07 What kinds of NBS monitoring data can I gather, and how should I manage these data?

Main data types, data sources and data generation techniques

Data gaps, biases and ways to address them

Why is it important to evaluate the impacts of NBS?

What constitutes NBS monitoring?

How do I develop a robust NBS monitoring plan?

How can I execute monitoring and impact assessment activities?

What indicators of NBS impact can I use?

How do I select appropriate indicators of NBS impact?

How can I ensure NBS work for Disaster Risk Reduction?

7 Data Requirements

Coordinating Lead author
Leo, L.S.

Lead authors
Kalas, M., Leo, L.S.

Contributing authors
Baldacchini, C., Budau, O.E., Castellar, J., Comas, J., Connop, S., Corbane, C., Decker, S., Draghia, M., Dubovik, M., Dushkova, D., Haase, D., Ivits, E., Körmöndi, B., Kumar, P., Laikari, A., Leopa, S., Littkopf, A., Ommer, J., Rinta-Hiiro, V., Spano, G., Spinnato, P., Vranić, S., Teixeira da Silva, R., Zavarrone E.

Summary

***What** is this chapter about?*

Chapter 7 offers an overview of the main types of data, data sources, and data generation techniques for NBS monitoring and impact assessment. After familiarising you with common data terminology and definitions (Section 7.1), we review the types of data associated with NBS monitoring and assessment (Sections 7.2–7.7), their use for indicator assessment (Section 7.8) and baseline construction (Section 7.9), and the principal aspects determining the quality of analysis (Section 7.10). Concepts are illustrated through examples and complemented with potential data sources. Finally, we reflect on data sharing,

data exchange, data management and dissemination of data gathered (Section 7.11).

How *can I use this chapter in my work with NBS?*

This chapter aids to understand the data requirements for evaluating NBS performance and impact. This chapter:

1) Provides knowledge regarding available data sources;

2) Assists in developing a robust plan for the collection, management and use of data;

3) Offers examples of how data have been collected and integrated by various EU Horizon 2020 projects; and,

4) Raises awareness of the challenges commonly encountered such as data gaps, data availability, data reliability and related potential error sources.

When *should I use this knowledge in my work with NBS?*

The knowledge provided in this chapter can be used in the planning phase of NBS projects in order to assess whether the required datasets can be obtained from external data sources or should be generated within the project. In the latter case, Chapter 7 provides guidance towards data generation/integration (e.g., modelling, measurement campaigns). This chapter also supports the development of standardised data management protocols for effective data sharing and data dissemination.

How *does this chapter link with the other parts of the handbook?*

Chapter 7 supports the development and execution of a robust monitoring and evaluation plan (Chapters 2 and 3), by detailing considerations related to data types, data integration, and the adequacy of data for indicator assessment and baseline construction. This chapter describes the data requirements for computing NBS indicators (Chapters 4-6 and Appendix of Methods).

Evaluating NBS benefits, co-benefits, and trade-offs can be a data intensive process. Understanding the data requirements is a critical element in relation to ensuring both the efficacy and cost-effectiveness of this evaluation process. In order to establish the monitoring plans and schemes described in previous chapters, and to deliver this over the range of relevant scales, it is therefore critical to generate data that are both applicable for the nature-based solution impact assessment, and that are comparable to the preceding monitoring campaigns. This chapter addresses the data requirements involved in evaluating the impacts that nature-based solutions manifest and explains the data building blocks involved in NBS monitoring and assessment procedures.

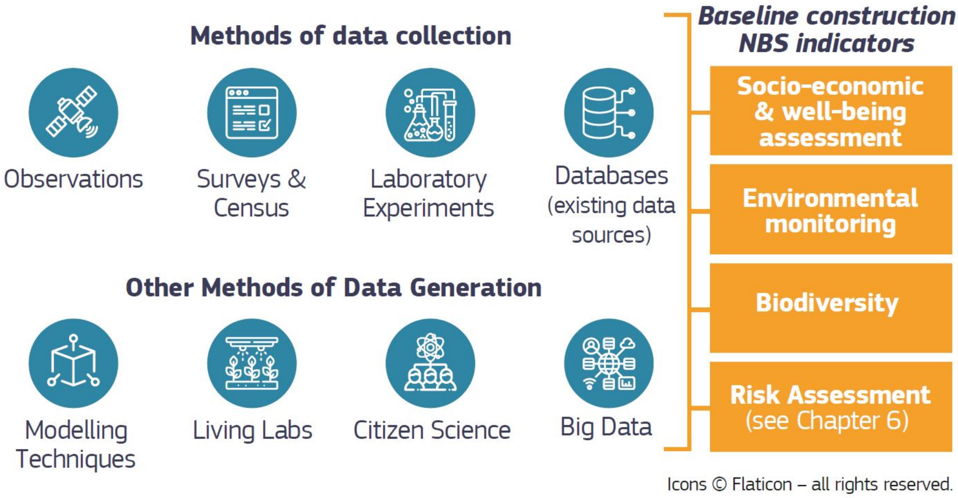


Figure 7-A. How can we generate data for NBS monitoring and evaluation?

7.1 Data terminology, definitions and key concepts

Data requirements for NBS monitoring and assessment span multiple and diverse data types and sources, and thus involve techniques, methods and concepts drawn from various disciplines of both natural and social sciences. This section provides the reader with a basic knowledge of the terminology and concepts commonly encountered when dealing with data requirements for the NBS evaluation process. It also contains explanations of the main data types and data aspects relevant for NBS assessment and thus aids the reader in navigating the rest of this chapter.

7.1.1 Spatial versus non-spatial data

Spatial data is a term used to describe data containing information about a specific location on the Earth's surface. Spatial data are essential for any mapping activity as they provide information on the exact location, shape, size, and orientation of a given entity (e.g., a river). Non-spatial data, on the contrary, contain information which is independent from any geometric and/or topological consideration (e.g., street names). Non-spatial data are also termed attributes as they are usually combined with spatial data to provide additional information on the specific geographic entities identified by a spatial dataset. For example, the geometric characteristics of a city district (spatial data) can be combined with information on air quality (non-spatial data) and displayed together on a map using a legend of colours, with each colour indicating a certain level of air pollution.

Spatial data are stored in spatial databases that are optimized for storing and querying data that represent objects defined in a geometric space. Depending on the way they are manipulated and stored, spatial data can be of two types: vector and raster. In vector form, spatial data are represented in form of points (e.g., the location of individual trees in a city), segments (e.g., the path of a river in the same city) and polygons (e.g., houses and urban green parks). In the simplest form of a raster, spatial data are represented as a matrix of cells (or pixels) organized into rows and columns (a grid) where each cell contains a value representing information (such as elevation, temperature, number of people). Satellite images, such as land cover/land use maps, are typical examples of raster spatial data. Manipulation, storage, and visualization of digital spatial and non-spatial datasets are commonly done using GIS (Geographic Information Systems) software like ArcGIS. Examples of spatial and non-spatial data of relevance for NBS monitoring are given in Section 7.8.

7.1.2 Baseline data

As defined by EUROSTAT, a baseline study is "an analysis of the current situation to identify the starting points for a programme or project. It looks at what information must be considered and analysed to establish a baseline or starting point, the benchmark against which future progress can be assessed or comparisons made." (EUROSTAT, 2014). In the context of NBS, the establishment of a baseline involves collecting a set of data that allows the description of the geo-morphological, socioeconomic conditions, living standards and livelihoods of NBS project-affected communities and their potential hosts prior to any NBS intervention. Those data will be used as a reference for monitoring the impacts of the NBS on the involved territories, thus allowing a comparison between the pre-project implementation state of play and the post-project implementation situation. The results of this monitoring process are the starting point <u>not</u> for the comparison between the changes occurred due to NBS interventions and other grey or hybrid solutions addressing the same issue, but for the assessments of the benefits attributable to NBS. Baseline data collection and requirements are the topic of Section 7.9.

> Data can take a variety of different forms and types depending on how it is generated. Here we explore this different types with a view to informing how they might contribute to an evaluation approach.

7.1.3 Control data

Impact evaluation mostly addresses the cause-and-effect questions and different methods can be used to establish what the causal effect (impact) of an NBS intervention on an outcome of interest is. These methods should estimate the so-called counter-factual: is a given NBS intervention effective compared to the absence of the intervention or to alternative, traditional engineering or planning solution? Control data are generally collected to assess counter-factual, and they consist in collecting the same variables, with the same methodology, as per the NBS intervention site, in a suitable, different site. Depending on the outcome to be evaluated, control data collection would need the identification of a suitable control area or control group. Further details on this aspect can be found in Chapters 2 and 3 of this Handbook.

7.1.4 Acquisition regime

Acquisition regime refers to the temporal interval over which a certain variable (e.g., temperature) or process is monitored. Typically, the timestamp assigned to a data point can refer to discrete observation/model time (which represents the sampling frequency) or the beginning or the end of the observation/aggregation time interval. Following the INSPIRE Directive (EC, 2007), acquisition regime can be distinguished into:

- Continuous data acquisition (Data are generated on a continuous basis)
- Demand driven data (Data are generated on demand)
- Once-off data (Data are generated only once in this configuration. No further observations in this configuration can be expected)
- Periodic data collection (Data are generated at regular intervals)

For example, relevant indicators such as residential property sale and rent value in the areas of future NBS implementation, can be solely available as once-off data. On the contrary, many of the datasets employed for baseline conditions characterisation (cf. Section 7.9) are typically retrieved from national statistics organisations or local municipalities, thus they have varying periodicity: at national level they are usually collected with a yearly periodicity, while at neighbourhood level, data collection is only done during national censuses, which are conducted every 5 to 10 years.

In many cases, data for the computation of NBS environmental indicators are acquired continuously, either as part of permanent monitoring networks established by environmental agencies and research institutions or as ad-hoc monitoring campaigns carried out within NBS projects. In the EU-H2020 project UNaLab, for example, continuous data collection has been used for quantifying physicochemical indicators, such as discharge and water quality, as well as for other environmental constituents (e.g., temperature, precipitation, and air quality).

In general, the choice of a certain acquisition regime over another should be dictated by (and lower than) the expected temporal dynamics of the process or variable under scrutiny. In practice, however, it is often a compromise between several factors, such as technological feasibility, project duration, resources, and funding availability. This means that adequate acquisition regimes should be carefully assessed to avoid data gaps, poor data adequacy (cf. Section 7.10), and limited data availability in the computation of NBS performance indicators as well as the establishment of a baseline.

7.1.5 Spatial scale of analysis

Spatial domain is another critical factor affecting data representativeness and adequacy. Data requirements in terms of spatial domain depends on a combination of (1) the scale of nature-based solution intervention (large vs. small scale NBS), and (2) the expected scale of the impact for each indicator being evaluated (some datasets are representative of small-scale processes while others provide impact at broader scales). This means that NBS evaluation indicators need to be assessed over the proper spatial scales. Those can be identified with the aid of other types of indicators which have been created with the specific purpose of measuring the spatial scale of NBS impacts (for example, the spatial extent of cooling effect in relation to reduced air temperature).

Thus, scale classification in terms of data requirements may include:

- Landscape or regional scale
- City scale
- Neighbourhood scale
- Street or pedestrian scale
- Nature-based solution footprint scale

The typical NBS scales involved are relatively small, namely data requirements are usually at the neighbourhood scale, the street or pedestrian level, and the NBS footprint scale. Nevertheless, datasets at larger scales become important when assessing the upscaling and replication potential of individual NBS interventions at city scale or at landscape/watershed scale (as in the case of NBS for disaster risk reduction – cf. Chapter 6) and, in that respect, they allow to establish robust baselines to guide planning and city-wide interventions.

An example is the series of NBS eco-gardens being implemented in kindergartens across the city of Poznan in the framework of the EU-H2020 project Connecting Nature. In terms of scales, the transition from hard impermeable surfaces, like asphalt, to vegetated surfaces, is expected to positively impact the thermal comfort at the scale of the kindergarten footprint. However, if a critical mass of nature-based solutions can be rolled out across the city in future, through the implementation of eco-gardens in social spaces and other mechanisms, it might be worth considering also the establishment of a baseline for thermal comfort at greater regional/administrative scale, so that changes compared to the baseline can be quantified in future.

For ease of comparison between indicators within a location, for ease of comparison of an indicator between cities, and in relation to exploiting data sources that are already collected, using standardised spatial scales can be beneficial. For example, Nomenclature of Territorial Units for Statistics (NUTS) spatial scales for indicator evaluation can provide a standardised scale (EUROSTAT, 2020). NUTS represent a geocode standard, developed and regulated by the European Union, for referencing the subdivisions of countries for statistical purposes. For EU member countries, a hierarchy of three NUTS levels was established, corresponding to increasing granularity of districts. Whilst not always corresponding to administrative divisions within a country, the NUTS spatial scales correspond with standardised data gathering and reporting that can be a useful data source for evaluation indicators, particularly those associated with economic evaluation. It is, however, important to note that NUTS scales will not be relevant for all expected spatial scales of impact.

7.1.6 Processing level

From a data processing perspective, the computation of a given NBS indicator consists of using existing data to create new types of data through some sort of transformation, such as an arithmetic formula or aggregation (e.g., spatial/temporal interpolation). Various degrees of data integration and manipulation are possible, which means that basic indicators can be used as input data for the computation of more sophisticated or synthetic indicators. In that respect, a straight indicator hierarchy has been recently proposed within the EU-H2020 Project Nature4Cities. This hierarchy classifies the indicators into three levels of processing (Figure 7-1). A **1st level indicator** is a value derived from a dataset, which describes the state of a phenomenon or the environment. If a 1st level indicator is introduced into an equation or model, it gets into the next level which is the **2nd level indicator**. If this one is used again in an equation or model, then it is a **3rd level indicator**. For each new level, assumptions are made and accumulated, and simplification or loss of quality may result.

INDICATOR DEFINITION AND HIERARCHY		EXAMPLES
1st LEVEL INDICATOR	A value derived from a specific dataset, which points to provide information about, and/or describes the state of a phenomenon/environment/area	MRT (Mean Radiant Temperature)
2nd LEVEL INDICATOR	1st level indicator proceeded into further equation or model	PET (Physiological Equivalent Temperature)
3rd LEVEL INDICATOR	2nd level indicator proceeded into further equation or model	PET Thermal Sensation Scale

Figure 7-1. Indicator Hierarchy adopted in the EU-H2020 project Nature4Cities.

Depending on the specific indicator and the temporal and spatial scales under consideration, some 1st, 2nd or even 3rd level indicators can be readily available from external data sources (e.g., national statistics organisations and environmental agencies). In most cases, however, the computation of NBS performance indicators entails the acquisition of the required datasets. These datasets can be retrieved from external databases (when available) or newly generated by conducting ad-hoc measurement campaigns and/or numerical modelling efforts (cf. Sections 7.2–7.6). In both cases, it is important to recognize that data themselves undergo different level of processing before becoming directly usable by non-technical experts. For example, satellite data such as Sentinel products are systematically provided at various processing levels.

In general, there are three levels of processing commonly encountered with any type of dataset:

- **Raw data**, namely data directly outputted by a measuring device or a numerical model (or any other data acquisition technique), with no (or minimal) data validation/verification, manipulation, or conversion into standard units and/or formats. These data are rarely usable by non-expert users.

- **Quality controlled data**, namely data which have been screened for outliers and other possible error conditions. Data points identified as problematic and erroneous are removed or flagged.

- **Final data products**, namely data which have been quality checked and have undergone various post-processing procedures to be converted into more useful parameters and data formats.

7.1.7 Data Generation and Collection Methods

Data collection should be based on solid planning, technical expertise, and a wide knowledge of the state of the environment and its functioning in relation to humans in order to ensure that the relevant and accurate data are garnered properly for the purpose of NBS monitoring and assessment. In general, data collection methods (also referred to as acquisition mode) used for NBS monitoring and assessment include a few standard ways of collecting data: (a) Observations, (b) Surveys and Census, (c) Laboratory Experiments.

Observations can be regarded as one of the main methods for monitoring the performance of NBS interventions and their impact on the socio-ecological system. This includes manual or automated collection of quantitative information (namely **direct measurements**, e.g., measurement of temperature) or can be defined as a detailed examination by watching, noticing or hearing (Kawulich, 2012) in case of qualitative information. Differently from survey, the observer does not influence the study in any way or attempt to intervene in it. As such, one of its advantage is the objectivity. In the rest of this chapter, observational data are differentiated into population observations and environmental observations due to their different techniques in data acquisition. For example, satellite and ground sensor observations are primarily used for environmental monitoring and further discussed in Sections 7.2.1 and 7.2.2, respectively.

On the other hand, people's behaviour and attitude towards NBS interventions can be also observed by other humans without direct interaction as explained in Section 7.3.2. Population observations function as an umbrella for different methods of collecting data on people's behaviour, attitudes, and, especially, their interaction with each other but also with nature. These methods have been increasingly used for monitoring social benefits of NBS. In this context, observations can be either quantitative (e.g., number of people visiting an NBS) or qualitative (e.g., how people interact with nature or an NBS).

Surveys and **Census** represent another important method of collecting environmental, socio-demographic and economic data and statistics for NBS assessment. An important source of survey data for NBS are administrative records, namely administrative data stored by the governments and other organizations such as annual reports on the state of environment, etc.

Differently from observations, surveys represent a research strategy to collect information in interaction with people (Ponto, 2015). Survey data are collected by having participants (sample group or population) responding to quantitative and/or qualitative questions. The responses of the sample group are statistically analysed and can be used as representative, under specified conditions, of a whole and for comparison. Census data differ from (quantitative) survey data only in terms of completeness and for temporal slices. Indeed, while survey data are based on a population sample, census data are universal by considering every individual. In regard to NBS, survey data can be used for defining a baseline and for further monitoring of socio-economic and health benefits and impacts. Section 7.3.1 addresses survey data in more detail.

It should, however, be noticed that the term survey is also frequently used in the context of environmental monitoring, mainly to indicate data collection methods which require sampling (e.g., removal of the soil) of the object of investigation. This type of survey is for example used to monitor biodiversity at the NBS site (cf. Section 7.2.3).

Laboratory Experiments are useful when the researchers intend to control the results of the study always in a cause and effect pattern (Sullivan et al., 2016). Differently from observational studies which randomly select a sample and may find correlations between variables (Rosenbaum, 2010), laboratory studies can control or manipulate some or all variables that might affect the phenomenon under study and thus identify and confirm the potential mechanisms underlying observed responses (Montgomery, 2008). In the context of NBS, laboratory studies can help assessing either people behaviour towards NBS or the environmental performances of different NBS. In either application, laboratory data could be particularly valuable when used as pilot studies and/or at the planning phase of an NBS intervention, as discussed in Section 7.6.

Data collected through the aforementioned methods are typically complemented by data generated through modelling approaches. **Numerical simulations** and **modelling** refer to a fundamental part of the methodologies used in NBS monitoring and will be discussed in Section 7.5. Modelling is a process of abstraction and generalization aimed at developing adequate models (representations) of the real-world systems to be examined (Grützner, 1996).

The models developed for data simulation purposes can be classified as simplified (non-physics-based) model and numerical models (although other categories and classifications exist). Simplified conceptual models are a representation of physical processes and require significantly less computer effort than the numerical models. They are particularly appropriate to simulate datasets for large study areas and/or stochastic modelling for probabilistic based risk assessment (including elements of randomness, e.g., probability distributions and generalised linear models) and multi-scenario modelling on a bigger scale with availability of quality observational datasets. Numerical models are mathematical equations that attempt to simulate a state variable by solving equations developed by applying laws of physics and typically require solving them computationally. Therefore, the numerical models are developed to represent/simulate detailed state variables (e.g., temperature, precipitation) dynamics. Depending on their spatial representation of the problems in hand, the models use lumped (variables of interest are a function of time only) or spatially distributed approach and can be dimensionally classified into one-dimensional (1D), two-dimensional (2D) and three-dimensional (3D) models.

Citizen Science is a research focus that enables citizens and stakeholders to be actively engaged in science data generation and monitoring programs. It refers to *"the general public engagement in scientific research activities when citizens actively contribute to science either with their intellectual effort or surrounding knowledge or with their tools and resources"* (Serrano et al., 2014). The European Environment Agency define three types of citizen science activities based on the degree of citizen involvement: 1. *contributory* – meaning that citizens are involved in data collection; *2. collaborative* - participants are involved in more than data collection such as in data analysis, project design, and results dissemination; and 3. *co-created* – where citizens are involved in basically every aspect of work. Citizen science opens new possibilities for data collection and analysis, introduces different perspectives and cooperation, but also offers various benefits for the community itself, such as public engagement, awareness raising, and lifelong learning opportunities in science (Hecker et al., 2018). In terms of data generation, citizen science can generate a range of different data types. This approach is primarily used for environmental monitoring, but there are also examples of social and economic applications. Citizen Science has also been increasingly used in NBS context. This will be discussed in Section 7.7.

Another emerging approach is **Big Data**. The term indicates data which are characterized by large variability, volume and variety, among other aspects. Big data can be considered as an evolution of "data mining", which refers to the development of datasets which are very large and can be identified with statistical significance (Sang, 2020). Data mining means searching for valuable information in a large database. Deploying data mining methods requires a type of expertise which is increasingly in demand, but this expertise is not domain-specific. It can be deployed where scientific theory has no more intelligent solution to offer (Sang, 2020). Despite the several pitfalls hidden into it, the use of big data could be key in the perspective of achieving a more solid and wide-ranging evidence of NBS impacts through on-going and future efforts in collaboratively and collectively preserving, organizing and sharing NBS related data (Hampton et al., 2013; see also Section 7.10.4). Examples on the use Big Data for NBS assessment are provided in, e.g., Section 7.8.

7.2 Environmental data of relevance for NBS monitoring and assessment

In Section 7.1.7, observational data were differentiated into *environmental* and *population* observations and a brief definition of both was provided. This section focuses on environmental data. A wide variety of approaches has been developed to observe environmental and ecological impact of NBS, taking experience from the previous background of the research community in these fields (Houghton et al., 2012; Lein, 2012). In fact, this represents one of the most established areas of nature-based solution evaluation.

A diversity of methods has been implemented that cover a broad range of the potential benefits, and trade-offs, associated with nature-based solution implementation. In terms of data types, there are two categories of environmental observations which are essential and widely used to assess and monitor the physical or environmental conditions of a NBS site and to establish a baseline: remote sensed data and in-situ observations and measurements. In some cases, these observations are also complemented by survey data gathered at the NBS site or available from national databases.

These measurement techniques allow to gather a large variety of environmental data. In that respect, the concept of "essential climate variables" (ECVs), might be useful (WMO, 2020). The concept of Climate Essential Variables was first used for the development of the Global Climate Observing System. The essential climate variables (ECVs) are formally defined as "physical, chemical, or biological variables or a group of linked variables that critically contributes to the characterization of Earth's climate" (Bojinski, 2014). The concept of essential variable has expanded also to other domains like biodiversity, ocean, social sciences, thus providing an excellent basis for building a NBS monitoring system. Another advantage of using the ECVs is that currently a lot of research is focusing to anchor the ECVs to Sustainable Development Goals and other international initiatives and their targets (e.g., ICCP, Sendai). Some studies place the ECVs between basic observations and indicators as single EV capturing a key process or structure can potentially contribute to multiple indicators, while similarly two or more ECVs can direct and use the same primary observations (Reyers, 2017).

A wide variety of approaches exist to observe the environmental and ecological impact of NBS. This section explores these methods, discusses how they can be applied and provides potential sources of data.

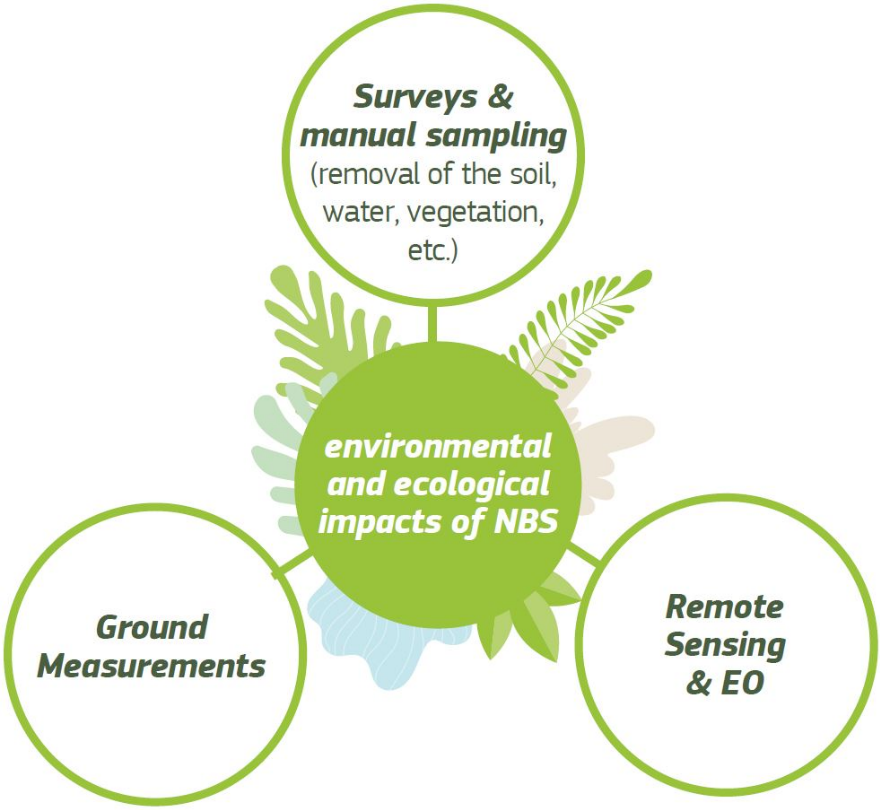


Figure 7-2. How can we generate and collect data to evaluate environmental and ecological impacts of NBS?

7.2.1 Remote sensing (RS) and Earth Observation (EO)

Remote sensing (RS) is the technique of observing and collecting information about an object or phenomenon from a distance, by means of sensors that are not in physical contact with the object of investigation (target). The platform employed to be "at a distance" from the target can be air-borne, space-borne or ground-based. Typical airborne platforms are drones and aircrafts, while satellites are used as space-borne platforms. Note that when the target of investigation is the Earth, the term Earth Observations (EO) is commonly used to indicate data gathered from Earth observing satellites. Finally, ground- (or sea-) based platforms consist of sensors mounted on tripods or moving vehicles. These platforms, along with drones, are mainly used for acquiring very detailed information at smaller spatial and temporal scales.

At present, a multitude of RS techniques is available, including visible and infrared imaging, light detection and ranging (LiDAR), and synthetic aperture radar (SAR). Multispectral sensors allow to study the changes of vegetation or built areas (land use changes), while thermal imagery can be used for measuring the urban heat island effect. Beside satellite imagery, aerial photography is another important source of information about the Earth surface: LiDAR sensors, for example, allow gathering high-resolution elevation data, which can be applied for measuring the heights of trees or buildings.

Remote sensing and EO are also frequently used to analyse forest dynamics, pollution level, changes in soil erosion, an estimate of the animal population, and the impact of natural disasters. In the context of NBS monitoring, they provide affordable, high quality mapping and monitoring of urban and environmental parameters at multiple spatial scales (Kabisch et al., 2016). Table 7-1 provides some key examples of how global Earth observation data can be integrated into NBS models. It highlights how RS data can be used to improve the understanding of the processes controlling spatial and temporal dynamics of NBS.

Although EO and remotely sensed data mainly generate low spatial resolution outputs, they constitute a valuable asset for generating knowledge on a variety of aspects, including ecosystem and land-use changes, changing agricultural and forestry practices and climate-related variables, such as Earth's surface albedo, on global and pan-European scales.

One of the main advantages of RS and EO is their low-cost and vast availability which can greatly contribute to monitoring of NBS. A list of sources for EO data is presented in Table 7-3. In general, freely accessible data (free of cost) is provided by public agencies, under potential conditions linked to the application envisaged and the nationality of the entity requiring access. European Space Agency (ESA) provides detailed information on access to Earth Observation data products at https://earth.esa.int/web/guest/data-access, where products can be browsed by mission and instrument, or by Earth topic, typology, and processing level. Data can also be bought from private companies operating commercial satellites, or by their numerous certified resellers. A unique source of freely available satellite data is the European Copernicus Program (https://www.copernicus.eu): the vast amount of EO data relevant to NBS monitoring is divided into 6 thematic domains. These data are freely available to all users via different channels. One of them is The Copernicus Open Access Hub which provides free and open access to not only raw and processed data, but also computational algorithms and cloud computing facility.

Table 7-1. Key examples of how global and European Earth observation data can be integrated into NBS models and how remote sensing can improve the understanding of the processes controlling spatial and temporal dynamics of NBS.

Theme analysed	Which particular data can be provided	Remote sensing data sources	Data Provider (SRS data product)
Climate change (remote sensing to monitor the rate, magnitude, and spatial and temporal effects of climate on ecosystems)	Contemporary observations of ecosystem status and trend, together with environmental models, can help to estimate the ecological and economic effects of climate change and to develop and assess adaptation and mitigation plans	Some satellite remote sensing missions provide long-term records of land surface temperature and of vegetation, from which indices useful for understanding the dynamics of climate change can be derived.	Gas concentration: Terra/Aqua (MODIS), Nimbus-7/Meteor-3/Earth Probe (Total Ozone Mapping Spectrometer (TOMS) (1978-2006), Sentinel-5P (TROPOMI) See also: Copernicus Open Access Hub (Table 7-3)
		Data on other high-priority variables, such as: a) evapotranspiration and b) soil texture, moisture and chemistry are also measured by remote sensing	a) Thermal remote sensing, VIs, climate data; b) RADAR, HSI. See also: Copernicus Open Access Hub (Table 7-3)
		Time-series data on vegetation derived from multiple sensors contribute to understanding the temporal variability and trends in vegetation processes and their relation to climate.	a) Biomass, C storage - LiDAR, RADAR, multiangle RS; b) Photosynthesis, C sequestration - fPAR, photosynthetic efficiency, fluorescence, MODIS NPP See also: Copernicus Open Access Hub (Table 7-3)
		Climatological, meteorological, hydrological datasets. Operational, real-time and re-analysis datasets.	ECMWF Climate Data Store

Ecosystem processes (how remotely sensed ecosystem variables can be used to understand, monitor, and predict ecosystem response and resilience to multiple stressors)	Cost-effective information on ecosystem extent, status, trends, and responses to stressors over large areas (e.g. for quantifying ecosystem services inputs and associations between productivity, nutrient retention, health benefits etc.)	Landsat-derived maps for ecosystem services provision or a potential loss of ecosystem function.	Barrier effect of vegetation (forest cover) - Landsat (TM, ETM+, OLI) Global forest cover change (200-2012); tree cover - Landsat (TM, ETM+, OLI) Landsat Tree Cover Continuous Fields (2000 and 2005)
		High spatial resolution and frequent revisits are most useful for documenting long-term effects of extreme events, such as severe storms, on ecosystem structure, function, and productivity, but increased spatial and temporal resolution imagery would likely result in a finer scale understanding of ecosystem responses to these events.	Biological control - changes in maximum NDVI (Terra/Aqua MODIS); pollination (vegetation phenology) - Terra/Aqua (MODIS) NDVI; Primary productivity - Terra/Aqua MODIS).
Ecosystem services (how remote sensing-derived products can be used to value and monitor changes in ecosystem services)	To document, monitor, and ultimately predict the extent and condition of certain ecosystem services (e.g. air purification, flood mitigation, water management, etc.) within a given area under current conditions and future policy scenarios. Also, to establish through analysis of remotely sensed vegetation cover the baselines for provisioning regulatory and cultural services in schemes of payments for ecosystem services.	Regular monitoring of ecosystem services such as: a) emissions of gases and carbon sequestration and storage; b) provision of shade and shelter: tree cover and plant canopy; c) temperature regulation (land and sea surface temperature); d) precipitation regulation (rainfall, evapotranspiration); e) water regulation: f) Inland water dynamic - Change in water stage and water body distribution; g) food - production of vegetal biomass; h) food - vegetation indices; provision of clean water, sustainable fisheries, and agricultural productivity with remote sensing from different sources.	a) (AVHRR), Terra/Aqua (MODIS), TRMM (CERES), NOAA AOML Surface CO2 Flux maps (1982–2009), LiDAR, RADAR, multiangle RS; b) Terra/Aqua (MODIS) - MODIS Vegetation Continuous Fields (2000-2013), Landsat (TM, ETM+, OLI) - Landsat Tree Cover Continuous Fields (2000 and 2005); c) Terra/Aqua (MODIS) - MODIS Land Surface Temperature and Emissivity, Sentinel 3 (SLSTR) for Land Surface Temperature; d) TRMM (PR, TMI, VIRS, CERES) precipitation estimates (1998-2015), Terra/Aqua (MODIS precipitation); e) Sentinel 3 (SRAL) altimetry; f) Terra/Aqua (MODIS) water mask, Landsat (TM, ETM+) – global surface water; g) Terra/Aqua (MODIS) – net primary production; h) Terra/Aqua

			(MODIS) - MODIS FAPAR, MODIS LAI, MODIS Chlorophyll α
Changes in land use and land cover	The global coverage and the spatial and temporal resolution of satellite observations allow mapping of these small- to large-scale changes. Note that more nations are launching satellites with high spatial resolution (30 m), but it is still a challenge to coordinate and calibrate the imagery from these systems to increase the frequency of observations.	Images with high temporal and low spatial resolution, such as those from MODIS, as well as images with high spatial and low temporal resolution, such as those from Landsat, or their combination.	MODIS, Landsat, or their combination. See also CORINE Landcover (Table 7-2)
		Images with high temporal resolution (daily for MODIS and visible infrared imaging radiometer suite vs. bimonthly for Landsat) capture the timing of vegetation changes, such as changes in phenology, and changes in chlorophyll levels.	Daily for MODIS and visible infrared imaging radiometer suite vs. bimonthly for Landsat
Species distributions, abundances, and life stages	Data on extrinsic environmental drivers such as land cover, primary productivity, density of human-made structures, habitat quality for given species.	Many of these variables are derived from existing multispectral sensors (e.g., MODIS).	Change in biomass, plant traits, land cover (Multitemporal RS)
		However, macroscale analysis may require deployment of new sensors such as satellite-based light detection and ranging (lidar) or 3-dimensional surface mapping and imaging spectrometers for better discrimination of features of heterogeneous terrestrial ecosystems. Derivation of data at finer spatial and thematic resolutions may require combination with on-site observation	a) Species map: Chemical or structural uniqueness, HSI, LiDAR, image texture; b) plant traits: spectral analysis or radiative transfer models; c) Spectral diversity of species (Range or variability of biochemistry, NDVI, or reflectance in set of pixels); d) Abundance of functional components (Spectral unmixing, MODIS Continuous Fields)

Degradation and disturbance regimes	To detect many types of disturbance that manifest in changes in land cover, air pollution, and different effects of global climate change.	Landsat data. Note that although global availability of hyperspectral data is limited, much progress has been made in the use of hyperspectral data to assess changes in ecosystems and function. Multi-sensor approaches may be particularly useful for assessing changes in ecosystems, especially when combined with ancillary data such as field observations and topographic data.	1) Fire occurrence and extent: Terra/Aqua (MODIS FIRMS), MODIS Burned Area Product, SPOT VGT Burned Area; 2) flood occurrence: Terra/Aqua (MODIS) - NRT Global Flood Mapping, TRMM (CERES) - Global Flood Monitoring System, DMSP (SSM/I), ERS-1, POES (AVHRR) -global inundation extent from multi-satellites (1993-2007; 3) drought occurrence: TRMM (PR, TMI, VIRS, CERES) - Satellite-Based Global Drought Climate Data Record, Eutrophication of water bodies - ENVISAT (MERIS), Terra/Aqua (MODIS), Sentinel 3 (OLCI) See also: EEA Air Pollution Index (https://www.eea.europa.eu/themes/air/air-quality-index)

This and other available RS and EO data repositories represent a valuable tool for NBS evaluation, as they offer continuous long-term monitoring, and allow going back in time (thanks to archived images) and construct a baseline. Furthermore, thanks to latest technological improvements, high spatial and temporal resolution and improved accuracy of data can be achieved in some cases. In general, the following, generally accepted characterization of spatial resolution can be used for terrestrial applications:

- Low or coarse resolution, >1 km (e.g., advanced very high-resolution radiometer [AVHRR]);
- Moderate resolution, 250 m–1 km (e.g., moderate resolution imaging spectroradiometer [MODIS]);
- High resolution, 30 m (e.g., Landsat);
- Very high, approximately a few meters (e.g., IKONOS, Quickbird, and airborne remote sensing campaigns).

Table 7-3. Earth Observation data sources and their accessibility - selection of representative EO images providers (source: ESA, 2019).

Satellite data platform	Source of EO data providers	Public access / free of cost data	Commercial data
ESA	https://earth.esa.int/web/guest/home	***v***	
EU Copernicus /Sentinel operated by ESA	https://sentinel.esa.int/web/sentinel/	***v***	
Sentinel Hub	https://www.sentinel-hub.com/	***v***	
EU Copernicus Open Access Hub	https://scihub.copernicus.eu/	***v***	
EU Copernicus Data and Information Access Services (DIAS)	https://scihub.copernicus.eu/twiki/do/view/SciHubWebPortal/WebHome#dias-box	***v***	
Copernicus portal	https://www.copernicus.eu	***v***	
Eumetsat	http://www.eumetsat.int/website/home/index.html	***v***	

European Environment agency (EEA)	https://www.eea.europa.eu/data-and-maps	v	
USGS (Landsat)	http://earthexplorer.usgs.gov/	v	
NOAA	http://www.ospo.noaa.gov/	v	
NASA	https://earthdata.nasa.gov/earth-observation-data	v	v
Digital Globe resellers	http://www.digitalglobe.com/partners/certified-resellers		v
Airbus	https://www.intelligence-airbusds.com/access-to-our-products/		v
Deimos	https://www.deimos-imaging.com/imagery-store/		v
Planet Labs	https://www.planet.com		v
ImageSat International NV	http://www.imagesatintl.com/about-us/		v
Urthecast	https://www.urthecast.com		v
MDA Geospatial Services	http://gs.mdacorporation.com/Partners/Partners.aspx		v
E-geos	http://www.e-geos.it/index.html		v
Satellite Imaging Corporation	http://www.satimagingcorp.com/		v
CGG	http://www.cgg.com/default.aspx?cid=7450		v
European Space Imaging	http://www.euspaceimaging.com/		v

Land info	http://www.landinfo.com/		v
Terra server	http://www.terraserver.com/		v
Apollo Mapping	https://apollomapping.com/		v

It is, however, important to notice that satellite observations have constrains and therefore should be ideally complemented by ground measurements and other high-resolution RS platforms such as drones. One of the main constraints of satellite images concerns the shadows due to the size of the frame, which can hide certain elements of the image and thus generate errors. This is particularly critical in dense environments such as cities. The **drone** technology is a viable way to provide the missing information and overcome this problem, as it offers the possibility to do 3D reconstruction and accurate geometric measurements. Indeed, while satellite imagery enables large spatial coverage with sometimes a resolution too low for the neighbourhood scale, drone imagery will collect high accuracy data in a more restricted area with the possibility of capturing different parameters depending on the drone equipment. This is particularly advantageous when there is a need for very detailed (or specific) and up-to-date information about the NBS intervention area.

Despite providing unique viewing angles otherwise not possible from manned aircraft, and representing a highly deployable technology already adopted in many applications (for humanitarian, safety, and economic reasons or simply for surveillance, precision agriculture and data/map acquisition), the use of drones for NBS monitoring remains at present quite unexplored. This is due to several limiting factors such as citizens safety, data and privacy topics, and the fact that some types of drone equipment are rather expensive and/or are restricted in flight limit zones where flight permission are required. Ground measurements, on the other hand, represent a more common and widely employed option to complement satellite data and they are also required for the validation of remote-sensed data. They are inevitable during the full process of NBS development. For example, to acquire a full cognition of the intervention area, the survey of its current biodiversity or the built surroundings can be performed only with ground measurements. This will be further discussed in Sections 7.2.2–7.2.3.

7.2.2 In-situ observations and ground measurements

In-situ (or local) observations is the technique of observing and collecting information about an object or phenomenon which is in close proximity to the observer or the measuring device (sensor). When in-situ observations are acquired by means of sensors placed either on or near the ground (or into deeper layers of it), then they are usually referred to as ground measurements. Data acquired through a standard weather station are an example of ground measurements. Weather and other types of field monitoring stations usually capture a multitude of qualitative and quantitative environmental data on a continuous basis, including meteorological, hydrological, and chemical parameters. This approach has the advantage that data are typically collected using verified scientific methods and can be fed into data modelling processes to enhance the predictive quality of the data.

In-situ observations and ground measurements can be utilized for the assessment and monitoring of the surface and subsurface including terrestrial ecosystems (e.g., biota and soils), assessment of contaminated land, the follow-up of in-situ remediation technologies (in particular those for soils, vegetation, groundwater), as well as for monitoring micro-climate variations and air quality at the NBS site (Gruiz et al. 2017). Relevant data sources of in-situ observations are given in Table 7-4. These data are generated through dedicated observation networks which provide long-term and continuous monitoring of various environmental and physical parameters.

In addition, the recent advancements in smart, low-cost sensors and wireless technology is allowing to develop dense and low-cost wireless sensor networks in cities. The Wireless Sensor Networks of Heraklion, Greece, is an example of it[58]. In general, Wireless Sensor Networks (WSN) can be used to measure air pollution, traffic, meteorological parameters, noise, water quality, animal tracking, different risks (landslides, forest fires, flooding, earthquakes), impact of industry (waste monitoring, machine conditions), health conditions (physical state tracking, health diagnosis). These data can be used as baselines for evaluation of NBS environmental impacts.

[58] http://www.rslab.gr/downloads_urbanfluxes.html

Table 7-4. Available data sources for in-situ observations and ground measurements (selection of six representative observation networks for environmental monitoring).

Name	Web link	Description
ICOS (Integrated Carbon Observation System)	http://www.icos-infrastructure.eu/	Measurement network dedicated to the monitoring of greenhouse gases budgets in 12 European countries since 2008 (Ciais et al., 2014).
GLEON (Global Lake Ecological Observatory Network)	https://gleon.org/	Grassroots network of limnologists, ecologists, information technology experts, and engineers who have a common goal of building a scalable, persistent network of lake ecology observatories (Weathers et al., 2013).
FLUXNET	https://fluxnet.org/	A global portal which hosts harmonized and integrated fluxes measurements (ecosystem carbon, water, and energy fluxes) provided by more than 800 sites (active or historic) around the globe. It includes smaller networks targeting specific land use types, such as urban area or inland water systems. Besides fluxes, ancillary atmospheric state variables, like temperature, humidity, wind speed, rainfall, and atmospheric carbon dioxide are also measured (Pastorello et al., 2017).
European Eddy Fluxes Database Cluster	http://www.europe-fluxdata.eu/home	The database hosts data acquired since 1996 in the context of previous and ended research projects, mainly funded by EU. Datasets include fluxes of different Green House Gases and ancillary atmospheric state variables, like temperature, humidity, wind speed, rainfall, etc.
European Environment agency (EEA)	https://www.eea.europa.eu/data-and-maps	The European Environment Agency gathers data and information on a wide range of topics related to the environment (pollution, water, climate, etc.)
EC Joint Research Centre (JRC) Data Hub	https://data.jrc.ec.europa.eu/	This catalogue contains a wide range of datasets of all science areas of the JRC

Given the extensive variety of parameters which can be measured through in-situ observations and the likewise wide range of NBS KPIs (see Chapter 4) which can be derived based on this data category, it would have been impossible to provides an exhaustive overview in the context of this handbook. However, it is important to notice that generation of in-situ observation data can represent a nature-based solution metric on its own (i.e., quantifying a change in air pollution level by direct measurement) as highlighted by the key examples reported in Table 7-5. Furthermore, these environmental and ecological data (Table 7-5) are usually combined together with other measured parameters to create a combined metric (i.e., making ground observations of tree species, size, and Leaf Area Index (LAI) to support modelling of air pollution fluxes). However, due to the scale of the research field related to ground observations and nature-based solution evaluation, identifying the most appropriate/effective metric can be challenging. This is where detailed consideration of the NBS type, and associated theory of change (Chapter 2) are critical.

Table 7-5. Examples of indicators that have the potential to generate data using ground observations and how they have been used to assess NBS impacts with respect to Challenges 1 (Climate Resilience), 2 (Water Management), 3 (Natural and Climate Hazards), 4 (Green Space Management), and 6 (Air Quality).

Essential Variables evaluated through ground measurements	Indicators	Challenges
Direct Measurement of air temperature	Heatwave incidence expressed as the number of combined tropical nights (>20°C) and hot days (>35°C) per annum	1
Direct measurement of precipitation volumes and stormwater flowrates entering and leaving a NBS	• Surface runoff in relation to precipitation quantity • Flood peak height (m)	2, 3
Direct measurement of water quality parameters	Water quality: total metals abatement (% reduction in metal pollutants with individual metal/metalloid pollutants selected based on initial conditions)	2
Direct measurement of air pollution parameters	Number of days during which ambient air pollution concentrations in the proximity of the NBS ($PM_{2.5}$, PM_{10}, O_3, NO_2, SO_2, CO and/or PAHs expressed as concentration of benzo[a]pyrene) exceeded threshold values during the preceding 12 months	6
Direct measurement of wind direction/speed	Total O_3, SO_2, NO_2, CO removed by NBS vegetation (unit of mass/year): modelled or measured	1, 6
Direct measurement of soil quality	• Total carbon removed or stored in vegetation and soil per unit area per unit time • Soil organic matter content (%)	1, 4
Direct measurement of Tree size and Leaf Area Index (LAI)	• Total carbon removed or stored in vegetation and soil per unit area per unit time • Total PM_{10} and $PM_{2.5}$ removed by NBS vegetation (g/m^2 per year)	1, 6

7.2.3 Surveys

Surveys are another valuable method of collecting in-situ data relevant to NBS environmental monitoring. Data acquisition is done through manual sampling (removal of the soil, water, vegetation, etc.) and samples are then analysed in laboratories or more often on-site by portable devices or in mobile laboratories (Gruiz et al., 2017). However, the data are usually accompanied by uncertainties due to spatial and temporal (in particular, seasonal) heterogeneities typical for different environmental parameters.

Surveys are essential for studying diverse ecological phenomena (e.g., plant successions, species' population dynamics in an ecosystem, lake eutrophication, etc.) connected with the implemented NBS (Clobert et al., 2018). As an example, surveys can be used to assess the role of NBS in biodiversity enhancement by monitoring the abundance of living species in the NBS area and in its proximity. Indeed, NBS may contribute to enhancing connectivity by creating ecological corridors in urban context, thus enhancing biodiversity (including rare and threatened species; Bonelli, 2018; Nieto et al., 2014). Several biodiversity monitoring protocols have been developed and tested so far, and they are often adapted to the local needs, based on the NBS type, size, and on the stakeholders involved. All the reported protocols commonly shared the systematic approach. Examples of adopted protocols are reported in Table 7-6.

Table 7-6. Examples of biodiversity monitoring protocols (based on the monitoring activities conducted in the EU-H2020 project proGIreg). Source: Baldacchini (2019).

Category	Monitoring Protocols Adopted
Pollinator biodiversity monitoring Pollinators play a key role in every terrestrial ecosystem. They are pivotal not only from a biodiversity conservation point of view, but also for food production and for global economy. Monitoring this insect group is very useful to evaluate the environmental status (EU Pollinators Initiative 2017, Underwood 2017).	*Site: Urban park (Turin, Italy).* **Data sampling is conducted along specific transects, which allows the recording of associations between flowers and pollinators**. Transect walks also offer the possibility to evaluate the success of NBS implemented by combining butterfly and bee responses at community level. Surveys are made from April to September. Windy and rainy days are avoided for all observations and samplings. **Bee surveys:** Each survey comprises 250m long linear transects walked in 50 min. Each transect start point and direction walked were randomly determined. All bees unambiguously identifiable are recorded and all others are caught for later identification. Bee richness and abundance are determined. The honeybee is identified to species level (*Apis mellifera*) while other bees are identified to genus level. Surveys are made at least one per month, between 9:00 am and 5:00 pm. **Flower surveys:** Larval food plants and adult nectar sources of butterflies as well as flower surveys are carried out in parallel to the bee and butterfly surveys along the transects.

	Butterfly surveys: Transects are 300-500 m long, depending on the investigated area (according to the "Pollard walk" (Pollard and Yates 1993). Butterfly species are identified, and individuals of each species counted. Surveys are made, every two weeks, between 10:00 am and 3:00 pm for butterflies.
Phytoplankton biodiversity monitoring Plankton plays an important role in fisheries, water pollution prevention and environmental impacts of water conservancy projects (Sun et al. 2018)	*Site: Renatured lake (Ningbo, China).* **Water samples are collected once a week, for two years, at 3 sampling points, set at the inlet, outlet and centre of the lake.** Samples are analysed under the microscope to identify the species and number of phytoplankton and zooplankton individuals present in each sample.

7.3 Socio-economic, demographic and behavioural datasets for NBS monitoring and assessment: Methods and sources

Socio-economic, demographic, and behavioural data are essential in any NBS monitoring protocol as they allow assessment of the socio-economic and socio-cultural impacts of NBS, while also offering insight on public perception, degree of acceptance and aesthetic and/or recreational merit. In the EKLIPSE Working Group impact evaluation framework, for example, they are required for evaluation of many KPIs related to Challenges 6-10 [59].

A valuable source of data which fall in this category is the Statistical Office of the European Union, Eurostat (Table 7-7). More generally, these data are usually available from government agencies such as National Bureaus (or Offices) of Statistics. However, data retrieved from the aforementioned sources have often constrains and limitations due to the unavailability of updated statistics, especially in small areas such as neighbourhoods and suburban areas, or due to the lack of analysis which target specific data needs for the implementation and monitoring of a NBS (e.g., distribution of people for single age group in small areas).

> Socio-economic data represent a valuable resource for evaluating nature-based solutions. This section explores types of socio-economic data, different methods for collecting them, and examples of their relevance.

[59] 6: Urban Regeneration; 7: Participatory Planning and Governance; 8: Social Justice and Social Cohesion; 9: Public Health and Well-being; 10: Potential for Economic Opportunities and Green Jobs (see Chapter 5)

Table 7-7. Relevant databases of statistical data (incl. socio-economic and demographic)

Name	Web link	Description
Eurostat (Statistical Office of the European Union)	https://ec.europa.eu/eurostat/data/database	Supplier of a broad range of socio-economic data. Specific data themes includes economy and finance; population and social conditions; industry, trade and services; among others (full list available at: https://ec.europa.eu/eurostat/data/browse-statistics-by-theme). It also provides statistics in alignment with the targets of the Sustainable Development Goals.
Socioeconomic Data and Applications Center (sedac)	https://sedac.ciesin.columbia.edu/	It includes various types of statistical data (in form of spatial dataset and maps) at global scale, including population density and distribution, anthropogenic biomes, population dynamics (migration, fertility, and mortality), poverty, etc.
OECD Datasets	https://data.oecd.org	Comparisons by topic and country of several categories of data
World Bank Open Data	https://data.worldbank.org/	It includes a variety of regional or county-level datasets in tabular format, vector or raster geographical data and unit-level data from sample surveys and administrative systems.
Infrastructure for spatial information in Europe (INSPIRE) Knowledge Base	https://inspire.ec.europa.eu	The INSPIRE Knowledge Base was developed after the adoption of the INSPIRE Directive (2007/2/EC). The Knowledge Base comprises of datasets on multiple environmental, demographic and socio-economic domains.
Risk Data Hub (DRMKC)	https://drmkc.jrc.ec.europa.eu/risk-data-hub	The risk data hub is an open access platform for risk related geospatial data in Europe. The data hub encompasses current and future hazard and exposure analysis as well as loss and damage data of historical events. The data is available on different scales based on the NUTS classification in Europe.
ClimateAdapt	https://climate-adapt.eea.europa.eu/#t-database	ClimateAdapt offers a list of statistical and spatial indicators on climate change adaptation. In addition, the database includes other data types (videos, publications, case studies and more).

In cases when data are unavailable (or inadequate), a customized data collection is required, which becomes the sole solution for monitoring the socio-economic performance of the NBS interventions. Under this perspective, a wide range of collection data methods exists including qualitative analysis (focus group, observational methods), surveys, and co-participation methods. Therefore, the following sections encompass the main approaches and methods adopted in this context and present practical examples of their applications. Although each data collection method is presented here as standalone, it is important to recognise that socio-demographic and behavioural data are often and preferably the result of mixed and integrated approaches which rely on multiple data types and methods discussed hereafter.

7.3.1 Quantitative, qualitative and map-based surveys

Surveys represent a well-known and widely adopted method of collecting sociodemographic, economic, and behavioural data. They can be differentiated into quantitative, qualitative, and spatially anchored (map-based) surveys, depending on the specific data needs and research approach adopted.

Quantitative surveys are primarily conducted with questionnaires. Following the definition of Creswell (1999), quantitative research aims at "explaining phenomena by collecting numerical data that are analysed using mathematically based methods (in particular statistics)". Data gathered through quantitative surveys are indeed – and by definition – expressed in numerical format and therefore they can be managed and analysed statistically (as opposed to qualitative survey data which are usually non numeric). The quality of collected data represents a crucial aspect in a quantitative survey. To ensure quality, relevance, simplicity, accuracy and clarity of the questionnaire (or any other measuring instrument) should be carefully verified before the start of the investigation. Choice of the proper sampling approach (probabilistic vs. not probabilistic), calibration of the measuring instrument (e.g., questionnaires) as well as identification of suitable strategies for data collection are also critical factors to be considered.

Qualitative surveys are primarily conducted with interviews. They are a common method adopted in qualitative research, which can be described as explanatory research aiming at understanding a context or underlying reasons and motivations (e.g. what are people perceiving about an NBS or why are they perceiving it like this?). In contrast to quantitative data, *qualitative data aim at describing, and not at predicting*. They are typically not numerical but can be analysed using more recent statistical methodologies that do not necessarily emphasise the numerical aspect but rather the relationships. In general, data gathered from qualitative surveys are more complex than quantitative ones and have also constrains in terms of generalisations and upscaling due to the small size of the population sample investigated. However, tools used for qualitative surveys are very versatile and have a participatory character. Common tools include open-end questionnaire, one-person-interview, and focus groups.

Focus groups are used to gather a larger number of information emerging from group discussions on a specific topic and are led by an expert moderator (facilitator). This measuring instrument has proven to be very useful in the building-up phases of any process, since it investigates perceptions, opinions, beliefs and attitude towards a product or process. Although this vast amount of information is difficult to categorise in a systematic way, it represents a valuable and effective tool to allow the monitoring and consequent adaptation of NBS planning and implementation. Focus groups would therefore be a useful opportunity for enabling people in participating in a real co-design NBS process and for preventing marginalization and social exclusion in the social-ecological context in which they are embedded. Furthermore, engaging stakeholder in the process of decision-making on NBS can, simultaneously, increase the performance of an intervention (Woroniecki, 2019).

Map-based surveys are online questionnaires that are increasingly used to enhance public participation as well as co-creation (Linden and Sheehy, 2004). This type of survey data allows for automatized spatial anchoring of the collected survey data. It is a participatory tool for collecting primarily socio-economic data but also for establishing the opportunity for citizens to actively engage in decision-making and, simultaneously, enhancing transparency, trust and satisfaction in planning processes. The added value of collecting spatial anchored survey data for NBS monitoring and assessment can be further highlighted by considering, for instance, monitoring small scale changes or understanding risk perceptions which are often place-based. These survey studies can also be conducted with the aid of various software products currently on the market. An example is Maptionnaire (https://maptionnaire.com), which is a software for map-based questionnaire to facilitate public participation. It can be used, for instance, to learn more about public perceptions and acceptance of NBS. The software offers a working space for direct data analysis and management. Furthermore, the data can be exported to shapefiles, XLSX and other data formats. Another example of a map-based surveys is using crowdsourcing application Ushahidi (https://www.ushahidi.com/).The application has been customized within the EU-H2020 project Operandum to collect information about the exiting NBS installation at the global scale using simple questionnaire with mapping application (see Figure 7-4 in Section 7.7).

Overall, surveys represent an effective method for collecting both qualitative and quantitative data relevant for monitoring the sociodemographic, economic, and socio-cultural system context in which NBS are embedded. Results derived from the EU-H2020 CONNECTING Nature project offer a meaningful example on how survey data can be used to assess socio-economic benefits from NBS. Specifically, the concept of semi-structured interviews using questionnaire was developed as part of the research work in the project. Data gathered from these interviews represent an example of 'process indicators' since they enable evaluating the processes involved in successful (and unsuccessful) nature-based solution delivery.

Figure 7-2 summarises the CONNECTING Nature study and shows the interview template developed for that purpose. In other cases, such as the EU-H2020-project Nature4Cities, specific questionnaires are developed in local language to clarify whether the local stakeholders in the pilot cities of the project understand the benefits and trade-offs of an NBS implementation case.

1. Introduction

- Short history about what this institution and the role of the expert there;
- How do you understand the NBS term? which NBS experiments do you know and which NBS we will discuss?
- How can you classify this NBS (e.g. single case studies, chance examples, on-going labs etc.)?
- What do you consider the most interesting, innovative and transformative case of NBS experiment (e.g. tools, methods, framework etc.)?
- What do you consider to be the key to success in this experiment? What are obstacles?

2. Description of NBS experiment(s)

- What is the location of the emerging NBS experiment(s)?
- What is/was your role and responsibility in the NBS experiment?
- What actors / stakeholders were involved in the experiment? (Initiating actors, partners, supporters, etc.)

3. Objectives and drivers

- What problem/s did the NBS try to solve? / What need did it respond to?
- What are the most important drivers of the NBS experiment(s)?
- What other categories of challenges does this NBS relate to (e.g. public health and well-being, economic development potential, green opportunities etc.).

4. Achievements / Multiple benefits / Impacts

- What do you think are the most interesting short-term outcomes / results of this experiment?
- what do you think are the long-term benefits?
- What benefits do you think the experiment had on (e.g. climate change, sustainable development, restoration of ecosystems and their functions, social cohesion and social integration... or other additional benefits)?
- How these benefits are / were identified and are they being monitored and/or evaluated?

5. Innovative and Transformational aspects of NBS experiment(s)

- What was innovative about the financing of the NBS? What sources of financing were used?
- What was the way of financing the NBS? Are there any financial construction, development plan or scheme?
- Were there any new business opportunities or (green) jobs created as a direct or indirect result of the project?
- What do you think is socially and organizationally innovative about the process of setting up the experiment?
- Did the NBS experiment(s) enhance stakeholder participation and include new (social) learning processes?
- Did the NBS experiment(s) include new types of collaborations for example between different societal sectors?
- Did the NBS experiment(s) included informal or formal networks for the organization and/or collaboration?
- Did the NBS experiment(s) include product or service innovation in terms of novel technologies used?
- Maybe the NBS experiment include novel environmental / ecological aspects/insights thet were used?

6. Monitoring, evaluation and final questions

- Do you know how the experiment(s) is going to be evaluated and monitored? If so, can you explain how?
- Are or did you use any novel monitoring and/or evaluation tool, Database, Cloud and/or Geospatial tools used for monitoring, controlling and communicating the NBS?
- What do you consider the biggest challenges/problems for emergent NBS experiments?
- Are you familiar with any novel, emerging, particularly interesting experiments outside Europe?
- Do you know any expert or organization that you suggest us to contact and why?

Figure 7-3. Interview template including the six-step iteration applied in the survey of Connecting Nature project (Dushkova and Haase, 2020).

In CONNECTING Nature, experts dealing with implementing NBS in particular cities were interviewed on emergent, innovative, and novel NBS using templates (questionnaires). The aim was to identify lessons learned that will benefit other cities and stakeholders who are interested in designing, implementing, and stewarding NBSs. The interviews were supplemented by site visits and participant observation including those during open public events, urban festivals, public lectures, guided excursions, and other events. The interviews allow to analyse the following aspects important when planning and implementing a specific NBS:

- Factors of success of NBS examples – what in particular has contributed to the successful existence of selected NBS examples (e.g., by looking at the history of their creation, their impact, governance models, methods of implementation, design and maintenance, additional benefits, costs and financing);

- Impact of NBS examples on the environment, economics, society and sustainable development of the city, to better face current societal challenges, especially the consequences of climate change in cities and urban regions;

- Trade-offs and conflicts around the NBS – identifying the potential barriers for the implementation of effective and durable NBS (Dushkova and Haase, 2020)

Besides, a broad category of computer-assisted approaches has become increasingly popular for conducting survey studies, such as computer-assisted web interview and computer-assisted self-interviewing, while more traditional tools such as paper and pen data collection, or questionnaires by post, tend to be less used. For example, a web-based survey has been developed in the scope of the EU-H2020 project EdiCitNet in order to collect data on the social, economic and environmental performance of Edible City Solutions (ECS)[60]. The web-survey adopts a colloquial and friendly language and has been co-developed with local ECS, building upon three main scientific theories on the emergence and diffusion of similar initiatives: strategic niche management, grassroots innovations and fertile soil (Sekulova et al., 2017; Seyfang and Longhurst, 2016; Wolffram, 2018).

7.3.2 Population observations

Although surveys remain the most popular data collection method used in research with humans, in-situ observations represent another possible – and usually complementary – approach for collecting sociodemographic and behavioural data in connection with an implemented NBS. As explained in Section 7.1, observational tools differentiate from surveys for the fact that data are collected *without* interacting with the object of the research: human behaviour is observed from afar, and it is registered, according to specific, validated protocols.

[60] ECS are edible nature-based solutions, i.e., NBS related to urban food production, processing and use

This type of in-situ observations is particularly useful when trying to gather up-to-date and detailed data in small areas such as neighbourhoods and suburban areas. For example, certain types of NBS such as public parks, urban forests, tree corridors, renatured river or lake shores, have the benefit (or co-benefit) to provide (or provide access to) a space that the population can use to visit green and/or blue spaces and/or for physical activity. To evaluate whether this is effective, systematic observation can be performed on-site in order to monitor the use of the NBS and to assess the related changes in time (before and after NBS implementation).

A method to quantify the use of a green/blue space is, for instance, the validated SOPARC (System for Observing Play and Recreation in Communities) tool (McKenzie et al. 2006; https://www.rand.org/health-care/surveys_tools/soparc/user-guide.html). SOPARC can provide data on the number of users and type of physical activity, which represent a common data requirement for Challenges 7 (Place Regeneration) and 11 (Health and Wellbeing), and related indicators.

To summarise the method, trained observers (possibly including participation of stakeholders) count the number of users at the NBS site and register the users' characteristics (sex and age group) and type of activity (e.g., sedentary, walking, or very active). These observations are systematic and periodic; measurements are taken in specific periods of time (morning, lunchtime, afternoon, and evening) and specific days (within one week). These periods are defined to get an overall estimate of the use of the site.

To evaluate the change in use and physical activity, systematic observations can be performed before and after the NBS implementation is monitored, taking care of repeating the data collection in the same season. In the case of NBS implementations in pre-existing public green area, a single post-implementation SOPARC assessment can be conducted, to describe NBS users and their behaviour.

While in-situ observations such the one collected with SOPARC provide standard quantitate data, other methodologies exist which also provide qualitative data. For examples, methodologies which integrate visual techniques such as photography, film, video, painting, drawing, collage, sculpture, artwork, graffiti, advertising, and cartoons are increasingly used in multiple disciplines (Pain, 2012). These methodologies can be used to measure in an indirect way the crowding of parks without quantitative research: the longitudinal mapping of graffiti can be considered as proxy of artistic expression or cultural dimension.

7.4 Data sources for the assessment of changes to health and wellbeing

There is an increasing recognition of NBS co-benefits as influential determinants of human health and well-being (Barton and Grant, 2006; Hartig et al., 2014; Kabisch et al., 2017). They relate to the provision and improved availability of urban green spaces and may result in better mental and physical health. A great number of the scientific literature provides results of how different urban nature-based solutions can affect the health of urban residents and present epidemiological evidence of public health benefits of green spaces (Beyer et al., 2014; ten Brink et al., 2016; Dushkova and Ignatieva, 2020; Frumkin et al., 2017; Groenewegen et al., 2006, Kabisch et al., 2017; Kabisch and Haase, 2018; Marcel et al., 2019; Williams, 2017; Wood et al., 2016). There are three urban health dimensions, namely environmental conditions and related health outcomes, urban equity and vulnerability as well as resilience to extreme climate conditions related to climate change.

There are many direct links between nature and human health and well-being which resulted from the epidemiological surveys. Thus, connection with nature, in addition to satisfying elementary human needs (e.g., food and natural resources supply), heals or mitigates the most diseases and can be defined as a health resource (which keeps people healthy) (Groenewegen et al., 2006; Kabisch and Haase, 2018). The recreational and healing value of nature for physical health and mental well-being has long been discussed (Beyer et al., 2014; Hartig et al., 2014; Marcel et al., 2019). However, nature also has another value for health, regardless of natural remedies (though often not consciously perceived). For example, the healing of space, outdoor training trails in parks, everyday use of urban green spaces and peri-urban recreation areas for sport and exercises (cycling, jogging, and Nordic walking). These health aspects of outdoor nature are used for promotion healthy life-style, especially for children, through the active nature experience, since many children in urban spaces no longer have the opportunity to acquire nature in everyday life experience (Kabisch and Haase, 2018). Thus, as a source of healing, and source of inspiration, nature plays an important role in the identity of people and in the development of its own "sense of place" (Frumkin et al., 2017).

Health & Wellbeing represents an emerging and often complex approach to evaluating NBS impacts due to issues of causality. This section explores the types of data and approaches that can be used to assess NBS impacts on health and wellbeing.

While the provision of nature-based solutions refers traditionally to environmental organizations and planners, greater involvement of the health sector will be important for maximizing benefits for both health and nature. Integrating policy on biodiversity, health and urban planning to realize joint benefits requires data from all fields to be linked and communicated to policy makers, to be considered in impact assessments and economic valuation of decisions (Kabisch et al., 2017).

Main types of data needed to study the relationship between NBS and human health are:

- Quantitative data from case studies – epidemiological survey and regional statistics; often, local practitioners benefit from quantitative data and it is helpful to consider early in the process what quantitative data could be obtained with reasonable effort. The use of routinely collected statistical data on local level should be maximized. Yet, the use of other types of arguments and measurements to complement the quantitative data is necessary to avoid that the lack of quantitative data is interpreted as a lack of evidence in general;

- Qualitative data (e.g., from semi-structured interviews) which can allow to capture all the needs of the varying community subgroups. The interviewing of the intended users of the intervention could be a good way to gain understanding of their needs as well as their experience with similar NBS implemented earlier in another place. Various techniques can be used to collect these data such as using maps during interviews to gain a robust understanding on how people use and move in and around local green space.

Literature review shows that very often the following study design was applied:

- Cross-sectional questionnaire survey of women or/ and men (mostly separating adults from children). Stratified random or cluster sampling design;

- Observational study of the usage of urban parks or other NBS - direct observation of park users as well as interviews with persons;

- Survey data combined with GIS and green space data, and their analysis;

- Ecological study of mortality and dasymetric mapping of air pollution and greenness;

- Observational ecological study comparing neighbourhood socioeconomic status of women and individual physical activity;

- Self-administered survey of persons on their perceived general health and the characteristics of their living environment;

- Health interview survey of persons that examined self-reported health, social contacts, and characteristics of the respondents' living environments.

Several guidelines were established by WHO (2017) for simple data collection methods to identify and assess the value of urban green and other nature-based solution for human health and well-being:

- Use observational data as a relatively simple and cost-efficient way to assess how many people are using green space, what types of people are using it, who they are using it with, for what purposes etc.;

- Use existing audit and observational tools to collect information on play and recreation in public areas;

- Consider simple and innovative monitoring techniques (e.g., user satisfaction counters like seen in public facilities);

- Engage with local networks and organizations as a way to collect feedback from community and green space users (e.g., engage with community councils or committees);
- Collaborate, where possible, with academic institutes and research centres which can aid with delivering effective monitoring and evaluation for the intervention as well as cost-efficient monitoring (e.g., through developing student research projects around the NBS intervention).

It is important to consider existing, routinely collected datasets and how these might be utilized. Some national or local municipality surveys may already have baseline information on how people currently use and value local NBS, what effects were reported and analysed. Good demographic data on local residents and intended users of the green space is critical for informing the planning and design of the intervention.

Often, socioeconomic status data but also other data (e.g., on environmental risk exposure, age and sex, or ethnic and other sociocultural parameters) are available through standard processes on local level. Such data may often be available in aggregated form for an urban/neighbourhood area rather than as individual data. In such cases the smallest-possible spatial unit should be considered, since understanding the population profile is important to define equity issues (WHO, 2017).

The role of citizen science and participatory research in evaluation should be considered. This may aid data collection and evaluation, and would also help to increase the active uptake of the NBS interventions.

The literature reports on **positive** health associations for a diverse range of NBS interventions such as street trees, green space establishment on vacant lots and greening school playgrounds. Reported benefits in terms of reduced exposure to air pollution are substantial, and usually complemented by others of social (green spaces for the public) and/or economic nature (new job and business opportunities).

However, implementation of urban green infrastructure can result in **negative** impacts on the local air quality such as the direct emissions of pollen, fungal spores and biogenic volatile organic compounds (bVOCs). It is thus of paramount importance an informed choice of the most appropriate species prior to deployment. The scale and physical dimensions of the deployment are also critical and need to be assessed case by case, and the outcomes of similar green infrastructures may vary considerably in different urban environments (Kumar et al., 2019).

However, it is important to think in a broader sense when planning NBS interventions. This means to realize the opportunities for collaboration with institutes such as schools, universities and health services which may enable access to relevant data sets and help with informing the design of the intervention. The potential of NBS co-design activities with schools and universities has been, for example, demonstrated in one of NBS being implemented within the framework of the EU-H2020 project OPERANDUM: these activities have shown to have the multiple benefit to introduce climate action in education with potential positive impacts towards the realisation of the objectives of SDG11 and SDG13. Also, broader interventions (such as urban extensions, large infrastructure projects or masterplans for residential areas) could consider and include urban green space and be informed by the benefits of such provisions.

7.5 Predicting the present and future impacts of NBS with modelling techniques

Modelling is a critical and often compulsory aspect of NBS impact assessment (Figure 7-3). It allows to simulate the efficiency of one or more components of NBS, and to monitor and evaluate progress towards its goals. Here, the term *modelling* is employed to denote any type of modelling for any Essential Variable. Various modelling approaches, from lumped to distributed models, require a varying level of complexity of the described environment.

> In addition to direct measure and observation, modelling also represents a potential mechanism for generating data on NBS impact assessment. This section discusses a range of modelling approaches and their potential applications.

Modelling NBS addresses the representation of processes that occur in the real world in space and time. The processes resulted or caused by NBS transform the environment through time and can be mostly described by dynamic models based on differential equations. The spatial interactions of different elements of NBS and NBS with the environment are mostly managed by geographic information systems (GIS). GIS can be used to provide input variables required by simulation models and yield visualization and analysis of output data. Other ways are represented by direct integration of numerical modelling which is a mathematical representation of a physical (or other) behaviour, based on relevant hypothesis and simplifying assumptions. Various simulation tools together with GIS are used to demonstrate modelling of, for instance, surface water pollution, spatiotemporal analysis of air pollution data, modelling of land use changes (Cohen-Shacham et al., 2016). Another type of modelling – physical modelling – is used to validate numerical modelling data; the use of physical models supports the understanding design concepts and processes. Modelling combined with scenarios provides insights into drivers of change, potential implications of different trajectories, and options for action (Sang, 2020). Section 7.1.7 presents a more detailed discussion on the modelling approaches and their complexity.

Modelling approaches are primarily adopted for one or more of the following purposes:

- **Identify and/or understand the underlying processes which describe with certain level of uncertainty relevant environmental (or behavioural) response/change of the urban system before (baseline) and after the NBS intervention.** For example, models can simulate different natural processes such as crop growth, flooding, and local climate regulation (e.g., Mohareb et al., 2012) by green space or soil nutrient flow. In that respect, the advantage of modelling techniques relies on the possibility of changing input data and parameters to be in the model. This allows to understand cause-effect relationships and to make predictions at a level which is not possible with observations.

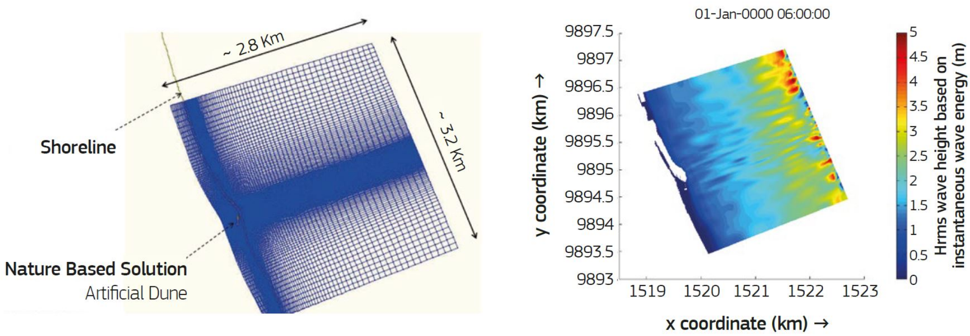
- **Identify vulnerable urban areas and/or areas which are more prone to certain natural hazards** (e.g., flooding). When implementing nature-based flood protection, for example, it is essential to conduct a probabilistic hydrological and hydraulic modelling assessment and map flood zones with the potential intensity and location of all relevant types of flooding (Mason et al., 2007; Pregnolato et al., 2016; Raymond et al., 2017). Such resulted maps of potential inundation will present a range of return periods and appropriate planning needs. Other techniques include modelling of flood peak reduction (Iacob et al., 2014) or modelling of options for stormwater management in the urban environment, including the quantification of SuDS benefits with the BeST model (Morales-Torres et al., 2016).

- **Generate (or use) simulation data to fulfil the data requirements for specific KPI, especially when other data collection methods are not feasible/too expensive, or data are simply not available or adequate.** For example, gross and net carbon sequestration of urban trees can be estimated with the iTree Eco model (Baró et al., 2014), which provides a database on ecosystem services rendered by different trees species in different climatic zones.

- **Improve awareness and perception of NBS co-benefits and efficacy through scenario and impact modelling.** For example, superior performances and co-benefits of a specific NBS versus more traditional interventions (e.g., grey infrastructure) can be verified through modelling studies (e.g., Gittleman et al., 2017), and effective communication of these results may enhance acceptance and engagement among stakeholders and policymakers. In that regard, it is worthwhile to mention that models not only represent the environmental impact of NBS, but they can also model the societal responses and participatory process by applying methods such as geodesign. As stated by Steinitz (2016), geodesign helps to find consensus around plans with sufficient detail to be workable, adaptable to the local needs and context and sustainable over time. Additionally, development of innovative social models for long-term positive management (e.g., Citizen Engagement for Health; Fernandez et al., 2015) may also contribute to increasing stakeholder awareness and knowledge about NBS and ecosystem services, as well as citizen participation in the management of NBS (Filibeck et al., 2016; Hansen et al., 2016).

- **Develop design scenarios for the selection of the optimal NBS** among the ones conceivable, and for estimation of efforts needed for its implementation and maintenance.

- **Forecast NBS performances and impacts over time and/or in connection with future climate projections**. In this regard, extensive research modelling efforts have been made to assess effectiveness of NBS in tackling challenges such as climate change, food security and water resources. Furthermore, the use of natural hazard modelling has been expanded and combined with numerical weather prediction and climate models to develop climate change adaptation and disaster risk reduction strategies that are resilient, adaptable, resource efficient, locally adjustable and optimised.



15.

Figure 7-4. Simulation of hydrodynamic and morpho-dynamic processes to assess the effect of NBS (artificial sand dune) on wave propagation. Left: Numerical Domain showing the position of the NBS along the shoreline. Right: model results showing the wave propagation (source: EU-H2020 project OPERANDUM; image credit: ARPAE-IT)

Despite their numerous advantages and countless applications, modelling techniques have also limitations and uncertainties which should never be neglected in the evaluation process and/or while using modelling results. Some of these limitations and uncertainties are intrinsic to the technical or mathematical structure (or logical framework) on which the model is built, and on the assumptions and/or approximations which may be embedded into it. For that, simulation results must be compared to and validated against observational data to ensure the validity of results and also the quantification of the overall uncertainty of the simulated scenario assessed. Errors and/or misleading results can also be generated by an "inappropriate" use of the model. Indeed, every model is built to address only specific research questions and is meant to be used only for certain specific applications and contexts. Knowledge of the model goals and capabilities is thus crucial in order to select "the right tool for the right problem".

A variety of numerical models exists that are used to simulate the state variables such as temperature, precipitation and evapotranspiration. Table 7-8 lists the relevant modelling tools for assessing ecosystem services provided by NBS. A non-exhaustive list of the most widely used numerical models can be classified under the following Challenge areas:

- Climate resilience
    - General circulation models (GCM) (Mechoso and Arakawa, 2015)
    - Weather Research and Forecasting Model (WRF) (Surussavadee et al., 2017)
    - complex numerical methods describe the interactions between vegetation and pollutants at the micro scale (Joshi and Ghosh, 2014) or simulate the emission and deposition processes based on trajectory and dispersion models, e.g. the atmospheric transport FRAME (Fine Resolution Atmospheric Multi-species Exchange) model (Bealey et al., 2007).

- Water management
    - MIKE11 (Thompson et al., 2017)
    - Soil Water Assessment Tool (SWAT; Arnold et al., 2012)
    - Storm Water Management Model (SWMM) (Rossman, 2015)
    - MODFLOW model (Langevin et al., 2017)
    - GREEN (JRC) (Grizzetti et al., 2012)

- Natural and climate hazards
    - Discrete Element Method (DEM) (Mahmood and Elektorowicz, 2016)
    - ADvanced CIRCulation (ADCIRC) (Luettich et al., 1992)

Table 7-9 presents a selection of studies obtained from the scientific literature, which show the ways simulation and modelling can be applied to the assessment of NBS impacts in the urban environment.

Table 7-8. Modelling tools for the assessment of the ecosystem services provided by NBS.

Tool/Model	Description	Source	Comment
Artificial Intelligence for Ecosystem Services (ARIES) / probabilistic model	A networked software technology that redefines ecosystem service assessment and valuation for decision-making, to map natural capital, natural processes, human beneficiaries, and service flows to society as a new way to visualize, value, and manage the ecosystems on which the human economy and well-being depend; to quantify the benefits that nature provides to society	http://aries.integratedmodelling.org/	ARIES is meant to enable simple use of complex models through artificial intelligence; as such, extensive training (annual intensive modelling schools) is only necessary for modellers who want to contribute to, and benefit from, ARIES models and data.
The Atlas of Natural Capital (ANK) / Spreadsheet	Up-to-date platform for knowledge and information dissemination enhancing the sustainable use of natural capital (currently more than 150 maps on ecosystem services in the Netherlands)	www.atlasnatuurlijkkapitaal.nl/en	Companies, governments and citizens can use data from ANK
The Ecosystem Services Mapping tool (ESTIMAP) / GIS application	A collection of spatially explicit models to support the mapping and modelling of ecosystem services at European scale. Its main objective is to support EU policies with spatial information on where ecosystem services are provided and consumed.	Zulian et al. (2014)	It is based on the ecosystem services cascade framework which is used as a frame for mapping; it includes four complete models: outdoor recreation, crop pollination, coastal protection and air quality regulation.
Benefits Estimation Tool (B£ST) / Spreadsheet	Benefits Estimation Tool – valuing the benefits of blue-green infrastructure. It assesses and monetizes many of the financial, social and environmental benefits of blue-green infrastructure; it enables users to understand and quantify the wider value of Sustainable drainage systems and natural flood management measures	https://www.susdrain.org/resources/best.html	A free tool and guidance for use on PCs. It makes assessing the benefits of blue-green infrastructure easier, without the need for full scale economic inputs; it can support investment decisions and help to identify stakeholders and find potential funding routes.
i-Tree (formerly Urban Forest Effects Model) / Desktop software	Based on peer-reviewed, USDA Forest Service Research, it offers several desktop and web-based applications to quantify the benefits and values of trees around the world, to aid in tree and forest	https://www.itreetools.org/	i-Tree is a combination of science and free tools; it provides users/managers with tools by allowing them to improve tree and forest management, plan strategically, increase

	management and advocacy, to show potential risks to tree and forest health		awareness, engage decision makers and build new partnerships.
ESValues / Spreadsheet	A collaborative platform that collects economic data from ecosystem services studies to produce value estimates by benefit transfer	https://esvalues.org/	It allows users to obtain economic values for the ecosystem services provided by an ecosystem and upload the parameters and estimates from these economic valuations
Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) / GIS software	A suite of models used to map and value the goods and services from nature that sustain and fulfil human life. It helps explore how changes in ecosystems can lead to changes in the flows of many different benefits to people. The toolset includes distinct ecosystem service models designed for terrestrial, freshwater, marine, and coastal ecosystems, as well as a number of "helper tools" to assist with locating and processing input data and with understanding and visualizing outputs.	https://naturalcapitalproject.stanford.edu/invest/	Free, open-source software models; it enables decision makers to assess quantified tradeoffs associated with alternative management choices and to identify areas where investment in natural capital can enhance human development and conservation.
A Global Standard for Nature-based Solutions / Spreadsheet	Developed by IUCN in order to create a common understanding and consensus on Nature-based Solutions, the Ecosystem Management Programme and Commission are jointly leading the collaborate process of elaborating a Global Standard for the Design and Verification of Nature-based Solutions.	https://www.iucn.org/theme/ecosystem-management/our-work/a-global-standard-nature-based-solutions	Not yet available (still in the developing stage)
Land Utilisation Capability Indicator (LUCI)	An ecosystem services modelling tool which illustrates the impacts of land use on various ecosystem services. It runs at fine spatial scales and compares the current services provided by the landscape with estimates of their potential capability. LUCI uses this information to identify areas where landscape usage change might be beneficial, and	https://www.lucitools.org/	LUCI is relevant for a range of users at multiple scales and levels of decision-making. It can be applied for applications around sustainable development, conservation, sustainable tourism, restoration, and policy-making.

	where maintenance of the status quo might be desirable.		
The NATURVATION index / Spreadsheet	The Naturvation Index (proposed by the EU-H2020 project NATURVATION) to evaluate nature-based solutions projects and identify how they contribute to sustainability goals.	https://naturvation.eu/assessment	Value and Benefit Assessment Methods Database and Framework for Urban Nature-based Solutions
Social Values for Ecosystem Services (SolVES) / GIS application	A GIS Application for Assessing, Mapping, and Quantifying the Social Values of Ecosystem Services – SolVES 3.0 tool which is ArcGIS 10-compatible.	https://solves.cr.usgs.gov/	SolVES derives a quantitative, 10-point, social-values metric, the "value index", from a combination of spatial and nonspatial responses to public value and preference surveys and calculates metrics characterizing the underlying environment, such as average distance to water and dominant land cover.
The Economics of Ecosystems and Biodiversity (TEEB) Valuation Database / Spreadsheet	The Manual presents an overview and explains the potential uses and functions of the TEEB Valuation Database. The Manual discusses the origin of the database; describes its content and structure; outlines its contents and discusses how it may be used, including important caveats.	http://www.teebweb.org/publication/the-economics-of-ecosystems-and-biodiversity-valuation-database-manual/	It allows for user the evaluation of ecosystem services, but not measure the quantities and not allows to input the data
Toolkit for Ecosystem Service Site-based Assessment (TESSA) / Spreadsheet and GIS application	The toolkit provides practical guidance on how to identify which services, what data are needed to measure them, what methods or sources can be used to obtain the data and how to communicate the results. The toolkit has attempted to find a balance between simplicity and utility and can be used by non-experts, yet still provide scientifically robust information.	http://tessa.tools/	It emphasizes the importance of comparing estimates for alternative states of a site (for example, before and after conversion to agriculture) so that decision-makers can assess the net consequences of such a change, and hence the benefits for human well-being that may be lost through the change or gained by conservation.

Copernicus, Corine Land Cover by EEA (European Environment Agency)	Copernicus Land Monitoring Service portfolio (both already operational and upcoming) products are divided into the following categories: Land Cover and Land Use Mapping Hot-spot Monitoring Biophysical Parameters Imagery, In Situ and Reference Data European Ground Motion Service	http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012/view	Corine Land Cover (CLC) 2012, Version 18.5.1. Processed by The European Topic Centre on Land Use and Spatial Information
The assessment of ecosystem and their services – approaches from LIFE program of European Commission	The assessment results helps explaining better to the general public and stakeholders the multiple benefits of LIFE projects in connection to society and the economy with which they interface. The document clarifies key concepts and offers an easy method to implement ecosystem services assessments according to the analytical framework developed under the EU Mapping and Assessment of Ecosystems and their Services (MAES) initiative. Some guidance on how to complete the relevant sections in the KPI Webtool is also given.	https://ec.europa.eu/environment/archives/life/toolkit/pmtools/life2014_2020/ecosystem.htm	The guide has four main components: 1. An introduction to key concepts and methodology. 2. The description of a simple approach to assess ecosystem services applicable to all LIFE projects independently from the method used to quantify them. 3. Guidance on how to complete the relevant sections in the LIFE KPI database. 4. A selection of further resources (https://ec.europa.eu/environment/archives/life/toolkit/pmtools/life2014_2020/documents/life_ecosystem_services_guidance.pdf)
Land Use-based Integrated Sustainability Assessment' modelling platform (LUISA) / GIS based modelling platform	LUISA is developed by Joint Research Centre (JRC) of the European Commission, which is primarily used for the ex-ante evaluation of EC policies that have a direct or indirect territorial impact. At its core is a discrete allocation method that allocates different land uses to most optimal 100m grid cells, given predefined suitability maps, regional land demands and the supply of land in a region. Linked to the allocated land uses are grid cell population counts, which are modelled separately prior to the land-use allocation. The chief outputs that LUISA generates are projected land use, population and accessibility distributions at the 100m grid cell level. Over 50 indicators of land functions are subsequently derived from those chief outputs. Those indicators can inform	https://publications.jrc.ec.europa.eu/repository/bitstream/JRC94069/lb-na-27019-en-n%20.pdf	

	policy effects on themes as varied as resource efficiency, ecosystem services and accessibility.		
Integrated system of Natural Capital and Ecosystem Services Accounting (KIP INCA) / Spreadsheet	KIP INCA aims to develop the first ecosystem accounts at EU level, following the UN System of Environmental-Economic Accounting- Experimental Ecosystem Accounts (SEEA-EEA). The application of the SEEA-EEA framework is useful to illustrate ecosystem accounts with clear examples and contribute to further develop to methodology and give guidance for Natural Capital Accounting.	https://publications.jrc.ec.europa.eu/repository/bitstream/JRC87585/lb-na-26474-en-n.pdf	

Table 7-9. Studies of the impacts of NBS, which show how numerical simulations and modelling can be applied.

NBS	Study	Simulation model	Findings
Air quality	Hirabayashi et al. (2012), Nowak et al. (2014)	**i-Tree Eco** estimates air pollution removal by trees based on well-established **deposition models** and hourly air quality and wind speed data from local weather stations **i-Tree Eco:** https://www.itreetools.org/tools/i-tree-eco	It allows to quantify the structure of, threats to, and benefits and values provided by forests.
	McDonald et al. (2007)	The fine resolution atmospheric multi-pollutant exchange (**FRAME**) atmospheric transport **models** designed to predict the impact of NBS implementation of air quality level, e.g. to estimate deposition of nitrogen, heavy metals and the surface concentrations of greenhouse gases by tree planting **FRAME:** https://frame-online.eu/	Tree planting was simulated by modifying the land cover database, using GIS techniques and field surveys to estimate reasonable planting potentials and predict increasing total tree cover
	Matos et al. (2019)	To **model the supply of air-quality regulation** based on urban green spaces characteristics and other environmental factors (lichen diversity in urban parks)	A model allows to estimate the supply of air quality regulation provided by green spaces in all green spaces of Lisbon based on the response to the following environmental drivers: the urban green spaces size and its vegetation density. The model helps to map the background air pollution
	Bruse (2007), Simon et al. 2019	Microscale simulations employed for street-scale evaluation with software such as **ENVI-MET**. **ENVI-MET:** https://www.envi-met.com/	the newest version of the microclimate model ENVI-met was compared against measured data
	Bagheri et al. (2017)	**FRAGSTATS software (Spatial Pattern Analysis Program for Categorical Maps) and a partial least square (PLS) model**	The model results indicate that reduction in the area of large green space patches promote air pollution,

		were applied to assess the effects of changes in the pattern of green space on air pollution. **FRAGSTATS:** https://www.umass.edu/landeco/research/fragstats/fragstats.html Book on **PLS**: https://doi.org/10.1007/978-3-319-64069-3; https://core.ac.uk/download/pdf/20267242.pdf	suggesting that there is a direct relation between increases in the area of large green space patches and air pollution reduction.
Green roofs for temperature reduction	Bass et al. (2002)	Use of **Mesoscale Community Compressible (MC2) model**, land use grid cell data, urban canyon model for Toronto, Canada. https://www.coolrooftoolkit.org/wp-content/uploads/2012/04/finalpaper_bass.pdf	A green roof strategy consisting of grass roofs (only 5% of the total city area) reduced temperatures by up to 0.5°C. Irrigating green roofs in the high-density areas produced a much more intensified cooling effect: 1-2°C temperature reduction.
	Chen et al. (2009)	**Coupled simulations of conduction, radiation and convection** for Tokyo, Japan	Installing grass roofs on medium and high-rise buildings has a negligible effect on the street level air temperature.
	Smith and Roebber (2011)	**Weather research and forecasting model** (**WRF**) coupled with an urban canopy model (**UCM**) applied for Chicago, US **WRF–UCM:** https://ral.ucar.edu/solutions/products/urban-canopy-model	Vegetative rooftops reduce evening and night-time temperatures by 3°C through increased albedo and evapotranspiration.
	Sun et al. (2012)	**Numerical model ENVI-met** and verified using field measurements adapted for Taiwan **ENVI-MET:** https://www.envi-met.com/	The maximum cooling effect of green roofs on ambient air temperature was 1.6°C
Urban land use	Haase et al. (2012)	Combination of **system dynamics (SD), cellular automata (CA) and agent-based model (ABM)** approaches to cover the	Using the example of urban shrinkage, it highlights the capacity of existing land-use modelling approaches to

		main characteristics, processes and patterns of urban land use and shrinkage in Leipzig, Germany	integrate new social science knowledge in terms of land-use, demography and governance.
	Schwartz et al. (2012)	It presents the **ABMland** - a tool for collaborative agent-based model development on urban land use change which allows for explicitly coding land management decisions. The software is implemented in Java building upon Repast Simphony and other libraries. **ABMland:** https://www.ufz.de/index.php?en=37897	ABMland allows for implementing agent-based models and parallel model development while simplifying the coding process. The models include six major agent types: residents, planners, infrastructure providers, businesses, developers and lobbyists. Their interactions are pre-defined and ensure valid communication during the simulation.
	Brown and Castellazzi (2014)	**Rule-based models** developed for sectoral strategies such as woodland expansion, wind energy, urban development as input for development scenarios using **LandSFACTS software** and the **Integrated Agriculture and Control System (IACS)** data in a stochastic process. **LandSFACTS:** https://www.hutton.ac.uk/research/departments/information-and-computational-sciences/tools/landsfacts/downloads **IACS**: http://ec.europa.eu/agriculture/direct-support/iacs/index_en.htm.	Such approach of translating scenarios, storylines and policy objectives into spatially explicit realization can be used with any spatial unit (land use or cover polygon, population ward, water catchment) to explore alternative options for land use and the role of particular NBS intervention.
	Hamad et al. 2018	Land use change scenario simulation using a **CA-Markov model** as one of the commonly used models among many LULC modelling tools and techniques	The models can support to optimize urban land use layout and assist with decision-making
Water management	World Bank (2017)	Modelling NBS for managing freshwater resources	Models for provision of safe drinking water, integrated river basin management, pollution management

	Brunetti et al. (2016, 2017)	**Surrogate-based modelling** for the numerical analysis of low impact development techniques	The hydraulic behaviour of the green roof, permeable pavement and stormwater filter were analysed by means of a model approach
	Sahukhal and Bajracharya, 2019	The water demand and supply modelling were conducted using the **water evaluation and planning (WEAP) model**, based on discharge data (can be obtained from Department of hydrology and meteorology). **WEAP:** https://www.weap21.org/	The performance of the model was assessed through statistical measures of calibration with the root mean square error and coefficient of determination. It allows to create different scenarios important for the analysis regarding the prioritization of demands in the near future for the purpose of sustainability of water resources, due to climate change impacts.
Natural Hazards	Li et al. (2019)	The study used the **Soil and Water Assessment Tool (SWAT)** module of a GIS platform to simulate the potential of wetlands against flood and droughts **SWAT**: https://swat.tamu.edu/	The SWAT model was forced with meteorological variables such as daily rainfall, temperature, wind speed, relative humidity, solar energy and it was found that restoration and reconstruction of wetland can reduce the impact of flooding and hydrological droughts.
	Vuik et al. (2016)	Modelling the effect of vegetation on flood wave attenuation using the **Simulating WAves Nearshore (SWAN**) model **SWAN**: http://swanmodel.sourceforge.net/download/download.htm	The study forced SWAN numerical wave model with bathymetry, ocean current, ocean water level, bottom fraction, and wind speed datasets to simulate and evaluate the effect of vegetation on flood wave attenuation. The datasets were retrieved field measurements performed on two salt marshes (cordgrass and grassweed) during the severe storms in the

			Netherlands from November to June 2014
	Wamsley et al. (2010)	Use of the **three-dimensional numerical model ADvanced CIRCulation (ADCIRC)** to evaluate the role of wetlands in reducing storm surges. **ADCIRC**: https://adcirc.org/	The study simulated the role of wetlands in reducing storm surges and concluded that wetlands may have capacity to reduce surges, but their effectiveness depends on the surrounding, coastal landscape and the strength and duration of the storm forcing
	Stark et al. (2016)	Use of the **two dimensional hydrodynamic model TELEMAC2D** to evaluate the role of wetlands during storm tides. **TELEMAC2D**: http://www.opentelemac.org/index.php/presentation?id=17	The study simulated the potential of wetlands in attenuating peak water level during storm tides. The result of simulation showed that peak water level reduction largely varies among individual flood events and between different locations in the marsh, but the tidal wetlands in combination with dikes provides more effective coastal protection
	Guida et al. (2015)	**Combination of hydrodynamic (e.g., 1D HEC-RAS) and geospatial modelling (e.g., HEC-GeoRAS)** to simulate the optimal flood risk reduction measures for the Lower Tisza River in Hungary. The main modelling tools and software used in the study are developed by the Hydrologic Engineering Center (HEC) - US Army Corps of Engineers, and available here: https://www.hec.usace.army.mil/software/	The study performed two scenarios such as levee removal and leave seatback to reconnect wetland and found that the wetland reduced flood heights and potential damage to human populations.
	Sang (2020)	Integrating Computational and Participatory Scenario Modelling for Environmental Management and Planning. **A range of modelling**	Comparative review of a wide range of models from a variety of scientific

Different categories of NBS		approaches such as GIS, optimisation and AI, simulation modelling, remote sensing, citizen science, and geodesign.	disciplines of interest with examples of their use for NBS)
	Nijhuis et al. (2016)	**Geodesign as a GIS-based planning and design method**, which tightly couples the creation of design proposals with impact simulations informed by geographic contexts. It comprises a set of geo-information technology driven methods and techniques for planning built and natural environments in an integrated process	It allows project conceptualization, analysis, design specification, stakeholder participation and collaboration.
	Steinitz (2016)	**Geodesign** is proposed as an iterative design method that uses stakeholder input, geospatial modelling, impact simulations, and real-time feedback to facilitate holistic designs and smart decisions.	It was shown how geodesign bridge geo-information technology, spatial design and planning. It showcases the ongoing effort to employ the potential power of using GIS to link different model types and ways of designing to make better plans.
Ecosystem services provided by NBS	Nelson and Daily (2010), Nelson et al. (2009)	**Modelling multiple ecosystem services**, biodiversity conservation, commodity production, and tradeoffs at landscape scales using spatially explicit modelling tool, **Integrated Valuation of Ecosystem Services and Tradeoffs** (**InVEST**) **InVEST**: https://naturalcapitalproject.stanford.edu/software/invest	It allows to predict changes in ecosystem services, biodiversity conservation, and commodity production levels. InVEST was applied to stakeholder-defined scenarios of land-use/land-cover change in order to help making natural resource decisions more effective, efficient, and defensible.

7.6 Mimicking the impacts of NBS: how laboratory data can help

Laboratory experiments can help assessing causal relationships based on the observation of the direct effects of NBS on a small-scale with rapid, and short-term ecological/environmental processes and society. It can be assumed that if a laboratory study is well-controlled, the factors that can cause the difference can be reliably identified. In contrast, all confounding factors cannot be ruled out in observational studies (Yuan et al., 2017). Thus, laboratory studies are generally assumed to mimic long-term impacts of NBS and can be useful when trying to assess ex-ante the performances of a NBS intervention.

For example, a series of laboratory flume experiments has been conducted within the EU-H2020 Project OPERANDUM in order to study how different soil surface conditions (smooth, compacted and non-vegetated surface, soil vegetated with standard herbaceous plants vs specifically selected deep-rooted herbaceous plants, etc.) may affect or improve the erodibility resistance of the riverbank of Panaro River (IT) over long term. The studies were antecedent to the actual NBS deployment and guided the choice of the NBS most appropriate to help preventing levee failures and inundations at this site.

In the context of research with human, a novel technique to measure the individual's psychophysiological response to environmental stimuli is represented by Immersive Virtual Reality (IVR). IVR involves the use of virtual devices that allow the individual to experience a simulated natural environment in a multisensory way. For example, the response on the induced stress of virtual environments at different degrees of biodiversity (Schebella et al., 2020) and the aesthetic value and perception of beauty of a virtual environment with multiple natural features (Vercelloni et al., 2018) can be assessed with this technique. During the NBS planning stage, IVR pilot studies could provide guidance on how to maximize NBS beneficial effects on human health and well-being.

Laboratory based simulation represents a powerful means of generating data on NBS performance. This section presents examples of how laboratory experiments can provide insights into real-world NBS performance.

7.7 Engaging the community in the data collection process: citizen science and its role in NBS monitoring

Citizen science has great potential in monitoring and evaluating NBS impact. It can represent a cost-effective way to gather data on a larger numeric and/or geographical scale than would otherwise be feasible. In addition to this, citizen science approaches can offer numerous benefits for society compared to other types of data generation, including:

- Great paybacks to both society and growing areas of science (such as nature-based solutions), including raising awareness of local risks and opportunities;

- Engagement and empowerment of the public by giving them a voice in science, policy and decision making;

- Societal benefits such as social cohesion, integration, and reconnection of communities with nature.

Citizen science has risen in popularity due to these numerous co-benefits for citizens. Citizen science-based data generation can also represent added value for local authorities: Although there can be a cost associated with running such activities, this can represent value for money compared to the economic cost of alternative monitoring methods, particularly if the added social benefits are factored into the 'value' of the approaches.

Citizen science is increasingly recognised as an effective way to generate substantial datasets that would not otherwise be possible using traditional scientific approaches. This section explores the benefits of such approaches and discusses examples of how communities can be engaged in data generation.

Whilst citizen science approaches are becoming increasingly adopted, they can also come with challenges. This includes challenges in relation to the quality of data generated. For example, evaluation methods may need to be basic for some indicators compared to the complexity that can be achieved through the use of specialists. Other challenges to wider adoption of citizen science projects include the need for training participants, and associated problems in retention following training, challenges in validating data quality and reliability, and eliminating sampling bias (Pocock et al., 2014; Lukyanenko et al., 2016).

Despite these challenges, citizen science approaches are increasingly being adopted, including in the evaluation of nature-based solutions. For example, citizens have been actively involved in data collection for earth observation, ground measurements, and survey data. Citizens have contributed by using technological advancements such as smartphones, low-cost sensors, and social media to record such diverse parameters as air quality, bird and butterfly counts, water quality, recreational value of greenspaces, and risk management. Data collected from such processes may represent an entire dataset or can be used as added value or for validation purpose for data collected using other methods. The following tools are being successfully and broadly applied for citizen science data collection.

Crowdsourcing encompasses obtaining a large amount of data from a crowd of people (or more often the general public) that shares information, voluntarily. This is often done through the internet and/or using smartphones. Each single data supplies is then aggregated to generate a cumulative dataset. Due to the large number of contributors, crowdsourcing requires an easy to use framework, instructions and communication setup to ensure engagement.

Crowd sensed data describes data which are specifically collected and shared by a large number of citizens through different types of devices, such as mobile phones, wearable sensors or vehicles (e.g., sensors mounted on bicycles to measure air temperature or air quality parameters). Whilst this method of data generation also requires participant permission, it can be less active than crowdsourcing, with data often collected passively through smartphones and sensors rather than active input by participants. This can include environmental factors such as ambient light, noise, location data, movement data, and air quality. Similarly to crowdsourcing, this method of participatory sensing can support the monitoring process over a range of spatial scales form small to large (Guo et al. 2015). It has several advantages such as low-cost sensing or high amount of data collected. However, the use of crowed sensed data can be constrained by issues such as sensor accuracy and participation of citizens.

Volunteered geographic information (VGI) is a type of crowdsourced information where data have spatial information attached. The crowdsourced data are usually collected in, or converted to, a mapped form with spatial (and temporal) dimensions. Leading examples for this are *OpenStreetMap* (OSM) or the use of online mapping and social media such as Twitter to communicate information about natural disaster events (e.g., hurricanes and earthquakes).

These and other citizen science approaches have been tested and implemented by various NBS projects. This includes the EU-H2020 project OPERANDUM in which citizen science approaches were integrated into the NBS implementation and monitoring. Indeed, the community neighbouring the NBS were engaged in the co-design of the nature-based solutions, and were actively engaged in data co-creation processes. At one of the OPERANDUM NBS sites (Finland), citizens measured snow depth with traditional and low-cost measurement instruments during the winter, while water quality and visibility as well as precipitation were measured throughout the year. The measurements were then shared in a web application which is linked to the database of the national weather service (where the data were compared and combined with remote sensing data). OPERANDUM also uses OSM data to derive information about critical infrastructure for the risk modelling. Furthermore, the project offers a web application for NBS crowdsourcing which engages the citizens to post information (through their mobile phone or the internet) about NBS projects implemented in the place where they live or more in general about NBS which they have knowledge of (Figure 7-4).

(a)

(b)

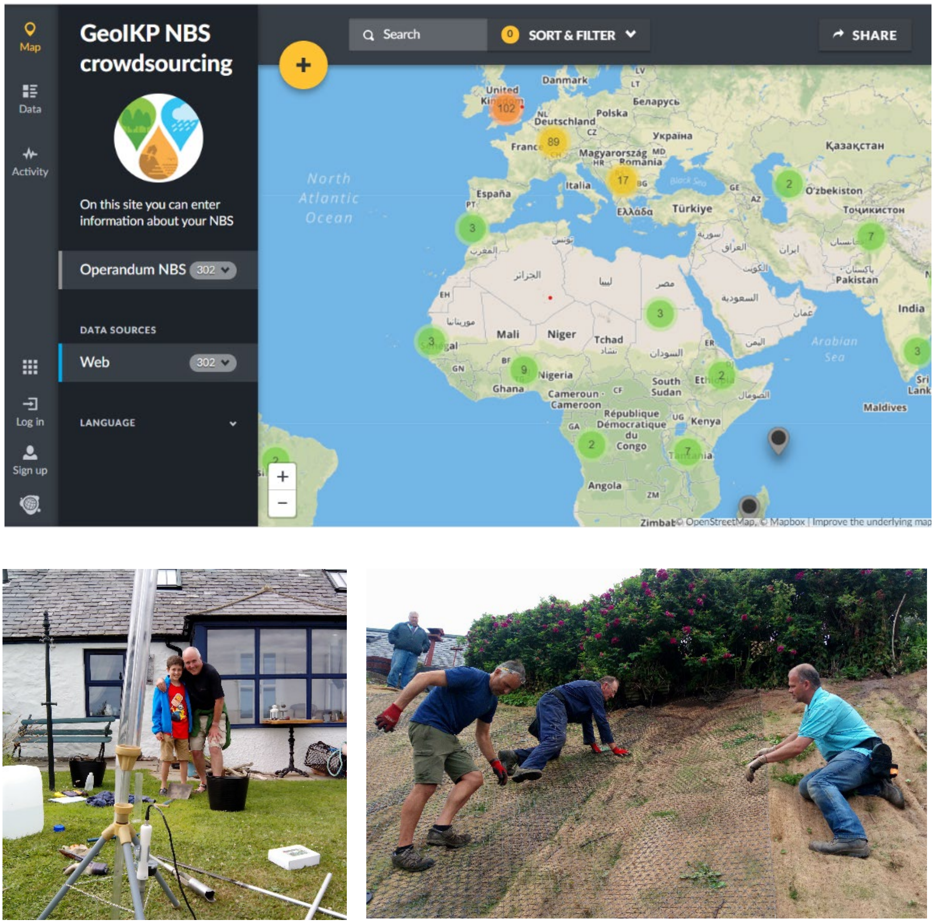


Figure 7-5. (a) Snapshot of the crowdsourcing app used in the EU-H2020 project OPERANDUM to engage the community in sharing information on NBS (source: http://crowd-geokip.kajoservices.com/views/map); (b) citizens involved in the NBS co-deployment and monitoring at Catterline (UK): on the left, residents helping to measure the permeability of the soil at their front gardens; on the right, residents fixing geo-grid on slope to prevent erosion and shallow landslides (source: EU-H2020 project OPERANDUM; photo credit: Alejandro Gonzalez-Ollauri).

7.8 Data integration

In previous sections, different data collection strategies have been explored for the purpose of fulfilling the data requirements for NBS monitoring and assessment. Data collection is however only the first steps in conducting a NBS assessment, since data gathered from different sources will often have to be analysed in combination and integrated together in order to provide valuable insights on the impacts and co-benefits of a NBS intervention in comparison to a baseline scenario.

In that respect, spatial modelling and spatial analysis may represent an effective strategy for the monitoring and/or planning of NBS, since it allows to integrate, analyse and visualize different data types. For example, using remote sensing data under a GIS environment, it is possible to provide geo-referenced information on the shape, size and distribution of different land-use classes of the urban environment (Herold et al., 2005). This allows monitoring of urban growth (area change, structures, land consumption, soil sealing) and land cover/land-use changes (loss of agricultural area, wetland infringement, loss of areas important for biodiversity, spatial distribution of inner-urban green and open spaces and natural areas) as well as mapping of various environmental parameters (data important for urban climate, access to and distribution of open space, calculation of sealed surfaces).

Typically, evaluation data is not generated in isolation, and there is a need to analyse data using integrated approaches. By doing so, it is possible to generate greater insights than are the sum of the individual data sources. This section explores different data integration approaches, providing specific examples, and data sources that can support data integration and interrogation.

High resolution remote sensing data can be combined with measured pollutant concentrations in a GIS environment, to map the removal of PM_{10} and ozone by urban trees and estimate the physical removal of pollutants by trees at specific locations. Various types of observations are usually used in combination with (and/or as input data of) modelling tools. Besides, results from 3D numerical models (e.g., Envi-met model, https://www.envi-met.com/) and other modelling techniques can be also usually imported in a GIS environment and combined with RS, EO and ground observations for planning purposes or for analysing present/future impacts of an NBS intervention. See Table 7-10 for more examples[61].

[61] Another relevant example of data integration through digital mapping (e.g., remote sensing, GIS) is provided in EKLIPSE (http://www.eklipse-mechanism.eu/home)

Table 7-10. Examples of data integrations used in NBS projects.

Project	Approach	Web link
Naturvation	Remote sensing, satellite imagery and digital orthophotos together with Geographic Information Systems (GIS) used to develop a digital elevation model and a digital surface model. Input data: qualitative and GIS data. Output data: quality of life, tree coverage; spending time in city parks, gardens, and open spaces.	https://www.naturvation.eu/
	Deterministic model which uses remote sensing of greenness as well as surface sealing to estimate recreation supply. Input data: Remote sensing data, NVDI and surface sealing. Output data: Spatially normalized minimum of green space provision per person suggested by the city administration (m^2 per Block; m^2/m^2)	
	A model based on remote sensing – MODIS NPP. Input data: allometric equations, net photosynthesis (PSNnet), average growths in diameter of specific tree species, trees diameter at breast high. Output data: Net primary productivity kg C per tree and year	
IMPRESSIONS	Mapping land use, ecosystem functions, and ecosystem services using cutting-edge remote sensing and machine learning techniques	http://www.impressions-project.eu/
	A coordinated effort to integrate and analyse a higher quantity and quality of CO_2 and CH_4 data, from in situ and remote sensing observations encompassing atmosphere, land and oceans.	
URBES	Remote Sensing of Urban Ecology (EO sensors, modelling algorithms)	https://www.biodiversa.org/121
	Spatial and remote sensing data analyses	

URBACT	Remote sensing (production of high spatial resolution, including the urban atlas, built-up areas, and air pollution) and so-called big data are used to compare and benchmark cities.	https://urbact.eu
OPERANDUM	Remote sensing data to monitor land surface parameters, Observation from Copernicus Land, Marine, Atmosfere, Climate Change, Emergency Services, NBS monitoring sensors installations (e.g., monitoring green roofs in Dublin), GHSL population distribution, EUROSTAT socio-economic indicators to compute the risk indicators, Local and EU scale hazard information at corresponding different return levels scenarios and critical infrastructure as an input to risk modelling, Local and continental ERA40 data reference climate data and CORDEX climate projections to assess different NBS scenarios for present and future climate.	https://www.operandum-project.eu
URBAN GreenUP	Mapping the removal of PM_{10} and ozone by urban trees by combining high resolution remote sensing data with measured pollutant concentrations to estimate the physical removal of pollutants by trees.	https://www.urbangreenup.eu/about/about.kl
	Mapping and assessing the contribution of urban vegetation to microclimate regulation, deriving a map of Land Surface Temperature based on Landsat 8 Data, using a model of Du et al. (2015), aggregating Land types to assess the changes in average temperature.	
	Mapping urban temperature using remote sensing (split window algorithm) and modelling techniques for assessing urban temperature and the indicator for microclimate regulation.	
PLUREL	Remote sensing and GIS for sustainable urban development science to provide geo-referenced information on the shape, size and distribution of different land-use classes of the urban environment. Main applications: • Monitoring urban growth (area change, structures, land consumption, soil sealing; • Monitoring land cover/land-use changes (loss of agricultural area, wetland infringement, loss of areas important for biodiversity,	www.plurel.net

	spatial distribution of inner-urban green and open spaces and natural areas); • Mapping of environmental parameters (base data important for urban climate, access to and distribution of open space, calculation of sealed surfaces).	

Another relevant example of data integration is represented by the use of Big Data in the context of NBS, where they can be helpful in decoding the complex relationship of socio-environmental cultural domain. Although there are not yet well-defined and generalized indices to be used (hence caution should be used in handling Big Data for NBS monitoring), appropriate measures could be constructed by combining different data types and data sources, such as (i) spatial data combined with health data on illness incidence, and (ii) spatial data on population density and social demographic indicators with a view to analyse climate change (Frantzeskaki et al., 2019). In that respect, a valuable source of Big Data is represented by the social media data, which can help identifying new habits and needs as drivers of uncommon way of life (Ilieva and McPhearson, 2018). Another source of big data is the data generated by consumer behaviour inspired by sustainable choices. Under this perspective, spatial, economic, preference and temporal data can be aggregated and analysed.

As further discussed in Section 7.9, the establishment of a baseline also required the integration of different data types. In this case, spatial data using remote sensing, earth observation and GIS technologies are usually combined with non-spatial data from field surveys and other sources if they are secondary data. In the EU-H2020 project UNaLab, for example, non-spatial datasets including both qualitative (surveys, questionnaires and scoring, etc.) and quantitative (environmental, social and economic statistical and legacy datasets) data were completed with spatial information for the evaluation of KPIs and the establishment of the baseline conditions.

The non-spatial or attribute or characteristic data typically include demographic variables, socioeconomic conditions and other non-spatial properties such as environmental culture or human/individual behaviour (cf. Sections 7.3–7.4). They are relevant not only for describing the status quo and planning the future strategy, but for identifying needs too. In the EU-H2020 project URBiNAT, the well-being, social cohesion and economic-social aspects of the project city have been analysed through collection of several types of non-spatial data. Other examples of how various types of non-spatial data can be combined for the purpose of NBS assessment are provided in Table 7-11.

In some cases, integrated datasets of relevance for NBS monitoring and baseline construction are also readily available from external sources. An excellent example is the Global Human Settlement Layer (GHSL) platform (https://ghsl.jrc.ec.europa.eu/download.php). GHSL produces global spatial information about the human presence on the planet and its changes over time. This is in the form of built up maps, population density maps, settlement classification maps and database on urban centres (see Table 7-12). The framework uses heterogeneous data including global archives of satellite imagery, census data, and volunteered geographic information and produces free information layers and knowledge reporting about the presence of population and built-up infrastructures at European and Global scales (Pesaresi, 2018).

Table 7-11. The use of non-spatial data applied in the NBS projects.

Project	Mode of acquisition	Main application	Source
CONNECTING Nature	Gathering knowledge from different stakeholders through surveys, questionnaires, workshops, reflexing monitoring webinars and round tables; co-creation and co-design events with policy makers and the communities-of-interest; statistical data and policy documents; set of non-spatial human-wellbeing and economic indicators (e.g., social cohesion, general wellbeing and happiness, levels of aggressiveness and violence, additional funding secured for NBS, etc.)	To identify new synergistic data-gathering techniques that make use of the latest available technologies and allow representation of traditionally under-represented groups in urban policymaking	https://connectingnature.eu/our-resources
UNaLab	Qualitative data (e.g., surveys, questionnaires and scoring) and quantitative data (environmental, social and economic statistical and legacy datasets)	To establish the baseline conditions, for evaluating the KPIs and complementing the spatial information with non-spatial attributes	https://unalab.eu/en/documents/d31-nbs-performance-and-impact-monitoring-report
EKLIPSE	“Air Quality” indicators developed within the EKLIPSE Working Group impact evaluation framework. • non-spatial indicators of gross quantities: annual amount of pollutants captured by vegetation; • non-spatial indicators of net quantities: net air quality improvement (pollutants produced—pollutants captured + GHG emissions from maintenance activities); • non-spatial indicators of shares: share of emissions (air pollutants) captured/sequestered by vegetation;	To assess ecological, economic and social value of NBS	http://www.eklipse-mechanism.eu/apps/Eklipse_data/website/EKLIPSE_Report1-NBS_FINAL_Complete-08022017_LowRes_4Web.pdf

	• the economic value of air or water purification measured using avoided costs for health care or replacement costs for artificial treatment		
OPERANDUM	Surveys on perception of NBS in local communities Surveys on implementation of the NBS in the Open-Air Laboratories	Asses the acceptance of the NBS by local communities to provide qualitative input into efficacy and co-benefits and societal impacts of the NBS. Monitor progress of the NBS installation to synthetize practical cook-books of NBS implementation	http://operandum-project.eu
NATURVATION	Urban Nature Atlas (UNA), a database and detailed characterization of 1000 NBS in 100 European cities; set of social indicators identified for the assessment of NBSs social impacts especially related to well-being and human health, education, social interaction, social justice, safety, job creation, urban green space accessibility and availability	To assess economic and social value of NBS	https://naturvation.eu/atlas
GREEN SURGE	on-spatial quality data gathered through interviews, questionnaires, and then used in public participation geographic information systems (PPGIS) and hedonic pricing	To support decision-making on urban green space-management, e.g. to assess how residents with different backgrounds value and use green areas across the cities	https://greensurge.eu/
Nature4Cities	Survey among local residents on how green space can contribute to quality of life and also to regional attractiveness	To develop a complimentary assessment tool on quality of life, to evaluate the environmental, social and economic benefits associated to NBS	https://www.nature4cities.eu/results
URBiNAT	Survey through validated questionnaires in multiple cities	To assess the level of well-being across the project cities	https://urbinat.eu

The GHSL database (in particular the Urban Centres Database UCDB) can be used as data source for assessing several indicators related to SDGs and in particular the indicators of success of nature-based solutions in cities both at the European and Global scale. In the EU-H2020 project OPERANDUM, for example, GHSL data are in combination with hazard information (e.g., flood extent) to derive the flood risk indicators such as population affected. Another example is the possibility to use GHSL datasets to investigate changes in the amount of greenness within cities in the periods centred on the years 1990, 2000 and 2015 (Corbane, 2018). Of relevance to indicators framework for NBS, GHSL multitemporal dataset on built-up (GHS-BUILT) and population (GHS-POP) can also be used to provide a quantitative assessment of changes in the Land Use Efficiency (LUE) indicator for more than 10 000 cities between 1990 and 2015 (Schiavina et al., 2019). This measures the land consumption rate to population growth rate and can be used as a proxy for land take. The LUE is recommended for estimating SDG indicator 11.3.1 which requires data on the spatial extent of the settlements and the dynamics of their population.

Table 7-12. Summary of main GHSL datasets at global and European Scales. GHSL datasets are described in detail in Florczyk et al. (2019). All datasets are freely accessible for download from the GHSL website managed by the European Commission: https://ghsl.jrc.ec.europa.eu/download.php

Dataset	Semantic	Format	Resolution	Date	Main input data source
GHS-BUILT	Built-up area and their densities at global scale	Raster	30 m–250 m–1 km	1975–1990–2000–2015	Satellite imagery
GHS-POP	Density of population at global scale	Raster	250m–1km	1975–1990–2000–2015	GHS-BUILT Census data GHS-BUILT GHS-POP
GHS-SMOD	Classification of Human settlements: urban centres, urban cluster, rural areas at global scale	Raster	1 km	1975–1990–2000–2015	Census data
UCDB	Description of spatial entities corresponding to accordingly to a set of multi-temporal thematic attributes at global scale	Shapefile Excel file	1 km	Different time depths with a maximum of 40 years	GHS-BUILT GHS-POP GHS-SMOD

					Other sources
FUA	Functional Urban Areas corresponding to urban centres and their commuting zones at global scale	Shapefile	1 km	2015	GHS-POP UCDB Global friction matrix

Table 7-12 provides a summary of the main datasets available in the GHLS suite, which includes, among others, the following data products.

1. The European Settlement Map (ESM_2015) which is a new spatial raster dataset mapping human settlements of 2015 in Europe. It is published in two layers: (a) Built-up areas at a spatial resolution of 2 meters, (b) Classification of the built-up areas into residential and non-residential at a spatial resolution of 10 meters.

2. The GHS-FUA Functional Urban Areas. This dataset delineates the spatial entities representing the commuting area of the Urban Centres of 2015 [9]. The dataset is provided in GeoPackage format.

3. The Urban Centres Database (UCDB) in which more than 10 000 individual cities are characterised by a number of variables (several are mulitemporal) describing the geography (e.g., temperature, elevation), socio-economic characteristics (e.g., population density, built-up surface), the environment (e.g., greenness, CO_2 emissions), potential exposure to natural hazards (e.g., exposure to floods, heatwaves) and SDG indicators The UCDB is provided in the form of vector shapefiles with attributes describing each spatial entity and in the form of an excel table with detailed description of each attribute. Furthermore, there is a dedicate webpage (https://ghsl.jrc.ec.europa.eu/ucdb2018Overview.php) which allows you to explore the different thematic attributes for each city (Figure 7-5).

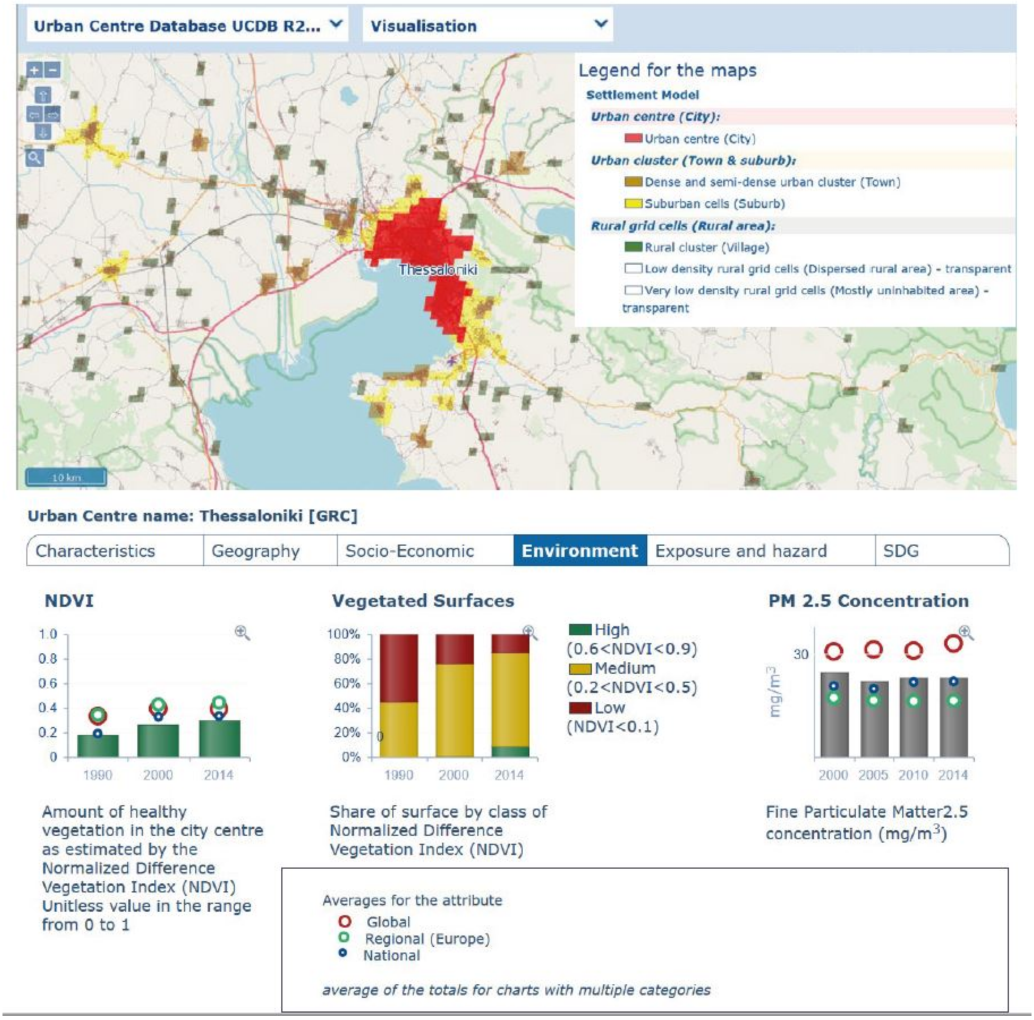


Figure 7-6. Example of the UCDB visualization for the urban centre of Thessaloniki (GRC) showing the environmental attributes.

7.9 Baseline Assessment

Baseline data collection is essential for any future evaluation of NBS performance. Baseline data should essentially be able to convey both the "state of play" (initial situation, from the social, economic, environmental points of view) as well as temporal and spatial trends of parameters, which will be further monitored and assessed throughout the project implementation and at its conclusion. The assessment is related to the performance evaluation of the NBS itself, and it is not aimed for the comparison between the NBS intervention and other grey or hybrid solutions dealing with the same issues. Especially for nature-based solutions, identifying initial trends allows an understanding of how the baseline conditions may change in the absence of the proposed actions, and thus for the definition of "business as usual" scenarios. Baseline data may indicate, for example, that a particular peri-urban habitat may have significantly shrunk in the last ten years and is continuing to shrink at an accelerated rate. Without an understanding of this trend, conclusions about the results of any action and its impact on the habitat would be erroneous. In fact, comparing the outcome (e.g., in year 2025) with the initial state (2020) – rather than with the "business as usual" scenario (for the year 2025) – would be flawed in this case.

Of critical importance to the value of data generated is the establishment of a baseline against which impacts of NBS implementation can be measured. This section explores the characteristics of an evaluation baseline, discussing the components of a baseline that need to be considered when planning NBS evaluation.

For physicochemical constituents, the baseline conditions should ideally be established prior to NBS implementation. In cases when the baseline measurements are not available, a site with similar conditions could be employed as a "proxy baseline". The latter approach naturally has its limitations in the representativeness as the reference site will not have the same exact conditions, and the results may be biased. Special regionalization methods could be employed to minimize the representativeness issues (e.g., selection of multiple sites with available measurements having similar characteristics to the NBS implementation site, in order to have a more representative sample). Spatial data can be employed for assessing the baseline conditions when combined with in situ measurements. However, historical and statistical datasets may have variable spatial and temporal resolutions, and they may not be consistent within a single urban area. Data aggregations or modifications may be necessary to overcome these challenges in applying the available datasets for pre-NBS baseline establishment.

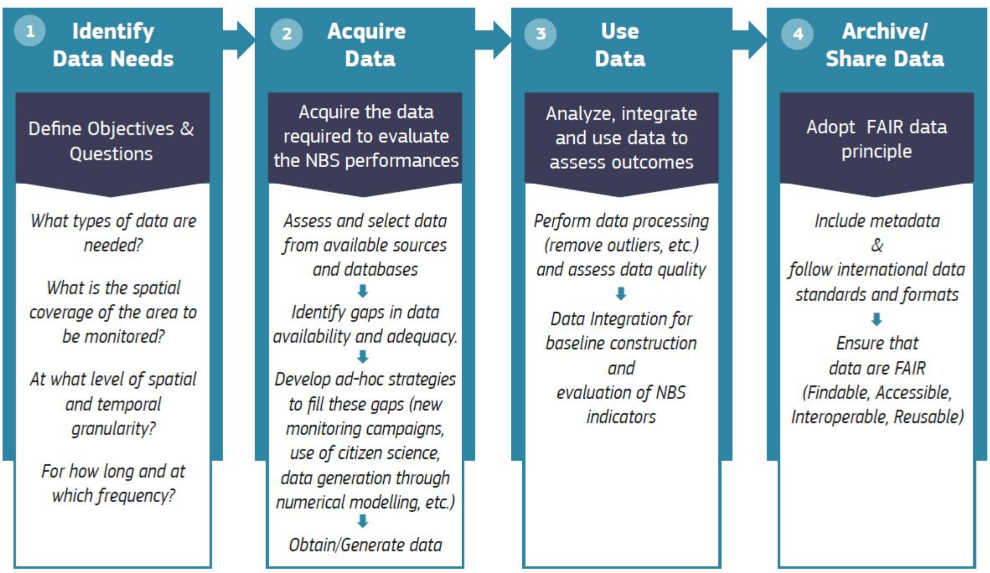


Figure 7-7. Key steps in the development of a robust data management plan to ensure data quality, data standards and data accessibility.

The lack of baseline data and/or the fact the baseline data collection is not always envisaged in an NBS project and often depends on (Bamberger, 2006):

- Lack of awareness on the importance of baseline data for NBS impact assessment;
- An inadequate and insufficient program planning and oversight;
- Budget/Time/ Political constraints;
- Delays in the administrative procedures (recruiting and training of the staff, acquisition of the necessary materials, commissioning consultants etc.) before the beginning of the baseline study;
- Evaluation not commissioned until late in the project cycle;
- Difficulties in identifying common data groups for the comparison;
- Lack of availability or low granularity of initial data.

Table 7-13 provides general guidelines on how to determine whether a baseline study is necessary, and to what extent (International Federation of Red Cross and Red Crescent Societies, 2013).

Table 7-13. Necessity of baseline data studies (based on the guidelines provided by the Planning and Evaluation Department (PED) of the International Federation of Red Cross and Red Crescent Societies).

Baseline study	Rationale
No study needed	Sometimes it is not necessary to study and collect baseline data because they are already known, e.g.: • The indicator value may be known to be "0" prior to the project start (for instance "none of the communities have been involved in NBS co-implementation before the project"). • The data could be available from other sources (i.e., from secondary data).
Shallow Study Needed	The number of baseline data and the methods to measure them are restrained in time, capacity and resources because they are available from other sources, therefore easily collectable, or it possible to replace expensive household surveys with less costly qualitative methods such as individual / group interviews or online surveys. For example, "Perceived neighbourhood green space safety", assessed via individual questionnaires using random sampling techniques.
In-depth Study Needed	Sometimes, it is necessary to have a more rigorous baseline study. Examples could be climate resilience improvement projects in which it is foreseen a renovation of the buildings' roofing, that could require the collection of data regarding energy and carbon emissions savings (i.e., from reduced building energy consumption (kWh/y and t C/y saved)),

	the development of specific questionnaires to be submitted to residents and a statistical analysis of the data.
Reconstruction of Baseline Data	When the baseline data study is needed but it was not conducted prior or near to the project beginning, a reconstruction of the baseline measurements is needed. The greater the time lag between the delivery of the project activities and the baseline study, the more likely the project will have a measurable effect on the indicators, leading to an underestimation of its impacts on the context.

Nevertheless, assessment of project outcomes and impacts should not be confined strictly to baseline and final analyses, because NBS projects may yield cascading results or externalities during the actual implementation. For example, in the cases in which a project implies an improvement of the green areas present in the neighbourhood, speculators may begin to invest in land ownership and families can decide to start improving the quality of their property. If the baseline data study is postponed for a long time, many of these important changes could be omitted.

If baseline data need to be reconstructed, there are several approaches which can be used to achieve a discreet result (Bamberger, 2010):

- Secondary data: checking documentary sources, such as annual reports of governmental agencies:

- Administrative data: feasibility and planning studies made prior to an intervention on a specific territory, application / registration forms, etc.;

- Recall: technique based on surveys or individual / group interviews, particularly useful for recalling major events or impacts of a new service (including ecosystem service), albeit subject to biases;

- Key informants: in-depth interviewing and involvement of external stakeholders (representatives of a society or a specific target group) which combines “factual” information with a particular point of view, offering a different perspective.

It should be, however, noticed that no data collection method is free from the possibility of inaccuracy. Due to this, the above-mentioned methods, and especially the ones relying on surveys and interviews, are usually accompanied by the Triangulation method. This allows to verify the results against data collected from other sources, to confirm accuracy and precision of the reconstructed baseline. Another term often encountered in baseline studies is Comparison (or Control) Group. It refers to a group of units (e.g., persons; census cells; households) that has not been affected by the project impacts and serves as a source of counterfactual causal inference (Maldonado and Greenland, 2002). The big challenge in this case is selecting a well-matched baseline comparison group.

A critical point whose importance is sometimes overlooked is the fact that spatial analysis of data for baselines requires *a priori* knowledge about both the data as well as the underlying processes (Csillag and Boots, 2005). This includes being aware of the possibilities and limitations of the various spatial statistics available, but also knowledge of existing urban policies, spatial plans and regulations which allow contextualization of findings.

Baseline studies, for example for Strategic Environmental Assessment (SEA, https://ec.europa.eu/environment/eia/sea-support.htm), include reviews of the policy context and a collection of detailed evidence on the state of the environment (context) in which a nature-based solutions project will deploy its activities.

Lack of statistical data can hinder the creation of a sufficiently robust baseline profile for one or several key NBS assessment domains, potentially leading to a limited understanding of pre-conditions and potential. One way of mitigating this risk, tested in proGIreg, was to include a "long list" of spatial indicators, ensuring that even though cross-city comparability may be limited, the key assessment topics are still characterised by a minimum of two data sets, selected from the most commonly used datasets of statistical offices across Europe. These have been grouped in key assessment domains, and descriptors (Table 7-14), with each descriptor further expanded through a set of indicators and datasets – 70 in total.

Based on the proGIreg experience, there are two recommendations which can be provided for the purpose of developing baseline analyses. The first is the allotment of sufficient time for data collection, as a task in itself which often involves sending out data requests to other institutions (e.g., regional offices). Beyond data availability, a key factor of success is the capacity of the cities themselves to work with data, and the need for close connection between different stakeholders involved in data management, analysis, policy makers, and the local communities (as both beneficiaries as well as data providers). This is likewise a process which should be planned carefully in time.

Table 7-14. Example of baseline data requirements (from EU-H2020 project proGIreg. More details can be found in Leopa and Elisei, 2020).

Assessment domain	Subdomain/descriptor and example data
1. Socio-Cultural Inclusiveness	1.1 Demographics (e.g., Population growth rate, migration rate)
	1.2 Social and cultural inclusiveness (e.g., Material deprivation rate)
	1.3 Education and access to social and cultural services and amenities
	1.4 Housing (e.g., Density of the built environment)

2. Human health and wellbeing	2.1 Health (e.g., Incidence of cardio and respiratory diseases, obesity rate)
	2.2 Wellbeing (e.g., Green space per capita, urban safety)
3. Ecological and environmental restoration	3.1 Land use and Vegetation
	3.2 Climate/Meteorological data
	3.3 Air Quality
	3.4 Soil
	3.5 Water
	3.6 Urban environment
4. Economic and labour market benefits	4.1 Market labour and economy indicators (e.g., Number of green jobs)
	4.2 Gentrification indicators (e.g., Average household disposable income, property values)
	4.3 Tourism and attractiveness indicators (e.g., Expenses in local retail business)
	4.4 Taxes, Investment and Financing (public investment programs)

7.10 Data adequacy and related aspects

Adequate *collection*, *management* and *use* of data is foundational for a holistic assessment of NBS performances. Challenges and requirements related to data needs and their collection addressed in the previous Sections emphasise the importance of generating reliable data. Table 7-15 lists the principal aspects determining the quality of analysis derived from the main data collection and generation methods in terms of potential error sources and their prevention and elimination.

This section discusses what is adequate in terms of data collection, management, and use. This includes a focus on data granularity, bias, accuracy, typical errors, and ways to prevent error.

This section focuses on the most common and critical challenges encountered when using data. Data utilization challenges generally fall into three categories: data quality, data appropriateness and data accessibility. Gaps and irregularities in spatial and/or temporal data series, as well as data accuracy and other error sources, affect the quality of data, while data granularity and resolution define if a dataset is appropriate with respect to the target of investigation. Together with accessibility and other key characteristics discussed at this end of this section, these aspects determine the overall adequacy of a dataset.

Table 7-15. Data accuracy, typical errors and ways to prevent errors for different NBS data generation and collection methods.

NBS data collection/ generation method	Data accuracy	Typical errors/biases	Ways to prevent errors
Observational data (Sections 7.1-7.2)	Depends greatly on data collection or generation methods, e.g., granularity and resolution of the measurements, quality of measurement systems, measurement scale or specification, and selection of samples.	Manual sampling data can contain uncertainties due to spatial and temporal heterogeneities or low-quality measurements. Random selection of samples may cause inaccuracies. Inadequate baseline or reference definition. Ambiguous or erroneous results when aggregating historical or legacy datasets with observational data (e.g., Scholes et al., 2013). Satellite-derived images can contain shadows due to the size of the frame or be of low spatial and temporal resolution.	Standardized sampling methods and protocols, appropriate measuring intervals, detection limits and calibration of the measurement instruments (e.g., Pepper, Brusseau, and Artiola, 2004). Accurate baseline or reference definition. Statistical manipulations, such as aggregation (scaling-up) of dis-aggregation (downscaling) of datasets with varying granularity, must be exercised cautiously (e.g., Scholes et al., 2013) Satellite observations must be validated against and complemented by ground measurements and/or other high-resolution RS-platforms such as drones or aircraft-based (e.g., Orgiazzi et al., 2017).
Surveys and census (Sections 7.1 and 7.3)	Survey data are usually collected from a group of participants which will represent a larger group. Accuracy of the data depends e.g. on the representativeness of the participant group and sample size. Statistical analysis can be used to estimate the accuracy.	Poor representativeness or small size of a research group. Data from qualitative survey can be complex. Constrains and limitations in availability of specific or updated statistical data.	Choosing data collection sources/methods which produce the desired information. In quantitative surveys, verifying quality, relevance, simplicity, accuracy and clarity of the questionnaire. In qualitative surveys, choosing proper approach and identifying suitable strategies for data collection.

Laboratory experiments (Sections 7.1and 7.6)	Laboratory experiments can control most of the variables under study and can offer the most accurate analysis methods. Representativeness of the samples and quality of the analysis define accuracy of the data.	Samples are not representative for the desired research subject (e.g., samples are not in their natural state) or the laboratory experiment is not mimicking the real-life situation or long-term effects. Instrumental or human errors.	Verification of the methods to mimic real-life situation and long-term effects. Well-controlled, standardised measurements with high-quality and calibrated instruments. Automated analysis can eliminate human errors.
Numerical simulations and modelling (Sections 7.1 and 7.5)	Models are simplifications of the real-world systems (Grützner, 1996) and some uncertainty should be accepted. The accuracy of the model depends mostly on the amount of accuracy and of the initial data, quality of the model, and skills of the model user (Government of South Australia, 2010).	Limitations and uncertainties related to the technical or mathematical structure on which the model is built. Inadequate calibration and/or validation due to low-quality or limited initial data. Inaccurate assumptions and/or approximations in the model. Inappropriate use of the model.	Use of high-quality models to address the specific, desired research questions Models are calibrated and verified against observational (field or laboratory) data to ensure the accuracy of results and the overall uncertainty. Sensitivity analysis performed for the parameters in the model (Government of South Australia 2010).
Citizen science (Sections 7.1 and 7.7)	In complex data collection methods, variability of data collected by volunteers as non-professionals can be greater compared to professionally collected data (Aceves-Bueno et al., 2017). However, citizen science can offer broader collection of data, analysis of the data accuracy is required in citizen science projects.	Sensor accuracy is too low. Too complex data collection methods for unexperienced users. Instructions are misunderstood. Challenges with validating the data quality (Pocock et al., 2014)	Clear protocols, frameworks, and instruments including those for transparent communication (e.g., Dickinson and Bonney, 2012; Dickinson, Zuckerberg, and Bonter, 2010). Proper training of the volunteers (e.g., Dickinson and Bonney, 2012). Adopt more advanced statistical analyses to identify errors (Dickinson, Zuckerberg, and Bonter, 2010; Pocock et al., 2014). Collection of a greater number of samples to eliminate sampling bias (e.g., Gardiner et al., 2012)

7.10.1 Data gaps and irregularities

In many cases, data gaps exist in monitoring efforts. Data gaps can be spatial or temporal. Also, low quality of the data can be considered as insufficient data collection. Data gaps can exist in all types of monitoring, including manual or automated measurements, surveys and questionnaires. Often, when the monitoring plan is built, the main aspects to be considered are the frequency of monitoring and distribution as well as the amount of monitoring sites. This is because data gaps are mainly caused by data provision interruption or insufficient observation coverage (both sampling frequency and spatial distribution). This data gaps may lead to data insufficiency which can disqualify the dataset from the holistic NBS performance assessment. Insufficient data collection may also originate from the lack of resources. In the interpretation of the monitoring results, it is critical to identify the data gaps. There are existing techniques to fill the data gaps e. g. spatial/temporal interpolation, but a special attention should be paid in order not to degrade the representatives of the data. Table 7-16 lists the data gaps identified by some of EU-H2020 projects on NBS.

Table 7-16. Data gaps identified in EU-H2020 projects (selected examples).

Project	Identified data gaps
ConnectingNature	Indicator data are foreseen to cover less than 50% of the Connecting Nature core indicator list. Therefore, there is a requirement for further rounds of identification of suitable data sources to be undertaken, and there may also be a need for new observations and site surveys to be undertaken to fill in any gaps.
proGIreg	Gaps in statistical data due to: • No cities have been able to provide all the requested data • Depending on the city, some data are not available on a yearly base
OPERANDUM	• Lack of hydro-meteorological observations time series/low station density which was partially resolved using remodelled ERA40 data set • Gaps in in-situ meteorological observations
Inala	• Some cities are not able to expose NBS monitoring data • Baseline data for some of the NBS are missing • During the monitoring period, there is a risk of gaps and time-series inhomogeneity (e.g., precipitation, air quality)
Urbina	The project involves and compares several European cities in order to develop sustainable health corridors. However, the availability of socioeconomic official data differs from city to city

As an example of how to analyse existing data gaps in monitoring, the California Department of Water Resources (2016) presents a data gap analysis flow chart for groundwater monitoring. First question when planning a data collection procedure is to consider the needed types of data, for instance water level and water quality. It should be then considered if the quantity and quality of the data are sufficient. After this, data gaps are identified. As mentioned, the data gaps can be spatial, temporal, or they can be related to low data quality. Temporal data gaps are related to insufficient frequency of the monitoring, and spatial data gaps to insufficient number of monitoring sites. As an example of low quality data, it can originate from insufficient collection or data management methods. After identification of the data gaps, causes for the existence of the gaps should be identified. The causes can be related to insufficient funding and resources but also to insufficient access to the data. Actions to reduce the amount of data gaps are to increase density, frequency, and quality of the monitoring.

7.10.2 Data granularity and resolution

Data granularity is one of the most critical parameters for successful evaluation of NBS performance and impacts, because it allows to define an effective and efficient solution, or (if not well dimensioned) can impede the achievement of the goals of a project. Data granularity indicates the level of detail expressed by each single part in a dataset. Different granularities indicate different levels of aggregation in the dataset. Examples of aggregation include:

- Temporal aggregations: year, month, minute, second
- Distance aggregations: kilometres (km), hectometres (hm), decametres (dam), metres (m), decimetres (dm), centimetres (cm), millimetres (mm)
- Geographic (or zonal) aggregations: world, continent, country, city, district, street, address
- Video aggregations: HD, FULL HD, 4K, 8K

Fine-granularity (low level of aggregation) provides more details than **coarse-granularity** (high level of aggregation) making it more helpful for decision-making. In fact, the higher amount of information ensured by fine-granularity permits to better target the problem to be solved (i.e., climate change, social issue, service inefficiency), by making the correlation between causes and effects more comprehensive.

Since a variety of data types (collected with a likewise variety of monitoring methods) are required to obtain a full NBS assessment in all its dimensions (ecological, social, etc.), it is imperative that the granularity of all the different datasets matches the scale of main driving processes behind the NBS and the impact of NBS interventions. A reliable evaluation cannot otherwise be obtained. As an example, in the EU-H2020 project proGIreg problems in data granularity were encountered due to the different scales at which statistical data are available in the different countries, and due to the small size of most of the implemented NBS with respect to the scale available for statistical data.

Unfortunately, a general formula for defining the granularity level does not exist. Thus, technical designers can leverage only on their good experience to set the correct aggregation in the range of fine-grain and large-grain, considering the variability of the monitored phenomenon and the level of detail needed for the evaluation and eventually the use of proxy variables to improve the granularity of the main variable. Table 7-17 shows the possible levels of data granularity required to evaluate the impact of an NBS for some specific examples.

Table 7-17. Examples of adequate vs inadequate data granularity levels.

Topic	Goal of the Study	Adequate/Possible Data Granularity	Inadequate/Wrong Data Granularity
Urban Heat	Assess daily fluctuations of the urban temperature	• Fine grain: 30 minutes • Medium grain: 60 minutes • Coarse grain: 180 minutes	• Over sampled: second, millisecond • Lower sampled: at day scale no changes can be observed
Flooding	Assess flooding events per year	• Fine grain: day • Medium grain: 5 days • Coarse grain: 30 days	• Over sampled: minute, second, millisecond • Lower sampled: at year scale no changes can be observed
Urban Green Areas	Estimate green density in the urban area	• Fine grain: 10 sq.m (*) • Medium grain: 200 sq.m • Coarse grain: 1 sq. Km	• Over sampled: sq.cm, sq. mm (*) • Lower sampled: 30 sq.Km
Urban Transportation	Assess yearly fluctuations of users of urban transportation	• Fine grain: number of passengers at 30 minutes (for each line) • Medium grain: number of passengers per day (for each line) • Coarse grain: number of passengers per month (total)	• Over sampled: number of passengers per second (for each line) • Lower sampled: number of passengers per year (total)

(*) sq. stands for square. For example, sq.m stands for square metre.

When talking about a representation (e.g., video streaming, image, photo, spatial data), granularity takes the name of **resolution** and indicates the size of the minimum unit/area in a representation (e.g., video streaming, image, photo, spatial data). Spatial resolution is a common and essential feature in monitoring systems and indicates the ability of the sensor to detect details of the complex environments, and the minimum area is measured in meters.

Low spatial resolution sensors (30–300 m) produce adequate results at large scales, although they are incapable of capturing greater amount of details as high spatial resolution outputs (less than 30 m). High resolution is essential for characterisation and interpretation of complex environments and models. As example, in urban flood and hydraulic studies of river and floodplain interactions, topographic details significantly influence the capability to discover the flow path interactions with the underlying terrain (Krebs et al., 2014; Mason et al., 2007).

In conclusion, to assess the impact of a NBS or the development and distribution of a phenomenon in the ecosystem, it is critical to define the correct level of aggregation, the data granularity, of the measurements for both the time (temporal granularity) and the location (spatial resolution). In that respect, fine-grain and high-resolution local monitoring sensors (or their combination) often represent the most suitable option to record the actual changes in the urban system fostered by the implemented NBS.

7.10.3 Data Accuracy

The **accuracy** is the qualitative parameter indicating the degree of correctness of a measure derived from the direct observation (sample) with respect to the objective true or the reference value. In other words, the accuracy quantifies how much a measure is near the actual value. The common way to express the accuracy is the percentage, calculated with respect to the full scale of the sensor, or with respect to the sample. As example, a temperature sensor with full scale of +-50° and accuracy of +-1% (+-0.05°), means that with an actual value of 30° the sensor could produce a measure in the range between 29.95° and 30.05° (Figure 7-6).

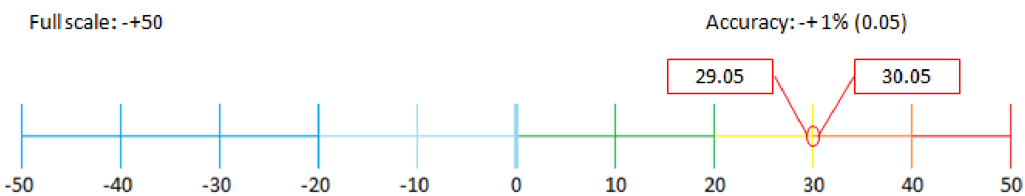


Figure 7-8. Temperature sensor with full scale of +-50° and accuracy of +-1% (+-0.05°): The sensor can produce a measure in the range between 29.95° and 30.05, if the actual value to be measured is 30°.

Another relevant qualitative parameter in the context of monitoring activities is the **precision** that indicates the degree of convergence (or dispersion) in a collection of samples. In other words, precision indicates how much independent samples are near among them. The precision is strictly dependent from the effectiveness of the combination of sensors adopted and methodologies implemented during the observations. In fact, despite each sensor expresses static qualitative performance, the combination of sensors with different methodologies could produce different precision and vice versa.

To better clarify the relationship between precision and accuracy, Figure 7-7(a) represents the results obtained with a good quality temperature sensor. That sensor has high precision and high accuracy and for each observation collects measures aggregated near the actual value. Figure 7-7(b) represents the results obtained with a temperature sensor with high precision and low accuracy that for each observation collects aggregated measures, but far from the actual value. Figure 7-7(c) represents the results obtained with a low quality temperature sensor with low precision and low accuracy that for each observation collects measures dispersed and far from the actual value.

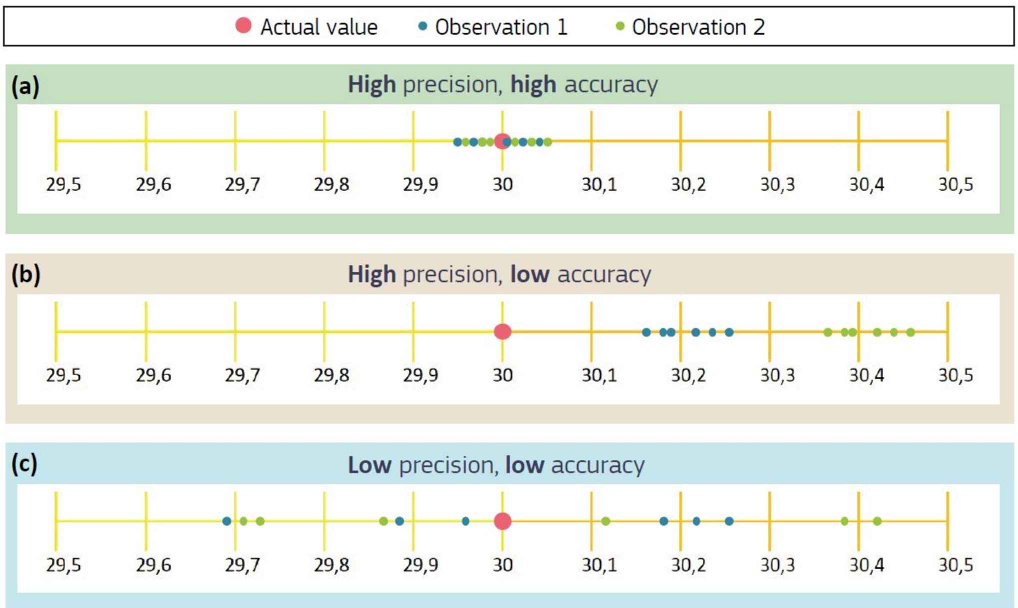


Figure 7-9. Measurements obtained with a temperature sensor which has (a) high precision and high accuracy (good quality sensor); (b) high precision bur low accuracy; (c) low precision and low accuracy (low quality sensor). The red dot represents the actual ("true") value of temperate. The blue and green dots represent the first sample collection (Observation 1) and second sample collection (Observation 2) respectively.

Accuracy and precision are critical qualitative parameters to be taken into account during the monitoring activities. In fact, they indicate the quality of data and, as a consequence, are decisive to approve or reject the models and related elaborations that are the base line for supporting the performance monitoring, impact assessment and more in general the decision making.

7.10.4 Biases, main error sources, and data reliability

Aggregation and resolution provide useful information about the dimension of the measures. However, the observations can be influenced by uncontrollable and predictable factors that can introduce accidental and systematic errors that could invalidate the sampled measurements.

Accidental errors are caused by unpredictable conditions (as lack of energy or connection, vibrations near an instrument, wind) that randomly influence the results and for this reason they cannot be avoided.

A **bias** is a systematic error that introduces a constant or proportional deviation (absolute or percentage) with respect to the actual value. Biases can be generated by different unfavourable conditions:

- Instrumental: inadequate, out of scale, or not well calibrated sensors;
- Methodology: approximated models, incorrect formulas and elaborations, inadequate experimental conditions (e.g., temperature, humidity, not appropriate insolation);
- Personal: lack of expertise in the operator, parallaxes, interferences, improper use of the sensors or the methodology.

Despite the accidental and systemic errors cannot be eliminated, a good and complete monitoring plan will permit to prevent and identify potential conditions that could generate errors. Identified errors can be solved or minimised with the application of the corrective actions, such as identification of the incorrect samples, definition of more precise methodologies, procedures and rules.

Error sources:

- Not identified and corrected systematic error;
- Lack of attention, or overload of work;
- Overlaps applying heterogeneous methodologies or procedures.

7.10.5 Data Accessibility

Quantitative and qualitative data generated throughout the NBS monitoring periods via remote and in-situ observations, questionnaires, surveys or other means may have different access rights (e.g., open, semi-open, or confidential) depending on the degree of confidentiality originally specified in the legal or data management plans. It may be openly available or subjected to access restrictions imposed by governing bodies or EU-level regulations, such as General Data Protection Regulation (GDPR) (EC, 2016). The latter concerns the personal data collection during, for example, Urban Living Lab (ULL) sessions, health and well-being surveys or other studies involving humans. Naturally, not all data generated can be made public, so any personally identifiable information, which can be potentially generated during the project, should be carefully considered before and throughout NBS implementation to avoid disclosing any sensitive information. Here, it should be noted that availability and accessibility mean "existence" and "possibility and ease of retrieval", respectively. While accessible data is concomitantly available, "availability" does not imply "accessibility".

Although municipalities or other data owners may be reluctant to make their data open access and share this data with the third parties, open data has numerous benefits over restricted access data. Often, numerous datasets do not bring any additional value because of their inaccessibility to the third parties. Open data can be widely utilised by research institutes and universities by applying it in research and education to generate, for instance, projections and scenarios based on the historical records. The possibility to use open datasets for producing various simulations and utilising them for NBS baseline conditions assessment brings an added value to the datasets and their owners.

"The amount of data generated throughout the duration of the NBS implementation process is vast. Data storage, management, ownership and access are among the critical factors that must be considered. Adoption of a data management plan is a transparent way to ensure data quality, data standards and data reusability." (Hawxwell et al. 2018)

Data accessibility plays a critical role in establishing a holistic NBS evaluation framework as it is essential for establishing pre-NBS baseline conditions. When only fragmented or irregular datasets are accessible, it creates considerable bias and the possible need for data aggregation or other modifications of data points leading to biased outputs. In that respect, caution should be exercised when, for example, EU-wide datasets available from external sources are integrated in the NBS monitoring framework.

Despite the restricted access to some of the datasets being generated during the NBS projects, many data and results are accessible through the platforms established by the projects. This is of outmost importance as data-informed decision- and policymaking are critical for a wider NBS implementation in urban areas. Not only open data provides such attributes to urban development, it encourages greater collaboration in NBS implementation through ample evidence of benefits and issues recorded and obtained via open data sources.

7.10.6 Metadata and data standardization

The increasing effort in providing science-based evidence of NBS effectiveness and (co-)benefits has resulted into increasing volumes of data required for and/or connected to the monitoring and assessment of NBS interventions. These data are often associated with single-case studies and disseminated to a small community (usually the group of main investigators involved in a given NBS project), but no established protocols are yet in place that guarantee their accessibility and long-term re-usability by the large community. This clearly undermines our ability to achieve statistically meaningful evidence and more generalizable results on NBS performances and impacts, besides impeding the possibility to take full advantage of data which already exist but are either not accessible or easy to understand.

It therefore of crucial importance that NBS-related data become aligned to FAIR data principles, following the example of other disciplines and research fields. FAIR is an acronym which stands for Findability, Accessibility, Interoperability, and Reusability of data (Wilkinson et al., 2016). These four principles have been endorsed by the EC (Hodson et al., 2018) and many other institutions worldwide as those that should guide the design and implementation of any good data management, in order to ensure and maximize digital data discoverability and exchange. In practice, this means that NBS data producers and publishers should make an effort in following the guidelines (FAIR principles) summarized in Figure 7-8a or, in simpler words, that NBS data should be supplemented by contextual documentation, provided with persistent identifiers and metadata, and common standards adopted for both data and metadata (Figure 7-8b). In this perspective, metadata are an essential aspect of data standardization.

Metadata, or data about data, enrich dataset with additional information such as basic characteristics of the datasets (e.g., measured phenomena, author, and spatial/temporal resolution), quality, and completeness. This allows users or computers to better assess datasets for a specific use. Metadata enable easier data discovery since it exposes information about the data which would normally be hidden within the dataset itself. This allows inspecting information such as quality, resolution or spatial/temporal coverage without opening/inspecting the dataset and allows seamless integration of data from different sources. Several International standards exist which facilitate an easier adoption of FAIR principles.

The FAIR Guiding Principles

To be Findable:
F1. (meta)data are assigned a globally unique and persistent identifier
F2. data are described with rich metadata (defined by R1 below)
F3. metadata clearly and explicitly include the identifier of the data it describes
F4. (meta)data are registered or indexed in a searchable resource

To be Accessible:
A1. (meta)data are retrievable by their identifier using a standardized communications protocol
A1.1 the protocol is open, free, and universally implementable
A1.2 the protocol allows for an authentication and authorization procedure, where necessary
A2. metadata are accessible, even when the data are no longer available

To be Interoperable:
I1. (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation.
I2. (meta)data use vocabularies that follow FAIR principles
I3. (meta)data include qualified references to other (meta)data

To be Reusable:
R1. meta(data) are richly described with a plurality of accurate and relevant attributes
R1.1. (meta)data are released with a clear and accessible data usage license
R1.2. (meta)data are associated with detailed provenance
R1.3. (meta)data meet domain-relevant community standards

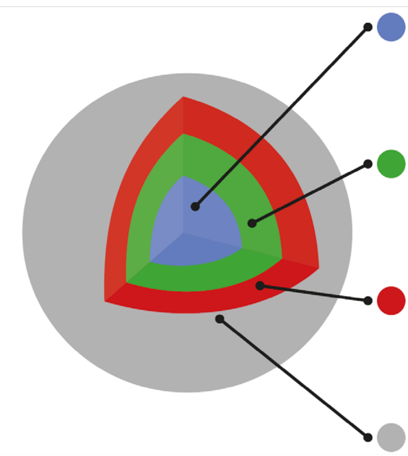


Figure 7-10. (Top) The set of Fair Principles (source: Wilkinson et al., 2016). (Bottom) a simplified schema explaining the key elements needed to ensure FAIR data (source: Hodson et al., 2018).

Table 7-18 lists some of the most relevant standards in the domain of geospatial data, metadata and services. Another example of standard is the EU Directive INSPIRE (https://inspire.ec.europa.eu/), which aims to create a European Union spatial data infrastructure where environmental data collected on a national basis can be shared and used on a pan-European basis. In recent years, the importance of data standardization has become clear also in the context of NBS and some NBS projects have made significant efforts in developing successful data management plans. For example, the EU-H2020 project OPERANDUM has developed a NBS data portal which is fully compatible with semantic web and is OGC and INSPIRE complaint. Data newly generated by the project (along with data gathered from external sources semi-automatically) are complemented with metadata and harmonized according to ISO standards, thus fulfilling the FAIR principles. For more information on FAIR recommendations and guidelines, the reader can refer to the EC report by Hodson et al. (2018). For examples of international standards applied in the context of NBS projects, see Vranic et al. (2019).

7.11 Conclusion

Successful evaluation of NBS performance and impact rely on the selection of the appropriate data collection methods, and the quality of data and its inherent characteristics (e.g., granularity and homogeneity) generated throughout the NBS monitoring period. This Chapter covered a variety of data types and data acquisition and generation techniques and discussed their benefits and limitations applicable to NBS impact evaluation.

Information for NBS impact evaluation, including a crucial step of baseline assessment, can be obtained via multiple sources, including in-situ measurements, laboratory experiments, remote sensing or Earth observation techniques, and citizen science. The selection of data collection methods should be based on solid planning, technical expertise, and a wide knowledge of the state of the environment and its functioning to ensure that the relevant and accurate data are collected for the purposeful NBS monitoring and assessment. Current and projected NBS impact can be further evaluated by modelling. All data produced during the NBS monitoring activities must undergo careful evaluation for possible biases and main error sources to ensure its adequacy and reliability.

Data collection and generation methods for NBS impact assessment discussed herein can be supplemented with a multitude of datasets obtained from the inter-European and international databases, although special care should be taken regarding their spatial and temporal resolution. Collected and generated data from a variety of sources can be integrated to provide valuable insights on the impacts and co-benefits of a NBS intervention in comparison to a baseline scenario.

Examples from the NBS projects regarding, for instance, non-spatial and spatial data integration, data gaps and modelling approaches to complement data generation were highlighted throughout the Chapter.

Table 7-18. Relevant International data standards following ISO, OGC, etc.

Category	International Standards	Description
Observations	**ISO 19156** (Observations and Measurements)	A conceptual schema for observations, and for features involved in sampling when making observations. It provides models for the exchange of information describing observation acts and their results, both within and between different scientific and technical communities.
	SensorML (OGC Sensor Model Language)	It provides a robust and semantically-tied means of defining processes and processing components associated with the measurement and post-measurement transformation of observations.
	SOS (OGC Sensor Observation Service)	It defines a web service interface which allows querying observations, sensor metadata, as well as representations of observed features. Also, this standard defines means to register new sensors and to remove existing ones
	SPS (OGC Sensor Planning Service)	It defines interfaces for queries that provide information about the capabilities of a sensor and how to task the sensor.
	STA (OGC SensorThings API)	It provides an open, geospatial-enabled and unified way to interconnect the Internet of Things (IoT) devices, data, and applications over the Web.
Geospatial Data	**ISO 19107** (Spatial schema)	Conceptual schemas for describing the spatial characteristics of geographic features, and a set of spatial operations consistent with these schemas.
	ISO 19125 (Simple feature access)	A simplified model of ISO 19107 which consists of two parts: 1) a common architecture for geographic information, and 2) a specific Structured Query Language (SQL) schema that supports storage, retrieval, query and update of simple geospatial feature collections.
	ISO 19136 (Geography Markup Language)	An XML encoding in accordance with ISO 19118 for the transport and storage of geographic information modelled in accordance with the conceptual modelling framework used in the ISO 19100 series of International Standards and including both the spatial and non-spatial properties of geographic features.

	ISO 19129 (Imagery, gridded and coverage data framework)	Framework for imagery, gridded and coverage data. This framework defines a content model for the content type imagery and for other specific content types that can be represented as coverage data.
Metadata	**ISO 19115** (Metadata)	It defines the schema required for describing geographic information and services by means of metadata. It provides information about the identification, the extent, the quality, the spatial and temporal aspects, the content, the spatial reference, the portrayal, distribution, and other properties of digital geographic data and services.
	ISO 19139 (Metadata XML schema implementation)	It defines XML based encoding rules for conceptual schemas specifying types that describe geographic resources. The encoding rules support the UML profile as used in the UML models commonly used in the standards developed by ISO/TC 211. The encoding rules use XML schema for the output data structure schema
Services	**ISO 19119** (Services)	Platform requirements on how services shall be created, in order to allow for one service to be specified independently of one or more underlying distributed computing platforms.
	ISO 19128 (Web Map Server)	Specifications on the behaviour of a service that produces spatially referenced maps dynamically from geographic information.
	ISO 19142 (Web Feature Service (WFS))	Specifications on the behaviour of a web feature service providing transactions on/access to geographic features in a manner independent of the underlying data store. It specifies discovery operations, query operations, locking operations, transaction operations and operations to manage stored parameterized query expressions.
	OGC WCS (OGC Web Coverage Service)	Specifies the behaviour of a service that serves multi-dimensional coverage data. WCS Core specifies a core set of requirements that a WCS implementation must fulfil.
	OGC CAT (Catalogue Service)	Catalogue services support the ability to publish and search collections of descriptive information (metadata) for data, services, and related information objects. Metadata in catalogues represent resource characteristics that can be queried and presented for evaluation and further processing by both humans and software.

Common Conceptual Model	**ISO 19103** (Conceptual schema language)	Rules and guidelines for the use of a conceptual schema language within the context of geographic information. The chosen conceptual schema language is the Unified Modelling Language (UML).
	ISO 19109 (Rules for application schema)	Rules for creating and documenting application schemas, including principles for the definition of features.
	ISO 19118 (Encoding)	Requirements for defining encoding rules for use for the interchange of data that conform to the geographic information in the set of International Standards known as the "ISO 19100 series".

7.12 References

Aceves-Bueno, E., Adeleye, A.S., Feraud, M., Huang, Y., Tao, M., Yang, Y. and Anderson, S.E., 'The Accuracy of Citizen Science Data: A Quantitative Review', *Bulletin of the Ecological Society of America*, Vol. 98, No 4, 2017, pp. 278-290. https://doi.org/10.1002/bes2.1336

Arnold, J.G., Kiniry, J.R., Srinivasan, R., Williams, J.R., Haney, E.B., and Neitsch, S.L., *Soil and Water Assessement Tool: Input/Output Documentation*, Texas Water Resources Institute, 2012.

Bagheri Z., Nadoushan, M.A., and Abari, M.F., 'Evaluation the effect of green space on air pollution dispersion using satellite images and landscape metrics: A case study of Isfahan City', *Fresenius Environmental Bulletin*, Vol. 25, No 12, 2017, pp. 8135-8145.

Baldacchini, C., *Monitoring and Assessment Plan*, Deliverable No. 4.1, proGIreg. Horizon 2020 Grant Agreement No 776528, European Commission, 2019, pp. 124. https://progireg.eu/fileadmin/user_upload/Deliverables/V2_D4.1_proGIreg_CNR_2020-06-13_amendment_02_.pdf.

Bamberger, P., 'Reconstructing Baseline Data for Impact Evaluation and Results Measurement', *PREM notes*, No 4, The World Bank, 2010. http://hdl.handle.net/10986/11075

Bamberger, P., Rugh, J. and Mabry, L., *Realworld Evaluation: Working Under Budget, Time, Data, And Political Constraints, Sage Publications*, Thousand Oaks, 2006.

Baró, F., Chaparro, L., Gómez-Baggethun, E., Langemeyer, J., Nowak, D.J., Terradas, J., 'Contribution of ecosystem services to air quality and climate change mitigation policies: The case of urban forests in Barcelona, Spain', *Ambio*, Vol. 43, 2014, pp. 466–479.

Barton, H., and Grant, M., 'A health map for the local human habitat', *Journal of the Royal Society for the Promotion of Health*, Vol. 126, 2006, pp. 252–253. doi: 10.1177/1466424006070466

Bass, B., Krayenhoff, S., Martilli, A., and Stull, R., *Mitigating the urban heat island with green roof infrastructure*, Urban Heat Island Summit, Toronto, 2002.

Bealey, W.J., McDonald, A.G., Nemitz, E., Donovan, R., Dragosits, U., Duffy, T.R., and Fowler, D., 2007. 'Estimating the reduction of urban PM10 concentrations by trees within an environmental information system for planners', *Journal of Environmental Management*, Vol. 85, 2007, pp. 44–58.

Beyer, K.M., Kaltenbach, A., Szabo, A., Bogar, S., Nieto, F.J. and Malecji, K.M., 'Exposure to neighborhood green space and mental health: evidence from the survey of the health of Wisconsin', *International Journal of Environmental Research and Public Health*, Vol. 11, 2014, pp. 3453-3472.

Bojinski, S., Verstraete, M., Peterson, T. C., Richter, C., Simmons, A., and Zemp, M., 'The concept of essential climate variables in support of climate research, applications, and policy', *Bulletin of the American Meteorological Society*, Vol. 95, No 9, 2014, pp. 1431-1443.

Bonelli, S., 'The first red list of Italian butterflies', *Insect Conservation and Diversity*, Vol. 11, 2018, pp. 506–5821.

Brown, I. and Castellazzi, M., 'Scenario analysis for regional decision making on sustainable multifunctional land uses', *Regional Environmental Change*, Vol. 14, 2014, p. 15.

Brunetti, G., Šimůnek, J., and Piro, P., 'A comprehensive numerical analysis of the hydraulic behavior of a permeable pavement', *Journal of Hydrology*, Vol. 540, 2016, pp. 1146–1161. https://doi.org/10.1016/j.jhydrol.2016.07.030

Brunetti, G., Šimůnek, J., Turco, M., and Piro, P., 'On the use of surrogate-based modeling for the numerical analysis of low impact development techniques', *Journal of Hydrology*, Vol. 548, 2017, pp. 263–277. https://doi.org/10.1016/j.jhydrol.2017.03.013

Bruse, M., *ENVI-Met Implementation of the Gas/Particle Dispersion and Deposition Model PDDM*, 2017. Available online: http://www.envi-met.net/documents/sources.PDF

California Department of Water Resources, *Monitoring Networks and Identification of Data Gaps BMP*, 2016, pp. 1-34.

Chen, H., Ooka, R., Huang, H., and Tsuchiya, T., 'Study on mitigation measures for outdoor thermal environment on present urban blocks in Tokyo using coupled simulation', *Building and Environment*, Vol. 44, No 11, 2009, pp. 2290-2299.

Ciais, P., Dolman, A.J., Bombelli, A., Duren, R., Peregon, A., Rayner, P.J., Miller, C., Gobron, N., Kinderman, G., Marland, G., Gruber, N., Chevallier, F., Andres, R.J., Balsamo, G., Bopp, L., Bréon, F.-M., Broquet, G., Dargaville, R., Battin. T.J., Borges, A., Bovensmann, J.H., Buchwitz, M., Butler, J., Canadell, J.G., Cook, R.B., DeFries, R., Engelen, R., Gurney, K.R., Heinze, C., Heimann, M., Held, A., Henry, M., Law, B., Luyssaert, S., Miller, J., Moriyama, T., Moulin, C., Myneni, R.B., Nussli, C., Obersteiner, M., Ojima, D., Pan, Y., Paris, J.-D., Piao, S.L., Poulter, B., Plummer, S., Quegan, S., Raymond, P, Reichstein, M., Rivier, L, Sabine, C., Schimel, D., Tarasova, O., Valentini, R., Wang, R., van der Werf, G., Wickland, D., Williams, M., and Zehner, C., 'Current systematic carbon-cycle observations and the need for implementing a policy-relevant carbon observing system', *Biogeosciences*, Vol. 11, 2014, pp. 3547–3602. doi: 10.5194/bg-11-3547-2014

Clobert, J, Chanzy, A., Le Galliard, J.-F., Chabbi, A., Greiveldinger, L., Caquet, T., Loreau, M., Mougin, C., Pichot, C., Roy, J. and Saint-André, L., 'How to Integrate Experimental Research Approaches in Ecological and Environmental Studies: AnaEE France as an Example', *Frontiers in Ecology and Evolution*, Vol. 6, 2018, p. 43. doi: 10.3389/fevo.2018.00043

Cohen, D.A., Setodji, C., Evenson, K.R., Ward, P., Lapham, S., Hillier, A., and McKenzie, T.L., 'How much observation is enough? Refining the administration of SOPARC', *Journal of Physical Activity and Health*, Vol. 8, No 8, 2011, pp. 1117-1123.

Corbane, C., Martino, P., Panagiotis, P., Aneta, F.J., Michele, M., Sergio, F., Marcello, S., Daniele, E., Gustavo, N., and Thomas, K., 'The grey-green divide: multi-temporal analysis of greenness across 10,000 urban centres derived from the Global Human Settlement Layer (GHSL)', *International Journal of Digital Earth*, Vol. 13, No 1, 2020, pp. 101-118.

Creswell, J.W., 'Mixed-method research: Introduction and application', In: G.J. Cizek (Ed.) *Handbook of educational policy* (pp. 455-472), Academic Press, 1999.

Csillag, F. and Boots., B., 'A Framework for Statistical Infer-ential Decisions in Spatial Pattern Analysis', *Canadian Geographer*, Vol. 49, No 2, 2005, pp. 172–179.

Dickinson, J.L. and Bonney, J.R.E. (Eds.), *Citizen science: Public participation in environmental research*, Cornell University Press, 2012.

Dickinson, J.L., Zuckerberg, B., and Bonter, D.N., 'Citizen science as an ecological research tool: challenges and benefits', *Annual review of ecology, evolution, and systematics*, Vol. 41, 2010, pp. 149-172.

Dushkova, D. and Ignatieva, M., 'New trends in urban environmental health research: from geography of diseases to therapeutic landscapes and healing gardens', *Geography, Environment, Sustainability*, Vol. 13, No 1, 2020, pp. 159-171. https://doi.org/10.24057/2071-9388-2019-99

Dushkova, D. and Dagmar, H., 'Not Simply Green: Nature-Based Solutions as a Concept and Practical Approach for Sustainability Studies and Planning Agendas in Cities', *Land*, Vol. 9, 2020, p. 19. 10.3390/land9010019.

European Space Agency (ESA), *Newcomers Earth Observation Guide*, 2019. Available at: https://business.esa.int/newcomers-earth-observation-guide.

European Parliament and of the Council of the European Union, 'Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE)', *Official Journal of the European Union* L 108, 2007, p. 1–14.

European Parliament and of the Council of the European Union, 'Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC', *Official Journal of the European Union* L 119, 2016, pp. 1-88.

Statistical Office of the European Union (Eurostat), *Glossary*, 2014. https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Baseline_study

Statistical Office of the European Union (Eurostat), Statistical regions in the European Union and partner countries: NUTS and statistical regions 2021, *Publications Office of the European Union*, Luxembourg, 2020. https://ec.europa.eu/eurostat/documents/3859598/10967554/KS-GQ-20-092-EN-N.pdf/9d57ae79-3ee7-3c14-da3e-34726da385cf

Frantzeskaki, N., McPhearson, T., Collier, M. J., Kendal, D., Bulkeley, H., Dumitru, A., Walsh, C., Noble, K., van Wyk, E., Ordóñez, C., Oke, C., and Pintér, L., 'Nature-based solutions for urban climate change adaptation: linking science, policy, and practice communities for evidence-based decision-making', *BioScience*, Vol. 69, No 6, 2019, pp. 455-466.

Frumkin, H., Bratman, G.N., Breslow, S.J., Cochran, B., Kahn Jr., P.H., Lawler, J.J., Levin, P.S., Tandon, P.S., Varanasi, U., Wolf, K.L. and Wood, S.A., 'Nature contact and human health: A research agenda', *Environmental health perspectives*, Vol. 125, No 7, 2017, p. 075001.

Gardiner, M.M., Allee, L.L., Brown, P.M., Losey, J.E., Roy, H.E., and Smyth, R.R., 'Lessons from lady beetles: accuracy of monitoring data from US and UK citizen‐science programs', *Frontiers in Ecology and the Environment*, Vol. 10, No 9, 2012, pp. 471-476.

Gittleman, M., Farmer, C.J., Kremer, P., and McPhearson, T., 'Estimating stormwater runoff for community gardens in New York City', *Urban ecosystems*, Vol. 20, No 1, 2017, pp. 129-139.

Government of South Australia, 'Chapter 15: Modelling Process and tools', *Water Sensitive Urban Design Technical Manual for the Greater Adelaide Region*, Government of South Australia, Adelaide, 2010, p. 48.

Grizzetti, B., Bouraoui, F. and Aloe, A., 'Changes of nitrogen and phosphorus loads to European seas', *Global Change Biology*, Vol. 18, 2012, pp. 769-782.

Groenewegen, P.P., van den Berg, A.E., de Vries, S. and Verheij, R.A., 'Vitamin G: effects of green space on health, well-being, and social safety', *BMC Public Health*, Vol. 6, 2006, p. 149.

Gruiz, K., Meggyes, T., and Fenyvesi, E., *Engineering Tools for Environmental Risk Management: 3. Site Assessment and Monitoring Tools*, CRC Press, 2017.

Grützner, R., 'Environmental modeling and simulation - applications and future requirements', *Environmental Software Systems*, Springer Science+Business Media, Dordrecht, 1996.

Guida, R.J., Swanson, T.L., Remo, J.W., and Kiss, T., 'Strategic floodplain reconnection for the Lower Tisza River, Hungary: opportunities for flood-height reduction and floodplain-wetland reconnection', *Journal of Hydrology*, Vol. 521, 2015, pp. 274-285.

Guo, B., Wang, Z., Yu, Z., Wang, Y., Yen, N., Huang, R., and Zhou, X., 'Mobile Crowd Sensing and Computing: The Review of an Emerging Human-Powered Sensing Paradigm', *ACM Computing Surveys*, Vol. 48, 2015.

Haase D., Haase A., Kabisch N., Kabischb S., and Rink D., 'Actors and factors in land-use simulation: The challenge of urban shrinkage', *Environmental Modelling and Software*, Vol. 35, 2012, pp. 92-103.

Hamad R., Balzter H., and Kolo K., 'Predicting land use/land cover changes using a CA-Markov model under two different scenarios', *Sustainable*, Vol. 10, 2018, p. 3421.

Hampton, S.E., Strasser, C.A., Tewksbury, J.J., Gram, W.K., Budden, A.E., Batcheller, A.L., Duke, C.S., and Porter, J.H., 'Big data and the future of ecology', *Frontiers in Ecology and the Environment*, Vol. 11, No 3, 2013, pp. 156-162.

Hansen, R., Rolf, W., Santos, A., Luz, A.C., Száraz, L., Tosics, I., Vierikko, K., Rall, E., Davies, C., and Pauleit, S., *Advanced Urban Green Infrastructure Planning and Implementation - Innovative Approaches and Strategies from European Cities*, Deliverable 5.2. Technical Report of the Green Surge Project, 2016.

Hartig T., Mitchell R., de Vries S., and Frumkin H., 'Nature and health', *Annual Review of Public Health*, Vol. 35, 2014, pp. 207–228.

Hecker, S., Haklay, M., Bowser, A., Makuch, Z., Vogel, J., and Bonn, A., *Citizen Science: Innovation in Open Science, Society and Policy*, UCL Press, London, 2018.

Herold, M., Couclelis, H., and Clarke, K.C., 'The role of spatial metrics in the analysis and modeling of urban land use change', *Computers, environment and urban systems*, Vol. 29, No 4, 2005, pp. 369-399.

Hirabayashi, S., Kroll, C.N., and Nowak, D.J., 'Development of a distributed air pollutant dry deposition modeling framework', *Environmental Pollution*, Vol. 171, 2012, pp. 9–17.

Hodson, S., Collins, S., Genova, F., Harrower, N., Jones, S., Laaksonen, L., Mietchen, D., Petrauskaité, R. and Wittenburg, P., *Turning FAIR into reality: Final report and action plan from the European Commission expert group on FAIR data*, Publications Office of the European Union, Luxembourg, 2018.

Houghton, J., Townshend, J., Dawson, K., Mason, P., Zillman, J., and Simmons, A., 'The GCOS at 20 years: the origin, achievement and future development of the Global Climate Observing System', *Weather*, Vol. 67, 2012, pp. 227-235.

Iacob, O., Rowan, J.S., Brown, I.M., and Ellis, C., 'Evaluating wider benefits of natural flood management strategies: An ecosystem-based adaptation perspective', *Hydrology Research*, Vol. 45, No 6, 2014, pp. 774-787.

Ilieva, R.T. and McPhearson, T., 'Social-media data for urban sustainability', *Nature Sustainability*, Vol. 1, No 10, 2018, pp. 553-565.

INSPIRE, *INSPIRE Knowledge Base*, 2019. Available from https://inspire.ec.europa.eu. Accessed 2019, July 29.

International Federation of Red Cross and Red Crescent Societies, *Baseline Basics*, 2013.

International Organization for Standardization (ISO), *ISO 19101-1:2014, Geographic information – Reference model – Part 1: Fundamentals*, International Organization for Standardization, Geneva, 2014.

International Organization for Standardization (ISO), *ISO/TC 211 Geographic information/Geomatics*, 2019.

Fernandez, F.J., Alvarez-Velazquez, L.J., Garcia-Chan, N., Martinez, A., and Velazquez-Mendez, M.E., 'Optimal location of green zones in metropolitan areas to control the urban heat island', *Journal of Computational and Applied Mathematics*, Vol. 289, 2015, pp. 412–425.

Filibeck, G., Petrella, P., and Cornelini, P., 'All ecosystems look messy, but some more so than others: A case-study on the management and acceptance of Mediterranean urban grasslands', *Urban Forestry and Urban Greening*, Vol. 15, 2016, pp. 32–39.

Florczyk, A.J., Corbane, C., Ehrlich, D., Carneiro Freire, S.M., Kemper, T., Maffenini, L., Melchiorri, M., Pesaresi, M., Politis, P., Schiavina, M., Sabo, F., and Zanchetta, L., *GHSL data package 2019*, Publications Office of the European Union, Luxembourg, 2019.

Hawxwell, T., Mok, S., Mačiulyte, E., Sautter, J., Theobald, J.A., Dobrokhotova, E., and Suska, P*., Municipal Governance Guidelines*, Urban Nature Labs (UNaLab) Deliverable D6.2, 2018.

Kabisch, N. and Haase, D., 'Urban nature benefits – Opportunities for improvement of health and well-being in times of global change', *Newsletter on Housing and Health*, Vol. 29, 2018, pp. 1-11.

Kabisch, N., Stadler, J., Korn H., and Bonn, A., *Nature-based solutions to climate change mitigation and adaptation in urban areas,* Federal Agency for Nature Conservation, Bonn, 2016.

Kabisch, N., van den Bosch, M., and Lafortezza, R., 'The health benefits of nature-based solutions to urbanization challenges for children and the elderly – A systematic review', *Environmental Research*, Vol. 159, 2017, pp. 362-373.

Kawulich, B., 'Collecting data through observation', *Doing Social Research: A global context*, McGraw-Hill, Berkshire, 2012.

Krebs, G., Kokkonen, T., Valtanen, M., Setälä, H., and Koivusalo, H., 'Spatial resolution considerations for urban hydrological modelling', *Journal of Hydrology*, Vol. 512, 2014, pp. 482-497.

Kumar, P., Druckman, A., Gallagher, J., Gatersleben, B., Allison, S., Eisenman, T.S., Hoang, U., Hama, S., Tiwari, A., Sharma, A., Abhijth, K.V., Aslakha, D., McNabola, A., Astell-Burt, T., Feng, X., Skeldon, A.C., de Lusignan, S., and Morawska, L., 'The nexus between air pollution, green infrastructure and human health'*, Environment international*, Vol. 133 A, 2019, p. 105181.

Langevin, C.D., Hughes, J.D., Banta, E.R., Niswonger, R.G., Panday, S., and Provost, A.M., *Documentation for the MODFLOW 6 groundwater flow model (No. 6-A55)*, US Geological Survey, 2017.

Lein, J.K., *Environmental Sensing*, Springer, New York, 2012.

Leopa, S. and Elisei, P., *Methodology on spatial analysis in front-runner and follower cities*, Deliverable No. 2.1, proGIreg. Horizon 2020 Grant Agreement No 776528, European Commission, 2020, 61 pp.

Leopa, S.; Elisei, P., Knappe, D., Koeneke, H., and Nohra, G.C., *Spatial Analysis in Front-Runner and Follower Cities*, Deliverable No. 2.2, proGIreg. Horizon 2020 Grant Agreement No. 776528, European Commission, 2019.

Li, T., Guo, S., An, D., and Nametso, M., 'Study on water and salt balance of plateau salt marsh wetland based on time-space watershed analysis', *Ecological Engineering*, Vol. 138, 2019, pp. 160-170.

Linden, M. and Sheehy, N., 'Comparison of a Verbal Questionnaire and Map in Eliciting Environmental Perceptions', *Environment and Behavior*, Vol. 36, No 1, 2004, pp. 32–40.

Litwin, L. and Rossa, M., *Geoinformation Metadata in INSPIRE and SDI: Understanding. Editing. Publishing*, Springer Science and Business Media, 2011.

Luettich, R.A., Jr., Westerink, J.J., and Scheffner, N.W., *ADCIRC: An Advanced Three-Dimensional Circulation Model for Shelves, Coasts, and Estuaries, Report 1: Theory and Methodology of ADCIRC-2DDI and ADCIRC-3DL, Dredging Research Program Technical Report DRP-92-6*, U.S. Army Engineers Waterways Experiment Station, Vicksburg, 1992.

Lukyanenko, R., Parsons, J., and Wiersma, Y.F., 'Emerging problems of data quality in citizen science', *Conservation Biology*, Vol. 30, 2016, pp. 447-449.

Mahmood, A.A. and Elektorowicz, M., 'A review of discrete element method research on particulate systems', In *IOP Conference Series: Materials Science and Engineering*, Vol. 136, No 1, 2016, p. 012034.

Maldonado, G. and Greenland, S., 'Estimating causal effects', *International Journal of Epidemiology*, Vol. 31, No 2, 2002, pp. 422–429.

Marcel, M.R., Stadler, J., Korn, H., Irvine, K., and Bonn, A. (Eds.), *Biodiversity and Health in the Face of Climate Change*, Springer International Publishing, Cham, 2019.

Mason, D.C., Horritt, M.S., Hunter, N.M., and Bates, P.D., 'Use of fused airborne scanning laser altimetry and digital map data for urban flood modelling', *Hydrological Processes*, Vol. 21, No 11, 2007, pp. 1436-1447.

Matos, P., Vieira, J., Rocha, B., Branquinho, C., and Pinho, P., 'Modeling the provision of air-quality regulation ecosystem service provided by urban green spaces using lichens as ecological indicators', *Science of The Total Environment*, Vol. 665, 2019, pp. 521-530.

McDonald, A.G., Bealey, W.J., Fowler, D., Dragosits, U., Skiba, U., Smith, R.I., Donovan, R.G., Brett, H.E., Hewitt, C.N., and Nemitz, E., 'Quantifying the effect of urban tree planting on concentrations and depositions of PM10 in two UK conurbations', *Atmospheric Environment*, Vol. 41. No 38, 2007, pp. 8455-8467.

McKenzie, T.L., Cohen, D.A., Sehgal, A., Williamson, S., and Golinelli, D., 'System for Observing Play and Recreation in Communities (SOPARC): Reliability and Feasibility Measures', *Journal of Physical Activity and Health*, Vol. 3, Suppl. 1, 2006, pp. S208–S222.

Mechoso, C.R. and Arakawa, A., 'NUMERICAL MODELS: General Circulation Models', In G.R. North, Pyle, J.A., and Zhang, F. (Eds.), *Encyclopedia of Atmospheric Sciences* (2nd ed.), Academic Press, 2015, pp. 153-160.

Mohareb, E. and Kennedy, C., 'Gross direct and embodied carbon sinks for urban inventories', *Journal of Industrial Ecology*, Vol. 16, No 3, 2012, pp. 302-316.

Montgomery, D.C., *Design and analysis of experiments*, John Wiley & Sons, New York, 2008.

Morales-Torres, A., Escuder-Bueno, I., Andrés-Doménech, I., and Perales-Momparler, S., 'Decision Support Tool for energy-efficient, sustainable and integrated urban stormwater management', *Environmental Modelling and Software*, Vol. 84, 2016, pp. 518-528.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D. R., Chan, K.M.A., Daily, G.C., Goldstein, J., Kareiva, P.M., Lonsdorf, E., Naidoo, R., Ricketts, T.H., and Shaw, M.R., 'Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales', *Frontiers in Ecology and the Environment*, Vol. 7, No 1, 2009, pp. 4–11.

Nelson E.J. and Daily G.C., 'Modelling ecosystem services in terrestrial systems', *F1000 Biology Reports*, Vol. 2, 2010.

Nieto, A., Roberts, S.P.M., Kemp, J., Rasmont, P., Kuhlmann, M., García Criado, M., Biesmeijer, J.C., Bogusch, P., Dathe, H.H., De la Rúa, P., and De Meulemeester, T., *European Red List of Bees*, Publication Office of the European Union, Luxembourg, 2014.

Nijhuis, S., Zlatanova, S., Dias, E., van der Hoeven, F., and van der Spek, S. (Eds.), 'Geo-Design Advances in bridging geo-information technology, urban planning and landscape architecture', *Research in Urbanism*, Vol. 4, TU Delft Open, Delft, 2014.

Nowak, D.J., Hirabayashi, S., Bodine, A., and Greenfield, E., 'Tree and forest effects on air quality and human health in the United States', *Environmental Pollution*, Vol. 193, 2014, pp. 119–129.

Open Geospatial Consortium (OGC), *OGC Sensor Observation Service Interface Standard (v2.0)*, 2012.

Open Geospatial Consortium (OGC), *Open Geospatial Consortium*, 2019. Available from http://www.opengeospatial.org/. Accessed 2019, July 18.

Orgiazzi, A., Ballabio, C., Panagos, P., Jones, A., and Fernández-Ugalde, O., 'LUCAS Soil, the largest expandable soil dataset for Europe: a review', *European Journal of Soil Science*, Vol. 69, No 1, 2018, pp. 140-153.

Pain, H., 'A literature review to evaluate the choice and use of visual methods', *International Journal of Qualitative Methods*, Vol. 11, 2012, pp. 303–319.

Pastorello, G., Papale, D., Chu, H., Trotta, C., Agarwal, D., Canfora, E., Baldocchi, D., and Torn, M., 'A new data set to keep a sharper eye on land-air exchanges', *Eos, Transactions American Geophysical Union*, Vol. 98, No 8, 2017.

Pepper, I.L., Brusseau, M.L., and Artiola, J., *Environmental monitoring and characterization*, Elsevier Science & Technology, 2004.

Pesaresi, M., 'Principles and Applications of the Global Human Settlement Layer', *IGARSS 2018 - 2018 IEEE International Geoscience and Remote Sensing Symposium*, Valencia, 2018, pp. 2047–2050.

Pocock, M.J.O., Chapman, D.S., Sheppard, L.J., and Roy, H.E., *A Strategic Framework to Support the Implementation of Citizen Science for Environmental Monitoring, Final report to SEPA*, Centre for Ecology and Hydrology, Wallingford, 2014.

Pollard, E. and Yates, T.J., *Monitoring butterflies for ecology and conservation*, Chapman & Hall, New York. 1993.

Ponto, J., 'Understanding and Evaluating Survey Research', *Journal of The Advanced Practitioner in Oncology*, Vol. 6, No 2, 2015, pp. 168–171.

Pregnolato, M., Ford, A., Robson, C., Glenis, V., Barr, S., and Dawson, R., 'Assessing urban strategies for reducing the impacts of extreme weather on infrastructure networks', *Royal Society Open Science*, Vol. 3, No 5, 2016.

Raymond, C.M., Pam, B., Breil, M., Nita, M.R., Kabisch, N., de Bel, M., Enzi, V., Frantzeskaki, N., Geneletti, D., Cardinaletti, M., Lovinger, L., Basnou, C., Monteiro, A., Robrecht, H., Sgrigna, G., Munari, L., and Calfapietra, C., *An Impact Evaluation Framework to Support Planning and Evaluation of Nature-based Solutions Projects. Report prepared by the EKLIPSE Expert Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas*, Centre for Ecology and Hydrology, Wallingford, 2017.

Reyers, B., Stafford-Smith, M., Erbs, K.-H., Scholes, R.J., and Selomane, O., 'Essential Variables help to focus Sustainable Development Goals monitoring', *Current Opinion in Environmental Sustainability*, Vol. 26, 2017, pp. 97–105.

Rosenbaum, P.R., *Design of observational studies*, Springer, New York, 2010.

Rossman, L.A., *Storm Water Management Model User's Manual Version 5.1*, United States Environmental Protection Agency, Cincinnati, 2015.

Sahukhal R. and Bajracharya T.R., 'Modeling water resources under competing demands for sustainable development: A case study of Kaligandaki Gorge Hydropower Project in Nepal', *Water Science and Engineering*, Vol. 12, No 1, 2019, pp. 19-26.

Sang, N. (Ed.), *Modelling Nature-Based Solutions: Integrating Computational and Participatory Scenario Modelling for Environmental Management and Planning*, Cambridge University Press, Cambridge, 2020.

Schebella, M. F., Weber, D., Schultz, L., and Weinstein, P., 'The Nature of Reality: Human Stress Recovery during Exposure to Biodiverse, Multisensory Virtual Environments', *International Journal of Environmental Research and Public Health*, Vol. 17, No 1, 2020, p. 56.

Schiavina, M., Melchiorri, M., Corbane, C., Florczyk, A.J., Freire, S., Pesaresi, M., and Kemper, T., 'Multi-Scale Estimation of Land Use Efficiency (SDG 11.3.1) across 25 Years Using Global Open and Free Data', *Sustainability*, Vol. 11, No 20, 2019, p.5674.

Scholes, R.J., Reyers, B., Biggs, R., Spierenburg, M.J., and Duriappah, A., 'Multi-scale and cross-scale assessments of social–ecological systems and their ecosystem services', *Current Opinion in Environmental Sustainability*, Vol. 5, No 1, 2013, pp. 16-25.

Schwarz, N., Kahlenberg, D., Haase, D., and Seppelt, R., 'ABMland - A tool for collaborative agent-based model development on urban land use change', *Journal of Artificial Societies and Social Simulation*, Vol. 15, No 2, 2012, p. 8.

Sekulova, F., Anguelovski, I., Argüelles, L., and Conill, J., 'A 'fertile soil' for sustainability-related community initiatives: A new analytical framework', *Environment and Planning A*, Vol. 49, No 10, 2017, pp. 2362–2382.

Serrano Sanz, F., Holocher-Ertl, T., Kieslinger, B., Sanz Garcia, F., and Silva, C.G., *White Paper on citizen science for Europe*, 2014. Available from https://ec.europa.eu/futurium/en/system/files/ged/socientize_white_paper_on_citizen_science.pdf

Seyfang, G. and Longhurst, N., 'What influences the diffusion of grassroots innovations for sustainability? Investigating community currency niches', *Technology Analysis and Strategic Management*, Vol. 28, No 1, 2016, pp. 1–23.

Simon, H., Fallmann, J., Kropp, T., Tost, H., and Bruse, M., 'Urban Trees and Their Impact on Local Ozone Concentration — A Microclimate Modeling Study', *Atmosphere*, Vol. 10, No 3, 2019, p. 154.

Smith, K.R. and Roebber, P.J., 'Green roof mitigation potential for a proxy future climate scenario in Chicago, Illinois', *Journal of Applied Meteorology and Climatology*, Vol. 50, No 3, 2011, pp. 507-522.

Stark, J., Plancke, Y., Ides, S., Meire, P., and Temmerman, S., 'Coastal flood protection by a combined nature-based and engineering approach: Modeling the effects of marsh geometry and surrounding dikes', *Estuarine, Coastal and Shelf Science*, Vol. 175, 2016, pp. 34-45.

Steinitz, C., 'Beginnings of Geodesign: a personal historical perspective', *Research in Urbanism Series*, Vol. 4, 2016, pp. 9-22.

Sullivan, L.M., Weinberg, J., and Keaney Jr., J.F., 'Common statistical pitfalls in basic science research', *Journal of the American Heart Association*, Vol. 5, No 10, 2016, p. e004142.

Sun, C.Y., Lee, K.P., Lin, T.P., and Lee, S.H., 'Vegetation as a Material of Roof and City to cool down the temperature', *Advanced Materials Research*, Vol. 461, 2012, pp. 552-556.

Sun, L., Wang, W., Gao, F., Cao, C., and Tang, J., 'Distribution and Influencing Factors of Plankton in an Artificial Lagoon in Ningbo', *Asian Journal of Ecotoxicology*, Vol. 4, 2018, pp. 60-67

Surussavadee, C., 'Evaluation of WRF near-surface wind simulations in tropics employing different planetary boundary layer schemes', In *8th International Renewable Energy Congress (IREC)*, Amman, 2017, pp. 1-4.

ten Brink, P., Mutafoglu, K., Schweitzer, J.P., Kettunen, M., Twigger-Ross, C., Baker, J., Kuipers, Y., Emonts, M., Tyrväinen, L., Hujala, T., and Ojala, A., *The health and social benefits of nature and biodiversity protection*, Institute for European Environmental Policy, London/Brussels, 2016.

Thompson, J.R., Iravani, H., Clilverd, H.M., Sayer, C.D., Heppell, C.M., and Axmacher, J.C., 'Simulation of the hydrological impacts of climate change on a restored floodplain', *Hydrological Sciences Journal*, Vol. 62, 2017, pp. 2482-2510.

Underwood, E., Darwin, G., and Gerritsen, E., *Pollinator initiatives in EU Member States: Success factors and gaps. Report for European Commission under contract for provision of technical support related to Target 2 of the EU Biodiversity Strategy to 2020 – maintaining and restoring ecosystems and their services*, Institute for European Environmental Policy, Brussels, 2017.

Vercelloni, J., Clifford, S., Caley, M.J., Pearse, A.R., Brown, R., James, A., Christensen, B., Bednarz, T., Anthony, K., González-Rivero, M., and Mengersen, K., 'Using virtual reality to estimate aesthetic values of coral reefs', *Royal Society Open Science*, Vol. 5, No 4, 2018, p.172226.

Vranic, S., Kalas, M. Leo, L.S., Bertini, F., Sabbatini, T., Neupane, B., Debele, E., and Barisani F., *GeoIKP Deployment and Maintenance Report, Deliverable No. 7.9, OPERANDUM*, Horizon 2020, Grant Agreement No. 776848, European Commission, 2019.

Vuik, V., Jonkman, S.N., Borsje, B.W., and Suzuki, T., 'Nature-based flood protection: The efficiency of vegetated foreshores for reducing wave loads on coastal dikes', *Coastal engineering,* Vol. 116, 2016, pp. 42-56.

Wamsley, T.V., Cialone, M.A., Smith, J.M., Atkinson, J.H., and Rosati, J.D., 'The potential of wetlands in reducing storm surge', *Ocean Engineering*, Vol. 37, 2010, pp. 59–68.

Weathers, K.C., Hanson, P.C., Arzberger, P., Brentrup, J., Brookes, J., Carey, C.C., Gaiser, E., Hamilton, D.P., Hong, G.S., Ibelings, B., and Istvánovics, V., 'The global lake ecological observatory network (GLEON): The evolution of grassroots network science', *Limnology and Oceanography Bulletin*, Vol. 22, No 3, 2013, pp.71-73.

World Health Organization (WHO), *Urban Green Space and Health: Intervention Impacts and Effectiveness. Meeting report. Bonn, Germany, 20–21 September 2016*, WHO Regional Office for Europe, Copenhagen, 2017.

Wilkinson, M.D., Dumontier, M., Aalbersberg, I.J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.W., da Silva Santos, L.B., Bourne, P.E., and Bouwman, J., 'The FAIR Guiding Principles for scientific data management and stewardship', *Scientific Data*, Vol. 3, No 1, 2016, pp. 1-9.

Williams, A., *Therapeutic Landscapes*, Routledge, London, 2017.

Wolfram, M., 'Cities shaping grassroots niches for sustainability transitions: Conceptual reflections and an exploratory case study', *Journal of Cleaner Production*, Vol. 173, 2018, pp. 11–23.

Wood, C.J., Pretty, J., and Griffin, M., 'A case-control study of the health and well-being benefits of allotment gardening', *Journal of Public Health*, Vol. 38, 2016, pp. e336-e344.

World Bank, *Implementing nature-based flood protection: Principles and implementation guidance*, World Bank, Washington, DC, 2017.

World Meteorological Organization (WMO), *Essential Climate Variables*, 2020. Available from https://public.wmo.int/en/programmes/global-climate-observing-system/essential-climate-variables.

Woroniecki, S., 'Enabling Environments? Examining Social Co-Benefits of Ecosystem-Based Adaptation to Climate Change in Sri Lanka', *Sustainability*, Vol. 11, No 3, 2019, p. 772.

Yuan, Z. Y., Jiao, F., Shi, X. R., Sardans, J., Maestre, F. T., Delgado-Baquerizo, M., Reich, P. B., and Peñuelas, J., 'Experimental and observational studies find contrasting responses of soil nutrients to climate change', *eLife*, Vol. 6, 2017, e23255.

Zulian, G., Polce, C., and Maes, J., 'ESTIMAP: a GIS-based model to map ecosystem services in the European union', *Annali di Botanica*, Vol. 4, 2014, pp. 1-7.