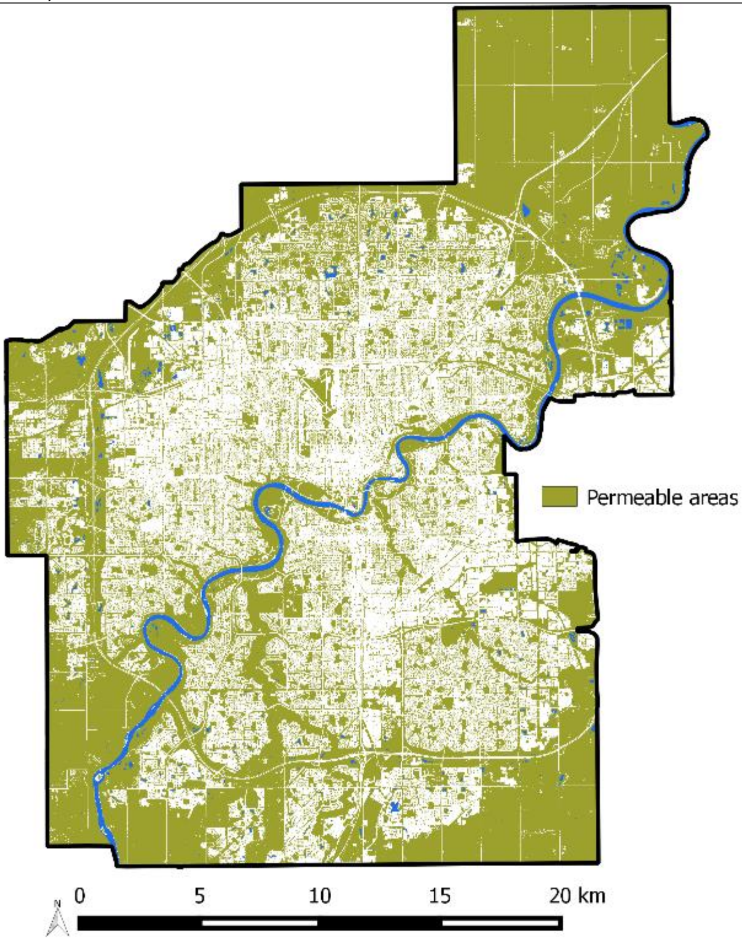
Connectivity Analysis (Indicator 2 of CBI) Edmonton	With barriers/ Without connectors Scenario 1	With barriers/ With connectors Scenario 2	Without barriers/ Without connectors Scenario 3	Without barriers/ With connectors Scenario 4
Total Connectivity (ha)	Option A: 128.1 Option B: 128.5	Option A: 133.3 Option B: 133.7	169.1	320.1
Intra/Within-Patch Connectivity (ha)	Option A: 80.3 Option B: 80.5	Option A: 80.3 Option B: 80.5	85.6	85.6
Inter/Between-Patch Connectivity (ha)	Option A: 47.8 Option B: 48.98	Option A: 53.1 Option B: 53.2	83.5	234.5
Total area of Natural Areas (ha)	Option A: 7456.3 Option B: 7433.7	Option A: 7456.3 Option B: 7433.7	7456.3	7456.3

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	128.1 ha = 0 points

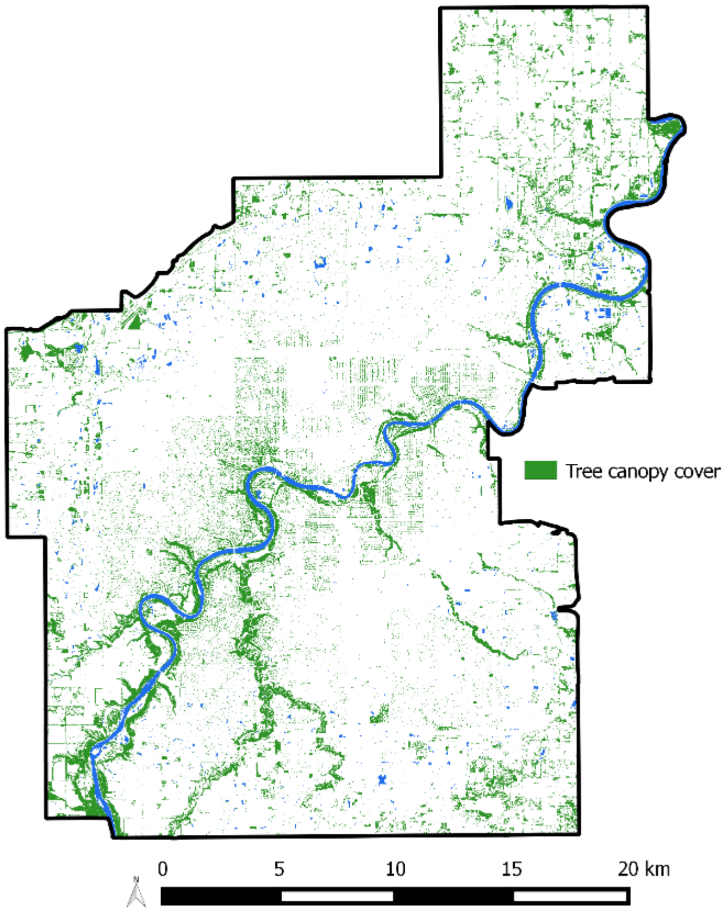
Indicator 11 – Regulation of Quantity of Water

Table 21: Results for indicator 11, Edmonton

Map of permeability	
CBI value/score	2 points (61% permeable area)

Indicator 12 – Climate Regulation: Carbon Storage and Cooling Effect of Vegetation

Table 22: Results for indicator 12, Edmonton

Map of the extent of tree canopy cover	
CBI value/score	0 points (8.27%)

5 DATA PROCUREMENT PLAN UPDATE

5.1 SATELLITE DATA

Upon the submission of a Category-1 proposal (Cat-1 ID 30132) for image access, the EO4CBI project got access to an image quota as provided in Table 23 below.

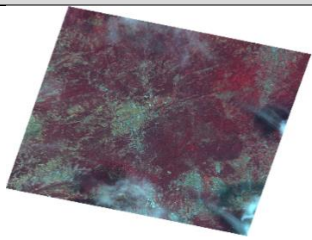
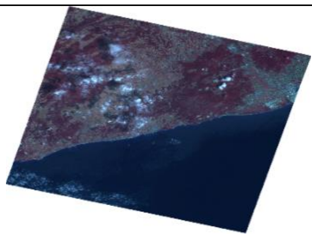
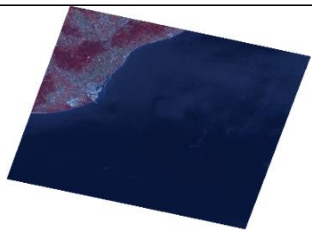
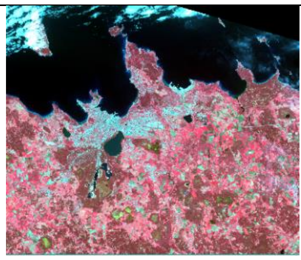
Table 23: Allocated Cat-1 quota

Sensor	Cat-1 Quota
Spot-5/-6/-7	10 SPOT 5 archive, 10m (all production levels) products archive 2500km^2 of SPOT 6&7 6m Color or 1.5m Black&White (all production levels), out of which 2500km^2 of new acquisitions ESA SPOT online archive (MS and PAN)
RapidEye	60 credits for Level 3A tiles (or Level 1B products)

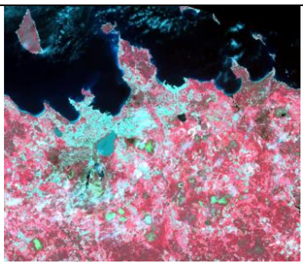
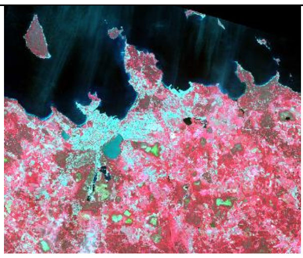
However, during the first year of the project and in correspondence to the surface area sizes of the three prototype cities and image availabilities, not the entire quota has been used up. Table 24 below provides an overview of the satellite images that have been procured from the quota in that 1-year period: three SPOT-5 archive scenes over Barcelona and five RapidEye archive scenes over Edmonton. For the city of Tallinn, it was not necessary at all to use any images from the quota because Tallinn is one of the test sites that were covered by the SPOT-5 Take 5 experiment[6]. The SPOT-5 Take 5 experiment was carried out during the decommissioning phase of SPOT-5 and aimed at simulating image time series that are expected from ESA's Sentinel-2 mission (10m in multispectral mode).

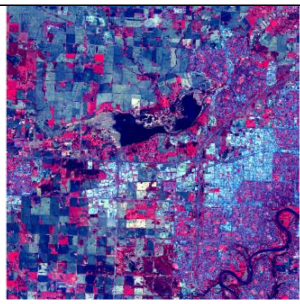
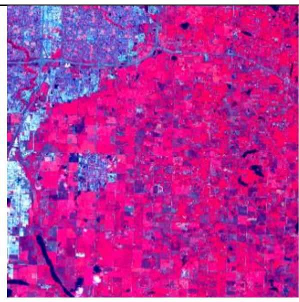
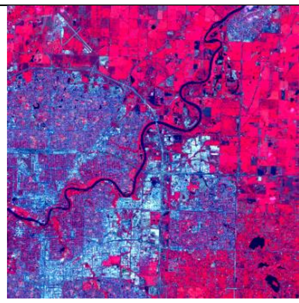
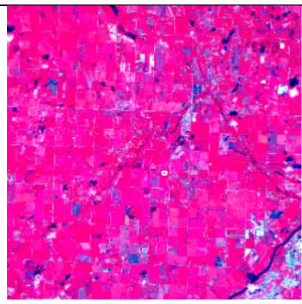
[6] https://spot-take5.org/client/#/products/SPOT5

Table 24: Tabular overview of procured EO data

Image details	**Quicklooks**
Barcelona	
SPOT-5, 10m, 19/07/2014 C1F30132_eo4cbi_SPOT5_BCN_SO15014753-3-01_5044266140719100647 2J0	
SPOT-5, 10m, 24/07/2014 C1F30132_eo4cbi_SPOT5_BCN_SO15014753-1-01_504426714072410102 71J0	
SPOT-5, 10m, 24/07/2014 C1F30132_eo4cbi_SPOT5_BCN_SO15014753-2-01_504626714072410102 52J0	
Tallinn[7]	
04/05/2015 SPOT5_HRG2_XS_20150504_N1_TUILE_TallinnEstoniaD0000B0000 SPOT5_HRG2_XS_20150504_N2A_TallinnEstoniaD0000B0000	
19/05/2015 SPOT5_HRG2_XS_20150519_N1_TUILE_TallinnEstoniaD0000B0000 SPOT5_HRG2_XS_20150519_N2A_TallinnEstoniaD0000B0000	

[7] The quicklooks only show the image product N1 that was also used for the production.

13/06/2015 SPOT5_HRG2_XS_20150613_N1_TUILE_TallinnEstoniaD0000B0000 SPOT5_HRG2_XS_20150613_N2A_TallinnEstoniaD0000B0000	
03/07/2015 SPOT5_HRG2_XS_20150703_N1_TUILE_TallinnEstoniaD0000B0000	
07/08/2015 SPOT5_HRG2_XS_20150807_N1_TUILE_TallinnEstoniaD0000B0000 SPOT5_HRG2_XS_20150807_N2A_TallinnEstoniaD0000B0000	
22/08/2015 SPOT5_HRG2_XS_20150822_N1_TUILE_TallinnEstoniaD0000B0000 SPOT5_HRG2_XS_20150822_N2A_TallinnEstoniaD0000B0000	
Edmonton	
17/05/2015 1263707_2015-05-17_RE4_3A_314051	

17/05/2015 1263807_2015-05-17_RE4_3A_314051	
07/07/2015 1263708_2015-07-07_RE3_3A_314051	
07/07/2015 1263808_2015-07-07_RE3_3A_314051	
07/07/2015 1263908_2015-07-07_RE3_3A_314051	

5.2 ANCILLARY DATA

For the two European cities (Barcelona, Tallin) the ancillary data used include the Copernicus Urban Atlas (from the local component[8]) and OpenStreetMaps (roads)[9]. The Urban Atlas data was used to refine the candidate natural areas extracted from the classification of SPOT-5 (Take-5) images. Areas overlapping with continuous urban fabric were excluded from the natural areas with the assumption that the ecosystems in such areas are intensively managed. For Barcelona, besides the Urban Atlas and the OSM, urban natural parks layer obtained from the city was used to include areas which were

[8] http://land.copernicus.eu/local/urban-atlas/view
[9] https://www.openstreetmap.org

otherwise excluded from the produced natural areas layer.

For Edmonton, the ancillary data used include mainly the OpenStreetMaps (roads, buildings footprint). The OpenStreetMaps data were used to refine the level 1 products of candidate natural areas, degree of imperviousness and tree canopy cover which were obtained from the classification of and prediction from RapidEye images. Since there was no Urban Atlas data for Edmonton, a continuous urban fabric was produced from Landsat 8 time series data. Areas overlapping with the produced urban fabric were regarded as managed and were excluded from the natural areas layer. In addition, agriculture layer was produced from Landsat 8 time series images and was used to exclude croplands from the natural areas layer.

6 OBSERVATIONS, CONCLUSIONS AND RECOMMENDATIONS

During the production of the indicators on of the very first issue that pops up is the varying definitions of natural areas in the three pilot cities. The CBI User Manual (CBD, 2010, updated 2012 and 2014) provides a working definition:

> "Natural areas comprise predominantly native species and natural ecosystems, which are not, or no longer, or only slightly influenced by human actions, except where such actions are intended to conserve, enhance or restore native biodiversity."

Natural ecosystem are further defined as areas that have not undergone larger disturbances or have been man-made. Examples are forests, mangroves, freshwater swamps, natural grasslands, streams or lakes. While generally parks, golf courses, and roadside plantings are not considered as natural, they can be included in the computation if they are dominated by native species. Moreover, restoration efforts are taken into account.

It becomes clear, that on the one hand there exists some degree of freedom in this definition, mainly to account for geographic, climatological and historic differences of cities across the globe. On the other hand, several of the listed exemplary classes (ecosystems) cannot be well captured and distinguished from related classes by remote sensing data alone. On top of this general observation, in the framework of the EO4CBI the three pilot cities treat classes differently (an issue that is already described in chapter 5 of the deliverable D1.1 – Requirements Baseline). While, for example, Tallinn considers their coastal and beach structures to be natural, Barcelona defines them as man-made. When it comes to information retrieval by means of remote sensing data, mapping urban parks as natural areas by means of species occurrence or discriminating between tame and wild pastures is almost impossible. It should be noted that this issue of course also concerns the validation of the product. From that perspective it would be recommended to fine-tune the user manual towards a better streamlining of the definition, which would finally also allow for a better comparability between cities concerning their CBI score.

Looking at the technological means of information retrieval, EO data have the strong advantage of being able to capture large regions at the same time (makes them very cost-efficient; which is particularly more valid with the launch of Sentinel data that are made available to users free of charge). On the flipside, there exist limitations of satellite data (compared to local data) in terms of spatial and temporal resolution and, therefore, the capability to capture smaller features. Moreover, satellite data are able to capture land cover, but have difficulties in providing reliable information on land use (see the previous discussion on the natural areas); proxies have to be used if possible at all.

While iterating with the users during the production and output review cycles, most of the user cities encouraged the integration of local information to make the product more corresponding to the reality on the ground. The major problem with this local data integration is the fact that the product would then very much resemble the local data and at the same time very much deviate from an EO-based product (with the inherent risk of finally overselling EO data). However, the objective of the project, which has been re-iterated by several users during the collection of the user requirements, is the evaluation of the added-value that EO data can bring to the production of local data that can be used in the framework of the CBI and possibly beyond. This evaluation should both consider the thematic and geometric quality of the product, but also the cost-benefit ratio between the project outcome and the currently available local data: the project is able to cover large area and deliver a product that is of sufficient quality compared to the locally available data to be eligible for further use, considering the price advantage that Sentinel data possess.

During the production and while iteratively exchanging with the users on the quality of the products, it was recognised that the users often provided feedback and recommendations for adjusting the products for characteristics of the data that are beyond the limit of EO data. Examples of those remarks were e.g.:

- Include urban parks into the natural areas if they contain specific species that have their habitat there;
- Discriminate between tame grassland or pastures (not natural) and natural grasslands without anthropogenic impact (natural);
- Include beaches and coastal areas that are natural and exclude areas that are not natural.

It is obvious that the satellite data used in this project are not able to capture most of those differences as they are very much related to land use parameters. It was, therefore, decided to follow a two-step approach, that is, create (i) a basic product that is based on satellite data and other publicly-available ancillary data (such as OpenStreetMap), and add (if requested and feasible from a data availability perspective) (ii) an advanced product on top of it to fulfil some of the requests of the users. However, the risk exists that the advanced product in the end very much resembles possible local data sets that are already available and does, therefore, not provide a lot of added value.

The quality of the basic products (natural areas, permeable areas, tree canopy cover) produced from satellite images depends on the spatial, spectral and temporal resolution of the images. Comparing the data used for the three cities, for instance, in the mapping of natural areas, land cover types such as grasslands, meadows and pastures resemble annual croplands and it was difficult to detect them from single time-step SPOT images available for Barcelona. Since time series data was available for Tallinn, mapping of the indicators particularly, the natural areas and permeable areas, was relatively easier compared with single time-step SPOT images used for Barcelona. RapidEye images used for Edmonton have advantage over SPOT images due to the high resolution (5m) and availability of more bands (e.g. Red-edge band) which enables better detection of the indicators. However, since RapidEye images were also available only for the same period, it was necessary to support the analysis with time series Landsat images.

Therefore, it was observed that multi-temporal or high spectral resolution images are essential and future availability of time series Sentinel-2 images will have a greater advantage in this regard. However, given the limitations in the spatial and spectral resolution of Sentinel-2 images, differentiating trees from bushes, shrubs and grasslands remains a challenge for the accurate mapping of indicators such as tree canopy cover. It should also be note that selection of Sentinel-2 images for mapping of a particular indicator should be based on the local context. For instance, in some tropical cities during dry periods, trees appear more green compared with other vegetation; thus, images from dry period could be more appropriate for mapping tree canopy cover but this may not be applicable for cities in temperate regions.

Apart from the limitations of the data used, adapting the definitions of the indicators to what is detectable by EO data remains a challenge. For instance, natural areas in some cases (e.g. Tallinn) include sand dunes which are not easily mapped from EO data. Since definitions vary from city to city, developing a uniform standard EO-based method is also a challenge. Accurate mapping of tree canopy cover was also not possible just using SPOT and RapidEye images. Thus, the product for tree canopy layer includes shrubs, bushes and other vegetation that were difficult to separate from trees. Nevertheless, given all the limitations mentioned above the products were produced with an acceptable accuracy. The mapped tree canopy cover was 22.46% for Tallinn core city and 20.73% for Barcelona core city which is comparable with the results of Copernicus High Resolution tree density layer (16.53% for Tallinn and 14.47% for Barcelona). It is likely that Copernicus 20m product underestimates the tree cover.

The new method to produce indicator 2 has been incorporated as standard in the user manual of the CBI after first attempts by the initial proponents of the Index led to unclear results. However, there are advantages as well as disadvantages in the context of its operational implementation that should be mentioned:

- Advantages:
    - Indicator 2 is useful for identifying options to increase the connectivity of natural areas within cities and for determining the impacts of development on connectivity.
    - It provides an opportunity to include the effect of barriers in the connectivity measurements.
    - It provides a more accurate representation of connectivity than other measures of connectivity by accounting for both intra-patch and inter-patch connectivity. Both of them must be considered since the persistence of many wildlife populations depends on their ability to move between habitat patches and within them. Connectivity measures that only measure between-patch connectivity lead to contradictory results when patches are fragmented, e.g., when an unconnected patch is split into two patches and would now be considered as connected to each other if they are < 100 m apart.

- Disadvantages/limitations:
    - In the calculation of IND2, attention needs to be given to situations where barriers are closer to 50 m buffer of natural area. The 50 m buffer could then overlap with a barrier (roads), and even cross the barrier. Therefore, the buffer can sometimes connect patches on the other side of the road that are more than 100 m apart from each other and are not connected (see chapter B for more detailed information). In each city a few errors related to this issue were observed, and subsequently, data was corrected manually.
    - Different (groups of) species have different movement distances. Therefore, the distance of 100 m does not apply to all species equally. Different species also experience differing resistance values of the land cover (Zeller et al. 2012). These differences can be included in the method, but then IND2 would consist of different values for different (groups of) species.

Therefore, the following recommendations for the future operationalisation of the connectivity indicator are given:

- Given that the objective of IND2 is to maintain practicality and comparability over time, the types of fragmentation geometries chosen for each city should be kept consistent throughout the time and across space.
- It is important to use a consistent total size of the natural areas in the denominator of the connectivity equation in order to monitor connectivity over time. Otherwise, the connectivity that existed to the locations where habitat was lost at a later point in time would not be detected by the difference in the indicator: IND2 (time2) - IND2 (time1). Therefore, if the connectivity analysis in the first year was done based on subtraction of the area of the barriers (fragmentation geometry) from the size of the natural areas (option B in Tab. 3), connectivity monitoring for the upcoming years should be done in the same way.
- A comparison of within-patch and between-patch connectivity is useful for monitoring over time to better understand the observed changes (see scenarios in Table 10).

7 REFERENCES

Asgary, A. (2012): Measuring the connectivity of natural areas in the City Biodiversity Index (CBI) using the effective mesh size (meff). Unpublished Honours Thesis. Concordia University, Department of Geography, Planning and Environment. 90 pp.

Breiman L (1996) Bagging Predictor. Mach Learn 26: 123–140. doi: 10.1007/bf00058655.

Breiman L (2001) Random Forests. Mach Learn 45: 5–32.

Brook, B.W., Sodhi, N.S. & Ng, P. K.L. (2003). Catastrophic extinctions follow deforestation in Singapore. Nature. 424, 420-426. doi: 10.1038/nature01795

CBI User's Manual. (2014). Chan, L., Hillel, O., Elmqvist, T., Werner, P., Holman, N., Mader, A. and Calcaterra, E., 2014. User's manual on the Singapore Index on Cities' Biodiversity (also known as the city Biodiversity Index). Singapore: National Parks Board, Singapore.

Conrad C, Dech S, Dubovyk O, Fritsch S, Klein D, et al. (2014) Derivation of temporal windows for accurate crop discrimination in heterogeneous croplands of Uzbekistan using multitemporal RapidEye images. Comput Electron Agr 103: 63–74. doi: 10.1016/j.compag.2014.02.003.

Convention on Biological Diversity CBD (2010). User's manual for the City Biodiversity Index. Retrieved from: http://www.cbd.int/authorities/doc/User%27s%20Manual-for-the-City-Biodiversity-Index27Sept2010.pdfb

Crase B, Liedloff AC, Wintle BA (2012) A new method for dealing with residual spatial autocorrelation in species distribution models. Ecography 35: 879–888. doi: 10.1111/j.1600-0587.2011.07138.x

De'Ath G (2007) Boosted trees for ecological modeling and prediction. Ecology 88: 243–251. pmid:17489472 doi: 10.1890/0012-9658(2007)88[243:btfema]2.0.co;2

Deslauriers et al. (in prep.): Measuring connectivity of natural areas in cities as an indicator in the City Biodiversity Index (CBI): Theory and applications.

Deslauriers, M. (2013): Measuring the connectivity of the greenway network in Southwest Montreal: Scenarios for enhancing the wellbeing of biodiversity and humans. Unpublished Honours thesis, Concordia University, Department of Geography, Planning and Environment. 84 pp.

Di Giulio, M., Holderegger, R., & Tobias, S. (2009). Effects of habitat and landscape fragmentation on humans and biodiversity in densely populated landscapes. Journal of Environmental Management, 90(10), 2959-2968. doi: 10.1016/j.jenvman.2009.05.002

Elith J, Leathwick JR, Hastie T (2008) A working guide to boosted regression trees. J Anim Ecol 77:802–813. doi: 10.1111/j.1365-2656.2008.01390.x. pmid:18397250

European Environment Agency (EEA) and the Swiss Federal Office for the Environment (FOEN) (2011): Landscape fragmentation in Europe. Joint EEA-FOEN report. EEA Report No 2/2011. Authors: Jaeger, J.A.G., Soukup, T., Madriñán, L.F., Schwick, C., Kienast, F. ISSN 1725-9177, ISBN 978-92-9213-215-6, doi:10.2800/78322. Luxembourg, Publications Office of the European Union. 87

pp. Available in printed form and as PDF online: http://www.eea.europa.eu/publications/landscape-fragmentation-in-europe/ - Winner of the IENE Project Award 2011.

Girvetz, E.H., Jaeger, J.A.G., Thorne, J.H. (2007): Comment on "Roadless Space of the Conterminous United States". – Science vol. 318 no 5854 (23 Nov. 2007): 1240b.

Gislason PO, Benediktsson JA, Sveinsson JR (2006) Random forests for land cover classification. Pattern Recogn Lett 27: 294–300. doi: 10.1016/j.patrec.2005.08.011.

Heller, N. E. & Zavaleta, E. S. (2009). Biodiversity Management in the Face of Climate Change: A Review of 22 Years of Recommendations. Biological Conservation, 142, 14-32. doi: 10.1016/j.biocon.2008.10.006

Jaeger, J.A.G. (2000): Landscape division, splitting index, and effective mesh size: New measures of landscape fragmentation. – Landscape Ecology 15(2): 115–130.

Jaeger, J.A.G., Bertiller, R., Schwick, C., Müller, K., Steinmeier, C., Ewald, K.C., Ghazoul, J. (2008): Implementing landscape fragmentation as an indicator in the Swiss Monitoring System of Sustainable Development (MONET). – Journal of Environmental Management 88(4): 737-751.

Jaeger, J.A.G., Schwarz-von Raumer, H.-G., Esswein, H., Müller, M., Schmidt-Lüttmann, M. (2007): Time series of landscape fragmentation caused by transportation infrastructure and urban development: a case study from Baden-Württemberg (Germany). – Ecology and Society 12(1): 22. [online] URL: http://www.ecologyandsociety.org/vol12/iss1/art22/

Kohsaka, R., et al. (2013): Indicators for Management of Urban Biodiversity and Ecosystem Services: City Biodiversity Index. - In. T. Elmqvist et al. (eds.): Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities. Springer, New York, pp. 699-718.

LaPoint, S., Balkenhol, N., Hale, J., Sadler, J., van der Ree, R. (2015): Ecological connectivity research in urban areas. Functional Ecology 29: 868-878.

Leathwick JR, Elith J, Hastie T (2006) Comparative performance of generalized additive models and multivariate adaptive regression splines for statistical modelling of species distributions. Ecol Model 199: 188–196. doi: 0.1016/j.ecolmodel.2006.05.022

Moser, B., Jaeger, J.A.G., Tappeiner, U., Tasser, E., Eiselt, B. (2007): Modification of the effective mesh size for measuring landscape fragmentation to solve the boundary problem. – Landscape Ecology 22(3): 447-459.

R Development Core Team (2008) R: A Language and Environment for Statistical Computing. ISBN 3-900051-07-0. R Foundation for Statistical Computing, Vienna, Austria.

Roch, L., Jaeger, J.A.G. (2014): Monitoring an ecosystem at risk: What is the degree of grassland fragmentation in the Canadian Prairies? – Environmental Monitoring and Assessment 186(4): 2505-2534, doi: 10.1007/s10661-013-3557-9. + Erratum 186(5): 3299-3301, doi: 10.1007/s10661-014-3641-9.

Rodriguez-Galiano VF, Ghimire B, Rogan J, Chica-Olmo M, Rigol-Sanchez JP (2012) An assessment of the effectiveness of a random forest classifier for land-cover classification. ISPRS J Photogramm Remote Sens 67:93–104. doi: 10.1016/j.isprsjprs.2011.11.002.

Taylor, P.D., Fahrig, L., Henein, K. and Merriam, G. (1993). Connectivity is a vital element of landscape structure. Oikos, 68(3) 571-573. http://www.jstor.org/stable/3544927

Watts, R.D., Compton R.W., McCammon J.H., Rich, C.L., Wright, S.M., Owens, T., Ouren, D.S. (2007): Roadless Space of the Conterminous United States. Science 316, issue 5825, pp. 736-738.

Zeller, KA, McGarigal K, Whiteley AR (2012): Estimating landscape resistance to movement: a review. Landscape Ecology 27: 777-797.

Zhu Z, Woodcock CE, Rogan J, Kellndorfer J (2012) Assessment of spectral, polarimetric, temporal, and spatial dimensions for urban and peri-urban land cover classification using Landsat and SAR data. Remote Sens Environ 117: 72–82. doi: 10.1016/j.rse.2011.07.020.