ESA DUE Innovator III

Earth Observation in support of the City Biodiversity Index

D2.3 Final Report (Public version)

DOCUMENT RELEASE SHEET

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CHANGE RECORD

Date	Page(s)	Description of Change	Release
17/05/2017		First draft	D1.0
21/06/2017		Update based on feedback received during the final review meeting; update of executive summary	I1.0

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0 EXECUTIVE SUMMARY

Contrary to common assumptions, urban ecosystems provide innumerable and often undervalued ecosystem services to the local area. However, urban biodiversity is under threat due to the expansion of urban areas and the increase of population numbers. Actions to conserve biodiversity need to start with stock-taking and identifying baselines, followed by regular monitoring of the success of conservation initiatives.

The City Biodiversity Index (CBI) was developed as a self-assessment tool to evaluate the state of biodiversity in cities, benchmark and monitor the progress of their biodiversity conservation efforts against their own individual baselines and provide insights for improving conservation efforts. The EO4CBI project provided support to ten selected pilot cities by producing the four indicators 1, 2, 11 and 12, i.e. "Proportion of natural areas in the city", "Connectivity measures or ecological networks to counter fragmentation", "Share of permeable surfaces", and "Proportion of tree cover extent". The major aim was to assess the potential of EO data to support the production of certain CBI indicators. EO data employed were SPOT-5 and RapidEye at the beginning and Sentinel-2 during the second half of the project.

At the outset of the project the cities for the most part expected from the project to get information on the location of their natural assets. In addition, in particular the cities with existing good local data wanted to learn about the usefulness of satellite data in the context of producing certain CBI parameters and the monitoring of the aforementioned natural assets, i.e. their development over time. Overall, the project succeeded in developing workflows that allowed to deliver products of good quality to the cities which was confirmed by a quantitative validation and feedback that was collected from the cities. Most cities explicitly commented on the good potential of the approach, which could be very helpful for cities, either for all four or some of the four indicators.

Most of the cities stated that local data with a higher resolution would exist, in particular related to indicator 1 (share of natural areas), but they also acknowledged the high costs involved in creating these local data. On the other hand, the high potential of the temporal resolution of Sentinel-2 data was highlighted, i.e. the possibility to get annual updates of the data. Several cities expressed their strong interest in having not only information from one point in time, but establishing a monitoring capacity which could make use of EO data.

As a solution, it is therefore suggested to produce a city baseline as a starting point for the monitoring that is as good as possible to capture the current situation using very high-resolution information and all kinds of ancillary data (knowing that this would be a costly undertaking) and employ EO data and their analysis as the much cheaper means for backdating (i.e. looking into the past) and monitoring future changes. This would allow for installing a biodiversity monitoring system that makes use of both the (cost-intensive) very detailed local data and the inexpensive regular updates. This would also better meet the interest of several cities to have the possibility to compare one city to peer cities, even though the CBI was conceived as a self-assessment tool, such that the development over time is the more appropriate measurement for this comparison.

Looking forward towards the future of the CBI, the project agrees with a majority of the user cities that the CBI has a high potential to be applied widely as a monitoring tool but that there also is room for improvement regarding the scoring system for several reasons (value ranges make score improvements almost impossible; number of classes is too low; threshold for maximum score for indicators 1 is too low; this does not help the assessment and subsequent information to cities' policy- and decision-makers in its current form). It is, therefore, recommended to switch to at least a relative scale and, ideally, to a continuous scale to improve the scoring and make it more meaningful. Moreover, project partners and cities agreed that the CBI in its current state lacks visibility as well as uptake by cities. There is no dedicated website and generally not a lot of information about the CBI available on the web so far. It was, therefore, considered necessary to increase or improve coordination and management of the CBI and create one place, a kind of CBI "one-stop shop", where all this information is pulled together and hosted. This would also greatly increase the practical value of the CBI in the framework of international policies and targets/goals, such as the SDGs or in the follow-up of the Quintana Roo Communiqué.

1 WHAT WAS THE PROJECT ABOUT?

1.1 THE PROJECT

1.1.1 SETTING THE SCENE

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

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

1.1.2 THE CITY BIODIVERSITY INDEX

The World Summit on Sustainable Development in 2002[1] 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[2] aim to improve the status of biodiversity and to reduce the pressures on biodiversity by 2020.

At the Ninth Conference of Parties to the Convention on Biological Diversity (CBD) in May 2008[3], the former Singapore Minister of National Development, Mr. Mah Bow Tan, proposed the development of a city biodiversity index (CBI) as a self-assessment tool for cities to evaluate their biodiversity conservation efforts over time. Subsequently, Singapore hosted three expert workshops in 2009, 2010 and 2011. The technical development of the draft CBI was led by a panel of seven experts from NParks, London School of Economics, German Institute of Housing and Environment, Stockholm Resilience

[1] https://sustainabledevelopment.un.org/milesstones/wssd
[2] https://www.cbd.int/sp/targets/
[3] https://www.cbd.int/doc/?meeting=cop-09

Centre, ICLEI-Local Governments for Sustainability, International Union for Conservation of Nature and the Secretariat of the Convention on Biological Diversity. The Global Partnership on Local and Sub-national Action for Biodiversity promoted the CBI.

At the Tenth Meeting of the Conference of Parties to the CBD (COP-10) in October 2010, the CBI was endorsed as part of the Plan of Action for Sub-national Governments, Cities and Other Local Authorities for Biodiversity[4]. The Plan encourages Parties to engage cities and local authorities in implementing the CBD, and includes the CBI as a tool for cities to monitor their biodiversity conservation efforts. In recognition of Singapore's leadership in the technical development of the index, it was named the Singapore Index on Cities' Biodiversity (SI). At the High-Level segment of COP-10, Mr. Mah offered the World Cities Summit (WCS) and the Mayors' Forum as platforms for sharing of best practices and as preparatory meetings for cities to report on their progress in biodiversity conservation and the application of the SI.

The City Biodiversity Index was developed as a self-assessment tool to evaluate the state of biodiversity in cities, benchmark and monitor the progress of their biodiversity conservation efforts against their own individual baselines and provide insights for improving conservation efforts (Chan et al., 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).

Practically, the CBI consists of two parts:

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

b) the city's self-assessment of the 23 indicators (see Table 1-1) based on the guidelines and methodology provided.

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

Table 1-1: CBI indicator list

Core components	Indicators
	1. Proportion of Natural Areas in the City

[4] https://www.cbd.int/doc/decisions/cop-10/cop-10-dec-22-en.pdf

Native Biodiversity in the City	2. Connectivity Measures
	3. Native Biodiversity in Built Up Areas (Bird Species)
	4. Change in Number of Vascular Plant Species
	5. Change in Number of Bird Species
	6. Change in Number of Butterfly Species
	7. Change in Number of Species (any other taxonomic group selected by the city)
	8. Change in Number of Species (any other taxonomic group selected by the city)
	9. Proportion of Protected Natural Areas
	10. Proportion of Invasive Alien Species
Ecosystem Services provided by Biodiversity	11. Regulation of Quantity of Water
	12. Climate Regulation: Carbon Storage and Cooling Effect of Vegetation
	13. Recreation and Education: Area of Parks with Natural Areas
	14. Recreation and Education: Number of Formal Education Visits per Child Below 16 Years to Parks with Natural Areas per Year
Governance and Management of Biodiversity	15. Budget Allocated to Biodiversity
	16. Number of Biodiversity Projects Implemented by the City Annually
	17. Existence of Local Biodiversity Strategy and Action Plan
	18. Institutional Capacity: Number of Biodiversity Related Functions
	19. Institutional Capacity: Number of City or Local Government Agencies Involved in Inter-Agency Cooperation Pertaining to Biodiversity Matters
	20. Participation and Partnership: Existence of Formal or Informal Public Consultation Process
	21. Participation and Partnership: Number of Agencies/Private Companies/NGOs/Academic Institutions/International Organisations with which the City is Partnering in Biodiversity Activities, Projects and Programmes
	22. Education and Awareness: Is Biodiversity or Nature Awareness Included in the School Curriculum
	23. Education and Awareness: Number of Outreach or Public Awareness Events Held in the City per Year

1.2 THE OBJECTIVES

In preparing this 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 the 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 assess the potential of EO data to support the production of certain CBI indicators. They are designed in a way to be directly usable by cities to assess their performance regarding their biodiversity targets.

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

1.3 THE SELECTED INDICATORS

The following sub-chapters are taken from the User's Manual of the Singapore Index on Cities' Biodiversity (Chan et al., 2014[5]) and describe the four selected indicators in more detail, presented in separate tables concerning the rationale behind them, the variables and calculation required, and the thresholds for the scores.

1.3.1 Indicator 1 – Proportion of Natural Areas in the City

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

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

calculating this indicator

Score

Based on the assumption that, by definition, a city comprises mainly manmade landscapes, the maximum score will be accorded to cities with natural areas occupying more than 20% of the total city area.

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

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

Rationale for selection of indicator

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

Variables and calculation

How to calculate the 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*) (based on Jaeger, 2000)

Source of data are satellite images

Score

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

- 0 points: < 200 ha
- 1 point: 201 - 500 ha

- 2 points: 501 - 1000 ha
- 3 points: 1001 - 1500 ha
- 4 points: > 1500 ha

1.3.3 Indicator 11 – Regulation of Quantity of Water

Rationale for selection of indicator

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

Variables and calculation

How to calculate the indicator?

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

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

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

Score

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

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

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

Rationale for selection of indicator

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

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

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

Variables and calculation

How to calculate the indicator?

Carbon storage and cooling effect of vegetation

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

Data sources include city councils and satellite images

Score

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

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

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

1.4 THE CITIES

The project was divided into two phases of both one year duration. The first year, also called prototyping, aimed at developing the approach to produce the four indicators, whereas the second year, the so-called roll-out, was used to implement the developed approach in several other cities.

In the prototyping phase, three cities were mapped, two of which are located in Europe (Barcelona and Tallinn), while the third one is situated in Canada (Edmonton). In the roll-out phase, seven cities were added, located on all continents except Asia (North America: Portland, South America: Buenos Aires, Africa: Addis Ababa, Australia/Oceania: Hamilton, Europe: Lisbon, Luxembourg, Stockholm; see the distribution in Figure 1-1).

Figure 1-1: Map of the distribution of the EO4CBI cities; in green colour the phase 1 cities, in grey colour the phase 2 cities (NB: Barcelona was mapped in both phases)

2 REQUIREMENTS, SPECIFICATIONS AND PRODUCTION

The user requirements have been collected by means of (i) a dedicated questionnaire that was sent to the city representatives and (ii) direct discussions by phone, Skype or e-mail.

The requirements were confined in a way as the products to be developed had to comply with the specifications given in the CBI User Manual as the major guideline for the technical production. However, in particular indicator 1 possesses some degree of freedom with respect to the definition of "natural areas". This flexibility aims at allowing cities from different geographic and climatic conditions to take into account local specificities. As described in the following chapter, this flexibility led to some issues during the development and production period. The specifications for the other three indicators are stricter, which does, however, not pose any major problem, and the new methodology for indicator 2 was actually developed by the project partner Concordia University.

The user requirements questionnaires also collected information on spatial scales required to comply with local needs, required formats to be provided, the correct local coordinate system and available ancillary data that might be helpful during the production and/or validation process.

Taking into account the boundary conditions of the CBI User Manual and matching those with the specific requirements of the cities, this information has been translated into detailed technical specifications that form the basis for the production, first of the prototype and then, considering the lessons learned, of the products for the roll-out.

2.1 MAJOR CHALLENGES

Several challenges came up when analysing the requirements and drafting the technical specifications. The most important question was related to indicator 1: what do cities understand as "natural areas" and which land cover/use classes best correspond to this definition?

The CBI working definition states that "natural areas comprise predominantly native species and natural ecosystems" (Chan et al., 2014). Natural ecosystems include all areas that are natural and not highly disturbed or completely man-made, e.g. forests, mangroves, freshwater swamps, natural grasslands, streams, lakes, etc. as well as parks with dominant native species. Also considered are restored ecosystems and naturalised areas.

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. It turned out that all cities have a broadly similar understanding of those areas, but show variations in certain details. It was, however, important to find a correspondence between the landscape elements and land cover classes that can be mapped from satellite data. The cities' definitions that cover the following land cover/use classes can serve as a common denominator:

- Forests (natural, unmanaged);
- Grasslands/meadows and fallow pastures;
- Wetlands; and
- Peatlands and bogs.

Differences, however, exist regarding coastlines, forests/shrubs, urban parks and riparian zones. Now, the major problem with these differences is the separation of those elements on the satellite images. While different land cover classes are oftentimes easy to differentiate, it is almost impossible to clearly detect land use characteristics, such as separating managed from unmanaged grasslands or forests. From that perspective, it would be recommended to fine-tune the user manual towards a better streamlining of the definition.

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, their 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.

A possible solution would be the integration of available local data into the production process, which was also encouraged by most of the user cities. This would, however, have consequences such as (i) the risk to produce a copy of the local data set (and at the same time very much deviate from a purely EO-based product, with the inherent risk of finally overselling EO data) and (ii) create an incomparability between the cities' products based on the varying availability of these local data sets (see further discussions on this potential issue in chapter 4). It was, therefore, decided to put the focus on the production of a basic product that is based on the satellite images and publicly available ancillary data, such as OpenStreetMaps (OSM). Consequently, the products will be comparable across cities and the project objective to "assess the potential of EO data to support the production of certain CBI indicators" will be better fulfilled. This decision is reflected in the technical specifications of indicator 1.

Another challenge during the production process was the availability of appropriate and suitable satellite images to be able to capture the various elements that constitute the different products. This was particularly pertinent for Barcelona and Edmonton in phase 1 of the project for which only mono-temporal data from SPOT-5 and RapidEye could be procured. Consequently, no phenological information could be used to distinguish different types of vegetation. Tallinn, however, was one of the test sites of the SPOT-5 Take 5 experiment during which the then upcoming Sentinel-2 sensor characteristics were simulated by the SPOT-5 satellite during its decommissioning phase. This allowed time series acquisitions so that Tallinn was covered by five cloud-free images between April and August.

The launch of the Sentinel-2 satellite in 2015 improved this situation by providing the opportunity to get EO time series free of charge. Therefore, for the cities that were mapped in phase 2 of the project phenological information was available which allowed for a better discrimination of certain vegetation types.

However, focusing on the free and multi-temporal Sentinel-2 data also implied that the image resolution (10 m ground resolution) remained at the edge of what is usually considered to be acceptable for urban analyses. This affected the capturing of smaller landscape elements, such as single trees, bushes or tree groups.

The following tables summarize the detailed technical specifications of the deliverable products. More details on e.g. delivery formats or projections are available in the project deliverables D1.2 and D2.1.

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

Product	**Land use/land cover maps**
Content	The product consists of land cover/use maps for the cities derived from high resolution EO data. The service comprises land cover maps for one reference year (mostly 2015 or 2016) derived from high resolution EO data. It includes - 5 major classes such as Agriculture; Buildings, roads, paved grounds, mining areas; Forest; Meadows, grasses and pastures; and Water. - Vegetated and not vegetated areas layer - Candidate natural areas levels 1 and 2 layers
Input data	Satellite data: • SPOT-5 • SPOT-5 Take 5 • RapidEye • Sentinel-2 OpenStreetMaps
Temporal Requirement	Phase 1 cities: 2014/2015 Phase 2 cities: 2015/2016

Table 2-2: 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.
Temporal resolution	Phase 1 cities: 2014/2015 (mono-temporal) Phase 2 cities: 2015/2016 (multi-temporal time series)

For the other indicators, the definition in the CBI User Manual is clearer and stricter. Indicator 2, for which the standard CBI calculation method has been developed by the project partner Concordia University (Deslauriers et al., 2017, based on Jaeger, 2000), measures the degree of connectivity of natural areas within cities. Connectivity is defined as "the degree to which the landscape facilitates or impedes movement among resources" and it can be "measured by the probability of movement between all points or resource patches in a landscape" (Taylor et al., 1993).

Table 2-3: 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 (or within the natural areas in the landscape/city).
CBI indicator	Total connectivity [ha]
Input data	GIS data layers of indicator 1 Ancillary data about barriers and connectors (e.g., roads, built-up areas, and semi-natural areas) which are used for the delineation of the fragmentation geometry and connectors. These ancillary data sets should ideally be provided by the cities; if they are not available, public data might be used instead (such as OSM).
Temporal Requirement	Phase 1 cities: 2014/2015 Phase 2 cities: 2015/2016

A high share of impervious surfaces poses a threat to cities and their citizens because of the increased amounts of water that are entering the cities during or immediately after strong precipitation events (e.g. flash or river floods). As such events are estimated to increase as an effect of climate change, there is a need to adapt to these risks. An increased proportion of vegetation allows to reduce the rate of water flow through cities, i.e. the share of permeable surfaces (indicator 11, see Chan et al., 2014) serves as an indication of the amount of vegetation in cities which allows to mitigate the risks.

Table 2-4: Technical specifications for product 1 of indicator 11 – Share of permeable areas

Product	**Degree of permeability**
Content	The service will comprise: 1. Map of predicted degree of permeable surfaces 2. Map of improved degree of permeable surfaces using open street maps (roads & buildings)
CBI indicator	Proportion of permeable areas in the city [%]: This product is the share of permeable areas in the city obtained as a percentage cover of the total area of the city.

Input data	Satellite data: • SPOT-5 • SPOT-5 Take 5 • RapidEye • Sentinel-2 OpenStreetMaps
Temporal Requirement	Phase 1 cities: 2014/2015 Phase 2 cities: 2015/2016

Indicator 12 was conceived as a proxy for the climate regulation functions of carbon storage and of the cooling effect of vegetation (see Chan et al., 2014). Plants capture carbon dioxide during photosynthesis, so it is assumed that the extent of tree canopy cover can serve as an indirect measure of carbon sequestration and storage. It was, however, stressed by several users that they do not see this assumption to be true as the amount of stored carbon would need a volumetric measure which is not provided by the extent of tree canopy cover relative to the city's surface area.

Table 2-5: Technical specifications for product 1 of indicator 12 – Tree canopy cover

Product	**Tree canopy cover**
Content	The service will comprise: 1. Map of predicted tree canopy cover 2. Map of improved tree canopy cover using land cover layers (agriculture, grasslands, meadows, pasture) and OpenStreetMaps (roads)
CBI indicator	Proportion of tree canopy cover in the city [%]: This product is the share of tree canopy cover in the city obtained as a percentage cover of the total area of the city.
Input data	Satellite data: • SPOT-5 • SPOT-5 Take 5 • RapidEye • Sentinel-2 OpenStreetMaps
Temporal Requirement	Phase 1 cities: 2014/2015 Phase 2 cities: 2015/2016

2.2 SOLUTIONS AND RESULTS

The key task for a successful implementation of the project was to find appropriate solutions to the main challenges that the project faced.

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 phase 1 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 and distinguish them in mono-temporal 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 to mono-temporal SPOT images. RapidEye images used for Edmonton have an advantage over the selected SPOT images due to the higher 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 mono-temporally only, it was necessary to support the analysis with time series Landsat images.

The availability of time series of Sentinel-2 images offers a great advantage in this regard. However, given the limitations in the spatial 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 (see for example the cross-comparison done for Barcelona in chapter 4). It should also be noted that the 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 greener compared to 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.

Having said that, urban applications are generally only possible with images of a high or very high spatial resolution. Table 2-6 provides an overview of the main characteristics of these two main types of satellite sensors as well as their application in the context of this project.

Table 2-6: Comparison of the different sensors and their application in the EO4CBI project (sources: Jacobsen, 2011; Zhang and Kerle, 2008)

Main characteristics	Description
Spatial resolution	High resolution (HR) sensors start at a ground sampling distance (GSD, or ground resolution) of 30m and go down to 1,5m. Very high-resolution (VHR) images have a ground resolution of 1m and smaller (Jacobsen, 2011). Most satellite sensors collect panchromatic (PAN) and multi-spectral (MS) images simultaneously; the resolution of PAN images is usually four times better than the one of MS images (e.g. SPOT-5: PAN 2,5m, MS 10m). EO4CBI: in the framework of the project, only HR sensors were used; however, RapidEye with 5m has a higher GSD than SPOT-5 and Sentinel-2 with both 10m (in the visible and near-infrared spectrum, S-2 also has 6 bands at 20 m in near and short-wave infrared and 3 bands at 60 m mainly for atmospheric corrections). In particular,

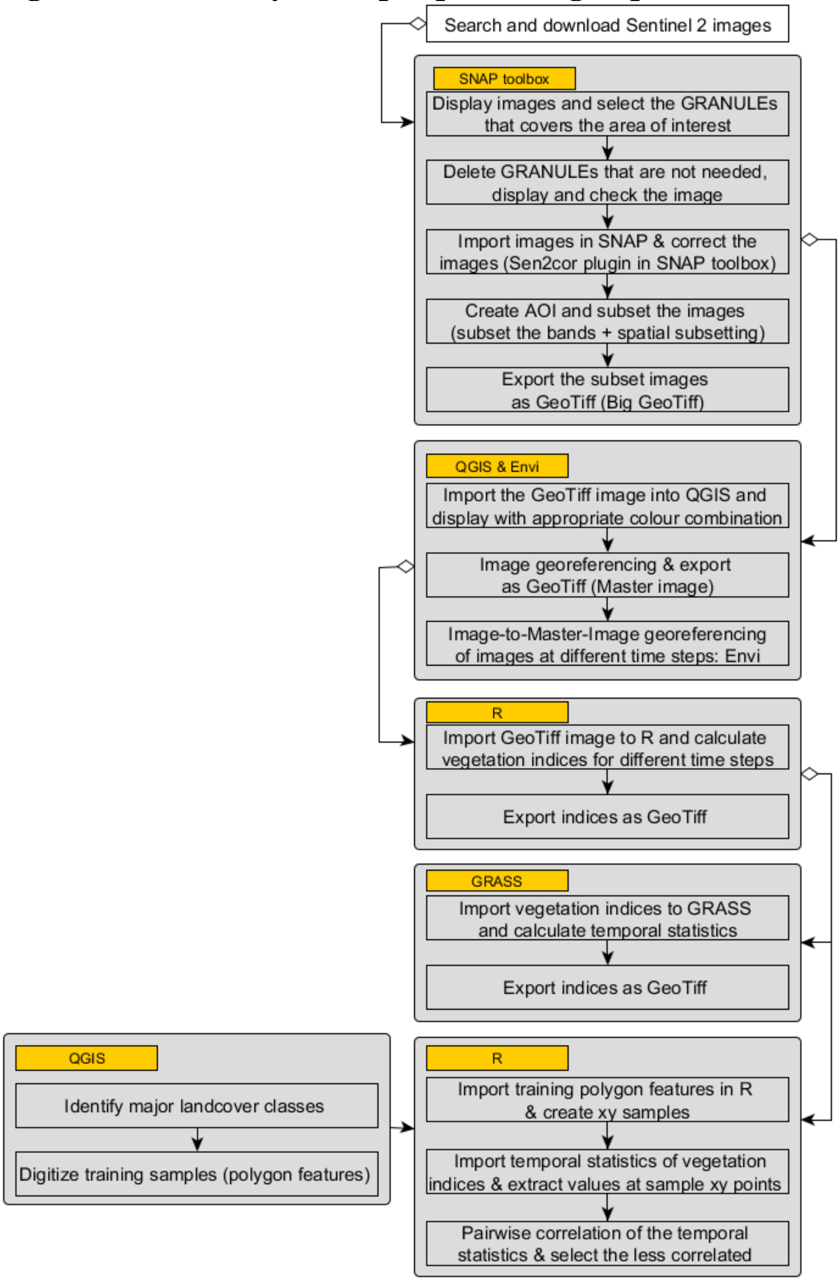
	SPOT-5 and Sentinel-2 are on the edge for urban assessments.
Spectral resolution	Most satellite sensors collect in the visible and near-infrared wavelengths (both PAN and MS); MS images oftentimes come in 3-4 spectral bands. Several sensors also collect up to short-wave infra-red, but these sensors are mostly high-resolution (not VHR). EO4CBI: while SPOT-5 has the rather typical 4 bands (green, red, near infrared, short-wave infrared), RapidEye possesses a 5th band (next to blue, green, red, and near infrared) which corresponds to the red edge and provides a great help to distinguish vegetation types. S-2 possesses 13 bands of varying spatial resolution (blue, green, red, near infrared at 10 m, 6 bands at 20 m in near and short-wave infrared, 3 bands at 60 m mainly for atmospheric corrections).
Temporal resolution	Revisit cycles of single near-polar orbiting satellites are usually 2-3 weeks. Exceptions are the sensors that can point their instrument off-nadir, however, as these images are oblique, their processing is more difficult. Deploying constellations of satellites helps increasing the revisit period up to daily repeat cycles. EO4CBI: while the average frequency of successful acquisitions of SPOT-5 and RapidEye does mostly not allow for time series to map phenology, S-2 provides a full coverage of the earth very 5-10 days, therefore time series are available.
Spatial coverage	In general, it can be assumed that the higher the resolution, the smaller the swath width; i.e. VHR sensors have a narrower swath width than HR sensors. EO4CBI: RapidEye and SPOT-5 have similar swath widths of 77 km and 60km, respectively. The swath of Sentinel-2 is with a width of 290km between four to almost six times wider than the other two satellites.
Pricing	Almost all VHR satellites are operated by commercial companies which sell the images mostly at commercial rates (exceptions are related to data provision in the framework of public agreements, such as in the context of disaster management). The commercialisation is also true for many HR sensors. Some exceptions employing an open data policy are the American Landsat and the European Sentinel

	satellites. EO4CBI: both SPOT-5 and RapidEye images are usually sold at commercial rates, while the Sentinel-2 data are free of charge.

In terms of indicator production, in particular the challenges of the definition of natural areas and the subsequent land cover/land use classification of the EO images and the usefulness of multi-temporal data had to be tackled. In general, the indicators (except indicator 2) were produced using standard EO image processing and classification techniques. First of all, and prior to production of the indicators, the Sentinel-2 images were corrected for atmospheric errors using the Sen2cor plugin in the SNAP toolbox[6] which converts level 1C to level 2A product. The corrected level 2A images were georeferenced using the free GIS software QGIS to assign real-world coordinates to each pixel of the images. The time-series datasets were georeferenced to a master image (image-to-image georeferencing in IDL-ENVI and QGIS) and stacked for classification in the free software environment R 3.2.5.

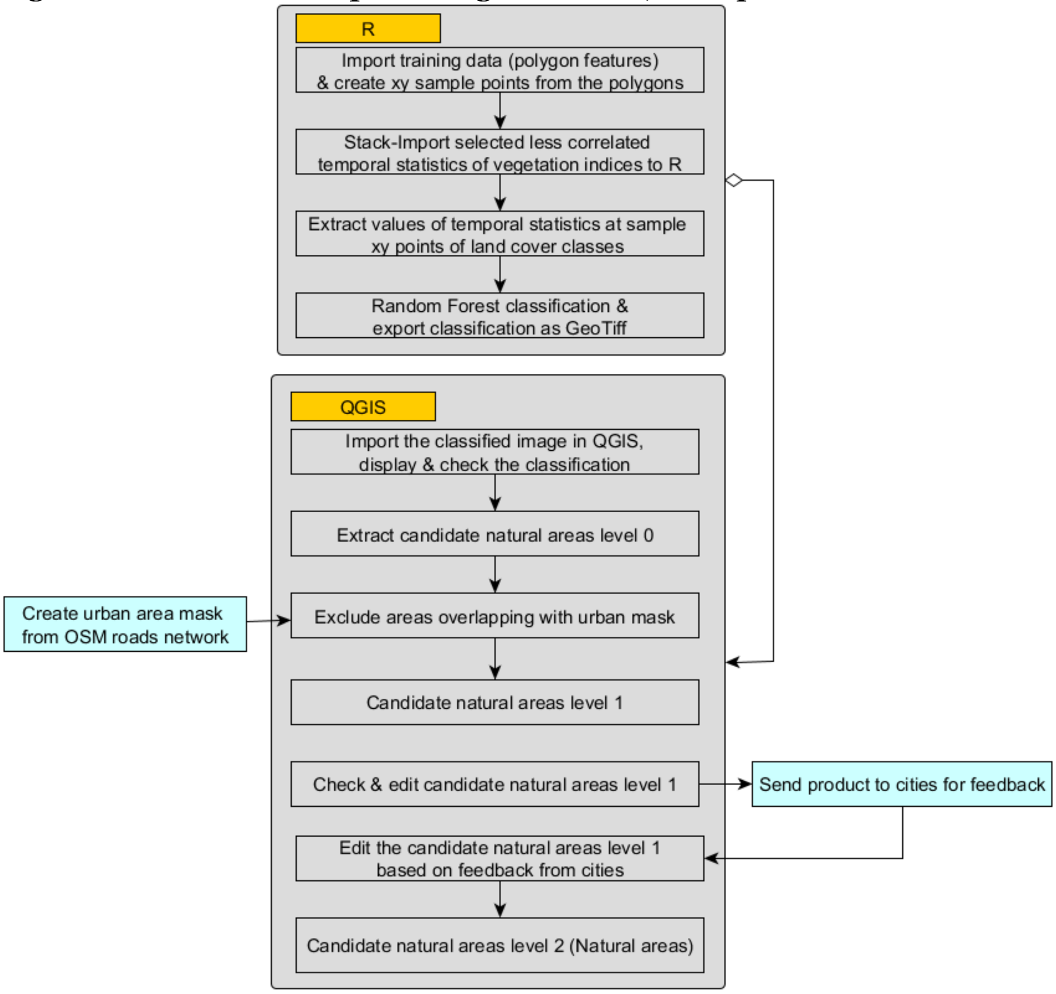
[6] http://step.esa.int/main/toolboxes/snap/

Figure 2-1: Summary of the pre-processing steps for Sentinel-2 images



Afterwards, random forest classifiers (indicator 1; Breiman, 1996; Breiman, 2001) and boosted regression trees (indicators 11 and 12; e.g. Elith et al., 2008) based on sample sites were used before the final CBI value could be extracted. In the Random Forest 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). The 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).

Figure 2-2: Workflow for producing indicator 1, basic product



As already explained in the previous chapter, the production of indicator 1 was subdivided into a *basic* and an *advanced* product. The basic product is the main product for indicator 1 and solely derived from satellite data and other publicly available ancillary data (such as OpenStreetMaps; see also Figure 2-2). Due to the characteristics of the input data it can achieve a certain depth of information and accuracy, but is relatively inexpensive due to the large coverage and low costs of the satellite data (the new Sentinel-2 data are free of charge). The use of satellite data also makes the product objective and repeatable which is an important factor for the implementation of monitoring activities. On top of the basic product an advanced product can be created (if requested and feasible from a data availability perspective) to fulfil some additional needs of the users. In the context of this project, the latter was only produced for Barcelona (see cross-comparison of results in chapter 4).

Boosted Regression Trees (BRTs) (Elith et al., 2008) were used to predict the degree of imperviousness (indicator 11, see Figure 2-3) and the percent of tree canopy cover (indicator 12, see Figure 2-4) from

Sentinel-2 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).

Figure 2-3: Workflow details for the computation of indicator 11

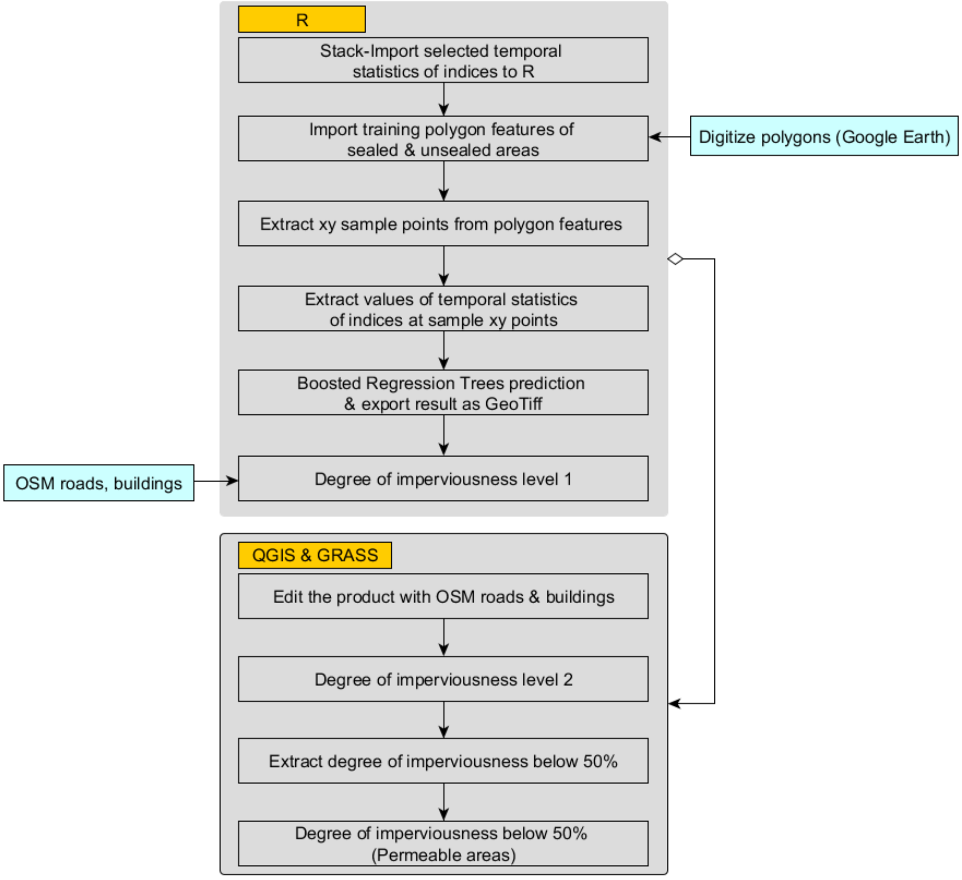
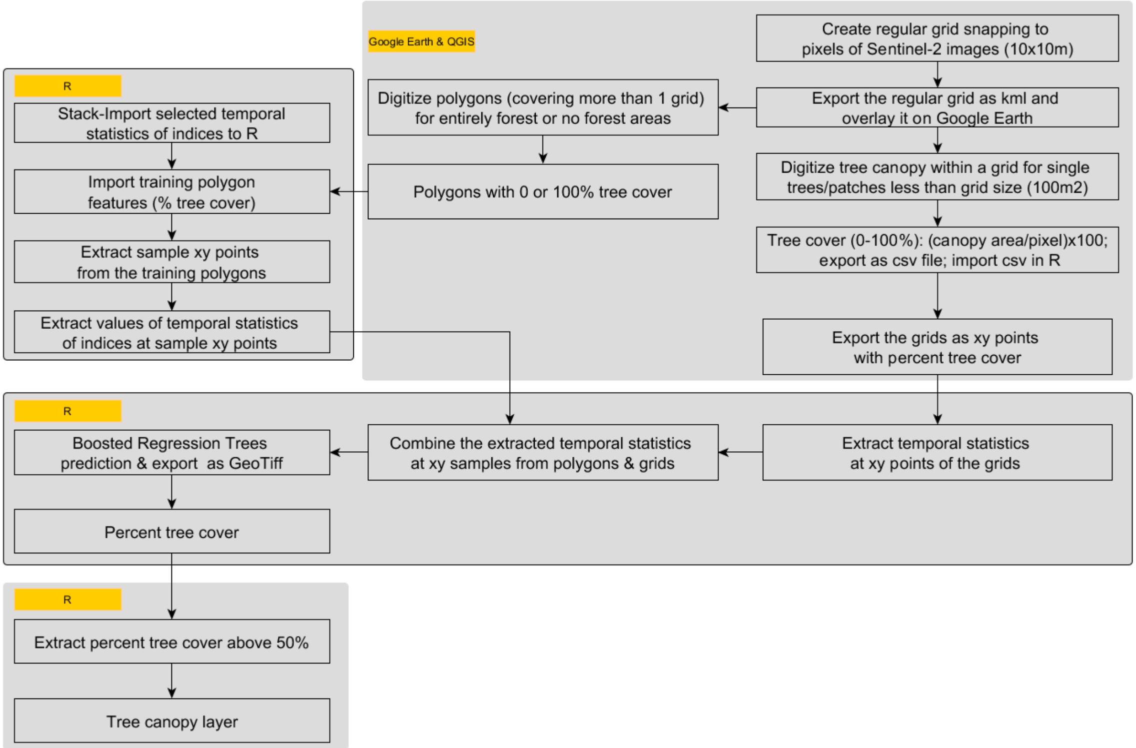


Figure 2-4: Workflow details for the computation of indicator 12



The indicator 2 production differs from the other three indicators because it uses a completely different approach. The effective mesh size is a landscape metric (Jaeger, 2000, Jaeger et al., 2008, Deslauriers et al., 2017) that employs the EO-derived indicator 1 map as one of the input parameters (next to barriers and connectors data).

During a user workshop, indicator 2 and its implementation were criticised by the City of Edmonton regarding four aspects. These were resolved in a discussion between city representatives and the researchers from Concordia University on May 3, 2017:

(1) Is it appropriate to apply a landscape metric (effective mesh size “m_{eff}”) to measure connectivity that was originally developed for assessing fragmentation? - Response: The "effective mesh size" was developed originally independent of the definition of "connectivity" by Taylor et al. (1993). It was later discovered that it corresponds directly to this definition by Taylor et al. (1993). Accordingly, this metric is very appropriate for measuring landscape connectivity.

(2) Does it make sense to keep the denominator of the “m_{eff}” constant for the evaluation of changes over time/trends? - Response: The area used in the denominator (A_{total}) is the total area of the landscape for which the level of connectivity is measured. When a different area is used for different time steps, then the results describe the levels of connectivity of two different landscapes. To monitor the degree of connectivity in the same landscape, the same A_{total} needs to be used to account for the fact that some connectivity is lost with the shrinkage or destruction of habitat patches. The same logic needs to be applied when measuring the degree to which connectivity increases over time due to the

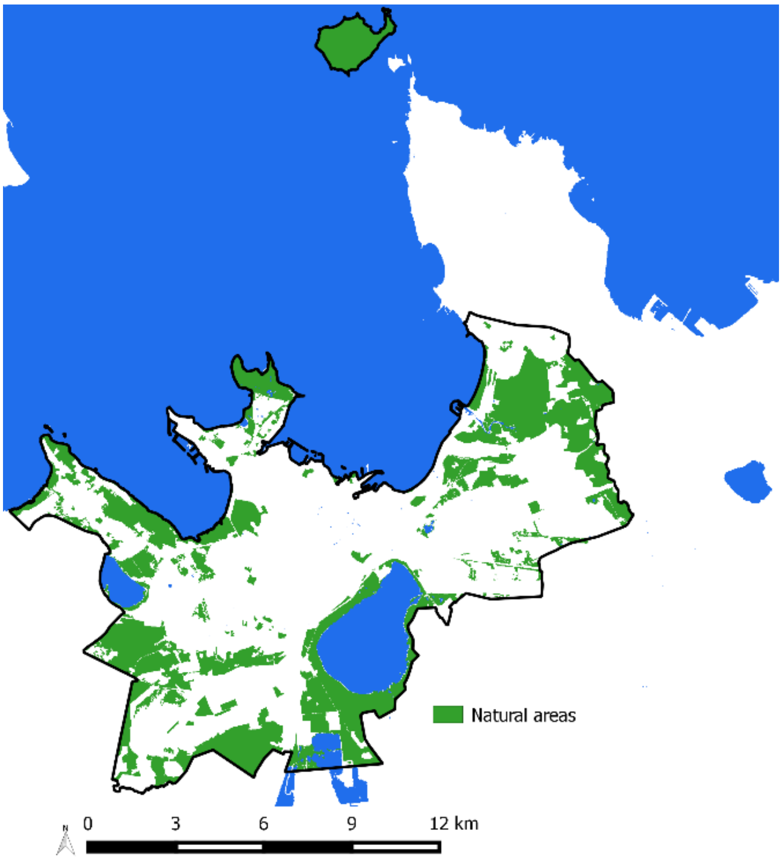
creation of new natural areas (see Deslauriers et al., 2017 for more detailed information).

(3) It was recommended to better differentiate between functional and structural connectivity and to include crossing structures that allow animals to overcome barriers. - Response: It is possible to also measure functional connectivity, but such methods require much higher efforts, e.g., telemetry studies of wildlife movement, which may be intimidating to city planners, whereas the current Indicator 2 is much more user-friendly (Deslauriers et al., 2017). It provides meaningful results without compromising practicality. Wildlife passages can be included in the formula for effective mesh size (Jaeger 2002, 2007). However, it is usually not known what values should be assigned to the connectivity strength of these crossing structures, and therefore, are currently not possible to include in the calculations.

(4) It was suggested to demonstrate the practical applicability in an example. This was done using the golf course Meadowbrook in southwestern Montreal (Deslauriers et al., 2017, section 4 "Connectivity analysis for the proposed greenway network of southwestern Montréal"). The study focused on changes in connectivity that would result from the loss of particular natural areas as a result of increased urban development. Future scenarios were established by identifying natural areas that could be preserved or restored to increase connectivity and to offset the effect of developing Meadowbrook in southwestern Montréal. The results showed that Indicator 2 is suitable for comparing current and potential future connectivity scenarios and for predicting changes incurred by the addition or removal of particular patches.

The maps and tables below present one exemplary result for each of the indicators.

Table 2-7: Results for indicator 1, Tallinn (SPOT-5 Take 5)

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

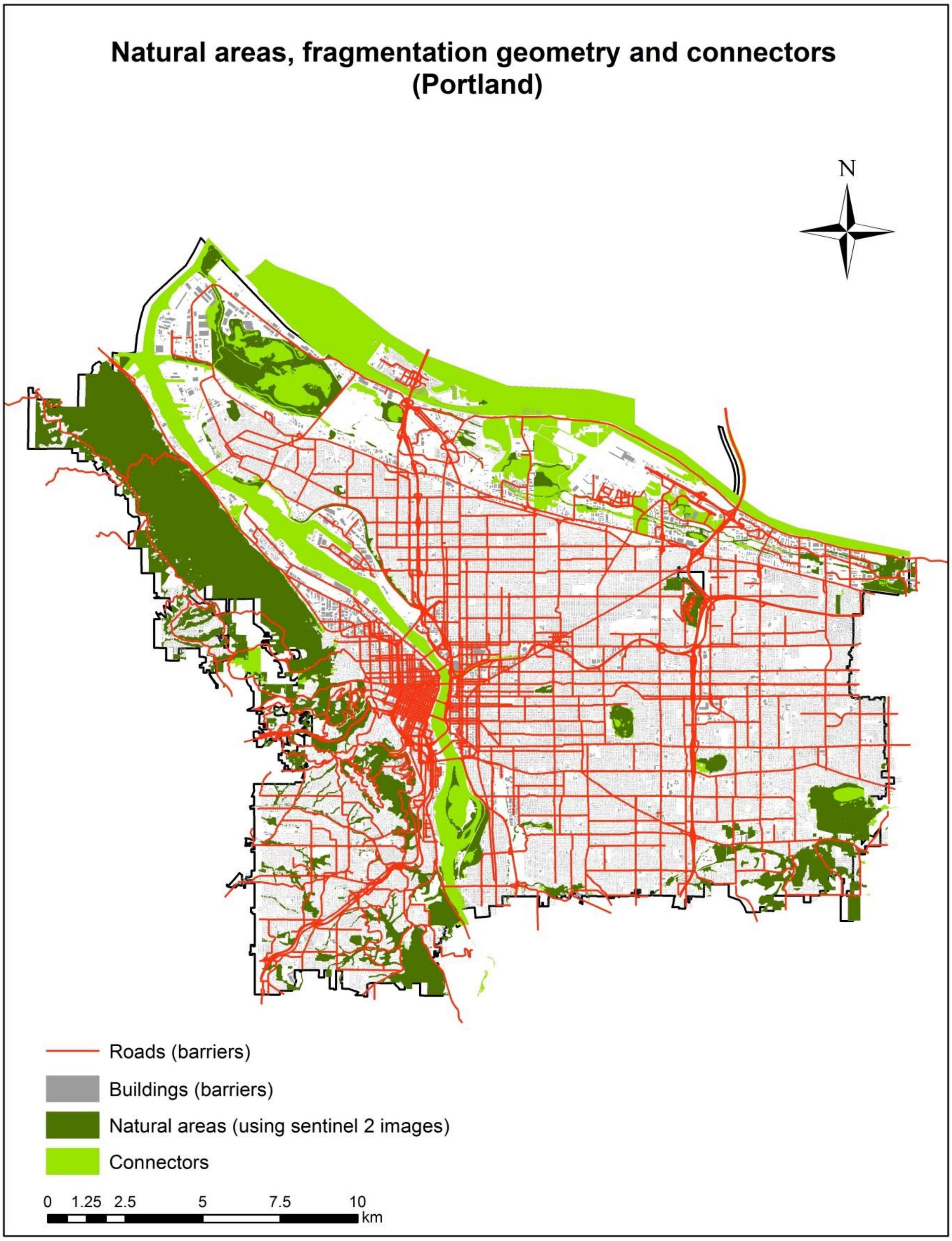


Figure 2-5: Natural areas, fragmentation geometry, and connectors in Portland (natural areas based on Sentinel-2)

Table 2-8: Results for indicator 2, Portland

Connectivity Analysis (Indicator 2 of CBI) Portland	With barriers/ Without connectors	With barriers/ With connectors (Including rivers)	With barriers/ With connectors (Excluding rivers)	Without barriers/ Without connectors	Without barriers/ With connectors (Including	Without barriers/ With connectors (Excluding

					rivers)	rivers)
	Scenario 1	Scenario 2	Scenario 2'	Scenario 3	Scenario 4	Scenario 4'
Total Connectivity (ha)	Option A: 533.99 Option B: 543.90	Option A: 538.06 Option B: 548.05	Option A: 536.75 Option B: 546.71	1769.49	2661.46	1788.12
Intra/Within-Patch Connectivity (ha)	Option A: 520.45 Option B: 530.12	Option A: 520.45 Option B: 530.12	Option A: 520.45 Option B: 530.12	1322.68	1322.68	1322.68
Inter/Between-Patch Connectivity (ha)	Option A: 13.54 Option B: 13.79	Option A: 17.61 Option B: 17.94	Option A: 16.30 Option B: 16.60	446.81	1338.78	465.44
Total area of Natural Areas (ha)	Option A: 6010.49 Option B: 5900.91	Option A: 6010.49 Option B: 5900.91	Option A: 6010.49 Option B: 5900.91	6010.49	6010.49	6010.49

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	2 points (533.99 ha)

The scenarios presented in the result tables for indicator 2 allow for interesting comparisons. They identify the contribution of connectors (for Portland even with and without the river) to connectivity and the reduction in connectivity due to the barriers in the city. For example, in scenario 4 (without barriers with connectors including rivers), connectivity is almost 5 times as high as in the standard scenario 1, whereas the contribution of connectors in scenario 2 (with barriers considered) is much lower, only about 4 ha. This indicates the large fragmentation effect of the barriers that are present in the city.

Table 2-9: Results for indicator 11, Edmonton (RapidEye)

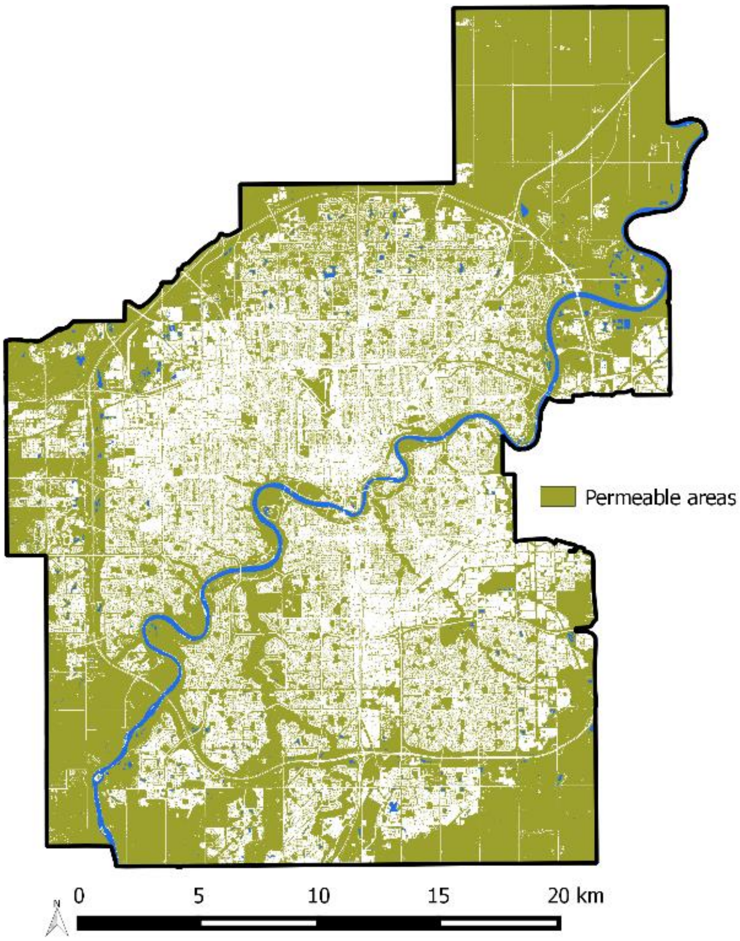
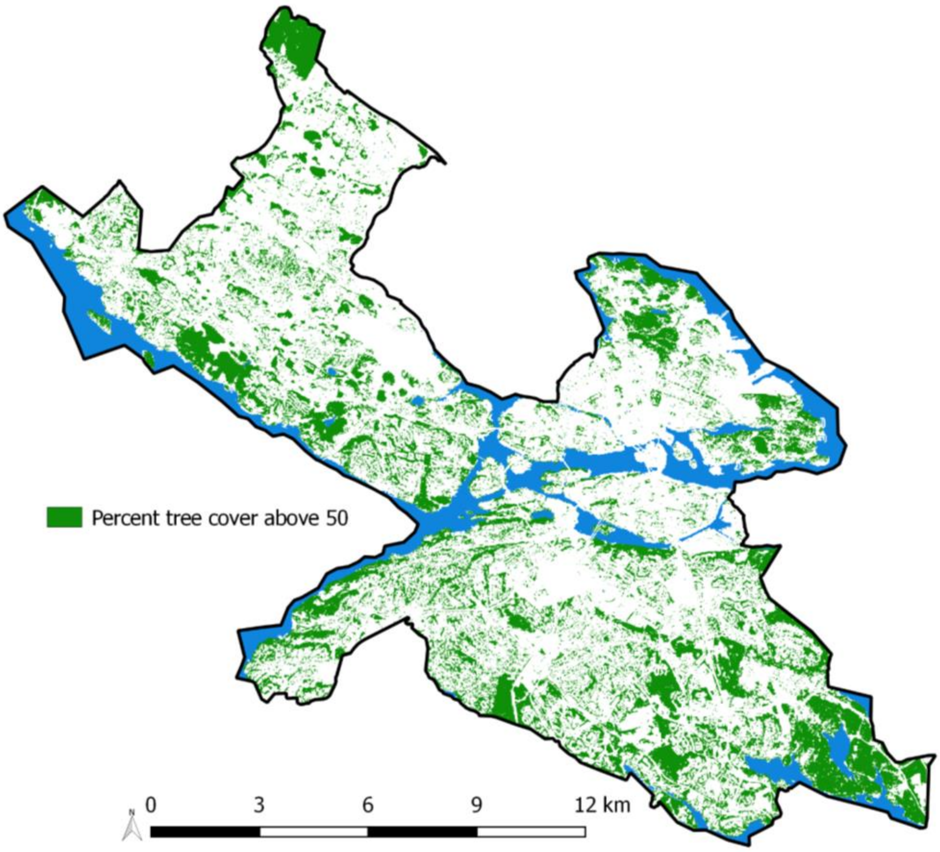
Map of permeability	
CBI value/score	2 points (61% permeable area)

Table 2-10: Results for indicator 12, Stockholm (Sentinel-2)

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

3 QUALITY AND USER FEEDBACK

3.1 CONCEPTUAL CONSIDERATIONS

The only 100% accurate representation of reality is, after all, reality itself. Anything else is, to a greater or lesser degree, an abstraction of reality, being less than 100% accurate. In this sense, land cover maps are an abstraction of the Earth's land surface at a given point in time, space, nomenclature and scale, with a defined level of accuracy.

To know how much information is lost – how accurate the map is - we need to systematically assess their quality. Map quality control in general follows a comprehensive validation protocol and encompasses two main aspects: i) the checking of the logical consistency and conformance to technical specifications, and ii) the accuracy assessment of the positional accuracy and the thematic accuracy (incl. completeness & correctness), as well as temporal accuracy (i.e. validity of data with respect to time).

The main objective of accuracy assessment is to derive a quantitative description of the quality of geospatial land cover and land monitoring maps. An accuracy assessment itself consists of three consecutive steps in the validation protocol: sampling design, response design and analysis[7].

The Committee on Earth Observation Satellites (CEOS) Land Product Validation (LPV) sub-group on land cover[8] has developed a series of "recommendations for the accuracy assessment of global land cover maps". These guidelines have been considered for the validation of the products.

In the EO4CBI project, three mapping products are to be validated:

- Binary maps of the proportion of natural areas (natural/not natural);
- Binary maps of permeable surfaces (permeable/not permeable); and
- Binary maps of tree canopy cover (tree cover/no tree cover).

Two different levels of quality information are available. The first is the quantitative level of product accuracy derived by means of a point-based validation of the three indicators 1, 11 and 12. Indicator 2 underwent a different, i.e. qualitative accuracy assessment. It includes the cross-checking of the final output by selecting each individual group of connected patches and verifying if they are correctly connected by visually comparing them against the barriers and the 50 m buffers of natural areas. In addition to the quality control during the spatial analysis, the final products of indicator 2 were also evaluated by validating the accuracy and consistency of the connectivity values through the comparison of the four scenarios (see the long description in the Product Validation Plan). The values for total connectivity and between-patch connectivity from scenario 1 to 4 usually exhibit an increasing trend.

[7] Stehman, S.V. & Czaplewski, R.L. (1998). Design and analysis for thematic map accuracy assessment: fundamental principles. Remote Sensing of Environment. 66, 331-344.
[8] http://lpvs.gsfc.nasa.gov/

In practice, for all products except indicator 2 a stratified point sample is used for each of the pilot cities and products. The points are interpreted by an independent operator and the typical accuracy parameters are provided (overall accuracy as acceptance criterion, errors of commission and omission, mean absolute error as well as uncertainty). A potential bottleneck for the execution of the validation was the availability of suitable local reference data, which could be overcome by the use of web-based tools such as Google Earth. However, online sources like Google Earth have limitations such as unknown image acquisition dates or time difference between the images and the product to be validated.

The second piece of information on the quality of the products is the user utility assessment that was collected by means of a questionnaire and provides some standardised information on the product quality in relation to the user requirements as well as free-text feedback on various quality-related aspects.

Product quality is not an absolute measure, but a relative one because it depends on the intended use of the product. Based on the user needs, quality can have many different facets which need to be taken into account during any validation or quality control measure. In several cases, it is impossible for a single product to meet all the quality criteria; in some special cases, certain criteria may even be mutually exclusive. The following collection of criteria has been elaborated by the FP6 GNU project and intends to increase the general understanding on the users' perspective on product quality (see Figure 3-1). Product design should aim at covering as much of it as is feasible and realistic.

- Support the users' work – integration in users' procedures, fulfils users' needs
- Applicability – completeness, timeliness, resolution
- Sustainability of the data systems – INSPIRE compliant, interoperability, meta data
- Service orientation – transparent production chain
- Reliability – known production method, independent quality control, limitations specified

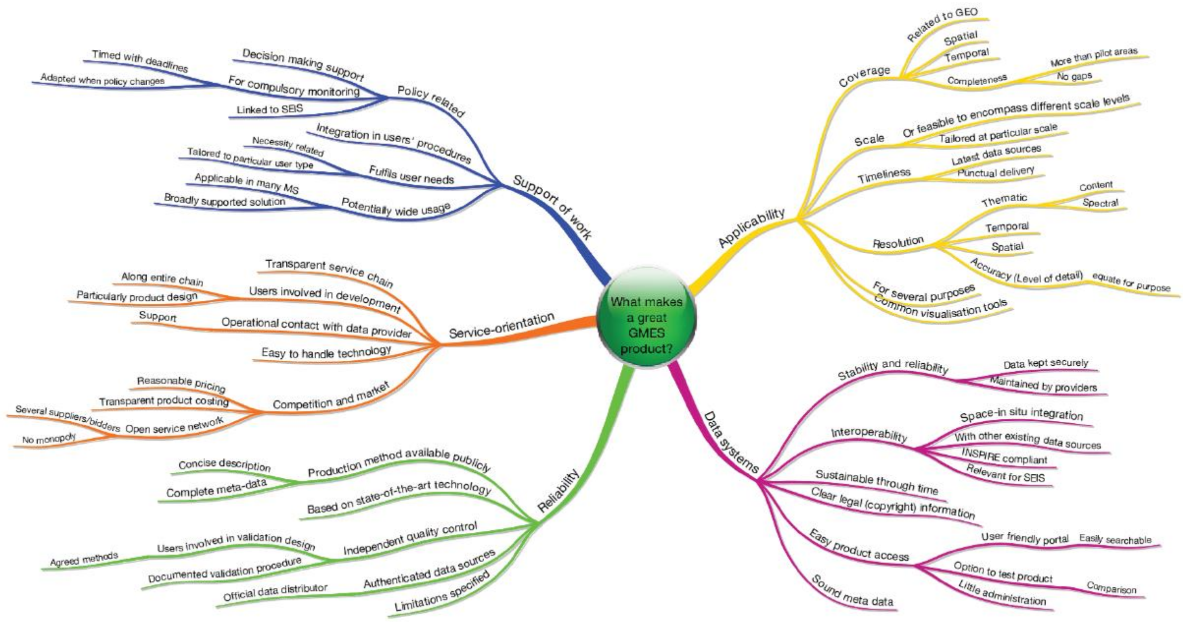


Figure 3-1: Quality criteria, as collected by the FP6 project GMES Network of Users (GNU)

3.2 ACCURACY STATISTICS

Looking at the product validation, the overall the targeted acceptance values (i.e. overall accuracy > 85 % and errors of commission and omission < 15 %) were achieved (see Figure 3-2).

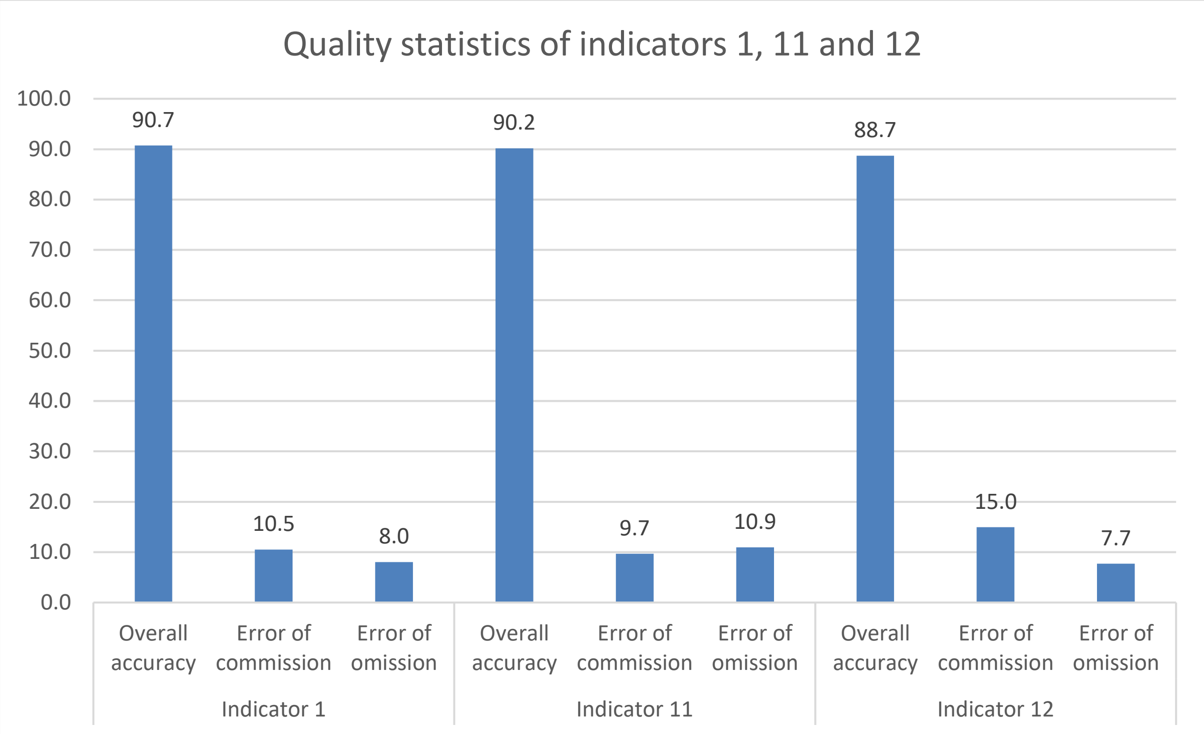


Figure 3-2: Quality statistics of indicators 1, 11 and 12 [%]; average of all cities

The picture gets a bit more nuanced, though, as soon as the results for the individual cities are evaluated (see Table 3-1).

For indicator 1, the range of overall accuracy statistics goes from 82 % in Hamilton to 97.6 % in Lisbon. Two cities are below the target accuracy, but not very far. Regarding the errors of commission and omission, each time two values stand out: 25 % error of commission in Barcelona (municipality) using the Sentinel-2 data and 17 % in Buenos Aires; 21 % error of omission in Hamilton and 18.2 % in Edmonton.

Concerning indicator 11, the overall accuracy values range from 85 % in Luxembourg-South to 96.5 % in Portland. Three cities are slightly above the threshold of 15 % for the error of commission, i.e. Buenos Aires and Hamilton with 17 % and Barcelona (SPOT-5) with 16.8 %. As to the error of omission, 27 % in Luxembourg-South stand out which is related to the difficulties in correctly classifying grasslands into more and less natural ones.

Indicator 12 is the indicator with the highest variability in the accuracy statistics. The overall accuracy ranges from 96 % in Addis Ababa to 69.5 % in Buenos Aires. The error of commission is very high in Buenos Aires with 58 % and still too high in Hamilton with 26 %. The errors of omission are slightly too high in Portland and Stockholm with both 19 %. The very low overall accuracy in Buenos Aires is almost entirely driven by the many commission errors, i.e. the wrong classification of trees when there haven't been any. For the most part, this is related to the spatial resolution of the satellite data and the mixed signature of green and non-green areas. Buenos Aires contains a lot of small and very small patches of trees and oftentimes, the validation point covers an area just next to the tree or tree group, but still within the same EO data pixel.

Table 3-1: Summary of accuracy statistics

	Indicator 1			Indicator 11			Indicator 12		
	Overall accuracy	Error of commission	Error of omission	Overall accuracy	Error of commission	Error of omission	Overall accuracy	Error of commission	Error of omission
Barcelona (SPOT-5)*	93.8	4.4	8.0	89.5	16.8	4.3	90.2	11.2	8.4
Edmonton	86.2	9.5	18.2	96.3	4.3	3.0	91.9	11.9	4.5
Tallinn	89.8	11.2	9.2	90.6	3.3	15.8	90.3	6.6	12.8
Addis Ababa	95.0	5.0	5.0	88.0	12.0	12.0	96.0	6.0	2.0
Barcelona (S-2)	84.5	25.0	6.0	90.9	11.2	17.2	94.5	8.0	3.0
Buenos Aires	90.5	17.0	2.0	88.0	17.0	7.0	69.5	58.0	3.0
Hamilton	82.0	15.0	21.0	86.0	17.0	11.0	84.0	26.0	6.0
Lisbon	97.6	4.8	0.0	93.0	6.0	8.0	94.0	9.0	3.0
Luxembourg	91.5	9.0	8.0	85.0	3.0	27.0	94.0	8.0	4.0
Portland	95.0	8.0	2.0	96.5	3.0	4.0	87.0	7.0	19.0
Stockholm	92.0	7.0	9.0	88.0	13.0	11.0	84.0	13.0	19.0
SUM	997.8	115.9	88.4	991.8	106.6	120.3	975.4	164.7	84.7
Average	90.7	10.5	8.0	90.2	9.7	10.9	88.7	15.0	7.7

(NB: for Barcelona only the values for the municipality are provided)

3.3 USER FEEDBACK

An evaluation of the feedback provided by the city representatives can be made both quantitatively, using the section of the user questionnaire that contained tick boxes to vote for the "value" of the product (low, moderate or high) with respect to the general fitness-for-purpose of the CBI products with respect to the cities' needs as well as certain parameters (thematic content, spatial resolution, temporal resolution and spatial coverage), and qualitatively by analysing the comments in the free-text sections.

For the statistical evaluation of the tick boxes, points were assigned for the three levels "low" (1 point), "moderate" (2 points) and "high" (3 points). The points were summed up for (i) each indicator to identify the indicator with the highest benefit to the users, and (ii) per quality criterion. It has to be noted that there has been no feedback from Addis Ababa, so the points do only come from nine of the 10 cities.

First of all, all cities considered the products to be of moderate (4 cities) to high (5 cities) relevance with respect to the needs of the cities and city institutions. Looking at the total number of points for the different indicators (see Figure 3-3), indicator 11 (share of permeable surfaces) possesses the highest value, followed by indicator 12 (tree cover density). Assumedly, the higher score, in particular compared to indicator 1 (share of natural areas) is related to the fact that cities usually do not have any information on those values which makes the CBI data quite valuable. On the other hand, for the share of natural areas, oftentimes very detailed local data are available which is of better quality than the CBI data derived from rather coarse resolution satellite data (at least compared to the local data often derived from aerial images and field work). Indicator 2 gets the lowest overall value, but the project partner Concordia University clarified the issues with the city officials from Edmonton who were the most critical (see chapter 2.2).

In particular, this comparably low spatial resolution of the EO-derived data is also visible in the ranking of the points for the different quality criteria (see Figure 3-4), where the spatial resolution is clearly behind the other criteria. However, what cities value, also for indicator 1 (see previous paragraph), is the temporal resolution, i.e. the potential for getting annual updates of the indicators based on Sentinel-2.

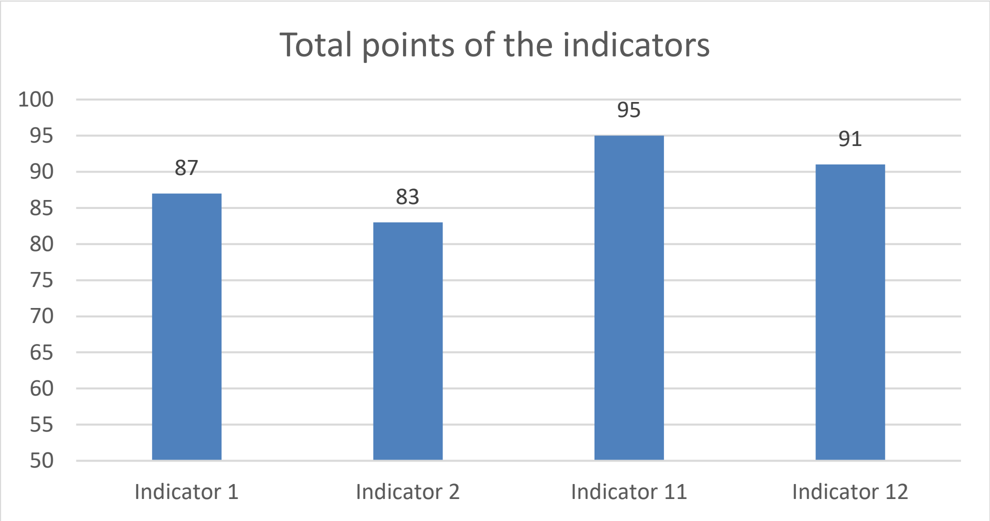


Figure 3-3: Total points of the indicators, based on the tick boxes (of a possible maximum of 108 points[9])

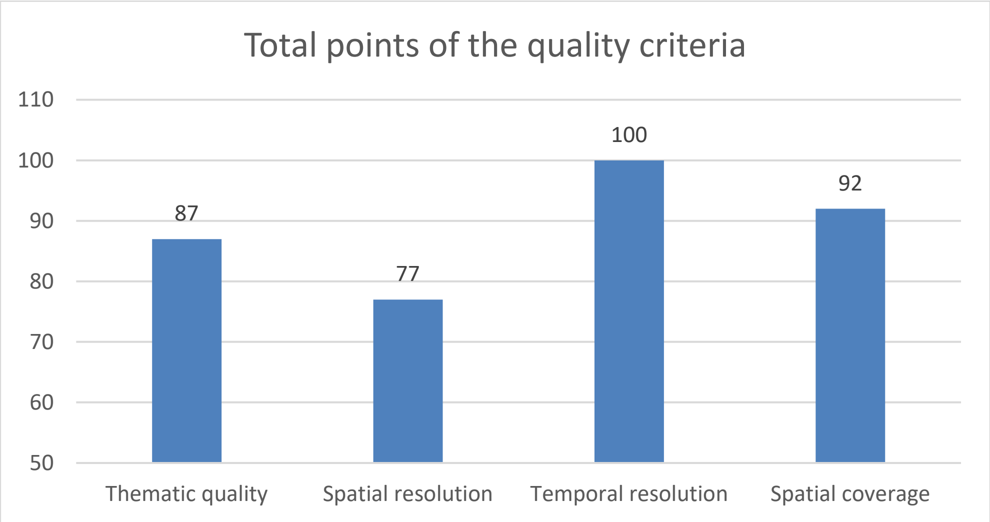


Figure 3-4: Total points of the quality criteria, based on the tick boxes (of a possible maximum of 108 points[10])

Next to the user questionnaires, more detailed verbal feedback was collected during the eo4cbi User Forum that was held on 13 March 2017 in Barcelona. A selected number of cities could be invited to allow for an animated discussion on the project, the different indicators and the CBI as a tool.

[9] Nine cities (excluding Addis Ababa) giving a maximum of three points (high value) for four indicators.
[10] Nine cities (excluding Addis Ababa) giving a maximum of three points (high value) for four quality parameters.

4 DISCUSSION AND RECOMMENDATIONS

This chapter discusses the project's achievements, but also the issues it had to deal with and the lessons learned from the technical implementation of the project on the one hand and the user feedback on the other.

In the previous chapters, several challenges and issues were identified and solutions described. It is, however, necessary to discuss some of these items further, both on the individual level of the indicators and the level of the CBI as a tool and concept. This also includes a discussion on the EO data used and their usefulness in urban biodiversity applications, i.e. trying to reply to the question "which sensor brought the best results". To approach this discussion, the CBI results for Barcelona (specifically, the indicators 1, 11 and 12), the only city that was mapped with different sensors, were cross-compared and analysed. The technical discussion also includes a reply to the initial criticism of some user cities towards indicator 2 (see chapter 2.2). Next to the more technical discussion, the CBI as a conceptual tool will also be assessed regarding its elements, implementation and uptake.

Simply put, at the beginning of the project the cities for the most part expected from the project to get information on the location of their natural assets. In addition, in particular the cities with existing good local data wanted to learn about the usefulness of satellite data in the context of producing certain CBI parameters and the monitoring of the aforementioned natural assets. The resulting data the cities received from the project were in general perceived as a good information source; also, the validation results indicate that the products are to a large extent of acceptable quality (see the analysis in chapters 3.2 and 3.3). However, the devil is in the details, i.e. there exist nuances in this overall perception that need to be taken into consideration.

Including the qualitative information contained in the user feedback questionnaires, some very valuable conclusions can be drawn from this user assessment:

- Confirming the overall evaluation of the CBI products (moderate to high), most cities explicitly commented on the good potential of the approach which could be very helpful for cities, either for all or some of the indicators. Tallinn stated that due to the unavailability of local data, the CBI products would be very useful for them; the same statement came from Buenos Aires. Edmonton and Stockholm particularly highlighted the potential relevance of indicators 11 and 12.
- Most of the cities stated that local data with a higher resolution would exist, in particular related to indicator 1 (share of natural areas), but they also acknowledged the high costs involved in creating these local data.
- On the other hand, the high potential of the temporal resolution of Sentinel-2 data was stressed, i.e. the possibility to get annual updates of the data. That being said, several cities suggested the option to create a (cost-intensive) high resolution baseline that could be annually updated with the Sentinel-2 derived information so that such high-resolution baselines would only be

required every 10-20 years.

- Several cities highlighted the importance of linking the EO-derived information to ground truthing/field verification to confirm or correct the EO-derived estimates by field work.
- Even though the CBI was conceived as a self-assessment tool, the advantage of getting comparable data over a large number of cities using EO data was positively evaluated; so, there is an interest in having the possibility to compare one city to peer cities.
- Several cities also expressed their strong interest in having not only information from one point in time, but establishing a monitoring capacity which could make use of EO data.
- More specifically, some cities expressed the need for having more precise definitions of the different indicators; it was also highlighted that the detection of trees would be difficult with EO data of 10 m resolution and that knowledge of local habitats would be beneficial for increasing the accuracy of the products.

To pick one of the points from the list above: should the CBI be a self-assessment tool only or would it also be suitable for a comparison of cities? Although some cities are interested in comparing themselves to peer cities, most cities argued that it should rather be a self-assessment tool as it was conceived originally; in particular, as city conditions are so different that it will be hard to compare them anyway. This would, consequently, also remove some of the problems with creating incomparable indicator 1 data caused by the varying definitions (see chapter 2.1). As most cities agreed that it would in any case be much more interesting and relevant to compare development trends over time (i.e. monitoring) than the inventory data, each city could start from a different point. As a solution, it could therefore be suggested to produce a city baseline as a starting point for the monitoring that is as good as possible to capture trends using very high-resolution information and all kinds of ancillary data (knowing that this would be a costly undertaking) and employ EO data and their analysis as an inexpensive means for backdating (i.e. looking into the past) and monitoring (see also the roll-out analysis in chapter 5.2).

In direct relation to the use of the CBI as a tool, the project partners agree with a majority of the cities that the current scoring system of the CBI is very problematic for several reasons and does not help the assessment and subsequent information to cities' policy- and decision-makers. It is argued that, for one, the value ranges of the classes make it almost impossible to improve on the score except if you are already pretty close to the threshold between two classes. Moreover, related to the first issue, the number of classes is too low. Third, the maximum threshold to get into the highest scoring for indicator 1 is too low as well. It is recommended to switch to at least a relative scale and, ideally, to a continuous scale to improve the scoring and make it more meaningful (see also chapter 5.1).

The discussion of the more technical issues is subsequently done along the cross-comparison of the CBI results for Barcelona. As previously mentioned, the municipality of Barcelona served as a specific test bed because it was mapped in both project phases based on two sensors (mono-temporal SPOT-5 as well as multi-temporal Sentinel-2). This allowed for a comparative analysis of the indicators which lead to some conclusions on the advantages and disadvantages of the sensors employed (see also Table 2-6 in chapter 2.2). Both, the municipality and the project partners performed an analysis of the results of the two phases and compared the EO4CBI spatial data of all indicators with locally available data sets. Indicators 1, 11 and 12 were analysed spatially and statistically concerning overlapping areas as well as errors of commission and omission, i.e. areas which have only been mapped by either the city or the project. It is important to highlight in this context that, comparing the outcomes of the project validation (see Table 3-1) with the cross-comparison carried out by Barcelona Regional (see the following paragraphs), the differing results of the quality control are to be explained by the difference in the methodology of controlling the quality of the data (point-based sampling by the project, full spatial overlap by the city).

The analysis looks on the one hand at the CBI indicator values, i.e. the percentage values for the indicators 1, 11 and 12 (see Figure 4-1), and on the other hand at the overlapping, i.e. the common areas of the products from the city and the project, as well as the areas which have only been mapped by one of them, and provides a comparison between the two project phases (i.e. between the results based on SPOT-5 and Sentinel-2). Figure 4-2 shows the absolute areas (in [ha]) for the three categories "overlap", "error of commission" and "error of omission" for the three indicators 1, 11 and 12. The red coloured bars present the SPOT-5 based values, whereas the blue coloured bars show the Sentinel-2 based values.

For indicator 1, two values that were introduced in chapter 2.1 are presented, i.e. (i) the basic product (for the most part derived from EO data alone) and (ii) the advanced product (in the case of Barcelona enhanced by the inclusion of local data in phase 1 and the integration of user comments (but no local data) in phase 2).

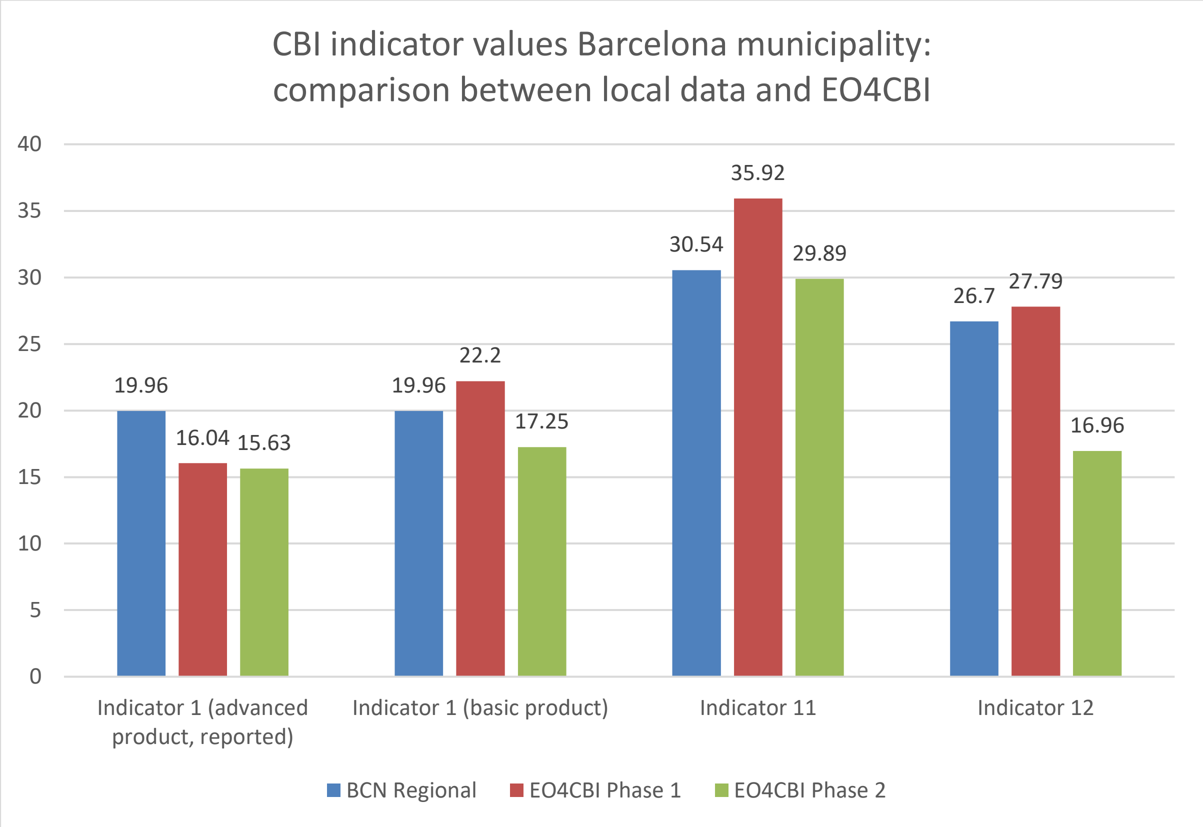


Figure 4-1: Comparison of the CBI indicator values using local data and EO4CBI results; Barcelona municipality

<u>Note:</u> For indicator 12, Barcelona has used more than one scenario and, by consequence, provides a range of values from 22.8 % to 26.7%. the relevant bar in the diagram presents the maximum of these values.

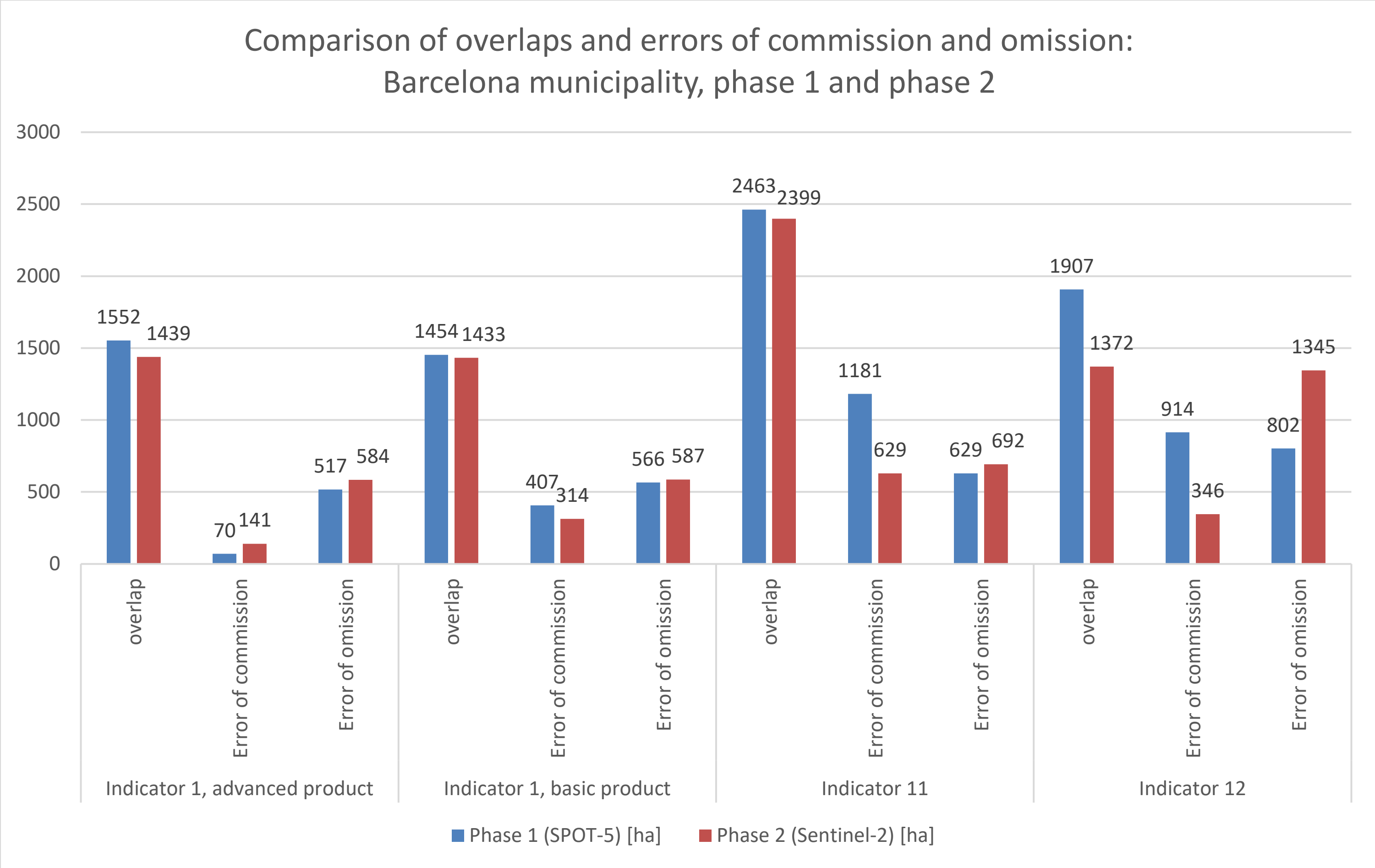


Figure 4-2: Comparison of overlaps as well as errors of commission and omission; Barcelona municipality

<u>Note:</u> The local data represent the reference data; consequently, the error of commission corresponds to patches that were erroneously classified by EO4CBI, whereas the error of omission stands for patches which have been left out by EO4CBI.

First of all, a look at the indicator values used for the CBI (i.e. the shares of natural areas, permeable surfaces and tree cover extent; see Figure 4-1) provides no clear picture as to the behaviour of a certain sensor compared to the other one or the local result. Concerning indicator 1, both sensors underestimate the share of natural areas compared to the local value, in particular when looking at the advanced product. The basic product, however, shows a higher value of the SPOT-5-based product, whereas the Sentinel-2-based data remain relatively constant under the local value. This indicates that the inclusion of local data leads to a relatively big correction of the product, in particular reducing the error of commission (see Figure 4-2). Likewise, it is clear that for the advanced product there is a higher overlap based on the inclusion of local data (phase 1) than by integrating comments alone (phase 2). Also, the error of commission is much lower and the error of omission somewhat lower for the data-enhanced product (phase 1) than for the commented product. The values for the mainly EO-based basic product are closer to each other, the overlap area is a bit smaller than for the advanced product and the errors larger, in particular the error of commission (the error of omission is almost identical).

Regarding indicator 11, the share of permeable surfaces in the city, the values derived from Sentinel-2 and local data are almost identical (around 30 %), while permeable surfaces are overestimated based on SPOT-5 data (36 %). This is also reflected in the high difference in the error of commission which is almost twice as high for the SPOT-5 based product than for the one derived from Sentinel-2. In terms of overlap and error of omission, the area differences are of the same range, i.e. the phase 1 overlap is around 60 ha higher, whereas the phase 2 error of omission is also around 60 ha higher. The spatial overlay of the results clearly indicates the weakness of the EO4CBI product in the dense city centre where it overestimates permeable surfaces, mainly by erroneously including trees, although they are often planted in impervious surfaces, but have a bigger tree crown that is misinterpreted as permeable surface. Another weakness is the omission of beach-like structures and some urban parks.

Indicator 12 provides the most heterogeneous picture. The city provides a range of values from 22.8 % to 26.7 %, based on different scenarios they used for mapping the tree cover extent. While the SPOT-5-based product is rather close to the upper limit of this range, the Sentinel-2 based product is still almost 6 % below the lower limit. So, Sentinel-2 seems to underestimate tree cover extent. Looking at the spatial overlay of the data sets from EO4CBI and Barcelona, SPOT-5 seems to have difficulties in correctly classifying shrubs. As those areas are all classified as trees, they lead to an overestimation in those areas. Overall, this overestimation is counterbalanced by a strong underestimation of street trees. Interestingly, the omissions are even larger using the Sentinel-2 images compared to the SPOT-5 images, but the error of commission is much smaller with Sentinel-2. This on the one hand confirms the assumption that the low spatial resolution of SPOT-5 and Sentinel-2 are problematic for urban assessments, e.g. for mapping street trees, but on the other hand seems to indicate that the Sentinel-2 time series help to distinguish different types of vegetation, e.g. trees and shrubs, so that the commissions can be reduced.

So, with respect to the question whether one sensor is better than the other and, therefore, should be preferred in urban biodiversity assessments, no fully conclusive answer is possible, although there is a tendency towards the advantages Sentinel-2 provides regarding the time series data and the potential for capturing phenological development throughout the year.

For indicator 2, the colleagues from Barcelona prepared an overview map (see Figure 4-3) of the unconnected patches that aims at specifically highlighting the issue of using (administrative) borders as extent borders for a connectivity analysis. It is argued that although the patches at the northern city borders appear to be disconnected inside the city boundaries, they are connected outside of them, by which overall connectivity would be higher in reality than what is reflected in the map. Cities who wish to include this connectivity can use a buffer (of an appropriate width) around their city boundaries and calculate the value of indicator 2 for this larger area and report it as additional information in Part 1 of the CBI.

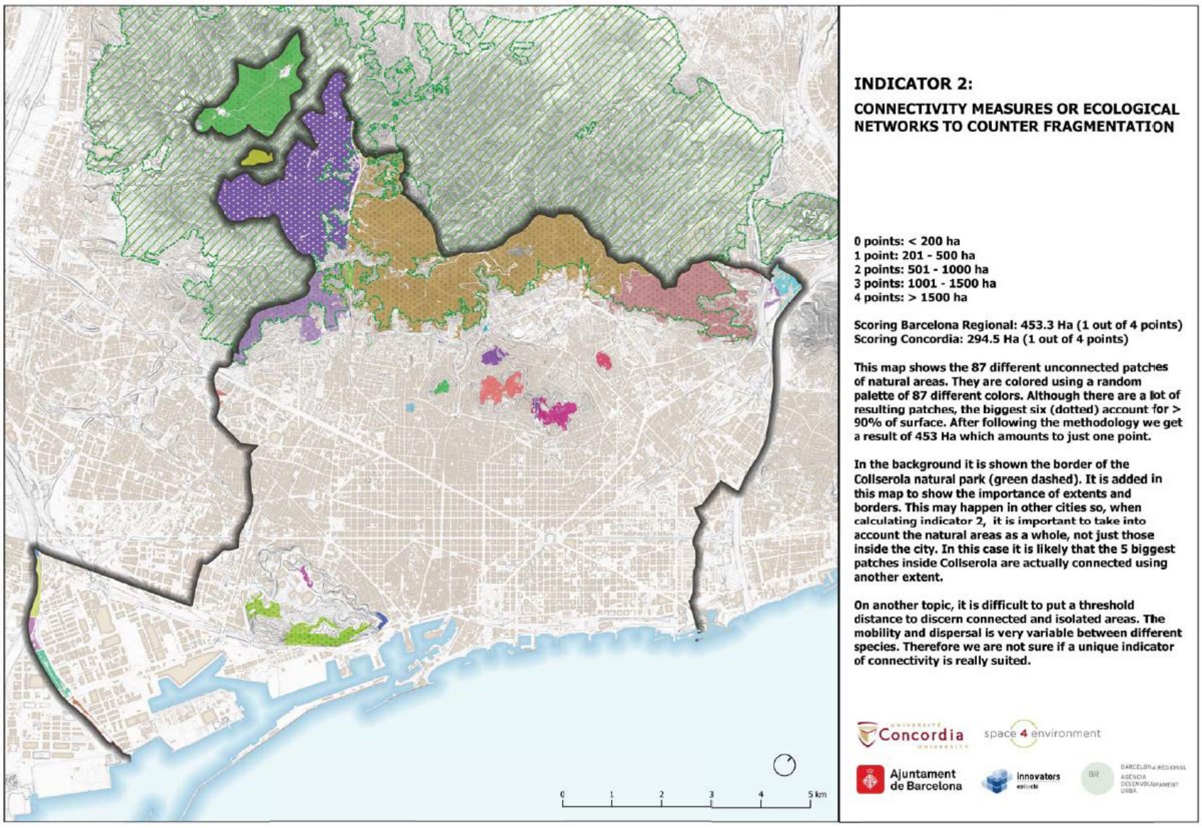


Figure 4-3: Assessment of unconnected patches, indicator 2; Barcelona municipality (source: Barcelona Regional)

The concept of naturalness was discussed against the concept of greenness. Using EO data, the mapping of greenness would be more reliable than naturalness. This difficulty was already reflected in the mapping of “candidate” natural areas. A future revision of the definition of "natural areas" in the CBI User Manual could take this into account by including more areas that correspond to "greenness", if the cities agree with this idea.

Finally, some words are required concerning the current CBI coordination and management (also see further discussion in the next chapter 5). The project partners and the cities who attended the User Forum agreed that the CBI in its current state lacks visibility on the one hand and uptake by cities on the other. There is no dedicated website and generally not a lot of information about the CBI available on the web so far. It was therefore considered necessary to increase or improve coordination and management of the CBI and create one place where all this information is pulled together and hosted. This would also greatly increase the practical value of the CBI in the framework of international policies and targets/goals, such as the SDGs[11] or in the follow-up of the Quintana Roo Communiqué[12].

[11] https://sustainabledevelopment.un.org/sdgs
[12] https://www.cbd.int/cop/cop-13/other/pr-quintana-roo-en.pdf

5 THE FUTURE: ROLL-OUT ANALYSIS

Regarding the future roll-out of the project results, it will be necessary to differentiate between "coordination" and "implementation" of the CBI.

5.1 CBI COORDINATION & MANAGEMENT

As mentioned in the project recommendations, the CBI is generally lacking visibility and ownership of one dedicated organisation that would be the driver behind the system. Despite the mentioning of the index at various scientific conferences (e.g. lately in the follow-up of the Quintana Roo Communiqué) and the CBI User Manual being available online (Chan et al., 2014), it is difficult to obtain detailed and up-to-date information about the use of the CBI.

A first step towards increasing the visibility and applicability of the CBI would therefore involve:

- Identification of an organisation dedicated to the coordination and management of the CBI, as part of their daily activities. Ideal partners could be internationally active networks like IPBES or the Biodiversity Office of ICLEI in South Africa who are already knowledgeable about the CBI.
- Availability of on-line information about the CBI, such as a more detailed description of the indicators with examples, updated list of cities that have implemented the CBI, a list of frequently asked questions, best practice examples and a helpdesk for interested users.
- Revision of the scoring system to better account for changes / improvements in the indicator performance.
- Implementation of a kind of reward system which allows cities to promote themselves with the achievements they have made.

Some of these steps go beyond the direct influence of this project, but we recommend to ESA to support this action to further promote that CBI as a very useful tool for cities to assess their progress with respect to their self-defined biodiversity goals.

5.2 CBI IMPLEMENTATION

For the roll-out of the CBI implementation, a number of scenarios can be envisaged:

- Monitoring and back-dating of the 4 indicators for cities with an already established initial CBI inventory (see chapter 5.2.1);
- Full implementation of the 4 indicators for cities with no initial CBI inventory (see chapter 5.2.2); or
- Employ CBI-based system of indicators for better integration into land-use planning and

international policy processes (see chapter 5.2.3).

5.2.1 CBI IN CITIES WITH AN INITIAL INVENTORY

Cities with an already existing initial CBI inventory are mostly interested in monitoring changes / progress. These changes can be mapped between the initial inventory and today or by back-dating, i.e. starting from the initial survey and looking even further back in time.

In both cases, the initial survey has mostly been developed on spatially very detailed, local data. If these data are available in GIS compatible format, they could be used as input for change detection in combination with lower resolution satellite data. Even though boundaries might not be geometrically identical, thematic changes of features can often be detected and classified.

The advantage of combining geometrically detailed local information with EO data is related to the higher frequency of image availability – allowing to characterise existing geometric objects with improved thematic information based on multi-temporal (i.e. seasonal) data – in combination with an efficient processing and analysis of the EO data.

The City of Edmonton reported a cost in the order of a 6-digit figure for the local ecosite-mapping project[13] that provided part of the spatial information of the local CBI implementation, while the EO4CBI project estimates around 25-30 person days for the implementation of the 4 indicators, excluding any preparatory data collection, data pre-processing and discussions.

Table 5-1: List of CBI cities

Cities with an initial CBI implementation	Cities that have been testing the CBI
1. Brazil: Curitiba	1. Australia: Joondalup
2. Belgium: Brussels Capital Region	2. Cambodia: Phnom Penh
3. Canada: Edmonton	3. Cambodia: Siem Reap
4. Estonia: Tallinn	4. Canada: Montreal, Ottawa
5. France: Montpellier	5. France: Paris
6. Germany: Frankfurt	6. Indonesia: Padang
7. Indonesia: Bandung	7. Indonesia: Pekanbaru
8. Japan: Nagoya	8. Lao PDR: Vientiane
9. New Zealand: Waitakere City	9. Lao PDR: Xayaboury
10. Singapore	10. Malaysia: Sibu
11. Thailand: Bangkok	11. Malaysia: Kuantan
12. Thailand: Chiang Mai	12. Philippines: Iloilo City
13. Thailand: Krabi	13. Philippines: Puerto Princesa City
14. Thailand: Phuket	14. Philippines: Quezon City
15. United Kingdom: London	15. Spain: Ourense
	16. USA: Montpelier
	17. USA: Kings County
	18. Viet Nam: Danang
	19. Viet Nam: Hanoi

The City of Edmonton also expressed their interest in change (trend) information based on the results

13 http://www.nswa.ab.ca/sites/default/files/documents/14.04.10_Ecosite%20Mapping%20Pres_NSWA_Print.pdf

of this project. The information provided by EO data can be used for monitoring under given prerequisites:

- Use of local input data (i.e. from the initial CBI)
- Availability of multi-temporal EO data
- Update of existing information instead of creation of new basic data
- Review of the CBI scoring system to allow progress to be more readily visible in the indicator scores.

The implementation of a monitoring task would use existing local data for each of the indicators as starting point and update the information with the help of multi-temporal EO data.

Any of the cities listed in Table 5-1 are potential candidates for such a trend monitoring.

5.2.2 CBI IN CITIES WITHOUT INVENTORY

A second group of cities with potential interest in the CBI are those cities that have not yet done a CBI implementation and that do not dispose of detailed local information. These cities are the ideal candidates for the implementation of the approach developed and tested in the EO4CBI project.

Even if the EO based approach does not provide the most detailed information spatially, it is a consistent approach, while consistency is most important for change mapping and monitoring.

5.2.3 CBI-BASED SYSTEM OF INDICATORS FOR BETTER INTEGRATION INTO LAND-USE PLANNING AND INTERNATIONAL POLICY PROCESSES

The third implementation path of the results from the EO4CBI project is making use of the institutional relations built-up with major stakeholders (i.e. ICLEI) and would support them with geospatial data that are based on the methodology that was developed in the framework of EO4CBI and, by consequence, (i) would directly contribute to their work on mainstreaming mapped urban natural assets into the land-use planning process, and (ii) align the work with international policy processes (e.g. CBD-COP, SDGs).

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