



# Improving the availability of data and information on species, habitats and sites

## Focus Area A

Guidance on the application of existing scientific approaches, methods, tools and knowledge for a better implementation of the Birds and Habitat Directives



# Imprint

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## Table of Contents

<b>I. Monitoring of species and habitats</b>	<b>4</b>
<b>I.1</b> Introduction	5
<b>I.2</b> Smart sampling and data analysis	8
<b>I.3</b> Observation technologies	18
<b>I.4</b> Modelling approaches	20
<b>I.5</b> Key findings	23
<b>I.6</b> References	26
Annex 1: Monitoring of natural habitats	31
<b>II. Contribution of Remote Sensing Techniques for monitoring Natura 2000 sites</b>	<b>40</b>
<b>II.1</b> Introduction	41
<b>II.2</b> Current use of Remote Sensing for Natura 2000 monitoring	47
<b>II.3</b> Key findings and recommendations	51
<b>II.4</b> References	59
Annex 1: Examples of useful satellite imagery	67
<b>III. Access to data and information</b>	<b>68</b>
<b>III.1</b> Introduction	69
<b>III.2</b> Strategies, approaches and practical examples to improve data and information access	71
<b>III.3</b> Key findings and recommendations	83
<b>III.4</b> References	85

## Foreword

*By DG ENV*

*With these handbooks, the European Commission intends to support Member State authorities and other stakeholders in making better use of scientific knowledge in implementing the EU Birds and Habitats Directive. Building on the evidence gathered during the Fitness Check of the EU's nature legislation, this project made the effort to mobilise the scientific community in order to close knowledge gaps, to offer solutions to strategic problems and to enhance the accessibility of scientific information to policy makers and all players involved in implementation.*

*The handbooks cover the most important areas as identified in the Fitness Check. These comprise methods for monitoring, reporting and assessing conservation status as well as information and approaches required for effective site and network management, including setting conservation objectives, preparing management plans, implementing conservation measures and evaluating their impact.*

*By analysing relevant knowledge, evidence, tools, approaches and good practices and by bringing together scientists and scientific networks of relevance, the handbooks try to bring the scientific community closer to those that implement the nature directives on the ground.*

## Background

The Birds Directive established an EU-wide protection regime in 1979 for all bird species naturally occurring in the EU, including a classification by Member States of Special Protection Areas (SPA) for threatened and migratory birds. This approach was extended through the Habitats Directive in 1992. The Habitats Directive also provided for the establishment of a representative system of legally protected areas throughout the EU, known as Special Areas of Conservation (SAC). Together, SPAs and SACs form the Natura 2000 network. The aim of both Directives is to ensure the long-term sustainability of the habitats and species they have been set up to protect. Together the Nature Directives provide a comprehensive protection regime for certain particularly rare and threatened species and for typical and valuable habitats in the EU.

Between 2014 and 2016, the European Commission carried out a Fitness Check of both Directives. Based on this comprehensive evaluation it was concluded that the Nature Directives “remain highly relevant and are fit for purpose”, but also that achieving the objectives and realizing their full potential will depend upon substantially improving their implementation. The review proposed that improvements are needed both in their effectiveness and efficiency and in working in partnership with different stakeholder communities in the Member States and across the EU in order to deliver practical results on the ground.

The Fitness Check also recognised that the existence of remaining knowledge gaps may have led to inefficiencies. Specifically important is access to adequate, reliable knowledge, which is essential for many of the activities associated with the implementation of the directives. The EU Biodiversity Strategy for 2030 formulates 17 commitments (targets) under two main headings: Nature Protection and an EU Nature Restoration Plan. The targets and how to measure success are yet to be defined. Legally binding EU nature restoration targets will be proposed in 2021. By 2030, significant areas of degraded and carbon-rich ecosystems are restored; habitats and species show no deterioration in conservation trends and status; and at least 30% reach favourable conservation status or at least show a positive trend.

The Biodiversity Strategy 2030 highlights nature-based solutions (NBS) as a means to help achieve a number of the restoration ambitions while linking to other policies (primarily climate change mitigation and adaptation and urban biodiversity).



## The E-BIND handbooks

The E-BIND handbook(s) are meant to assist decision makers, spatial planners, conservationists, NGOs and other organisations involved in the implementation of the Birds and Habitat Directives. The handbook(s) contains good practical examples, literature references and links to relevant websites.

The two handbooks cover the focus areas:

- A. Improving the availability of data and information on species, habitats and sites
- B. Scientific support for successful implementation of the Natura 2000 network

**Focus Area A**, availability of data and information on habitats and species and sites (this handbook) seeks to provide in the lack of data and access to data, including remotely sensed information and monitoring data. The handbook consists of the following three sections:

- I. **Monitoring of species and habitats**
- II. **Contribution of Remote Sensing Techniques for monitoring Natura 2000 sites**
- III. **Access to data and information**

**Focus Area B** focuses on the effectiveness of the Natura 2000 network and conservation successes, and therefore looks at habitat management and restoration, as well as the wider landscape with Green Infrastructure and Ecosystem services. That handbook consists of the following three sections:

- I. **Guidance and tools for effective restoration measures for species and habitats**
- II. **Green infrastructure and network coherence**
- III. **Co-benefits (ecosystem services) of measures to consolidate the Natura 2000 network**

CHAPTER A.I.

# Monitoring of species and habitats

Anne Schmidt & Chris van Swaay



## I.1 Introduction

*This chapter of the handbook focuses on the monitoring of species and habitat types targeted by the Birds Directive and Habitats Directive both inside and outside the Natura 2000 network. It discusses both the current practices by e.g. the different Member States (as far as information is available) and the opportunities for improvements in terms of approaches, methods and techniques offered by the scientific community.*

*The monitoring of species and habitat types is needed for policy purposes, e.g. reporting by the EU Member States (Birds Directive Article 12 and Habitats Directive Article 17) as well as site management and protection. Information is needed on the different aspects of the conservation status of species and habitat types in relation to environmental pressures (e.g. climate change), human activities and conservation and restoration measures (for more details see DG environment, 2015).*

### I.1.1 Definition of monitoring

There is not a common definition for monitoring, but most definitions (see for example side box) refer to the detection of changes in an object by means of systematic observations.

### I.1.2 Different perspectives and common ground

**The context of the monitoring, the question that needs to be answered by e.g. a policy maker or site manager, is very important as it defines the way the data needs to be collected and analysed.** While policy makers are interested in more general figures such as national trends in the population size of species, site managers are more interested in the specific characteristics of their site and in the effectiveness of conservation measures. Site managers often like to perform repeated surveys or surveillances with the purpose to keep track of changes as a consequence of management practices. **Regularly repeated surveys can be considered as a form of monitoring.**

The implementation of the Birds and Habitats Directives concerns different type of activities performed by different type of organisations. The information needed for these type of activities differs. For example the appropriate assessment (Habitats Directive Article 6.3) requires information on the status of a species or habitat type on site level (high spatial resolution), whereas the conservation status assessment (Habitats Directive Article 17) requires trends on a national / biogeographical level (high temporal resolution). There is a trade off in time and space. **The challenge is to harmonise the monitoring (e.g. by means of protocols) as much as possible in order to be able to use the data and information for multiple purposes.** The ideal solution would be to design a multipurpose monitoring system, but due to the different user requirements this is a challenging if not impossible task.

#### Definition of monitoring

*Grujter et al. (2006) defines monitoring as “collecting information on an object through repeated or continuous observation in order to determine possible changes in the object”. Juergens (2006) defines the monitoring of biodiversity as “the systematic and focused observation and measurement of present changes of biodiversity in its various forms (genes, taxa, structures, functions, ecosystems) usually within a defined context defined by e.g. a research question or a management goal”.*

GEO-BON is developing the “Essential Biodiversity Variables” (EBVs) framework (*Pereira et al., 2013; Jetz et al., 2019*) with the purpose of representing a **minimal set of fundamental observations needed to support multi-purpose, long term biodiversity information needs at various scales** (*Walters and Scholes, 2017*). The EBVs fall in six classes: genetic composition, species populations and ranges, species traits, community composition, ecosystem structure and ecosystem function. These EBVs overlap to a large extent with the different aspects of the conservation status of species (species distribution/range and population, habitat for species) and habitat types (distribution/range, area, structure and function) of the Birds and Habitats Directive.

### 1.1.3 Smart sampling and data analysis methods

**Both regularly repeated surveys and monitoring are based on sampling.** Many sampling-related methods and techniques are generally applicable: in space, in time and in time-space (*Grujter et al., 2006*).

Different monitoring objectives require different sampling designs. That makes it difficult to design a multipurpose monitoring system. Trend monitoring (e.g. the increase or decline in population size of species) requires other sampling strategies than status monitoring (e.g. the estimate of the total number of individuals). If one wants to study causal relationships, e.g. the effects of conservation measures on the status of a species, a specific sampling scheme is required such as a Before-After-Control-Impact (BACI) design.

The conservation status is a legal concept from the Habitats Directive. It describes the status of a species or habitat type targeted by the Directive and is assessed based on several conservation status parameters, namely the distribution and range of the species/habitat type, the population size of the species/the habitat area and the area and quality of the habitat for species/the structure and function of habitat type. In addition (mainly based on the trends) the future prospects of all these parameters are estimated. The conservation status in fact is based on the aggregation of the assessment of all these parameters.

In [chapter 1.2](#) existing sampling and data analysis methods are described to retrieve information on the conservation parameters of the species and habitat types.

### 1.1.4 Observation technologies

There are different ways to collect data on species and habitat types. The most classical way of data collection is a field survey (field observations and measurements). This is often labour intensive. Nowadays there are different techniques available for collecting data such as DNA sampling, camera traps, etc., that can be (partly) automated and might be less labour intensive.

In [chapter 1.3](#) a selection of observation technologies is described that are or might be applied to collect data on species and habitat types.

**Status** being the state or condition in a certain moment at time (e.g. the total number of birds at a certain location at a certain moment in time).

**Trend** being a change or direction (e.g. an increase in the number of birds at a certain location during a certain period).



### I.1.5 Modelling techniques

Nowadays there are data modelling techniques available by means of which relevant information is retrieved from non-structured opportunistic data. These techniques and methodologies are very valuable to fill in the gaps in data and information needed for the implementation of the Birds and Habitats Directives, amongst others concerning the distribution of species and habitat types. These models can help as well to explain the occurrence and/or abundance of species and habitat types in relation to the environmental conditions including certain pressures and threats.

In [chapter I.4](#) modelling techniques are described by means of information that can be retrieved on different conservation parameters of species and habitat types, specifically species and habitat type distribution.

### I.1.6 Monitoring approaches, constraints and priorities

**Different monitoring approaches are followed by the Member States depending on the availability of funding and the existence of volunteer networks.**

There is a difference between the MS with regard to state funding and the involvement of skilled amateur volunteers. Where state agencies have small budgets, there are fewer skilled professionals or amateurs, and socioeconomic conditions prevent development of a culture of volunteerism (*Danielsen et al., 2009*). The resulting lack of knowledge about trends in species and habitats presents a serious challenge for detecting, understanding, and reversing declines in natural resource values (*Danielsen et al., 2009*).

Some MS build on existing monitoring programmes by adapting or extending monitoring schemes. Other MS start from scratch (based on best practices) and develop monitoring programs tailored to e.g. the reporting obligations.

Priorities need to be set depending on the resources that are available (in terms of budget as well experts and/or volunteers). In order to meet the objectives of the directives the most logic choice is to focus on those species and habitat types that are most threatened and where knowledge is lacking.

#### Expert volunteers as an example of citizen science

The best monitoring strategy depends on the availability of resources, tools and people: even for professional monitoring experts are needed and not always available. In biodiversity monitoring and conservation volunteers are becoming more and more important.

**In the EU there is a strong gradient in volunteer participation from Northwest to Southeast.** E.g. in the UK, the Netherlands and the Nordic countries the number of volunteers as well as their knowledge is high. As a consequence reports on the state of biodiversity (e.g. the Article 17 reporting) in these countries rely heavily on such volunteer expert data. The most important driver for the expansion and sustainability of volunteer participation is enthusiasm. *Bell et al. (2008)* conclude that “volunteer engagement should be geared towards enlivening and motivating participants, by providing an inspiring environment where trust, respect, recognition, value and enjoyment can flourish”.

## I.2 Smart sampling and data analysis

This chapter focuses on sampling strategies for the collection of data and how to process the resulting data to obtain reliable estimates (status and trends) on quantitative as well as qualitative aspects of the conservation status of species and habitat types.

### I.2.1 Species

The latest Article 17 reporting (2019) still shows large gaps (Figure 1), especially for population trends. This paragraph will discuss how to obtain both range- and population trends.

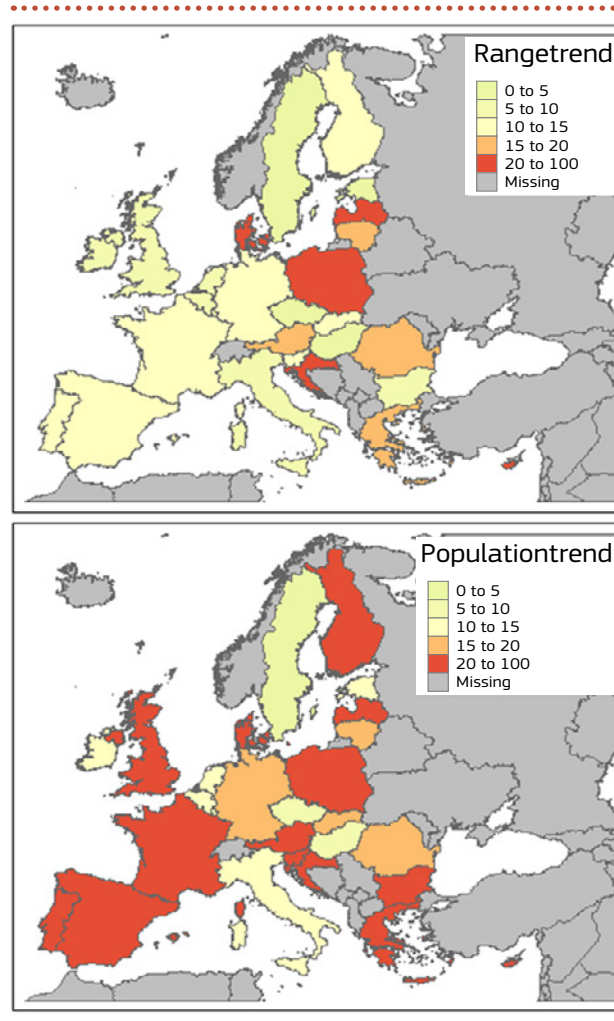
With the exception of some large, striking and popular species, from whom we might know each individual, we have to rely on **clever sampling combined with statistical techniques to obtain a reliable estimate of the status and trend of species' distribution, range and population.**

#### **We distinguish population trends and distribution trends.**

Each needs a different sampling strategy, and the results don't have to be correlated. *Dennis et al. (2019)* show e.g. that for moths in Scotland, negative population trends showed varied distribution trends, and an increasing distribution is likely to be driven by a warming summer climate facilitating range expansion, whereas population declines may be driven by reductions in habitat quality, changes in land management practices and warmer and wetter winters. Furthermore population trends are more sensitive to changes, especially declines, where distribution tends to react later and is more sensitive to expansions.

**Regardless of being used by either professionals or via citizen science, it is important that methods have been tested for observer variation.** Actually most citizen science projects have been tested for this (it is a typical question coming up in reviews), where the relatively expensive monitoring by professionals is not always evaluated on this point.

**Until recently trend monitoring data was almost always collected via strict protocols, thus ensuring high quality time-series. Recently "big unstructured data", which comprises large amounts of data collected for loosely defined**



### Trends

One of the major aspects in establishing the conservation status of a species is the trend.

The **Population trend** gives an indication of changes in the number of individuals. This is a very sensitive measure, but for many species it requires strict protocols and a large effort. It is feasible for popular species groups, as birds and butterflies. In some cases (e.g. in the Article 17 assessment) distribution on a 1x1km grid is considered a substitute for population if no other population unit such as individuals is available.

**Distribution trends** can be generated from opportunistic records, e.g. as coming from citizen science projects. Such trends tend to be less sensitive, and negative trends can remain hidden for some years, depending on the grid size used (e.g. 10x10km in Article 17 reporting, 2x2km in the Area of Occupancy (AOO) of the Red List assessment).

**Figure I.1**

Percentage species range- or population trend marked as unknown for all combinations of species and biogeographic region in the Article 17 report of 2019.

**“observatory purposes”, have become an important source of biodiversity data.** So far such opportunistic citizen science data can only be used for distribution trends if rigorous models correct for observation, reporting and detection biases (*Bayraktarov et al., 2019*). Big unstructured data, although abundant, typically have a high level of noise to signal ratio which obscures the signal on real trends (*Cunningham & Lindenmayer, 2017*). Moreover, data collection without specified (testable) objectives may not measure the “correct” variables to answer questions about biodiversity (*Bayraktarov et al., 2019*).

## Population

### a. Population size

**Establishing population size in exact numbers can be a challenge. Distance sampling and territory mapping** are survey techniques for estimating bird abundance (*Bibby et al., 2000; Buckland et al., 2001*). **But for other, often smaller, animals and plants, it can be difficult or even impossible to measure the exact population size**, even if they occur in small and closed populations without contact to other populations. **As a consequence in the latest version of the Article 17 reporting for the Habitats Directive, the reporting unit for many species was changed to 1x1km** (*DG Environment, 2017*). But even then this can rely heavily on sampling intensity. Where relevant and possible detection probability should be taken into account, e.g. by occupancy modelling (see for more details the next paragraph). For pelagic birds, cetaceans and marine reptiles line transect surveys in a regular pattern (e.g. *Panigada et al., 2011*) in combination with distance sampling make it possible to get population estimates of some of the more common species. Aerial surveys proved to be more efficient than ship surveys, allowing more robust estimates (*Panigada et al., 2011*). When applying such techniques it is important to take detectability into account. For some cetacean species, mark-recapture methods can be applied using photo-identification of recognizable individuals (*Evans & Hammond, 2004*). Anyway the power to detect trends in cetaceans is low. *Tyne et al. (2016)* showed in a test case with a Spinner dolphin that it would take nine years to detect a 5% annual change in abundance (with a power of 80%), so if the trend was a decline, the population would have decreased by 37% prior to detection of a significant decline.

Most of the fish and lampreys listed in the Annexes of the Habitats Directive occurring in the sea are anadromous (or have anadromous populations), i.e. they migrate between rivers (where they spawn) and the sea. As there are many barriers in most rivers, migrant fish can be monitored at those sites.

### b. Population trend

**Although it can be a challenge to measure the exact population size, there are good techniques available to measure changes in population size:** the population trend. **For population trends regular counts (one way or the other) are the basis. Counts can be**

**Distance sampling** = During a transect walk the distance to the object is estimated.

**Territory mapping** = Territories are distinguished after multiple visits.

**performed by transects, plots, camera-traps** etc. It is important that such methods are harmonised, with each country delivering the same parameters (e.g. the population trend and the confidence interval), not necessarily standardised: methods may differ in detail (the trend can e.g. be produced from transect counts in one country, and camera-traps in another country). The method should guarantee that the results (the trends and their statistical uncertainty) can be combined for use at a higher (e.g. European or EU) level. In the calculation of European bird trends (PECBMS: [pecbms.info](http://pecbms.info)) and butterfly trends (eBMS via ABLE: [butterfly-monitoring.net](http://butterfly-monitoring.net)) this is already incorporated (see also the example in the side box).

This can be achieved by:

- » Ensuring that the protocols are well described and maintained, and can deliver the data needed.
- » Setting up a method to account for the differences in the results, and combining them at a larger scale or further back in time (when e.g. new techniques were not yet available).

In this way new techniques and methods can be combined with older, long time-series, thus enabling a view back into time but still use new innovative techniques. However calibration is needed when detection probabilities change.

Although statistical techniques offer the possibility to combine many short time-series to produce a long-term trend (see e.g. *Hallmann et al., 2017*), the power of monitoring is in long time-series with regular counts. Such counts are made on sample points, transects or plots (further referred to as sample points). Sample points can be arranged in different ways:

- » Random: locations are chosen at random, e.g. in the [Wider Countryside Butterfly Survey](#).
- » Grid: locations are in a strict grid. A typical example is the [Biodiversity Monitoring Switzerland](#), where species, habitats and water is monitored in a regular grid. In some areas (Kantons) the density is higher than in others, because of additional funding. At sea these can also be a regular pattern of transects (see e.g. *Panigada et al., 2011*).
- » Free choice: participants can choose their own favoured location. As good as always these will be volunteers, professionals can be directed to random, grid or targeted monitoring locations.
- » Targeted: monitoring focuses on specific sites, species or habitats, e.g. species mentioned in the annexes of the Habitats Directive or other (policy) relevant species (e.g. in [Flanders](#)).

Random and grid based approaches have the advantage of delivering reliable trends, where no weighting or stratification is necessary. However rare species or habitats are easily missed and as a result are underrepresented in the network, and often no trends can be calculated for such rare species, which often are policy-relevant (e.g. because they are mentioned in the annexes of the Habitats Directive). Furthermore random and grid-based networks are expensive if counts by

### European bird monitoring data: harmonised, not standardised

For the PanEuropean Common Bird Monitoring Scheme (PECBMS) coordinators of national bird monitoring schemes deliver their national results to the PECBMS coordination unit annually. The data delivered are:

- » the national yearly indices per species,
- » the all-sites yearly totals (= the sum of birds counted across all sites per year) and their standard errors,
- » the covariances between the yearly figures.

The method to come to the national data can differ from country to country (the field methods do not have to be standardised, some countries apply e.g. the labour-intensive territory mapping, while others may use transect counts), but as the national output is harmonised (all countries deliver the same set of data) they can be used to calculate European trends.

For more details see [pecbms.info/methods/pecbms-methods](http://pecbms.info/methods/pecbms-methods)



people have to be made: volunteers tend to focus on attractive sites, as nature reserves, meaning many points have to be counted by professionals. However for automated methods (e.g. camera-traps) this is not an issue, even if a large number of potential volunteers is available (e.g. in the United Kingdom). Automated methods can also be a good alternative for the lack of volunteers or (funding for) professional experts for less known species groups (e.g. bees), but these techniques are new and will need some time to further develop. However the first steps on using camera-traps with image recognition through artificial intelligence (AI) have been made, and in the coming years these will become more generally available.

**Free-choice networks are mostly used in citizen-science based monitoring:** volunteers can choose their own sites. This will lead to an overrepresentation of sites in nature reserves and urban areas. Such data can be corrected by stratified weighting for the more common and widespread species, as long as there is enough data from unattractive sites (usually large-scale agricultural areas). **Advantage of this system is that rare and policy relevant species are favoured**, and in general there will be enough sites for those species.

**Targeted monitoring, usually by professionals** (but not always, see e.g. [www.meetnetten.be](http://www.meetnetten.be)), **can be an effective way to get population trends of a chosen set of species.** It can be costly (certainly if there are many species and many locations), and strict quality control is needed, as detection probabilities for many species are so low, that multiple visits during a year are needed, which is not always done. For species for which the detection probability is known (e.g. butterflies and dragonflies; *Van Strien et al., 2013*) we can calculate the minimal number of visits (in the case of butterflies and dragonflies: at least three per season), and this will be even more for shy or night-active species (for whom the detection probability will be even lower), for which often experience and a lot of expert knowledge is needed to find them. Another disadvantage is that **only target-species are counted, and trends in other species will be missed.** Also the results cannot be used for community indicators (e.g. Ellenberg indicators in plants).

For the calculation of population trends several techniques are available, usually based on a Generalized Linear Models (GLM) or Generalised linear mixed models (GLMM) with poisson distribution, such as TRIM (*Pannekoek & Van Strien, 2001*, now available as [R-package rtrim](#)) and the Generalized Abundance Index (*Dennis et al., 2016*).

Joining efforts by creating a **central data and information point** can be an effective way to improve the consistency and harmonisation of monitoring methods across the EU. For birds this was created by the [European Bird Census Council](#), who run the Pan-European Common Bird Monitoring Scheme (PECBMS) since 2002. Recently the ABLE-project (Assessing Butterflies in Europe) started, building on the [European Butterfly Monitoring Scheme \(eBMS\)](#) with the ambition to form a central database for all butterfly and moth monitoring counts in Europe. When this project is finished in December 2020, there should be butterfly-monitoring in most EU countries.

**It would be good to build on these examples and experiences and start up similar initiatives for other species groups.**

## Species distribution

**In general distribution maps (giving the distribution, often in units as 1x1km squares or 10x10km squares) and distribution trends are not based on systematic counts, but on opportunistic data.** Long-term monitoring schemes provide high-quality data, often on an annual basis, but are taxonomically and geographically restricted. By contrast, opportunistic biological records are relatively unstructured but vast in quantity (*Isaac et al., 2014*). With the growth of online portals, such as [ebird.org](http://ebird.org), [observation.org](http://observation.org) and [iNaturalist.org](http://iNaturalist.org), usually with associated smartphone apps, next to local and national biodiversity databases (e.g. [artportalen.se](http://artportalen.se) or [ndff.nl](http://ndff.nl)), the number of records has grown almost exponentially in recent years. Some of these online portals lend their data to [gbif.org](http://gbif.org), the Global Biodiversity Information Facility, which held 1.3 billion records in June 2019. GBIF data is freely available for download for research and conservation. One of the main flaws is that validation and quality control depends on the data-source, and as such part of the data can be unreliable. In some countries sharing of distribution data is not encouraged by the member states, and as a result the data which is available is limited and divided over several data sources. In other countries holiday records from naturalists from other countries could make a considerable difference. Without the uploading of such records to GBIF, or downloading them from GBIF, a lot of valuable distribution data might not be used. **The EU could play a role in encouraging all member states to make distribution data available via GBIF.**

Distribution data tends to be **presence/absence** (or better: detection/not detection). Although part of the data can be real counts, without a protocol or clear method description, such counts cannot be used easily for (range) trends. *Isaac et al. (2014)* compared a set of methods that employ data filtering criteria and/or correction factors to deal with variation in recorder activity. They found that simple methods produce biased trend estimates, and/or had low power, and should be avoided. No method was wholly unaffected by all forms of variation in recorder activity, although some performed well enough to be useful. Sophisticated methods that model the data collection process offer the greatest potential to estimate timely trends, notably Frescalo and occupancy-detection models (see *Isaac et al., 2014* for more details).

**It should be noted that especially the most sophisticated models for distribution trends are also 'data-hungry' and require a lot of input.** Next to that there is a minimum quality of visits required. Ideally participants record all species of a species group. This works well in some species groups (e.g. butterflies), but fails in other species groups, most notably birds, where recorders usually don't have the habit of producing complete species lists. Future sampling therefore should concentrate on ways of enhancing the quality of species lists per visit.

In some countries bird atlases have been produced following strict protocols (e.g. *Schekkerman et al., 2012*), which allow estimates of the population size as well as for comparison between periods and thus establishing species distribution trends. However such atlases are very labour-intensive and only possible in a limited number of counties and species-groups.

## From observations to distribution map to trends in distribution: the Netherlands as an example

Distribution data is collected in different ways. To illustrate the magnitude, we will give an example using the information available on the Grayling (*Hipparchia semele*) in the Netherlands in 2017. Here this is a characteristic butterfly of dry heathland and coastal dunes.

Targeted data collection, following a protocol:

**Repeated surveys:** every six years almost all nature reserves (including all Natura 2000 areas) are investigated by professionals on the distribution (at least on a 100m scale) of a group of species (birds, plants, and a selection of butterflies, dragonflies and grasshoppers). 1490 records of the Grayling were recorded in 2017 under the SNL-protocol.

**Population monitoring:** following a strict protocol for population monitoring by volunteers, this also generates distribution data. 407 counts of the Grayling were recorded in 2017 for population monitoring. Targeted distribution research, especially for rare and/or hard to detect species, often on the Habitats Directive. As the Grayling is not on the Habitats Directive, no records were collected in the Netherlands under this project.

**Opportunistic records:** almost all occasional observations in the Netherlands are entered via one of the online portals ([waarneming.nl](http://waarneming.nl), [telmee.nl](http://telmee.nl)), most of them via a smartphone-app. In 2017 the Grayling was recorded on 2425 occasions as single opportunistic record.

After validation all observations are included in the National Database Flora and Fauna (NDDFF). Validation is based on the following principles:

**Automatic validation:** all records run through a script which checks for distribution (is the observation at or near a known location), time of year (does this species occur in this stage in this time of the year) and ...



**Figure I.2**

Grayling (*Hipparchia semele*). © Chris van Swaay, De Vlinderstichting/Dutch Butterfly Conservation.

For anadromous fish and lampreys, often recorded only in a few localities in the river systems, e.g. the spawning grounds or at fish passes, the complete migration route in the rivers from the mouths in the sea to the highest known stretches should be included in the distribution (*DG Environment, 2017*).

**Range** and **range trend** are special cases of distribution and distribution trend, as they are based on 10x10km grid cells. Range is defined as 'the outer limits of the overall area in which a habitat type or species is found at present' and it can be considered as an envelope within which areas actually occupied occur. The range should be calculated based on the map of the actual distribution using a standardised algorithm. A standardised process is needed to ensure repeatability of the range calculation in different reporting rounds (*DG Environment, 2017*). The method for compiling range and range trend is described in detail in *DG Environment (2017)*. Advantages and disadvantages are comparable to other measures of distribution and distribution trend.

... numbers (are the numbers within the normal range for the species). If one of the features has declined, the observations go to an expert validator. All very rare species are also validated by an expert.

If there is proof entered with the observation (e.g. a photo or sound recording), part of them go through AI-based image-recognition. This does not work for all groups yet, but the quality is improving. If there is no match between the identification entered by the observer and the outcome of the image-recognition, the observation goes to the expert validator. In case of any other doubt, the observation also goes to the expert validator.

The **expert validator** checks the observations which were declined by the automatic validation or with photos which were declined.

The expert validator contacts the observer in case of disagreement or doubt. In most cases of wrong identification the observer follows the advice of the expert validator and changes the identification.

## Habitat for species

**A species needs a sufficiently large area of habitat of suitable quality and spatial distribution to survive and flourish.** To measure it we should take into account (*DG Environment, 2017*):

- » physical and biological requirements of the species; this includes prey, pollinators, etc.;
- » all stages of its life cycle are covered and seasonal variation in the species' requirements is reflected.

Monitoring the size, quality and spatial arrangement of the habitat of a species is not only difficult, but also subject to changes in the species' preferences: as a result of climate change some species have changed their habitat preferences and widened or narrowed down their range of preferred habitats. Although in some cases vegetation can be used as a proxy for habitat quality, this often neglects other requirements of species, i.e. food, shelter, interactions with other species, etc.

As a consequence of the difficulty in measuring habitat quality and -area for a species, in the previous reporting for Article 17 (*European Environmental Agency, 2015*) only 15% of the combinations of species, member state (MS) and Biogeographical Region (BGR) is reported as coming from a complete survey or statistically robust estimate (Figure I.3).

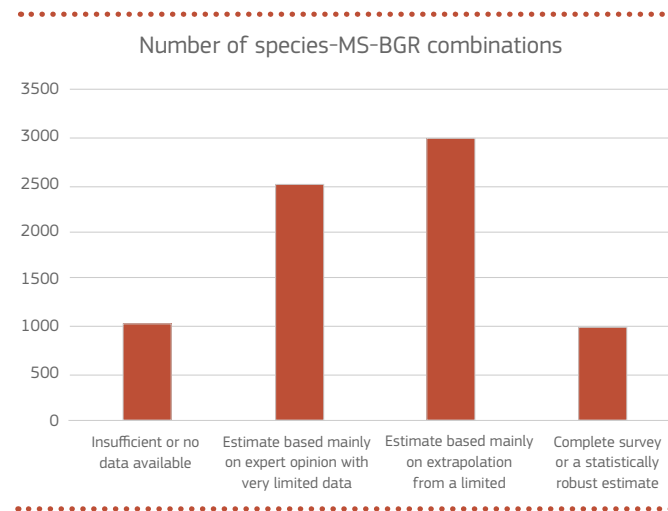
A Species Distribution Model (SDM) can be a way to combine requirements. Such explanatory modelling assess the availability of habitat for a species. This is discussed in more detail in chapter 4 (Modelling approaches).

### I.2.2 Habitat types

This subchapter gives an overview of sampling strategies and data analysis methods that are/ can be used for the monitoring of the habitat types of Annex I of the Habitats Directive.

#### Habitat typologies

There is an interpretation manual of the European Union Habitats (*EU, 2013*). This manual forms the basis for all habitat classification and is regularly updated, e.g. with the expansion of the EU Member States. **Although there is this common habitat typology, the interpretation of the habitat types of Annex I of the Habitats Directive differs per Member States and even within a MS** (*Evans, 2010*).



**Figure I.3**

Assessment of habitat quality and area for non-bird species in the article 17 reporting of 2013–2018 (*European Environmental Agency, 2020*).



For the Habitat Directive Article 17 reporting information is needed on the area (status and trends), the distribution (status and trends) and the structure and function or 'quality' of the habitat types on national and biogeographical level. For site management and protection similar but more detailed information is needed on these parameters.

*Lengyel et al. (2008b)* compared the different approaches and methods applied by MS to monitor habitat types, based on the descriptions (meta data) of habitat monitoring schemes collected within the [EUMON-project](#) and stored and maintained in the [EUMON database](#). *Lengyel (2008a)* sees promising developments in habitat monitoring, amongst others that most schemes monitor distribution and species composition of habitats as well environmental parameters. The main weakness is that in more than half of the schemes it is not clear how the collected data are analysed as this is not described in the monitoring schemes. Advanced statistics may be used infrequently because in most schemes sampling sites are selected based on expert/personal knowledge rather than predefined criteria derived from a sampling theory. *Lengyel (2018)* pleads for benchmarking of monitoring of species and habitat types. **By means of sharing and comparing different data and sampling analysis techniques e.g. between the Member States or site managers one can learn from each other and step by step improve these methods and possibly qualify or certify methods.** As explained in the former chapter on species, it is not necessary to use the same methodologies as long as the protocols are well described and lead to a similar outcome that can be compared.

Since 2008 developments have been made by the MS in habitat monitoring, but an extensive review of the current state of the art is missing. *Ellwanger (2018)* made a more recent comparison between the monitoring approaches of a selection of MS and concludes that there are considerable differences in terms of data sampling (e.g. sampling size) and data analysis (e.g. statistical robustness).

### Habitat area

**Habitat area is often monitored based on repeated/ sequential habitat mapping. Different approaches for habitat mapping are used, varying from field mapping to the interpretation of aerial photographs and automated classification of remote sensing imagery.** Often a combination of different methods is applied depending on the habitat type or group of habitat types. The Czech Republic for example have interpreted Habitats Directive Annex I habitats by the national system of biotopes and carried out an extensive field mapping of the entire Czech Republic in the fine-scale 1:10.000 (*Guth & Kučera, 2005*). A large amount of field data was collected of all biotopes, mainly about their distribution, spatial dimensions, and qualities.

Due to differences in the interpretations e.g. in the field or of the aerial photographs, trends in habitat area are often difficult to assess or uncertain and inaccurate. As *Lengyel (2008a)* concludes **the information on how the data is analysed (meta data) to derive trends in area of habitat types is often missing in the national report of the MS.** Therefore the

uncertainty of the trends is unclear. A system with qualifiers as is being used by IPBES might be applied, but it requires transparency in the methods being applied by the different member states. It is up to the Member State to indicate the quality class without further information.

Remote sensing techniques might offer means to harmonise the data collection on the area and as well the distribution of habitat types as these methods are (partly) automated and can be standardised to a certain extent. Not all habitat types can be that easily detected by means of remote sensing so field work is often necessary.

### Habitat distribution

**Habitat distribution is estimated based on mapping as well as modelling.** The problem is that habitat maps are often only available of a selection of sites and not on a national or biogeographical scale. Habitat distribution modelling can give a more complete estimate of habitat distribution ([see chapter 1.4](#)).

### Habitat structure and function

**Structure and function is the key aspect for the assessment of the conservation status of habitat types as it provides information on the 'quality' of the habitats** (Ellwanger *et al.*, 2018).

**The assessment of habitat quality according to the requirements of the EC is based on the criteria habitat structures, habitat functions and typical species.** Structures are considered to be the physical components of a habitat type. These will often be formed by assemblages of species (both living and dead), but can also include abiotic features, such as gravel used for spawning. Functions are the ecological processes occurring at a number of temporal and spatial scales and they vary greatly between habitat types. Typical species are those which mainly occur in a habitat type or at least in a subtype of a variant of a habitat type (DG Environment, 2017). The species composition of a given habitat type may vary geographically.

**Individual attributes or sub-criteria have to be selected for each habitat type to assess habitat structure and function (habitat quality).** The data collected on the different criteria and/or subcriteria of the aspect structure and function needs to be aggregated and weighted (similar to the final assessment of the conservation status of a habitat type).

Ellwanger (2018) concludes that most of the monitoring approaches (of the MS included in his study) for assessing the structure and function of habitat types are based at least partially on sampling. The number of sampling areas depends on the occurrence of the habitat type (rare vs widespread) and other ecological and methodological factors, as well as efforts and costs. Each MS selects the sample plots differently. Overall, most MS conduct at least a partly systematic selection based on the distribution, the size (area) and characteristics of habitat types and/or other factors. Most MS used permanent plots, include area within and outside the Natura 2000 network and have standard assessment schemes.

None of the MS included in the study of *Ellwanger (2018)* made a statement on theoretical statistical strength of the samples for monitoring. This corresponds to what *Lengyel (2008)* concluded ten years before. There is a lack of a proper description of the data collection and analysis protocols that are used and on the certainty the information derived from these data.

#### a. Typical species

**Concerning the typical species most MS investigate plant species only (*Ellwanger, 2018*), most probably because plants are quite easily linked to habitat types (the habitat typology is heavily based on plant communities), whereas for fauna species it is much more difficult.** Some fauna species depend on more than one habitat type (e.g. for breeding, foraging, resting etc.) which is much more difficult. **In case animals species are investigated the most frequently, used animal groups are birds, butterflies and beetles. This is probably due to the fact that these species groups are relatively easy to detect and recognize and often observed by large volunteers networks.** In The Netherlands a method has been developed to assess structure and function of habitat types based on trends in the distribution of typical plant species (*Janssen et al., 2020*).

#### b. Aggregation methods

**There are different approaches for the aggregation of the data (assessment criteria) for the purpose of structure and function assessments.** For each habitat type an assessment needs to be performed of the area (km<sup>2</sup>) in good condition. As the condition is defined by different sub-parameters there should be a weighing between these sub-parameters as well a threshold for good condition. Measurements are being made at single plot and at site level. These measurements need to be aggregated on the level of a bio-geographical region. Different approaches are being followed by the Member States.

## 1.3 Observation technologies

**This chapter focuses on innovative techniques for the observation of species and habitat types. It is not meant to be complete.** A selection of techniques has been made and examples are given for certain species and habitat types. There is no description on data collection and analysis techniques in this chapter as this has been described in chapter 2, but different type of observations might require different sampling and data analysis methods. The costs of the different techniques are missing in this chapter. A lot of these techniques are still being developed (e.g. the automated detection of species on images) and therefore more experimental, which makes it difficult to estimate the costs of an operational system.

### I.3.1 Species

#### DNA sampling

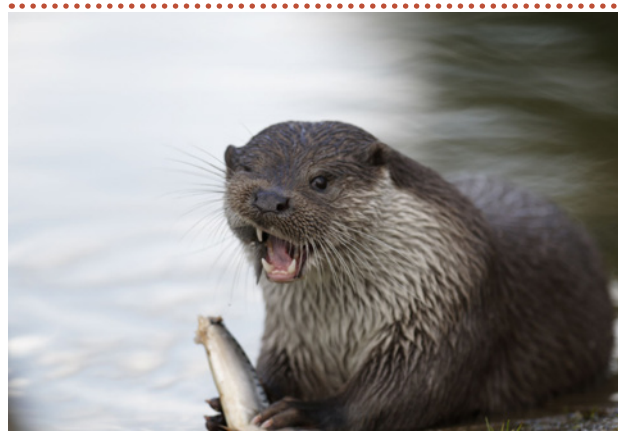
DNA barcoding is a method of species identification using a short section of DNA from a specific gene or genes. **A distinction can be made between destructive DNA sampling, where the species are sampled and identified in a destructive way (Yu et al., 2012; Ji et al., 2013) and non-destructive sampling where samples are collected from the environment of the species called environmental DNA (eDNA).** eDNA – defined here as: genetic material obtained directly from environmental samples (soil, sediment, water, etc.) without any obvious signs of biological source material – is an efficient, non-invasive and easy-to-standardize sampling approach (Thomsen & Willerslev, 2015; Baird et al., 2012). Environmental DNA has been obtained from ancient as well as modern samples and encompasses single species detection to analyses of ecosystems. In the future, we expect the eDNA-based approaches to move from single-marker analyses of species or communities to meta-genomic surveys of entire ecosystems to predict spatial and temporal biodiversity patterns (Thomsen & Willerslev, 2015). This technique is being used for different species groups (Bohman et al., 2014; Rees et al., 2014). In case the monitoring is focused on a single species e.g. rare withdrawn or nocturnal species, information can be collected from faeces, feathers, eggs, hairs etc. An example of this is the Eurasian otter (see side box).

#### Camera Trapping

A camera trap is a remotely activated camera that is equipped with a motion sensor or an infrared sensor, or uses a light beam as a trigger. Originally camera traps were mainly used to study relatively large animals (e.g. birds and mammals) for studies of nest ecology, detection of rare species, and estimation of population size and species richness. Rovero & Zimmermann (2016) provide a guide to the use of camera trapping for the most common ecological applications and research. At present cameras are being developed to monitor small mammals and other species groups (Hobbs et al., 2017).

#### Acoustic monitoring

Passive acoustic monitoring, or just ‘acoustic monitoring’, involves surveying and monitoring wildlife and environments using sound recorders (acoustic sensors). These are deployed in the field, often for hours, days or weeks, recording acoustic data on a specified schedule. After collection, these recordings are processed to extract useful ecological data – such as detecting the calls of animal species of interest – which is then analysed similarly to other types of survey data (Browning et al., 2017). Acoustic sensors are small, increasingly affordable and non-invasive, and can be deployed in the



#### Monitoring the Eurasian otter by means of DNA analysis of faeces (spraints)

Population size of European otters (*Lutra lutra*) was estimated in Pollino National Park (southern Italy) by genetic typing of fresh feces collected in the field. Of 187 fecal samples gathered, 185 (98.9%) yielded otter DNA, 77 (41.2%) were successfully typed, and 23 different genotypes were identified. A nonlinear regression between the number of typed spraints and the cumulative number of identified genotypes was repeated after randomization of the sample until it gave an estimated otter population of 34–37 animals (0.18–0.20 otters/km of watercourse). The applied method represents a valuable conservation tool, combining the advantages of an indirect survey with the accuracy of an exhaustive census (Prignioni, 2006).

The last recorded presence of the Eurasian otter (*Lutra lutra*) in the Netherlands dates from 1989 and concerned a dead individual. In 2002 a reintroduction programme was started, and between June 2002 and April 2008 a total of 30 individuals (10 males and 20 females) were released into a lowland peat marsh in the north of the Netherlands. Noninvasive genetic monitoring based on the genetic profiles obtained from DNA extracted from otter faeces (spraints) was chosen for the post-release monitoring of the population. To this end, the founding individuals were genotyped before release and spraints were collected in the release area each winter from 2002 to 2008. During winter 2007/08 47 individuals were identified, 41 of which originated from mating within the release area. This study demonstrates that noninvasive molecular methods can be used efficiently in post-release monitoring studies of elusive species to reveal a comprehensive picture of the state of the population (Koelewijn et al., 2010).

#### Figure I.4

Otter (*Lutra Lutra*) © Hugh Jansman from Wageningen Environmental Research (WENR)



field for extended times to monitor wildlife and their acoustic surroundings. The data can then be used for estimation of species occupancy, abundance, population density and community composition, monitoring spatial and temporal trends in animal behaviour, and calculating acoustic proxies for metrics of biodiversity. Provided the challenges of data analysis are addressed carefully, this can make acoustic sensors valuable tools for cost-effective monitoring of species and ecosystems and their responses to human activities (*Browning et al., 2017*). Examples of acoustic monitoring are the monitoring of bats and the monitoring of sea mammals.

### 1.3.2 Habitat types

#### Remote sensing

There are several scientific studies available that propose habitat monitoring methods based on remote sensing (see [chapter A.II on Remote Sensing Techniques](#)) (*Van den Borre et al., 2011; Corbane et al., 2014; Nagendra, 2013; Lucas et al., 2015*).

## 1.4 Modelling approaches

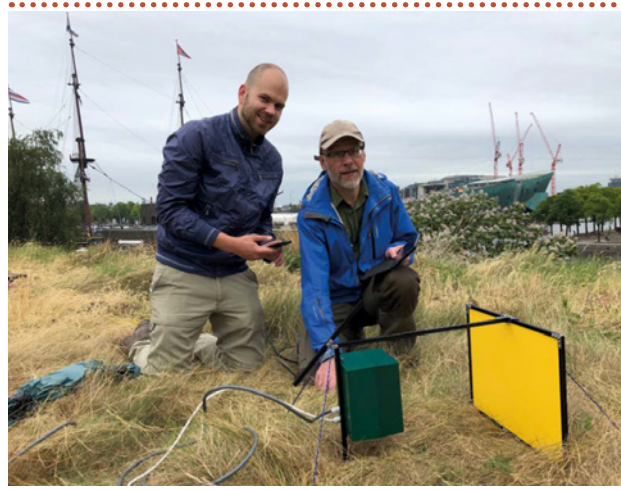
This chapter focuses on modelling approaches by means of which relevant information can be extracted on several aspects of the conservation status of species and habitat types. This chapter specifically focuses on species and habitat distribution modelling.

### 1.4.1 Definition of modelling

Models are a more and more popular way to describe the relationships between a species' distribution and/or trend, and the underlying drivers. Practically a model is a set of mathematical equations or logical rules that link a biodiversity variable of interest to one or more other variables e.g. environmental drivers (*Ferrier et al., 2017*).

#### Explanatory modelling

Explanatory modelling is conducted across space alone, at a single point in time (usually the present). Explanatory modelling of correlations, or associations, between a biodiversity-response variable observed at a sample of geographical locations, and a set of predictor variables measured, or estimated, at these same locations, can help to shed light on the relative importance of different drivers in determining spatial patterns in biodiversity, and on the form (shape) of these relationships. The fitting of correlative species distribution models (SDMs) relating obser-



**Figure I.5**

Example of a camera trapping set-up. (From [www.marine-terrein.nl/insecten-tellen-met-een-slimme-camera](http://www.marine-terrein.nl/insecten-tellen-met-een-slimme-camera)).

#### Monitoring invertebrate with camera traps and automatic image

Recent developments also include the use of camera traps to detect and count insects after identifying them via automatic image recognition. Although still in a testing phase, this new development could make it possible in future to monitor flying insects outside the relatively well-studied groups as butterflies and dragonflies, for which sound methods and many volunteers are available. In the Netherlands Naturalis Biodiversity Centre, EIS and the Radboud University are developing together with COSMONiO Imaging BV and with advise of Waarneming.nl (see [www.waarnemingen.nl](http://www.waarnemingen.nl)) such a system. One of the goals is to monitor the biomass of insects based on the counts of certain species.

vations of presence, presence-absence, or abundance of a given species to multiple environmental variables (e.g., climate, terrain, soil, land-use variables) is probably the best known, and most widely applied, manifestation of such data analysis (Ferrier *et al.*, 2017).

### Predictive modelling

The use of modelling to predict potential changes in biodiversity into the future as a function of ongoing impacts of environmental drivers (e.g. climate and land-use change), is called predictive modelling. Such modelling poses special challenges, as there is usually considerable uncertainty associated with the future trajectories of relevant environmental drivers, which themselves will be affected by socio-economic events and decisions that are yet to occur, and are therefore highly unpredictable. These uncertainties are often addressed through the use of scenarios, i.e. multiple plausible trajectories from environmental drivers, that account for the reality that not just one, but many, futures are possible (van Vuuren *et al.*, 2012). Model-based biodiversity projections under plausible scenarios of change in key drivers can contribute significantly to policy agenda setting, by helping to characterise and communicate the potential magnitude of ongoing change in biodiversity, and therefore the need for action. By extending scenarios to further consider the effects of alternative policy or management interventions, such projections can also play an important role in decision support, i.e. helping policy-makers, planners and managers to choose between possible actions for addressing the problem at hand, by modelling the difference that each of these alternatives is expected to make to projected outcomes for biodiversity (Cook *et al.* 2014; Ferrier *et al.*, 2017).

### 1.4.2 Species distribution modelling

Species distribution modelling (SDM) uses computer algorithms to predict the distribution of a species across geographic space and time using environmental data ([wikipedia.org](http://wikipedia.org)). Furthermore it generates functions or graphs to describe the relationship between the occurrence of the species and the environmental variable. Environmental data almost always includes climatic variables (e.g. temperature, precipitation) as well as other variables such as soil, land cover and pressure variables (e.g. Nitrogen deposition). **These models can help to understand how environmental conditions influence the occurrence or abundance of a species, as well as for predictive purposes.**

After building an SDM they can be used as predictive models, e.g. for species' future distributions under climate change scenarios (for birds: Huntley *et al.*, 2007; for butterflies: Settele *et al.*, 2008; for bumblebees: Rasmont *et al.*, 2015). The Bioscore program is another example (Hendriks *et al.*, 2016). BioScore 2.0 is a model which supports the analysis of potential impacts of future changes in human-induced pressures on European terrestrial biodiversity (e.g. mammals, vascular plants, breeding birds and butterflies).

### Models

In general models are developed using data available from the (recent) past. Such models describe the relationship between variables (e.g. environmental pressures) and population size, distribution or trend of a species. **Such models are called explanatory models** (Shmueli, 2010).

Once such explanatory models have been developed, and the relationship of interest is known, as are observed or estimated values of the relevant predictor variables, these can be combined to predict previously unknown values of the biodiversity-response variable. **Such models are called predictive models** (Shmueli, 2010). A typical example of such predictive models are those describing the expected future temperatures under several climate scenarios.

Building SDMs relies on data. The type of data determines the outcomes and risks. *Jetz et al. (2019)* give an overview of the effects of different types of raw data to build SDMs for Essential Biodiversity Variables (EBVs). They distinguish three major data types (incidental records, inventories over small or large areas and expert synthesis maps) which differ in spatiotemporal scope, in taxonomic scope, in the quality of the presence (+) and absence information (–) that they provide and in spatiotemporal specificity, which in turn determine the key characteristics that they can inform.

Although monitoring data has the advantage of generating spatiotemporally very reliable data as well as useful absences, they often represent small localities (e.g. plots, transects) and are heavily biased towards relatively small parts of the world. As a consequence SDMs are usually based on either opportunistic incidental records or on atlas distribution data (e.g. *Hagemerijer & Blair, 1997* for birds; *Kudrna et al., 2011* for butterflies).

Several methods have been developed for building SDMs. Most of them are available as R-package (e.g. *dismo*, *TRIMmaps* and *Biomod2*). [Maxent](#) is a standalone program especially useful for incidental records.

**SDMs are especially useful to establish the area and quality of habitat for a species (as required in the Article 17 reporting).**

### 1.4.3 Habitat distribution modelling

Habitat distribution models are similar to species distribution models, namely predictive models based on hypotheses as to how environmental factors control the distribution of habitats.

*Guisan & Zimmermann (2000)* present a review of predictive habitat distribution modelling. A variety of statistical models is currently in use such as Generalized Linear Models to Classification Tree and Regression Tree. The spatial distribution is simulated of respectively terrestrial plants species, aquatic plants, terrestrial animal species, plant communities, vegetation types, plant functional types, biomes and vegetation units of similar complexity.

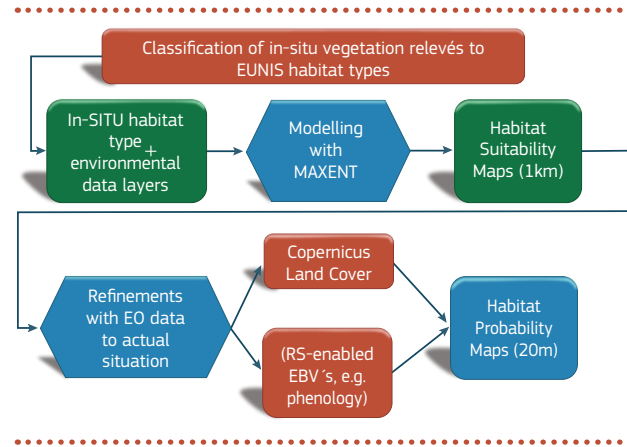
*Guisan & Zimmerman (2000)* consider the following four main sources of environmental data (to predict habitat distribution):

- » field surveys or observational studies
- » printed or digitized maps
- » remote sensing data
- » maps obtained from GIS based modelling procedures

An example of habitat distribution modelling are the distribution maps of the EUNIS grassland types developed by the *European Topic Centre Biodiversity (2018)*. Based on in situ vegetation relevés in combination with environmental data layers habitat suitability maps are modelled with MAXENT (see figure I.6). These habitat suitability maps are refined with the help of Copernicus land cover data and remote sensing enabled Essential Environmental Variables (see figure I.6).

Some key topics that determine the limitation of distribution models according to Guisan and Zimmermann (2000) are the accuracy and resolution of input maps, biotic interactions, causality, evaluation data, historical factors, response curves, sampling design, spatially explicit uncertainty assessment and spatial autocorrelation.

Habitat modelling is rapidly developing with very detailed spatial data such as COPERNICUS becoming available for modelling purposes ([www.copernicus.eu/en/services](http://www.copernicus.eu/en/services)).



**Figure I.6**

Flowchart of the methodology implemented to obtain habitat probability maps (*European Topic Centre Biodiversity, 2018*).

## I.5 Key findings

**In this chapter the key findings in terms of monitoring and possible improvements of monitoring for the purpose of the implementation of the Birds Directive and Habitats Directive are described.** These are based on a desktop survey and stakeholder consultation.

First the limitations for species and habitat type monitoring are explained. Second a selection is made of best practices (not exhaustive) as an example on how the monitoring can be improved. Third a future outlook is given on the next steps to be taken to improve current monitoring and how the scientific community can contribute to this improvement.

### I.5.1 Best practices / examples

#### Smart sampling and data analysis

Good data and statistically robust trends require a serious investment of time and money. Depending on the culture in a country (in some countries the view on the use of volunteer data is very different than in others, see *Bell et al. (2008)*) and the availability of resources (either time or money) each country has to make its own decisions. Methods don't necessarily have to be standardised, as long as they are scientifically sound and published in a peer-reviewed journal. New recent developments (e.g. occupancy modelling and Species Distribution models) offer new possibilities, but methods tend to be centred either around **volunteer-based** and **professional-based solutions**.

## Volunteer-based

For collecting species **distribution-data** (so also **range-data**, which is a special case of distribution-data) with volunteers, a user-friendly database, website and smartphone-app has to be setup, either nationally or by joining one of the major international ones (as iNaturalist.org, eBird.org or observation.org). The latter have the advantage that no extra investments are needed, as they are often already multilingual. However not all countries want their national distribution data to be shared on an international open platform.

Once such volunteer-based system has been set up with enough participants, opportunistic distribution data is fairly simple to collect via these online portals and/or GBIF. Such data will provide distribution maps of species. If enough data is available, **occupancy modelling is the best approach to produce trends on the distribution (or range) of species** (Isaac *et al.*, 2014).

For **population size and trends** protocols have to be described and implemented into a sampling scheme. Most efficient are targeted designs, in which only target species are monitored following a protocol which can be different for each species. A power-analysis will make clear how many sampling points are minimally needed to be able to detect trends. If there are enough volunteers, the step to the monitoring of whole species-groups will provide more information on the nature of trends in the target species. This however requires a long term investment in volunteer participation. As volunteers are often organised around organisations for their species-group, a monitoring scheme built around species-groups can be an efficient way to monitor also non-target species, allowing a better overview of changes in biodiversity and offering analysis data to study underlying causes.

For [birds](#) and [butterflies](#) **central European information points** are available, which can be a great help in starting up population monitoring, both volunteer- and professional-based. Such information points can act as catalysts, and could be of great value for other species groups as well.

Habitat parameters are hardly ever monitored in volunteer based systems, although data on typical or characteristic species collected by volunteers, can be the basis of models which can provide robust data on changes in habitat quality.

## Professional based

Collecting **distribution** and **range data** for relatively rare species and habitats is fairly straightforward by visiting each relevant site at regular intervals. However detection probability can be an issue, as an absence of a species is in fact a non-detection. Van Swaay & Van Strien (2015) show that in Dutch butterflies detection can vary between 40 and 80%. This means that for most butterfly species at least three visits are needed in a year to establish a significant absence (with  $p < 0.05$ ). This will apply even more for species (e.g. other insects, mammals, but also marine animals) with an even lower detection probability. Furthermore **such a method will probably miss new established species or sites, as it tends to focus on known sites**. For widespread species a random of regular grid can be applied to measure changes in

## Current limitations

- » First of all **funding of long term – national – monitoring systems are required** in order to develop a robust monitoring system for the purpose of better implementation of the Birds Directive and the Habitats Directive. In addition trained staff is needed. Another important aspect is the capacity and possibility to involve of expert-volunteers (citizen science). These aspects should influence the decision to be made on the general approach and priorities.
- » **Monitoring guidelines from the EC providing e.g. sampling designs, sampling sizes and data analysis methods are lacking at the moment** (Ellwanger, 2018). Therefore the MS are interpreting the current guidelines differently. Simple minimum requirements regarding sampling sizes and assessments methods for biogeographical region between MS should be agreed upon (Ellwanger, 2018).
- » Infrastructure both in terms of organisational and technical aspects can be a limiting factor as well (see [chapter A.III Access to data and Information](#)). **The access to data, tools, scientific publications for certain stakeholders is limited and might be improved.**
- » Recent observation techniques e.g. remote sensing (cross link with theme data and information access of this handbook) might offer opportunities to improve the current monitoring, but the **stakeholders such as site managers often have no access or lack the necessary data, computing capacity, standardising analysing tools and specific knowledge.**
- » Although in many cases there are good descriptions and experiences of decent methods to ...



their distribution. Based on those results Species Distribution Modelling (SDMs) can be used to calculate the distribution.

Applying occupancy modelling on data collected by professionals to establish the **distribution trend** will often be impossible, as these models require a lot of repeated visits. The results of sampling in targeted locations (relatively rare species) or sampling points in a regular or random grid (widespread species) can deliver information to establish the distribution trend. If enough (historic) parameter data is available, then SDMs for different periods can fill the gaps and can provide the data needed for the calculation of the distribution trend.

For rare species **population size** can be established by species-specific methods, e.g. mark-recapture, territory methods, or from distance sampling. For more widespread species this will be as good as impossible. If the population size is reported by 1x1km gridcells, it is also needed to visit all (potential) sites for each species. If enough data is available, as well as parameter data for SDMs, then those can be used to estimate the distribution in 1x1km cells.

For **population trend** the same applies as with volunteer based methods: a strict monitoring protocol has to be applied, which can be different for each species. For enough statistical power, a minimum number of sampling points is needed, depending on the variation of counted numbers.

For the habitat types a combination of sequential mapping (time consuming) supported by remote sensing techniques (cross link theme remote sensing in this handbook) and smart sampling strategies is recommended. Trend analysis for calculating trends in area and distribution ideally should be based on a statistical analysis in order to get figures on the uncertainty of calculated trends. The assessments of structure and functions might be harmonised by developing common indicators based on e.g. species composition (e.g. trends in the distribution of 'typical species' per habitat type per biogeographical region).

### Observation technologies

The development of observation technologies offers opportunities for more efficient and non invasive monitoring. It might also give more insight on the connection between different levels of biodiversity such as the species level (e.g. species traits), community level or landscape level (e.g. ecosystem functions) e.g. by means of eDNA sampling.

Depending on the species and/or habitat group different types of observation techniques are suitable. Monitoring guidelines might include an overview of these techniques.

Observation techniques need to be operational before applied by practitioners. This requires a good cooperation between technicians, scientists and practitioners. By means of a platform ([see chapter A.III Access to data and Information](#)) experiences, best practices and new tools can be exchanged.

### Modelling approaches

Species distribution modelling (SDM) can be an approach to get quantitative information on habitat quality and trends (and distribution, see above). However such models rely on input data,

... measure size and trend of species and habitats, a **major limitation can be the will of member states to implement such methods**. They require either enough funding to let professionals do the counts or measurements, and/or the investment of time and money in a long term volunteer network in co-operation with NGO's and other organisations and institutes. Without either of those, that is the major limitation in delivering reliable figures on numbers and trends.

which can differ from country to country. That makes it difficult to harmonise such models. Although methods for computing SDMs are available, they still require a large computational input and knowledge as well as regularly updated parameter information.

Parallel to the SDMs, habitat distribution modelling (HDM) can be a good approach to improve information on the status and trends in habitat distribution and quality (e.g. trends in species composition). This requires a further harmonisation of the interpretation of habitat types between MS including the indicators used to assess structure and function (quality). *Idem dito* as with the species distribution modelling the success relies heavily on input data.

## 1.5.2 Future outlook

It is clear that there are many new developments in terms of approaches, methods and technologies that might lead to an improvement of the current monitoring practices for the purpose of the implementation of the BD and HD, but that the uptake of these new tools seems limited. The underlying information on current monitoring activities of the MS for the purpose of e.g. reporting (article 12 BD and Article 17 HD) is only partly accessible (no documentation or in different languages and in grey literature).

- » **More insight in the different approaches and methods of the MS is required** in order to give a good overview of the state of the art in terms of methods that are actually applied. See [Annex 1](#) for a comparison of different methods for the monitoring of habitat types applied by the MS's. Currently this information is only partly accessible. The EUMON database is a starting point, but it isn't complete, not fully updated and the information is limited.
- » **Bench marking of current monitoring activities of the MS** as suggested by *Legyel (2018)* might give a better insight and improve the monitoring of species and habitat types. This would require a proper description of the current monitoring schemes, including sampling design, sampling size and the data analysis.
- » **Harmonization of biodiversity indicators and a common framework of Essential Biodiversity Variables (EBVs)** for the data to be collected, as being developed within GEOBON might improve the efficiency and effectiveness of monitoring activities on different scale levels.
- » **Further developments in observation techniques might provide more efficient methods for data collection on these EBVs.** In combination with the developments in modelling techniques (Big Data) this might offer more opportunities as well to harmonise the data analysis on different scale levels (e.g. national level and EU level).

This handbook is focused on the improvement of data and information for the implementation of the BD and HD, but a broader focus might be required as there are many related biodiversity conventions e.g. the Convention of Biological Diversity (CBD), Ramsar, Bonn, Bern etc that ask for similar information. The reporting formats of these conventions might be harmonised as well.

## I.6 References

- Altwegg, R. & Nichols, J. D. (2019). "Occupancy models for citizen-science data." *Methods in Ecology and Evolution* 10(1): 8–21.
- Baird, D. J. & Hajibabaei, M. (2012). Biomonitoring 2.0: a new paradigm in ecosystem assessment made possible by next-generation DNA sequencing. *Molecular Ecology*, 21: 2039–2044.
- Bayraktarov, E., Ehmke, G., O'Connor, J., Burns, E. L., Nguyen, H. A., McRae, L., Possingham, H. P. & Lindenmayer, D. B. (2019). "Do Big Unstructured Biodiversity Data Mean More Knowledge?" *Frontiers in Ecology and Evolution* 6(239).
- Bell, S., Marzano, M., Cent, J. et al. (2008). *Biodiversity Conservation* (17): 3443–3454.
- Benedetti-Cecchi, L., Crowe, T., Boehme, L., Boero, F., Christensen, A., Gremare, A., Hernandez, F., Kromkamp, J. C., Nogueira Garcia, E., Petihakis, G., Robidart, J., Sousa Pinto, I. & Zingone, A. (2018). Strengthening Europe's Capability in Biological Ocean Observations. Muniz Piniella, A., Kellett, P., Larkin, K., Heymans, J. J. [Eds.] *Future Science Brief 3 of the European Marine Board, Ostend, Belgium*. 76 pp. ISBN: 9789492043559 ISSN: 2593–5232.
- Bibby, C.J., Burgess, N.D., Hill, D.A., Mustoe, S. (2000). *Bird census techniques*, 2nd edition. Academic Press, London, UK.
- Bohmann, K., Evans, A., Gilbert, M. T. P., Carvalho, G. R., Creer, S., Knapp, M., Yu, D. W. & de Bruyn, M. (2014). "Environmental DNA for wildlife biology and biodiversity monitoring." *Trends in Ecology & Evolution* 29(6): 358–367.
- Browning, E., Gibb, R., Glover-Kapfer, P. & Jones, K. E. (2017). *WWF Conservation Technology Series 1(2)*. WWF-UK, Woking, United Kingdom.
- Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Bochers, D.L. & Thomas, L. (2001). *Introduction to Distance Sampling: estimating abundance of biological populations*. Oxford University Press, New York.
- Callaghan, C.T., Rowley J.J.L, Cornwell, W.K., Poore, A.G.B. & Major, R.E. (2019). Improving big citizen science data: Moving beyond haphazard sampling. *PLoS Biol* 17(6): e3000357.
- Cerrano, C., Milanese, M., Ponti, M. (2017). Diving for science – science for diving: Volunteer scuba divers support science and conservation in the Mediterranean Sea. *Aquat Conserv* 27:303–323
- Chandler, M., See, L., Copas, K., Bonde, A.M.Z., López, B.C., Danielsen, F., Kristoffer Legind, J., Masinde, S., Miller-Rushing, A.J., Newman, G., Rosemartin, A. & Turak, E. (2017). Contribution of citizen science towards international biodiversity monitoring, *Biological Conservation*, Volume 213, Part B, 2017, Pages 280–294.
- Chanin, P. (2003). Monitoring the Otter *Lutra lutra*. *Conserving Natura 2000 Rivers Monitoring Series* No. 10, English Nature, Peterborough.
- Cook, B.I., Smerdon, J.E., Seager, R. & Coats S. (2014). "Global warming and 21st century drying." *Climate Dynamics* 43(9): 2607–2627.
- Corbane, C., Lang, S., Pipkins, K., Alleaume, S., Deshayes, M., García Millán, V.E., Strasser, T., Vanden Borre, J., Toon, S. & Michael, F. (2015). "Remote sensing for mapping natural habitats and their conservation status – New opportunities and challenges." *International Journal of Applied Earth Observation and Geoinformation* 37: 7–16.
- Cunningham, R.B. & Lindenmayer, D.B. (2017). *Approaches to Landscape Scale Inference and Study Design*. *Current Landscape Ecology Reports*. Vol 2: 42–50.
- Danielsen, F., Burgess, N. D., Balmford, A., Donald, P.F., Funder, M., Jones, J.P., Alviola, P., Balete, D.S., Blomley, T., Brashares, J., Child, B., Enghoff, M., Fjeldså, J., Holt, S., Hübertz, H., Jensen, A.E., Jensen, P.M., Massao, J., Mendoza, M.M., Ngaga, Y., Poulsen, M.K., Rueda, R., Sam, M., Skielboe, T., Stuart-Hill, G., Topp-Jørgensen, E. & Yonten, D. (2009). Local Participation in Natural Resource Monitoring: a Characterization of Approaches. *Conservation Biology*, 23: 31–42.
- De Knijf G. et al. (2019). Staat van instandhouding (status en trends) van de soorten van de Habitatrichtlijn. Algemene resultaten – rapportageperiode 2013–2018. Rapporten van het Instituut voor Natuur- en Bosonderzoek 2019 (6). Instituut voor Natuur- en Bosonderzoek, Brussel. DOI: doi.org/10.21436/inbor.15968946
- Dennis, E.B., Brereton, T.M., Morgan, B.J.T. et al. (2019). Trends and indicators for quantifying moth abundance and occupancy in Scotland. *Journal of Insect Conservation* (2019) 23: 369.

- DG Environment (2017). Reporting under Article 17 of the Habitats Directive: Explanatory notes and guidelines for the period 2013–2018. Brussels. Pp 188.
- Dixon, W. & Chiswell, B. (1996). Review of Aquatic Monitoring Program Design. *Water Research*, 30: 1935–1948.
- Ellwanger, G., Runge, S., Wagner, M., Ackermann, W., Neukirchen, M., Frederking, W., Müller, C., Ssymank, A. & Sukopp, U. (2018). Current status of habitat monitoring in the European Union according to Article 17 of the Habitats Directive, with an emphasis on habitat structure and functions and on Germany. *Nature Conservation* 29: 57–78. [doi.org/10.3897/natureconservation.29.27273](https://doi.org/10.3897/natureconservation.29.27273)
- European Commission (2013). INTERPRETATION MANUAL OF EUROPEAN UNION HABITATS. April 2013. EUROPEAN COMMISSION DG ENVIRONMENT. *Nature ENV B.3*. (link: [ec.europa.eu/environment/nature/legislation/habitatsdirective/docs/Int\\_Manual\\_EU28.pdf](https://ec.europa.eu/environment/nature/legislation/habitatsdirective/docs/Int_Manual_EU28.pdf))
- European Environmental Agency (2020). 'State of nature in the EU. Results from reporting under the nature directives 2013–2018'. (link: [www.eea.europa.eu/publications/state-of-nature-in-the-eu-2020](https://www.eea.europa.eu/publications/state-of-nature-in-the-eu-2020))
- European Environmental Agency (2015). 'State of nature in the EU. Results from reporting under the nature directives 2007–2012'.
- European Topic Centre Biodiversity (2018). Processing European habitat probability maps at 20m resolution for EUNIS grassland types based on vegetation relevés, environmental data and Copernicus HRL grassland. Prepared by Múcher, S.A. and Hennekens, S.M. from Wageningen Environmental Research.
- Evans, D. (2010). Interpreting the habitats of Annex I: past, present and future. *Acta Botanica Gallica*. Vol. 157: 677–686.
- Evans, P.G.H. & Hammond, P.S. (2004). Monitoring cetaceans in European waters. *Mammal Rev.* 34 (1), 131–156.
- Ferrier, S., Jetz, W. & Scharlemann, J. (2017). Biodiversity Modelling as Part of an Observation System. In: Walters, M. & Scholes, R.J. [Eds.], *The GEO Handbook on Biodiversity Observation Networks*, DOI 10.1007/978-3-319-27288-7\_13.
- Ganzevoort, W., van den Born, R.J.G., Halffman, W. et al. (2017). *Biodivers Conserv* 26: 2821. [doi.org/10.1007/s10531-017-1391-z](https://doi.org/10.1007/s10531-017-1391-z)
- García-Soto, C., van der Meeren, G. I., Busch, J. A., Delany, J., Domegan, C., Dubsy, K., Fauville, G., Gorsky, G., von Juterzenka, K., Malfatti, F., Mannaerts, G., McHugh, P., Monestiez, P., Seys, J., Węstawski, J.M. & Zielinski, O. (2017). Advancing Citizen Science for Coastal and Ocean Research. French, V., Kellett, P., Delany, J., McDonough, N. [Eds.] Position Paper 23 of the European Marine Board, Ostend, Belgium. 112pp. ISBN: 978-94-92043-30-6.
- Groot, G. A., Nowak, C., Skrbinišek, T., Andersen, L. W., Aspi, J., Fumagalli, L., Godinho, R., Harms, V., Jansman, H. A., Liberg, O., Marucco, F., Mysłajek, R. W., Nowak, S., Pilot, M., Randi, E., Reinhardt, I., Śmietana, W., Szewczyk, M., Taberlet, P., Vilà, C. & Muñoz-Fuentes, V. (2016). Harmonization of genetic markers in wolves. *Mammal Review*, 46: 44–59.
- Grujter, J., D. Brus. M. Bierkens & M. Kotters (2006). *Sampling for Natural Resource Monitoring*. Springer Verlag Berlin Heidelberg.
- Guth, J. & Kučera, T. (2005). "NATURA 2000 habitat mapping in the Czech Republic: methods and general results." *Ekológia (Bratislava)* 24.
- Guisan, A. & Zimmermann, N. E. (2000). "Predictive habitat distribution models in ecology." *Ecological Modelling* 135(2): 147–186.
- Hagemeyer W., Blair, M. & Loos, W. (2016). EBCC Atlas of European Breeding Birds. Version 1.3. European Bird Census Council (EBCC). Occurrence dataset [doi.org/10.15468/adtvf](https://doi.org/10.15468/adtvf) accessed via GBIF.org on 2019-07-31.
- Hallmann, C.A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., et al. (2017). More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLoS ONE* 12(10): e0185809.
- Hellawell J.M. (1991). Development of a rationale for monitoring. In: Goldsmith B. (eds) *Monitoring for Conservation and Ecology*. Conservation Biology, vol 3. Springer, Dordrecht.
- Hayhow, D.B., Burns, F., Eaton, M.A., Al Fulajj, N., August, T.A., Babey, L., Bacon, L., Bingham, C., Boswell, J., Boughey, K.L., Breerton, T., Brookman, E., Brooks, D.R., Bullock, D.J., Burke, O., Collis, M., Corbet, L., Cornish, N., De Massimi, S., Densham, J., Dunn, E., Elliott, S., Gent, T., Godber, J., Hamilton, S., Havery, S., Hawkins, S., Henney, J., Holmes, K., Hutchinson, N., Isaac,

- N.J.B., Johns, D., Macadam, C.R., Mathews, F., Nicolet, P., Noble, D.G., Outhwaite, C.L., Powney, G.D., Richardson, P., Roy, D.B., Sims, D., Smart, S., Stevenson, K., Stroud, R.A., Walker, K.J., Webb, J.R., Webb, T.J., Wynde, R. & Gregory, R.D. (2016): State of Nature 2016. The State of Nature partnership.
- Hendriks, M., van Hinsberg, A., Janssen, P. & de Knegt, B. [Eds.] (2016). BioScore 2.0: A species-by-species model to assess anthropogenic impacts on terrestrial biodiversity in Europe, PBL Netherlands Environmental Assessment Agency, The Hague.
- Heymans, J.J., Skogen, M., Schrum, C. & Solidoro, C. (2018). Enhancing Europe's capability in marine ecosystem modelling for societal benefit. Larkin, K.E., Coopman, J., Muniz Piniella, A., Kellett, P., Simon, C., Rundt, C., Viegas, C., Heymans, J.J. [Eds.] Future Science Brief 4 of the European Marine Board, Ostend, Belgium. 32 pp. ISBN: 9789492043580 ISSN: 2593-5232.
- Hobbs, M.T. & Brehme, C.S. (2017). An improved camera trap for amphibians, reptiles, small mammals, and large invertebrates. *PLoS ONE* 12(10): e0185026.
- Huntley, B., Green, R.E., Collingham, Y.C. & Willis, S.G. (2007): A climatic atlas of European breeding birds. RSPB/BirdLife International; Durham University & Lynx Edicions, Barcelona.
- Isaac, N.J.B., van Strien, A.J., August, T.A., de Zeeuw, M.P. & Roy D.B. (2014). Statistics for citizen science: extracting signals of change from noisy ecological data. – *Methods Ecol. Evol.* 5: 1052–1060.
- Janssen, J.A.M. (red.), Bijlsma, R.J. (red.), Arts, G.H.P., Baptist, M.J., Hennekens, S.M., de Knegt, B., van der Meij, T., Schaminée, J.H.J., van Strien, A.J., Wijnhoven, S., Ysebaert, T.J.W. (2020). Habitatrichtlijnrapportage 2019: Annex D Habitattypen; Achtergronddocument. WOt-technical report 171. Wettelijke Onderzoekstaken Natuur & Milieu, Wageningen.
- Jetz, W., McGeoch, M.A., Guralnick, R., Ferrier, S., Beck, J., Costello, M. J., Fernandez, M., Geller, G. N., Keil, P., Merow, C., Meyer, C., Muller-Karger, F. E., Pereira, H. M., Regan, E. C., Schmeller, D. S. & Turak E. (2019). "Essential biodiversity variables for mapping and monitoring species populations." *Nature Ecology & Evolution*.
- Ji, Y., Ashton, L., Pedley, S.M., Edwards, D.P., Tang, Y., Nakamura, A., Kitching, R., Dolman, P.M., Woodcock, P., Edwards, F.A., Larsen, T.H., Hsu, W.W., Benedict, S., Hamer, K.C., Wilcove, D.S., Bruce, C., Wang, X., Levi, T., Lott, M., Emerson, B.C. & Yu D.W. (2013). "Reliable, verifiable and efficient monitoring of biodiversity via metabarcoding." *Ecology Letters* 16(10): 1245–1257.
- Juergens, N. (2006.) "Monitoring of Biodiversity", In: Wilhelm Barthlott, K. Eduard Linsenmair, Stephan Porembski Eds. *Encyclopedia of Life Support Systems (EOLSS)*, Developed under the Auspices of the UNESCO, Eolss Publisher, Oxford, UK [<http://eolss.net>].
- Kalimanis, A.S., Panitsa, M., Dimopoulos, P. (2017). Quality of non-expert citizen science data collected for habitat type conservation status assessment in Natura 2000 protected areas. *Scientific Reports*. Vol 1.
- Kissling, W.D., Walls, R., Bowser, A., Jones, M.O., Kattge, J., Agosti, D., Amengual, J., Basset, A., van Bodegom, P.M., Cornelissen, J.H.C., Denny, E.G., Deudero, S., Egloff, W., Elmendorf, S.C., Alonso García, E., Jones, K.D., Jones, O.R., Lavorel, S., Lear, D., Navarro, L.M., Pawar, S., Pirlz, R., Rüger, N., Sal, S., Salguero-Gómez, R., Schigel, D., Schulz, K.-S., Skidmore, A. & Guralnick, R.P. (2018). "Towards global data products of Essential Biodiversity Variables on species traits." *Nature Ecology & Evolution* 2(10): 1531–1540.
- Koelewijn, H.P., Perez-Haro, M., Jansman, H.A.H., Boerwinkel, M.C., Bovenschen, J., Lammertsma, D.R., Niewold, F.J.J., Kuiters, A.T. (2010). The reintroduction of the Eurasian otter (*Lutra lutra*) into the Netherlands: hidden life revealed by noninvasive genetic monitoring. *Conservation Genetics* (2010) 11:601–614.
- Kudrna, O., Harpke, A., Lux, K., Pennerstorfer, J., Schweiger, O., Settele, J. & Wiemers, M. (2011): Distribution atlas of butterflies in Europe. Gesellschaft für Schmetterlingsschutz, Halle, Germany.
- Kuiters, A.T., de Groot, G.A., Lammertsma, D.R., Jansman, H.A.H. & Bovenschen, J. (2016). Genetische monitoring van de Nederlandse otterpopulatie; Ontwikkeling van populatieomvang en genetische status 2014/2015. Wettelijke Onderzoekstaken Natuur & Milieu. WOt-technical report 62. 50 blz.; 13 fig.; 6 tab.; 16 ref. 2 bijlagen.
- Lengyel, S., Kobler, A., Kutnar, L., Framstad, E., Henry, P.-Y., Babij, V., Gruber, B., Schmeller, D. & Henle K. (2008a). "A review and a framework for the integration of biodiversity monitoring at the habitat level." *Biodiversity and Conservation* 17: 3341–3356.
- Lengyel, S., Déri, E., Varga, Z., Horváth, R., Tóthmérész, B., Henry, P.-Y., Kobler, A., Kutnar, L., Babij, V., Seliškar, A., Christia, C., Papastergiadou, E., Gruber, B. & Henle K. (2008b). "Habitat monitoring in Europe: a description of current practices." *Biodiversity and Conservation* 17(14): 3327–3339.



- Lengyel, S., Kosztyi, B., Schmeller, D.S., Henry, P.-Y., Kotarac, M., Lin, Y.-P. & Henle K. (2018). "Evaluating and benchmarking biodiversity monitoring: Metadata-based indicators for sampling design, sampling effort and data analysis." *Ecological Indicators* 85: 624–633.
- Loaiciga, H.A., Charbeneau, R.J., Everett, L.G., Fogg, G.E., Hobbs, B.F., Rouhani S. (1992). Review of ground-water quality monitoring network design. *Journal of Hydraulic Engineering*, 118:11–7.
- Lucas, R., Blonda, P., Bunting, P., Jones, G., Inglada, J., Arias, M., Kosmidou, V., Petrou, Z.I., Manakos, I., Adamo, M., Charnock, R., Tarantino, C., Múcher, C.A., Jongman, R.H.G., Kramer, H., Arvor, D., Honrado, J.P. & Mairota, P. (2015). "The Earth Observation Data for Habitat Monitoring (EODHaM) system." *International Journal of Applied Earth Observation and Geoinformation* 37: 17–28.
- Múcher, C.A., Hennekens, S.M., Bunce, R.G.H., Schaminée, J.H.J. & Schaepman, M.E. (2009). "Modelling the spatial distribution of Natura 2000 habitats across Europe." *Landscape and Urban Planning* 92(2): 148–159.\*
- Nagendra, H., Lucas, R., Honrado, J.P., Jongman, R.H.G., Tarantino, C., Adamo, M. & Mairota, P. (2013). "Remote sensing for conservation monitoring: Assessing protected areas, habitat extent, habitat condition, species diversity, and threats." *Ecological Indicators* 33: 45–59.
- Panigada, S., Lauriano, G., Burt, L., Pierantonio, N. & Donovan, G. (2011). Monitoring Winter and Summer Abundance of Cetaceans in the Pelagos Sanctuary (Northwestern Mediterranean Sea) Through Aerial Surveys. *PLoS ONE* 6(7), 1–10.
- Pannekoek, J., van Strien, A. (2005). TRIM 3 Manual (TRends & Indices for Monitoring data). CBS, Voorburg.
- Pereira, H. M., Ferrier, S., Walters, M., Geller, G.N., Jongman, R.H.G., Scholes, R.J., Bruford, M.W., Brummitt, N., Butchart, S.H.M., Cardoso, A.C., Coops, N.C., Dulloo, E., Faith, D.P., Freyhof, J., Gregory, R.D., Heip, C., Höft, R., Hurtt, G., Jetz, W., Karp, D.S., McGeoch, M.A., Obura, D., Onoda, Y., Pettorelli, N., Reyers, B., Sayre, R., Scharlemann, J.P.W., Stuart, S.N., Turak, E., Walpole, M. & Wegmann, M. (2013). "Essential Biodiversity Variables." *Science* 339(6117): 277–278.
- Prigioni, C., Remonti, L., Balestrieri, A., Sgrosso, S., Priore, G., Mucci, N. & Randi, E. (2006). Estimation of European Otter (*Lutra lutra*) Population Size by Fecal DNA Typing in Southern Italy, *Journal of Mammalogy*, Volume 87, Issue 5, 17 October 2006, Pages 855–858. \*
- Rasmont, P., Franzén, M., Lecocq, T., Harpke, A., Roberts, S.P.M., Biesmeijer, J.C., Castro, L., Cederberg, B., Dvorák, L., Fitzpatrick, Ú., Gonthier, Y., Haubruge, E., Mahé, G., Manino, A., Michez, D., Neumayer, J., Ødegaard, F., Paukkunen, J., Pawlikowski, T., Potts, S.G., Reemer, M., Settele, J., Straka, J., Schweiger, O. (2015). Climatic risk and distribution atlas of European bumblebees. *BioRisk* 10 (Special Issue) – Pensoft, Sofia [etc.].
- Rees, H.C., Maddison, B.C., Middleditch, D.J., Patmore, J.R.M. & Gough, K.C. (2014). "REVIEW: The detection of aquatic animal species using environmental DNA – a review of eDNA as a survey tool in ecology." *Journal of Applied Ecology* 51(5): 1450–1459.
- Rovero, F. & Zimmermann, F. (2016). *Camera Trapping for Wildlife Research*. Pelagic Publishing.
- Schekkerman, H., van Turnhout, C., van Kleunen, A., van Diek, H. & Altenburg, J. (2012). Naar een nieuwe vogelatlas: achtergronden van de veldwerkopzet. *Limosa* 85: 133–141.
- Settele, J., Kudrna, O., Harpke, A., Kühn, I., van Swaay, C., Verovnik, R., Warren, M., Wiemers, M., Hanspach, J., Hickler, T., Kühn, E., van Halder, I., Velling, K., Vliegthart, A., Wynhoff, I. & Schweiger, O. (2008). Climatic risk atlas of European butterflies. *BioRisk* 1 (Special Issue) – Pensoft, Sofia [etc.].
- Šefferová, V. & Galvánková, J. & Rizman, I. (2015). Monitoring of plants and habitats of Community interest in the Slovak Republic. Results and assessment in the period of 2013–2015. [www.researchgate.net/publication/315897287\\_Monitoring\\_of\\_plants\\_and\\_habitats\\_of\\_Community\\_interest\\_in\\_the\\_Slovak\\_Republic\\_Results\\_and\\_assessment\\_in\\_the\\_period\\_of\\_2013\\_-\\_2015](http://www.researchgate.net/publication/315897287_Monitoring_of_plants_and_habitats_of_Community_interest_in_the_Slovak_Republic_Results_and_assessment_in_the_period_of_2013_-_2015)
- Shmueli, G. (2010). To Explain or to Predict?. *Statist. Sci.* 25, no. 3, 289–310. doi:10.1214/10-STS330. <https://projecteuclid.org/euclid.ss/1294167961>.
- Thomsen, P.F. & Willerslev, E. (2015). "Environmental DNA – An emerging tool in conservation for monitoring past and present biodiversity." *Biological Conservation* 183: 4–18.
- Tyne, J.A., Loneragan, N.R., Johnston, D.W., Pollock, K.H., Williams, R. & Bejder, L. (2016). Evaluating monitoring methods for cetaceans. *Biological Conservation* 201: 252–260.

- Vanden Borre, J., Paelinckx, D., Mûcher, C.A., Kooistra, L., Haest, B., De Blust, G. & Schmidt, A.M. (2011). "Integrating remote sensing in Natura 2000 habitat monitoring: Prospects on the way forward." *Journal for Nature Conservation* 19(2): 116–125.
- Van Strien, A.J., Gmelig Meyling, A.W., Herder, J.E., Hollander, H., Kalkman, V.J., Poot, M.J.M., Turnhout, S., van der Hoorn, B., van Strien-van Liempt, W.T.F.H., van Swaay, C.A.M., van Turnhout, C.A.M., Verweij, R.W.E.T. & Oerlemans, N.J. (2016). Modest recovery of biodiversity in a western European country: The Living Planet Index for the Netherlands. – *Biological Conservation* 200, 44–50.
- Van Strien, A.J., Soldaat, L.L. & Gregory, R.D. (2012). Desirable mathematical properties of indicators for biodiversity change. *Ecological Indicators* 14 (2012) 202–208.
- Van Swaay, C. & van Strien, A. (2015). Veldinventarisaties een (tref)kansenspel? *Vakblad Bos Natuur Landschap* 12 (116), 10–13.
- Van Vuuren, D.P., Kok, M.T.J., Girod, B., Lucas, P.L., & de Vries, B. (2012). Scenarios in global environmental assessments: Key characteristics and lessons for future use. *Global Environmental Change-Human and Policy Dimensions*, 22, 884–895.
- Walters, M. & Scholes, R.J. [Eds.] (2019). *The GEO Handbook on Biodiversity Observation Networks*, Springer Open. Winding, A., Bang-Andreasen, T., Hansen, L.H., Panitz, F., Krogh, P.H., Krause-Jensen, D., Stæhr, P., Nicolaisen, M., Hendriksen, N.B., Sapkota, R., Santos, S. & Andersen, L.W. eDNA in environmental monitoring. Aarhus University, DCE – Danish Centre for Environment and Energy, 40 pp. Technical Report No. 133.
- WWF (2018). *Living Planet Report – 2018: Aiming Higher*. Grooten, M. and Almond, R.E.A.[Eds.]. WWF, Gland, Switzerland.
- Yu, D.W., Ji, Y., Emerson, B.C., Wang, X., Ye, C., Yang, C. & Ding, Z. (2012). Biodiversity soup: metabarcoding of arthropods for rapid biodiversity assessment and biomonitoring. *Methods in Ecology and Evolution*, 3: 613–623.

## Annex I. Monitoring of natural habitats

### **Comparison of national monitoring schemes to assess the conservation status of natural habitats in accordance with Article 11 of the Habitats Directive in EU Member States**

This analysis was intended to compare different approaches to the implementation of Art. 11 of the Habitats Directive regarding the national schemes of natural habitats monitoring. It is planned to publish this assessment in Eurosite Management Toolkit ([mpg.eurosite.org](http://mpg.eurosite.org)) and maintain it as an interactive on-line survey, updated by conservationists and site managers depending on the development of monitoring schemes in their countries.

The presented assessment was conducted basing on the analysis of publicly available sources, collected from available national monitoring services, public reports and scientific articles. It was enriched with data from surveys completed by Anne Schmidt and John Janssen (for the Netherlands) and Wojciech Mróz (for Poland) on the basis of their personal experience in the development of monitoring methodology in these countries. Additionally, a general overview by *Ellwanger et al. (2018)* was a valuable source of information on Germany and the other 13 Member States.

The attached table contains data for 9 countries where independent natural habitats Art. 11 monitoring scheme are carried out, and for which the publicly available data allow such comparison. Note that in the case of the Netherlands there's no exact independent scheme but it is based on other programmes (vegetation mapping and a permanent plot grid). It should be also emphasized that presented data can be outdated (e.g. referring to the previous monitoring period) and present only the general shape of these monitoring programmes which can be differentiated for particular habitat groups. Therefore, it should be seen as a first glance at the situation in the various Member States. It could also rule out other valuable data sources that are not presented on the national monitoring websites and available reports. All the collected data concern only the monitoring and assessment of natural habitats listed in Annex 1 of the Habitats Directive. Data on populations of species listed in Annex 2 HD and their habitats are not included.

Anyway, taking into account the mentioned limitations of this analysis, we tried to formulate some general remarks in order to get an overview of the current state of HD Art. 11 monitoring and also to suggest possible actions that could improve the harmonization of these programmes on a European scale.

Main results of the analysis:

- » only 8 out of 27 Member States have successfully implemented the independent Art. 11 natural habitat monitoring scheme;

- » the existing schemes vary greatly in the number of plots, sampling pattern and approach to assessing the conservation status of habitats, e.g. Favourable Conservation Status (FCS) thresholds, analysis of habitat structure and functions. Moreover, the approaches to analysing habitat changes are quite different in all countries;
- » there are different approaches to syntaxonomy and various abundancy scales are used (Braun-Blanquet, Tansley, percentage);
- » differences in sample size and sampling pattern, different phytosociological approaches, make it difficult or even impossible to compare and analyse raw vegetation data between any of these countries.
- » existing monitoring schemes are not directly linked to and integrated with the data from other project and initiatives (e.g. Life projects, management plans, EIAs, scientific research, Horizon 2020 projects etc.). We were also unable to recognize any significant data flow between citizen science projects and initiatives and Art. 11 monitoring schemes.

### Conclusions

Given that the current state of Art. 11 natural habitat monitoring is so inconsistent, it is not possible to directly derive common detailed data from existing monitoring schemes even in countries where such independent systems have been established. The only standardized source of information on the conservation status of natural habitats is the 6-yearly reports prepared by each Member State pursuant to Article 17 of the Habitats Directive. These reports have very different levels of accuracy and in most cases, the assessment is made on the basis of a combination of scattered detailed studies and extrapolations based on the best expert assessment. Considering that the criteria for determining the favourable conservation status and the thresholds applied to vary significantly from one MS to another it can be assumed that the final result of assessment along entire Biogeographical Regions, especially those covering a bigger number of countries (such as Continental, Alpine, Mediterranean) could not fully reflect the variation of CS and can result in misleading conclusions about priorities for Natura 2000 conservation measures.

Perhaps the result of this short analysis could be also a good starting point for a discussion on the possibilities of harmonization of approaches to the monitoring obligations described in Art. 11 of the Habitats Directive?

Considering the level of advancement and the amount of effort Member States have put into developing their monitoring schemes, it is not possible to implement a separate, uniform tool for Art. 11 monitoring, as was the case with Art. 17 reporting. However, there's a great need for a clear link between detailed ground-based data collected by members states and Art. 17 assessment. One realistic and reliable source of information is data collected using remote sensing techniques, mainly satellite imagery, such as Copernicus. Despite several attempts to use it for the monitoring of natural habitats, this potential for standardized large-scale assessment of

changes in natural habitats still seems to be not fully used. EO data can be used to collect data on such indicators as scrub cover, NVDI, farming activity, humidity and distribution of selected alien plant species. However, for a group of indicators related to the quality of habitats, species diversity, the presence of rare and threatened species, it is still necessary to use ground-based methods to supplement even the most advanced RS technologies.

Possible improvement of the use of Art. 11 detailed monitoring data in the assessment at a level of biogeographical regions can be considered in three directions:

- » improving the use of existing detailed data, e.g. by the development of a common European simplified assessment protocol for a habitat assessment at a locality level. It can only contain very basic information about the structure of habitat and main threats to their conservation status;
- » testing the implementation of such European protocols in new natural habitat monitoring surveys. Such protocols could be completed together with more detailed, national forms as an additional task for local experts;
- » incorporating such forms into newly developed monitoring schemes, especially in countries that have recently joined the EU.

Additional explicit link of such simplified records based on common European protocols and the indicators estimated from Copernicus images with the GIS grid used in Art. 17 reporting would allow easy mapping of habitat conservation status variation and analysis of trends at the level of biogeographical regions.

In order to assess the costs and needs for the capacity for such a common approach, a basic feasibility study can be carried out in the countries with the most advanced Art. 11 monitoring scheme. It can be assumed that if field observers and experts included in standard monitoring programs were involved, such an approach could be realistic at least for a group of representative localities, which would create a valuable, standardized dataset improving the credibility of Art. 17 overall assessment of the habitats.



**Table I.1**  
Sampling pattern

Number of test areas / sample plots / relevés (per 6 years)	
<b>AT: Austria</b>	3198 test areas / 12792 sample plots
<b>CZ: Czechia</b>	permanent monitoring plots, number n/a
<b>DE: Germany</b>	63 sample plots per habitat type in each biogeographical region are selected. If less than 63 occurrences are known, the total occurrences are processed in monitoring (total census) ( <i>Ellwanger et. al, 2018</i> ).
<b>DK: Denmark</b>	2807 test areas / 28070 plots
<b>LT: Lithuania</b>	67 test squares / 1816 plots
<b>LV: Latvia</b>	n/a
<b>NL: The Netherlands</b>	There is a vegetation monitoring scheme with permanent plots ('Landelijk Meetnet Flora'). The set of permanent plots contain 10,000 sites which are resampled every four year. Moreover, all Natura 2000 sites are mapped. Vegetation relevés are made in all sites. From the last 10 years about 75,000 relevés were brought together, indicating that more than 7500 relevés are made each year. These plots relate to all vegetation types, not only to habitat types.
<b>PL: Poland</b>	ca. 6000 test areas /18000 relevés
<b>SK: Slovakia</b>	6668 test areas
Test areas/plots size and pattern	
<b>AT: Austria</b>	Test areas of 1x1 km size with 4 sample plots each
<b>CZ: Czechia</b>	Permanent monitoring plots (TMP), 5x5 m for non-forest habitats, 20x20 m for forest habitats, standing waters – whole reservoir, running waters – 1 km transect
<b>DE: Germany</b>	n/a
<b>DK: Denmark</b>	Each locality includes 8–12 small plots (5 m circles)
<b>LT: Lithuania</b>	Test squares – 17 km <sup>2</sup> , transect – 200 x 10 m
<b>LV: Latvia</b>	Transects with 3–10 sample plots. Different plot sizes depending on the habitat group (5–2500 m <sup>2</sup> )
<b>NL: The Netherlands</b>	There is no common monitoring scheme for habitats. There is however a scheme for vegetation mapping which is related to receiving subsidies for management (so called 'Subsidie Natuur en Landschapsbeheer'-scheme). These maps are also used as a basis for habitat maps. There is a field protocol for vegetation mapping and there is a protocol to translate vegetation units into habitat types for the terrestrial habitat types.  The marine and aquatic habitat types are monitored within the Marine Strategy Framework Directive MSFD and Water Framework Directive (WFD). This is carried out through a set of point sampling.
<b>PL: Poland</b>	Transects, size: 200x10 m; 3 relevés in each transect (size 5x5 m or 10x10 m)
<b>SK: Slovakia</b>	Permanent monitoring localities (PML). Size: 0,5–70 ha
Frequency of field surveys (years)	
<b>AT: Austria</b>	6 years
<b>CZ: Czechia</b>	Forests – 12 years, non-forest habitats and waters – 6 years
<b>DE: Germany</b>	6 years
<b>DK: Denmark</b>	3–6 years
<b>LT: Lithuania</b>	6 years
<b>LV: Latvia</b>	6 years
<b>NL: The Netherlands</b>	6–12 years
<b>PL: Poland</b>	6 years
<b>SK: Slovakia</b>	6 years

Syntaxonomical approach / Abundancy scale	
<b>AT: Austria</b>	List of species
<b>CZ: Czechia</b>	Phytosociological relevés, species abundance as a percentage
<b>DE: Germany</b>	List of species
<b>DK: Denmark</b>	List of species. Additionally, plant species measured by pinpoint (16 grid points in 0.5 m x 0.5 m frame).
<b>LT: Lithuania</b>	Phytosociological relevés according to Braun-Blanquet scale (7-grade)
<b>LV: Latvia</b>	List of typical species in small plots, 3-grade abundancy assesment (little/average/abundant)
<b>NL: The Netherlands</b>	Phytosociological relevés according to Braun-Blanquet scale
<b>PL: Poland</b>	Phytosociological relevés according to Braun-Blanquet scale (7-grade)
<b>SK: Slovakia</b>	Species abundance according to modified Tansley scale

Assessment of conservation status (biogeographical region, Natura 2000 site, test area)	
<b>AT: Austria</b>	Assessment is done at biogeographical region level.
<b>CZ: Czechia</b>	The assessment is done during the habitat mapping, referring to the patches of habitats but not to the permanent plots. Specific structure and functions are scored on a 3-point scale – favourable, less favourable, unfavourable.
<b>DE: Germany</b>	The degree of conservation of each habitat plot is included in the parameter. The degree of conservation of each habitat plot is based on specific assessment schemes of the components 'habitat structures', 'typical species', and 'pressures and threats' ( <i>Ellwanger et. al, 2018</i> ).
<b>DK: Denmark</b>	Assessment is done at biogeographical region level.
<b>LT: Lithuania</b>	Assessment of conservation degree at Natura 2000 site level.
<b>LV: Latvia</b>	Each locality is assessed referring to a number of indicators describing structure, typical species and impacts. Every indicator is rated on a 3-point scale. The maximal number of points depends on number of indicators and typical species assessed, e.g. maximal grade for grasslands is 54.
<b>NL: The Netherlands</b>	The main level is national/biogeographical. On site level assessments are made for the purpose of the Natura 2000 Standard DataForm.
<b>PL: Poland</b>	The conservation status of natural habitat is assessed both on a level of field plot and Natura 2000 site. The same scale as on BG level is used: FV-U1-U2.
<b>SK: Slovakia</b>	Yes. Evaluation of the conservation status of habitats at locality level is based on the evaluation of partial parameters: a) Quality of the habitat at the locality. b) Perspectives of the habitat at the locality. These parameters are evaluated during a field visit, according to a defined methodology for each habitat separately or by an expert estimate of the mapper. The method usually sets limits for individual conservation status categories (favourable, unfavourable-inadequate, unfavourable-bad).
Typical species of plants taken into account in the assessment	
<b>AT: Austria</b>	Yes – plant species.
<b>CZ: Czechia</b>	Yes. The conservation status of typical plant species is assessed while habitat mapping. Typical species of animals are not assessed.
<b>DE: Germany</b>	Yes. Typical plant species are recorded. typical animal species are recorded only for a few habitat types. In habitat type 3160 dragonfly species and in habitat type 8310 cavernicol species (especially bats) are recorded. In running waters, data of fishes and macrozoobenthos from the ecological status assessment according to the Water Framework Directive are used ( <i>Ellwanger et. al, 2018</i> ).
<b>DK: Denmark</b>	Yes – plant species.

**Table I.2**  
Conservation status assessment

<b>LT: Lithuania</b>	Yes – plant species.
<b>LV: Latvia</b>	Yes – plant species.
<b>NL: The Netherlands</b>	Yes – plant species.
<b>PL: Poland</b>	Yes. Typical plants species are recorded. In case of animal species – just bats in 8310.
<b>SK: Slovakia</b>	Yes. Typical plant species are recorded in PML. The abundancy of selected characteristic species is one of main parts of CS assesment.
<b>Thresholds of favourable conservation status, assessment of habitat structure and functions</b>	
<b>AT: Austria</b>	Assessment of conservation degrees of single plots. FV = A-proportion $\geq$ 50% and C-proportion $<$ 33.3%
<b>CZ: Czechia</b>	FSC of habitats is described in the catalogue of biotopes. Assessment of conservation degrees of single plots. FV = $<$ 1-% of partial areas assessed as “less favourable” and “unfavourable”.
<b>DE: Germany</b>	The evaluation is carried out according to an assessment scheme specific to the recorded species or habitat type. The aggregation of the partial assessments is based on the so-called Pinneberg Scheme ( <i>Ellwanger et al, 2018</i> ). Assessment of conservation degrees of single plots. FV = C-proportion $\leq$ 20%
<b>DK: Denmark</b>	Assessment of conservation degrees of single plots. FV = $>$ 50% A-proportion and $>$ 75% A+B-proportion (= C-proportion $<$ 25% and A-proportion $>$ 50%)
<b>LT: Lithuania</b>	The final assesment is conducted in the result of statistical and numerical analysis of values of indicators, gathered at monitoring localities.
<b>LV: Latvia</b>	Structure of habitat is assessed at each locality, e.g. a set of indicators for 6510 includes: coverage of bare ground (%), coverage of herbaceous plants (%), coverage of shrubs and trees (%), height of herbaceous layer (cm), number of herbaceous species in the plot (25m <sup>2</sup> ), condition. Every indicator is assessed in 0–3 scale, referring to given theresholds.
<b>NL: The Netherlands</b>	The assessment of habitat structure and function is based on a set of indicators ( <i>Janssen &amp; Bijlsma eds., 2020</i> ). It differs per habitat type. It is based on species composition (characteristic species) and in some cases vegetation structure. Also in some cases on landscape structure. We have gone through a process of making them more and more quantitative. They are now, at the national level (for the EU reporting), for most habitat types (not for all). At the site level we are working on more quantitative assessments. In all cases “functioning” is considered as more importance than structure. We consider the trend of characteristic species as an indicator for “function”. As an example: a heathland may have a poor, monotone structure, but as long as the characteristic plants and animals live there and are showing stable or positive trends the habitat is considered as rather good. Assessment of subparameter ‘structure and functions (without typical species)’ at Natura 2000 site level. FV = If A-proportion $\geq$ 75% and C-proportion $\leq$ 15%
<b>PL: Poland</b>	The assessment of habitat structure and function is assessed basing on the set of indicators (specific for every habitats type). They are either quantitative – e.g. coverage of expansive shrub species, number of characteristic species, amount of dead wood, or qualitative/descriptive – spatial structure of forest stand, invasion of alien species, water conditions, eolic processes in inland dunes. The assessment of “specific structure and functions” is based by the expert using the results of indictor values. Some of indicators are taken as cardinal ones – decreasing the overall assessment despite other indicators’ values. Each indicator and parameter are assessed on scale FV-U1-U2 both at a level of locality and Natura 2000 site.
<b>SK: Slovakia</b>	Assesment at a locality level. Set of standard criteria with different thresholds for each of habitat types. Criteria: number of characteristic taxa, number of indicative taxa, vertical structure, threat with expansive taxa, threat with invasive neophytes. No distinction between structure and functions. Both are considered in the CS assesment.

Table I.3

Public access, data flow and integration with other sources

Assessment of conservation status (biogeographical region, Natura 2000 site, test area)	
AT: Austria	No, only the report and general results
CZ: Czechia	Partly, the general statistics are available but not the complete database
DE: Germany	The results and reports are available, but not the whole database
DK: Denmark	Yes, full access. Open database.
LT: Lithuania	No, only the report and general results
LV: Latvia	No, only the report and general results
NL: The Netherlands	The vegetation relevés are accessible through a national vegetation database (LVD), which can be viewed online. The vegetation and habitat type maps will be made available through a database as well (this is under construction; NDVH)
PL: Poland	The access to data is limited to selected central, regional and local authorities. It can be also made available to other organizations after obtaining authorization from the central administration. There's no public access to detailed data, only general/overview reports are published.
SK: Slovakia	General reports and quantitative tables available online, no open database.
Results of citizen science projects are integrated with national monitoring scheme	
AT: Austria	n/a
CZ: Czechia	n/a
DE: Germany	n/a
DK: Denmark	n/a
LT: Lithuania	n/a
LV: Latvia	n/a
NL: The Netherlands	Yes for the characteristic species (NDFF database)
PL: Poland	No
SK: Slovakia	n/a
Results of other surveys/projects (Life projects, management plans, EIAs) are integrated with national monitoring schemes	
AT: Austria	n/a
CZ: Czechia	n/a
DE: Germany	n/a
DK: Denmark	probably (there's one central database)
LT: Lithuania	n/a
LV: Latvia	n/a
NL: The Netherlands	Yes, partly. Most EIA's are based on existing data. The same habitat maps are used, and the same data on species (NDFF), but often an EIA does not include making new maps or gathering new data. If it includes this, the data may go to the NDFF, NDVH or LVD.
PL: Poland	No. But in most cases EIA's reports and other assessments are usually done according to the "central" methodology.
SK: Slovakia	n/a

Results of citizen science projects are integrated with national monitoring scheme	
AT: Austria	No
CZ: Czechia	No
DE: Germany	No
DK: Denmark	No
LT: Lithuania	No
LV: Latvia	No
NL: The Netherlands	No
PL: Poland	Partly. There's joint database for habitats and species and some parts of the survey protocols are the same. But the field surveys are done in different localities by different teams.
SK: Slovakia	No

Natura 2000 site	
AT: Austria	<a href="http://www.umweltbundesamt.at/umweltthemen/naturschutz/schutzgebiete/natura2000">www.umweltbundesamt.at/umweltthemen/naturschutz/schutzgebiete/natura2000</a>
CZ: Czechia	<a href="http://www.nature.cz/natura2000-design-en/hp.php">www.nature.cz/natura2000-design-en/hp.php</a>
DE: Germany	<a href="http://www.bfn.de/themen/natura-2000.html">www.bfn.de/themen/natura-2000.html</a>
DK: Denmark	<a href="http://eng.mst.dk/nature-water/nature/natura-2000">eng.mst.dk/nature-water/nature/natura-2000</a>
LT: Lithuania	<a href="http://vstt.lrv.lt/lt/saugomu-teritoriju-sistema/natura-2000">vstt.lrv.lt/lt/saugomu-teritoriju-sistema/natura-2000</a>
LV: Latvia	<a href="http://www.daba.gov.lv/lv/natura-2000">www.daba.gov.lv/lv/natura-2000</a>
NL: The Netherlands	<a href="http://www.government.nl/topics/nature-and-biodiversity/natura-2000">www.government.nl/topics/nature-and-biodiversity/natura-2000</a>
PL: Poland	<a href="http://natura2000.gdos.gov.pl/natura-2000-w-polsce">natura2000.gdos.gov.pl/natura-2000-w-polsce</a>
SK: Slovakia	<a href="http://www.soposr.sk/natura/index.php?p=62&amp;lang=en">www.soposr.sk/natura/index.php?p=62&amp;lang=en</a>
General monitoring website	
AT: Austria	<a href="http://www.verwaltung.steiermark.at/cms/beitrag/11680234/74838463">www.verwaltung.steiermark.at/cms/beitrag/11680234/74838463</a>
CZ: Czechia	<a href="http://portal.nature.cz/publik_syst/ctihtmlpage.php?what=6165&amp;X=X">portal.nature.cz/publik_syst/ctihtmlpage.php?what=6165&amp;X=X</a>
DE: Germany	<a href="http://www.bfn.de/themen/monitoring">www.bfn.de/themen/monitoring</a>
DK: Denmark	<a href="http://mst.dk/natur-vand/overvaagning-af-vand-og-natur/terrestriske-naturtyper-og-arter">mst.dk/natur-vand/overvaagning-af-vand-og-natur/terrestriske-naturtyper-og-arter</a>
LT: Lithuania	<a href="http://am.lrv.lt/lt/veiklos-sritys-1/saugomos-teritorijos-irkrastovaizdis/igyvendinti-projektai">am.lrv.lt/lt/veiklos-sritys-1/saugomos-teritorijos-irkrastovaizdis/igyvendinti-projektai</a>
LV: Latvia	<a href="http://www.daba.gov.lv/lv/natura-2000-vietu-monitoringa-metodikas">www.daba.gov.lv/lv/natura-2000-vietu-monitoringa-metodikas</a>
NL: The Netherlands	
PL: Poland	<a href="http://siedliska.gios.gov.pl">siedliska.gios.gov.pl</a>
SK: Slovakia	<a href="http://www.soposr.sk/natura/index.php?p=7&amp;lang=en">www.soposr.sk/natura/index.php?p=7&amp;lang=en</a>
Natural habitats monitoring methodology/handbook/protocols	
AT: Austria	<a href="http://www.verwaltung.steiermark.at/cms/dokumente/12812743_123331268/74b35f03/REP0735_Band%201_Monitoring.pdf">www.verwaltung.steiermark.at/cms/dokumente/12812743_123331268/74b35f03/REP0735_Band%201_Monitoring.pdf</a>
CZ: Czechia	<a href="http://portal.nature.cz/publik_syst/files/met_mon_2014_a.pdf">portal.nature.cz/publik_syst/files/met_mon_2014_a.pdf</a> <a href="http://portal.nature.cz/publik_syst/ctihtmlpage.php?what=1665&amp;nabidka=rozbalitOdkaz&amp;idOdkazu=1241&amp;X=X">portal.nature.cz/publik_syst/ctihtmlpage.php?what=1665&amp;nabidka=rozbalitOdkaz&amp;idOdkazu=1241&amp;X=X</a>

Table I.4  
Data sources, links



<b>DE: Germany</b>	<a href="http://www.bfn.de/themen/monitoring/monitoring-ffh-richtlinie.html">www.bfn.de/themen/monitoring/monitoring-ffh-richtlinie.html</a>
<b>DK: Denmark</b>	<a href="http://novana.au.dk/naturtyper">novana.au.dk/naturtyper</a>
<b>LT: Lithuania</b>	<a href="http://am.lrv.lt/uploads/am/documents/files/saugom_teritorijos_kra%C5%A1tov/natura_2000/EB_buveiniu_monitoringo_metodiniu_pagrindu_parengimas_ataskaita_11%20dalis_final.pdf">am.lrv.lt/uploads/am/documents/files/saugom_teritorijos_kra%C5%A1tov/natura_2000/EB_buveiniu_monitoringo_metodiniu_pagrindu_parengimas_ataskaita_11%20dalis_final.pdf</a>
<b>LV: Latvia</b>	<a href="http://www.daba.gov.lv/lv/natura-2000-vietu-monitoringa-metodikas">www.daba.gov.lv/lv/natura-2000-vietu-monitoringa-metodikas</a>
<b>NL: The Netherlands</b>	Report 'Werkwijze monitoring en beoordeling Natuurnetwerk Nederland en Natura 2000' and a 'Vegetation Protocol'. Additional manuals exist for salt marsh-mapping, aquatic monitoring and geomorphological maps.
<b>PL: Poland</b>	<a href="http://siedliska.gios.gov.pl/pl/publikacje">siedliska.gios.gov.pl/pl/publikacje</a>
<b>SK: Slovakia</b>	<a href="http://www.sopsr.sk/natura/index.php?p=7&amp;lang=en">www.sopsr.sk/natura/index.php?p=7&amp;lang=en</a>
<b>Natural habitats monitoring results online</b>	
<b>AT: Austria</b>	
<b>CZ: Czechia</b>	<a href="http://portal.nature.cz/nd/x_nd_statistiky.php?X=X">portal.nature.cz/nd/x_nd_statistiky.php?X=X</a>
<b>DE: Germany</b>	
<b>DK: Denmark</b>	<a href="http://naturdata.miljoeportal.dk">naturdata.miljoeportal.dk</a>
<b>LT: Lithuania</b>	
<b>LV: Latvia</b>	
<b>NL: The Netherlands</b>	
<b>PL: Poland</b>	<a href="http://siedliska.gios.gov.pl/pl/wyniki-monitoringu">http://siedliska.gios.gov.pl/pl/wyniki-monitoringu</a>
<b>SK: Slovakia</b>	<a href="http://www.sopsr.sk/natura/index.php?p=7&amp;lang=en">www.sopsr.sk/natura/index.php?p=7&amp;lang=en</a>

CHAPTER A.II.

# Contribution of Remote Sensing Techniques for monitoring Natura 2000 sites

Sander Múcher & Gerard Hazeu



## II.1 Introduction

Remote sensing is becoming increasingly important in habitat mapping and monitoring due to the strong synoptic overview of its images in the temporal and spatial domain. **Early applications pertained to the visual interpretation of aerial photography, but more recently satellite imagery with a huge range of spatial and temporal resolutions is in use that increases the applicability from entire ecosystems to specific vegetation types.** The newest developments are the use of UAVs (Unmanned Aerial Vehicles) at the most detailed spatial scale (up to centimeter pixel detail) to support vegetation surveyors. Besides this, more and more satellite imagery is becoming available as open data, such as the imagery from the European SENTINELS, next to a much longer tradition in open data policy for American satellite sensors such as MODIS and Landsat, to widen the opportunities for their applications. Some vegetation mapping projects apply aerial photographs or remotely sensed imagery only to divide the area of interest into homogenous vegetation mapping units that are further labelled in vegetation types by field surveyors, while other classification methods produce vegetation or habitat maps directly from imagery by combining imagery with ground truth data. The latter approach is gaining momentum in light of major technological improvements, but also because it can speed up the mapping process compared to traditional methods.

Traditional vegetation and habitat mapping methods using visual interpretation of aerial photography in combination with field surveys work very well, but are often labor intensive and updating frequencies are normally low, while policies are demanding currently higher monitoring frequencies. Therefore terrain managers are looking for alternatives that can support the mapping and monitoring of vegetation in more efficient ways. New developments in remote sensing such as very high resolution (VHR) satellite imagery, LiDAR techniques that support the measuring of the vegetation structure and the application of UAVs that can fly at any requested time and spatial resolution and are not affected by cloud cover, can help to speed up the process of vegetation mapping and monitoring. Nevertheless, these methods are all quite new and are not yet that robust that they immediately convince vegetation surveyors and/or terrain managers who often lack the skills to apply these new methods. Using a mixture of remote sensing and field methods seems to deliver the best results. This requires ecologists and remote sensing experts to collaborate closely and review the newest methods and technologies. Some of these technologies and methods are demonstrated below, but first a short introduction to remote sensing.

**Early applications pertained to the visual interpretation of aerial photography, but more recently satellite imagery with a huge range of spatial and temporal resolutions is in use that increases the applicability from entire ecosystems to specific vegetation types.**

### II.1.3 Theory and definition

Remote sensing is the science of obtaining information about an object, an area, or phenomenon through the analysis of data acquired by a sensor that is not in contact with the object, area or phenomenon under investigation (Lillesand *et al.*, 2015). The human eye only detects the reflective solar radiance, the part of the electromagnetic range in the band length range 0.4–0.7 $\mu$ m. But remote sensing technology allows for the detection of other reflective and radiant (including thermal) energy band-length ranges. **Sensors can be divided into two broad groups—passive and active.** The earliest example of this is photography. With airborne cameras we have long been able to measure and record the reflection of light off of earth features. While aerial photography is still a major form of remote sensing, newer solid state technologies have extended capabilities for viewing in the visible and near-infrared wavelengths to include longer wavelength solar radiation as well.

### II.1.4 Sensor characteristics and important platforms of remotely sensed imagery (spaceborne, airborne [manned & unmanned])

The relevance of remote sensing as a source of information for e.g. grassland monitoring is conditioned by the following sensor characteristics:

- » **spatial resolution** – determines the amount of information in a remotely sensed image of a given area;
- » **temporal resolution** – revisit frequency (how often a satellite takes a picture of the same area) helps to distinguish abrupt and gradual changes, but also allows an improvement in the identification of grassland associations
- » **spectral resolution** – helps to distinguish between plants of different species and their traits;

Next to the sensor characteristics that determine the application domain, it is very important to have a good pre-processing line, which includes radiometric calibration including atmospheric correction, and cloud masking. Furthermore you need a good post-processing line, which includes for example time compositing of products derived from the calibrated satellite imagery: images can be combined, for example to remove clouds (accumulating images of the same area to increase chances of cloud free observations) and to create 8-day, monthly and annual composite (of variables such as spectral indices, like NDVI, or variables like fAPAR, SST).

#### Spatial and temporal resolution

The spatial resolution of spaceborne sensors today ranges from one kilometre to about 40 centimetres (Figure II.1). In general, a distinction is made between:

- » **Low Resolution** Optical Satellite Data:  $\geq$  1km spatial resolution by multi-spectral sensors like GOES, Meteosat, NOAA, SPOT-Vegetation.

#### Definition of remote sensing

Remote sensing is the science of obtaining information about an object, an area, or phenomenon through the analysis of data acquired by a sensor that is not in contact with the object, area or phenomenon under investigation (Lillesand *et al.*, 2015).

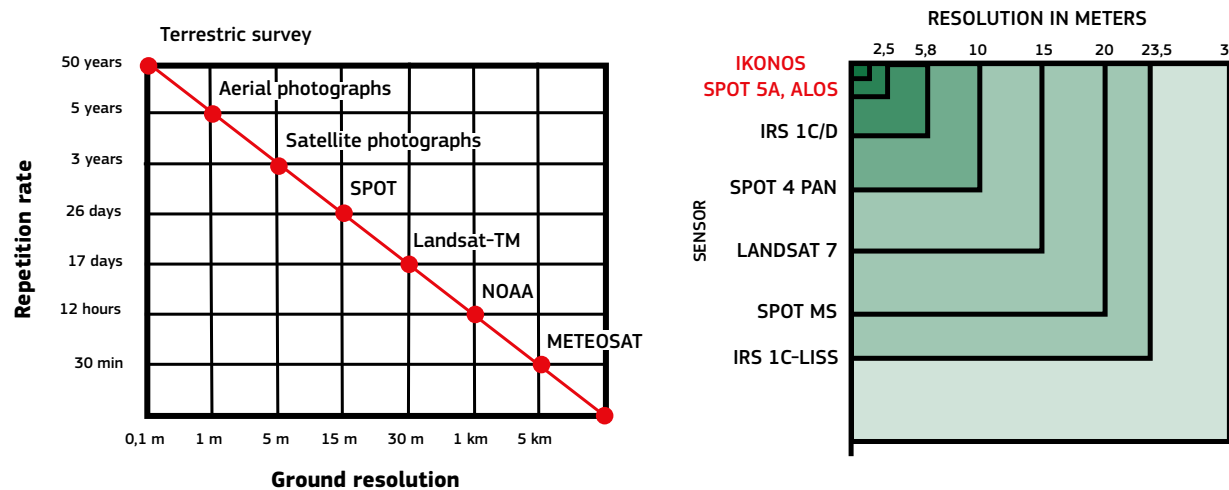


Figure II.1

Spatial and temporal resolution of satellite sensors.

Source: [dib.joanneum.ac.at/edtr/satsys.html](http://dib.joanneum.ac.at/edtr/satsys.html)

- » **Medium Resolution** Optical Satellite Data: 80–500m spatial resolution by multi-spectral sensors like MODIS, Landsat MSS, RESURS-01 (MSU-SK) and IRS-1C (Wide Field Sensor – WiFS).
- » **High Resolution** Optical Satellite Data: 5–30m spatial resolution by panchromatic or multi-spectral sensors or analogue camera systems such as Sentinel-2, Landsat TM, SPOT PAN and MS, IRS-1C/D (PAN and LISS), KFA 1000, MK4, etc.
- » **Very High Resolution (VHR)** Optical Satellite Data: 1–4m spatial resolution by panchromatic or multi-spectral sensors, e.g. Worldview-2 and Quickbird with half a meter resolution for panchromatic band and 2m for the multi-spectral bands.

See also [Annex I](#) for a long list of satellite sensors and their characteristics.

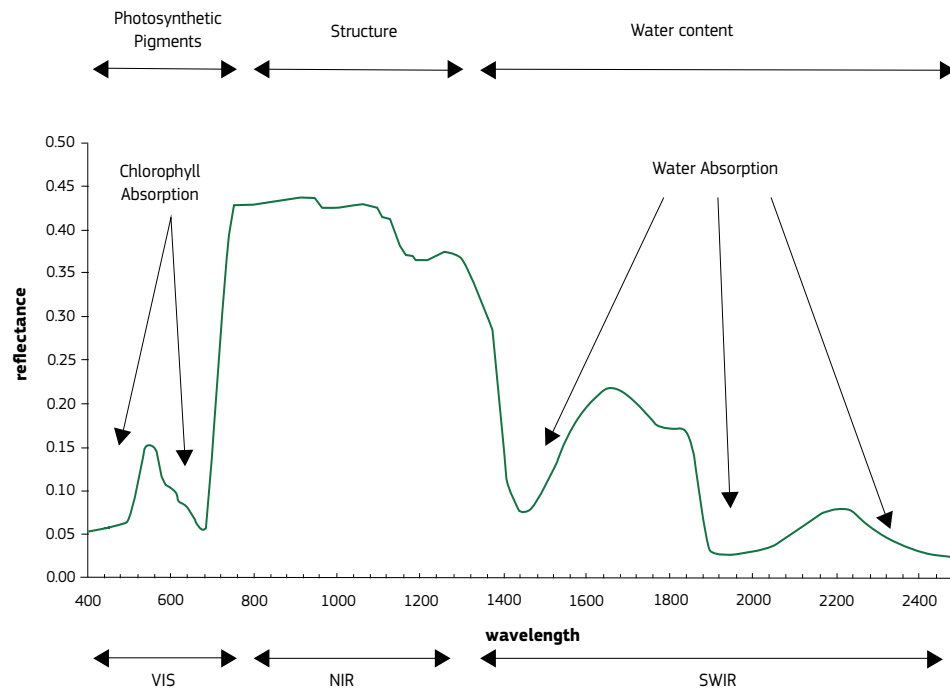
Airborne sensors can be distinguished in manned and unmanned sensors (better known as drones) and commonly have spatial resolutions between 40cm and 1cm.

There is a clear trade-off between spatial and temporal resolution. The higher the temporal resolution the lower the spatial resolution. The European Space Agency (ESA) is developing five new missions called Sentinels specifically for the operational needs of the European GMES programme. The Sentinel missions are based on a constellation of two satellites to fulfil revisit and coverage requirements, providing robust datasets for GMES Services. The Sentinels were launched from 2013 onwards. The mission orbits at a mean altitude of approximately 800 km and, with the pair of satellites in operation, has a revisit time of five days at the equator (under cloud-free conditions) and 2–3 days at mid-latitudes (source: [www.esa.int/Our\\_Activities/Observing\\_the\\_Earth/GMES/Overview4](http://www.esa.int/Our_Activities/Observing_the_Earth/GMES/Overview4)).

## Spectral resolution

An example of a typical spectrum for photosynthetic (green) vegetation is given in Figure II.2, but characteristic spectra relevant to land cover and habitat mapping are also available for non-photosynthetic (brown) vegetation, soils, water (in liquid and frozen form), bare areas and urban surfaces.

Within the vegetation (photosynthetic) spectra, characteristic features include the green peak, red edge and near infrared (NIR) plateau with absorption features (relating to moisture content) evident in the latter and also in the short-wave infrared (SWIR) wavelength regions. Reflectance in the visible regions is primarily a function of pigment concentrations in foliage whilst in the NIR and SWIR, the internal leaf structure and moisture content of the leaves respectively influence reflectance (Swain & Davis, 1978). In all cases, it should be noted that the reflectance of vegetation canopies is different from that of individual components (e.g. leaves, branches), because of the different contributions to the reflectance from plant materials and also the underlying surface and shadowing as a function of canopy heterogeneity, which particularly influences the NIR and SWIR wavelength regions. The loss of pigments, cell structure and moisture content during senescence of leaves leads to the loss of most of the characteristic features of green leaves (with the exception of the water absorption features) and the transition to the spectral curve typical of non-photosynthetic vegetation.



**Figure II.2**

Typical spectra for vegetation highlighting the main contributors to reflectance.



A large number of studies have used spectral reflectance data to differentiate plant species and communities on the basis of differences in spectral reflectance, with this being attributed largely to differences in foliar chemistry, the internal structure of leaves, moisture content and the overall canopy structure (e.g. in terms of shadowing and relative amounts of plant components (e.g. leaves, branches). As examples, *Lucas et al., (2008)* extracted reflectance spectra (based on CASI data) from the sunlit portions of delineated tree crowns in Australia savannas, discriminating species of Callitris, Eucalyptus, Acacia and Angophora through discriminant analysis. *Lu et al., (2009)* used hyper-spectral data to map the distribution of two spectrally similar grasses (*Miscanthus sacchariflorus* and *Phragmites australis*) in Japan on the basis of subtle differences in canopy density, leaf and canopy structure as well as biochemical properties. The benefits of using hyper-spectral data for mapping aquatic vegetation (e.g., different species of *Spartina* in San Francisco Bay, USA; *Rosso et al., 2005*), identifying and mapping invasive species (e.g. *Ustin et al., 2004; Hestir et al., 2008; Walsh et al., 2008; He et al., 2011*); and differentiating between trees of the same species that are of different ages and sizes have also been conveyed (*Christian & Krishnayya, 2009*).

### II.1.5 Remote sensing for Natura 2000 surveying (status) & monitoring (changes)

The Habitats Directive requires EU Member States to maintain and restore all habitats and species of “community interest” listed in annexes to the Directive.

A study of *Lengyel et al. (2008)* of 148 habitat monitoring schemes across Europe found that the majority of the programs were launched to comply with EU Directives, thus underlining their importance in European assessments of habitat change. At that time, the member states were only able to produce robust trend figures on the range of about 1.7% of habitat types and for no more than 4% of the populations of species listed. Most countries did not produce trend figures at all (*European Topic Centre Biodiversity, 2008*). Due to the lack of such information, remotely sensed observations are increasingly being considered by EU Member States to satisfy their reporting obligations under the Habitats Directive (*Lengyel et al., 2008; Vanden Borre et al., 2011b*). For instance, an approach proposed by *Jongman et al. (2006)* is based on environmental stratification along with detailed field surveys in selected sites, with this utilising remote sensing data in conjunction with GIS databases and modelling. Remote sensing data is also being used by other countries across the world to satisfy their conservation reporting requirements.

*Vanden Borre et al. (2011a)* discussed the opportunities for remote sensing with over 30 monitoring experts from administrations in 13 EU Member States. They see clear opportunities for its application in their work processes, see box [Remote sensing can help to measure habitat conservation status](#).

#### Aspects of habitat conservation status to be measured

Articles 11 and 17 of the Directive also require member states to report on five parameters of habitat conservation status every six years:

- » habitat area and geographic range,
- » habitat structure and function (quality),
- » and future prospects for habitat survival in the member state (*European Commission, 2005; Vanden Borre et al., 2011a*).

Remote sensing can also provide methods to monitor specific biophysical and biochemical indicators of ecosystem functioning (e.g. leaf area index, normalised difference vegetation index; Kerr & Ostrovsky, 2003; Mùcher, 2009). The strength of remote sensing is its ability to deliver quantitative measures of such parameters in a standardised manner with full coverage over larger areas, whereas field surveys can only deliver this through point sample measurements and subsequent interpolation. The provision of such data by remote sensing may open new ways of looking at the quality of Natura 2000 habitats (Vanden Borre, 2011b).

When we take grasslands as an example, remote sensing can contribute to:

- » Identify spatially the **land cover class grassland** and in some cases **specific habitat type**. There are many different local and regional grassland classification schemes (floristic, habitat, climatic, management, use etc.). In most cases floristic composition plays an important role and this is not that easy to distinguish from satellite imagery.
- » Identify **grassland quality parameters**. These parameters include amongst others LAI, fraction cover, canopy shade, gap fraction soil, biomass content, soil moisture (indirectly), canopy coverage etc. The biophysical parameters that can be retrieved from GMES data sources (e.g. GEOLAND-2) are amongst others:
  - LAI and FAPAR are also classical parameters to quantify green vegetation (so we refer in fact to green LAI or GLAI). They are strongly correlated with fCover (but the relation between LAI and fCover is far from linear). It is a direct input into grass vegetation density product.
  - fCover: fractional green vegetation cover (FVC) is a useful parameter for many environmental and climate-related applications. Comparing to previously used NDVI, it has several strong advantages: absolute parameter (sensor-independent), robustness to thin clouds, fully scalable at different spatial resolutions
  - Canopy Shade Factor (CSF): this parameter allows to characterize the amount level of shadows self-cast on the canopies, and so in many conditions to discriminate rough canopies (forests, shrub) from flat, homogeneous canopies (crops and grasslands)
  - fSoil: quantifies the gap fraction of soil in the image, and relies on the capacity to discriminate a third contributor that is brown or non-photosynthetic (NPV) vegetation. It can be most useful to identify intensive agriculture practices with bare soil event.
- » **Changes in extent and quality** of the habitat type.

Literature review shows that remote sensing can play further a role in: grassland transpiration, grassland emissions and fluxes, grassland dynamics and phenology, grassland albedo, grassland productivity, chlorophyll and water content and vegetation condition and structure.

### Remote sensing can help to measure habitat conservation status (Vanden Borre et al., 2011a)

#### Habitat area

The production of habitat distribution maps, at various scale levels, constitutes an obvious area of high potential for remote sensing, as experts indicated. The advent of hyperspatial and hyperspectral sensors has indeed greatly enhanced the possibilities of distinguishing related habitat types at very fine scales (Turner et al., 2003). The end-users need such maps in the first place for estimating and update the sampling frame (the statistical 'population') of habitats for which field sample surveys are in place. The use of remote sensing also provides a major opportunity for harmonising Natura 2000 habitat mapping throughout Europe.

#### Habitat structure and function (quality)

As stated already by Vanden Borre et al. (2011b) the usefulness of remote sensing for habitat quality assessment is less straightforward for many monitoring experts. However, airborne LiDAR data can provide much information about habitat structure and changes in the habitat structure, while hyperspectral and multispectral data can in most cases provide information about dominant species and changes in the coverage of those dominant species.

#### Change detection

Remote sensing is frequently identified as a powerful tool for detecting change (Kennedy et al., 2009; Mùcher et al., 2000). Remote sensing driven change maps not only provide excellent instruments for estimating trends in range and area, but they also localise the areas where change has occurred. Monitoring experts highly value this asset, because it allows subsequent field work to concentrate on these areas, possibly yielding a significant increase in cost-efficiency. In the Netherlands we will probably see that habitat maps remain likely to be derived from conventional vegetation maps updated once in the 12 years, but that more frequent updates will be based on remote sensing products such as LiDAR data, very high resolution satellite imagery and aerial photographs.

## II.2 Current use of Remote Sensing for Natura 2000 monitoring

### II.2.1 State of the art of Remote Sensing for Natura 2000 monitoring

The state of the art of remote sensing for Natura 2000 monitoring is told based on examples from European and national projects that clearly explain how remote sensing is being exploited in Natura 2000 monitoring.

Below is an overview of techniques and tools for different purposes in relation to Natura 2000 monitoring. It provides a link to the paragraph which further describes or gives examples of the method.

Tool	Scale	Purpose	Aspects of habitat conservation status that can be measured
<b>MODIS</b>	250m pixel size	Global monitoring and monitoring large areas. Typical MODIS products are: surface reflectance, surface temperature and emissivity, land cover, vegetation indices, e.g. NDVI, thermal anomalies /active fraction of photosynthetically active radiation (FPAR) / leaf area index (LAI), evapotranspiration, gross primary productivity (GPP) / net primary productivity (NPP), water, burned area, snow cover, sea ice, sea surface temperature.	<ul style="list-style-type: none"> <li>» habitat area</li> <li>» habitat structure and <b>function</b> (quality),</li> <li>» <b>changes</b> in area and quality (structure and function)</li> </ul>
<b>Landsat TM</b>	30m pixel size	Regional studies and recently also global studies, such as Global Forest Watch and Global Water Surface Explorer. Typical Landsat products are: surface reflectance, spectral indices such as NDVI, vegetation and moisture measurements, surface temperature, dynamic surface water extent, fractional snow covered area, burned area.	<ul style="list-style-type: none"> <li>» <b>habitat area</b></li> <li>» habitat structure and function (quality),</li> <li>» <b>changes</b> in area and quality (structure and function)</li> </ul>
<b>Sentinel</b>	10m pixel size	Regional and global studies. Typical Sentinel products are: surface reflectance, land cover, vegetation indices, e.g. NDVI, leaf area index (LAI), water.	<ul style="list-style-type: none"> <li>» <b>habitat area</b></li> <li>» habitat structure and function (quality),</li> <li>» <b>changes</b> in area and quality (structure and function)</li> </ul>
<b>Aerial photos</b>	20cm pixel size	Local and national studies, typically used for topographical surveying.	<ul style="list-style-type: none"> <li>» <b>habitat area</b></li> <li>» habitat <b>structure</b> and <b>function</b> (quality),</li> <li>» <b>changes</b> in area and quality (structure and function)</li> </ul>
<b>Airborne LiDAR and hyperspectral imagery &amp; UAVs</b>		Local studies such as specific Natura 2000 sites. Typical UAV (drone) products are: canopy.	<ul style="list-style-type: none"> <li>» <b>habitat area</b></li> <li>» habitat <b>structure</b> and <b>function</b> (quality)</li> <li>» <b>changes</b> in area and quality (structure and function)</li> </ul>

**Table II.1**

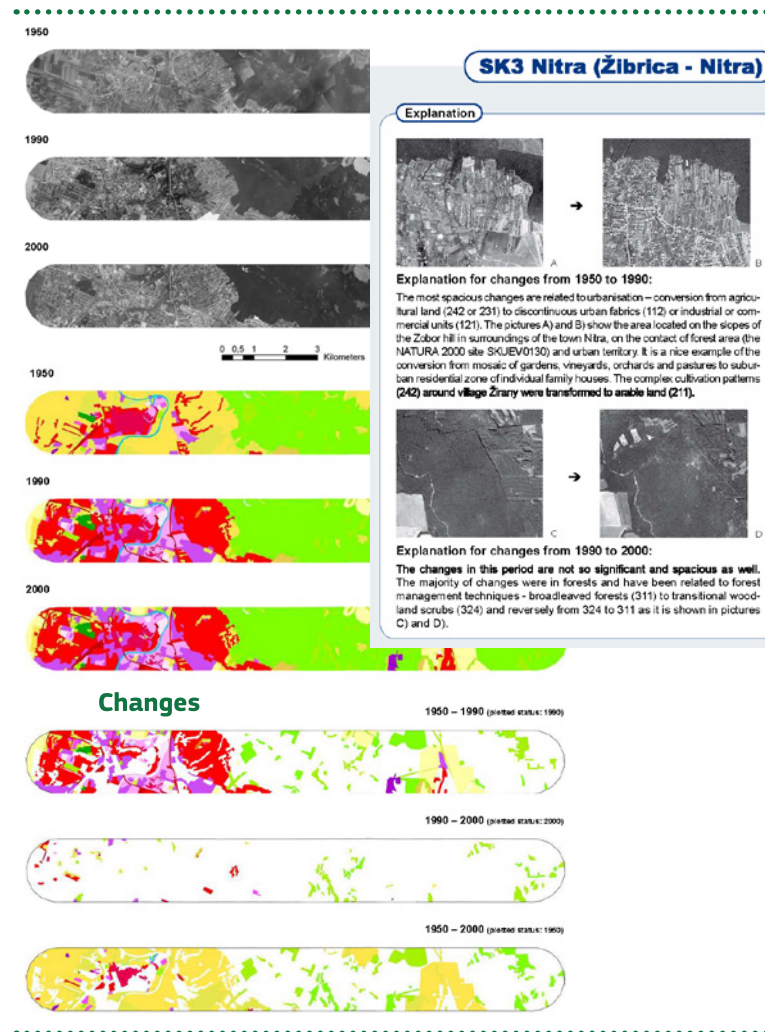
Remote sensing tools and methods.

## Mapping and monitoring habitat area

In the following sections examples are given on the use of remote sensing data for the mapping and monitoring of habitat area. The first example is based on the interpretation of historical aerial photographs to detect land cover changes in and around Natura 2000 sites since the early fifties. The second example concerns the Copernicus European land cover monitoring activities. The third example concerns the mapping of ecosystems (MAES), the fourth example mapping and monitoring of habitats using very high resolution data.

### a. Interpretation of land cover changes in and around Natura 2000 sites based on time series of historical aerial photographs

The EU project BIOPRESS funded within the EU Fifth Framework is taken as an example for the interpretation of land cover changes from historical aerial photographs in and around Natura 2000 sites. Historical aerial photographs from the 1950s provide useful information about the original state of natural areas before the process of land consolidation and the associated amount of land use changes. Moreover the land cover flows (transition from one land cover type in another land cover type) within and around protected sites also provide information about the effectiveness of protection. The BIOPRESS method was designed to produce land cover change information collected in an operational and consistent manner from samples (including transects) across Natura 2000 within the different biogeographical regions of Europe. Land cover was classified according to the CORINE Land Cover nomenclature with 44 classes at the highest level 3 (Heymann *et al.*, 1993). Change was captured by means of 'backdating' where the older data set is compared against the most recent. Change was recorded at a scale of 1:100.000 within 73 samples of 30 by 30km, and 59 transects of 2 by 15km at a scale of 1:20.000 for aerial photographs of the reference years: 1950, 1990 and 2000. Figure II.3 shows an example for the Nitra site in Slovakia.



**Figure II.3**

Detected land cover changes in Slovakia in and around Natura 2000 site "Nitra" since the early fifties, based on historical aerial photographs (Gerard *et al.*, 2006).

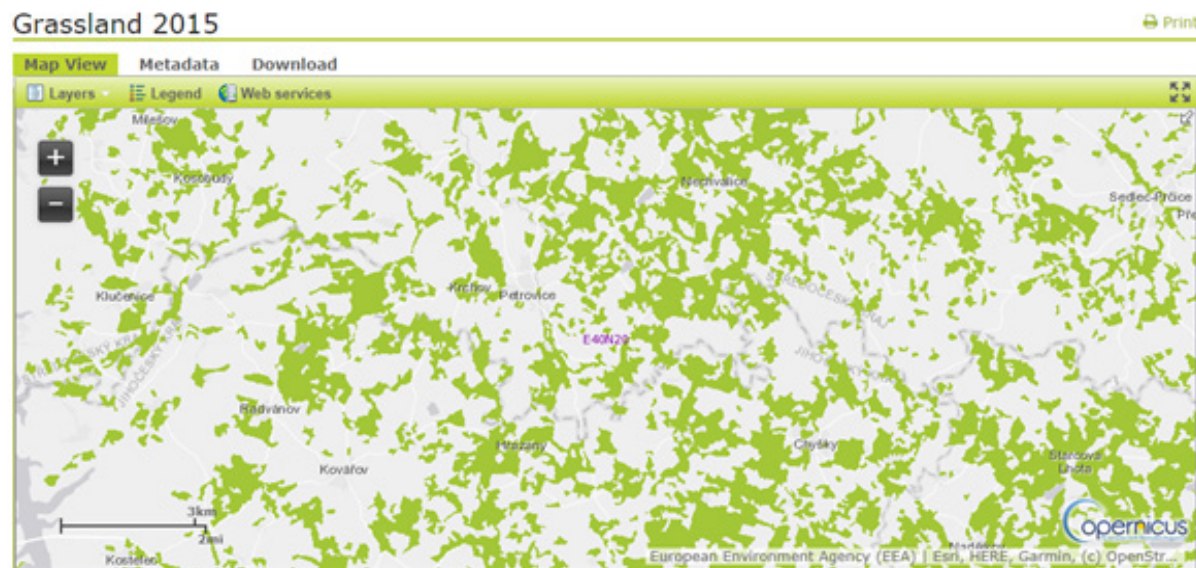


The degree of thematic detail and level of spatial detail of the land cover measured determines the type, amount and rate of change detected. Moreover the land cover flows can be associated with specific pressures such as urbanization, drainage, afforestation, deforestation, abandonment and intensification.

### b. European Land monitoring in the framework of Copernicus

European Land monitoring in the framework of Copernicus consists of two components, the pan-European land monitoring and the local or hotspot land monitoring. The pan-European component includes as main products the CORINE Land Cover (CLC), High Resolution Layers and image mosaics. The CORINE Land Cover is provided for 1990, 2000, 2006, 2012, and 2018. This vector-based dataset includes 44 land cover and land use classes with 25ha as minimum mapping unit (MMU). The time-series also includes a land-change layer, highlighting changes in land cover and land-use (5ha MMU). The use of CLC for ecosystem mapping and assessment and the mapping of High Nature Value Farmland is described in Feranec et al., 2016. The high-resolution layers (HRL) are raster-based datasets which provides information about different land cover characteristics and is complementary to land-cover mapping (e.g. CORINE) datasets (100\*100m aggregated products).

Five HRLs describe some of the main land cover characteristics: impervious (sealed) surfaces (e.g. roads and built up areas), forest areas, grasslands, water & wetlands, and small woody features ([land.copernicus.eu/pan-european](http://land.copernicus.eu/pan-european)). Figure II.4 presents an example of the HRL Grassland for Czech Republic. The local component focuses on different hotspots, i.e. areas that are prone



**Figure II.4**

Example for Czech Republic of the Copernicus High Resolution Layer grassland 2015, from: [land.copernicus.eu/pan-european/high-resolution-layers/grassland/status-maps/2015](http://land.copernicus.eu/pan-european/high-resolution-layers/grassland/status-maps/2015)

to specific environmental challenges and problems. It is based on very high resolution imagery (2,5x2,5m pixels) in combination with other available datasets (high and medium resolution images) over the pan-European area. The three local components are: Urban Atlas, Riparian Zones and Natura 2000. The rationale for the last two local components is provided by the need to monitor biodiversity at European level and to assess if the N2000 sites are being effectively preserved ([land.copernicus.eu/local](http://land.copernicus.eu/local)).

### c. Ecosystem Types of Europe

The dataset combines the Copernicus land service portfolio and marine bathymetry and seabed information with the non-spatial EUNIS habitat classification for a better biological characterization of ecosystems across Europe. As such it represents probabilities of EUNIS habitat presence for each MAES ecosystem type. The Ecosystem Type Map (ETM) is produced by applying different mapping rules on input datasets.

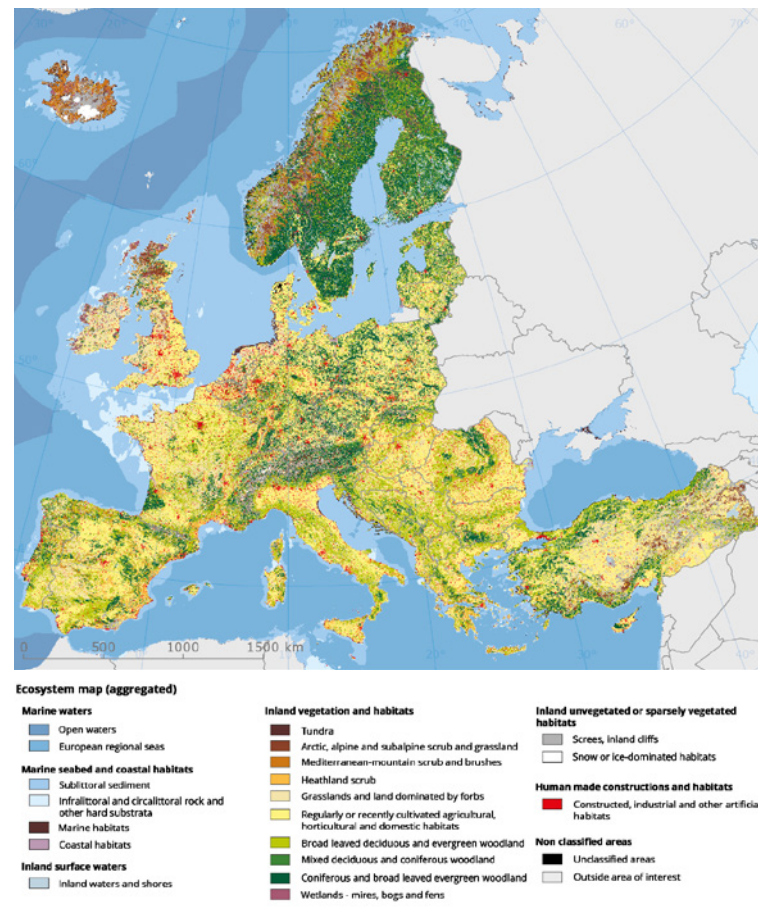
The newest version, v3.1, is based on the following input datasets:

- » Corine Land Cover 2012 accounting layer (instead of CLC 2012 status layer)
- » HRL Forests 2012 (Forest Type, Tree Cover Density)
- » HRL Imperviousness 2012
- » OpenStreetMap (OSM) data 2015 (main roads, land use information)

And further integration of new available Copernicus data

- » Urban Atlas 2012
- » Riparian Zones 2012
- » Natura 2000 2012
- » HRL Grassland 2012
- » HRL Permanent Water Bodies 2012

The resulting Ecosystem Type Map (v3.1) is displayed in the Figure II.5.



**Figure II.5**

Ecosystem Map (aggregated, v3.1) (Weis & Banko, 2018).



#### d. Earth Observation data for Habitat Mapping and Monitoring

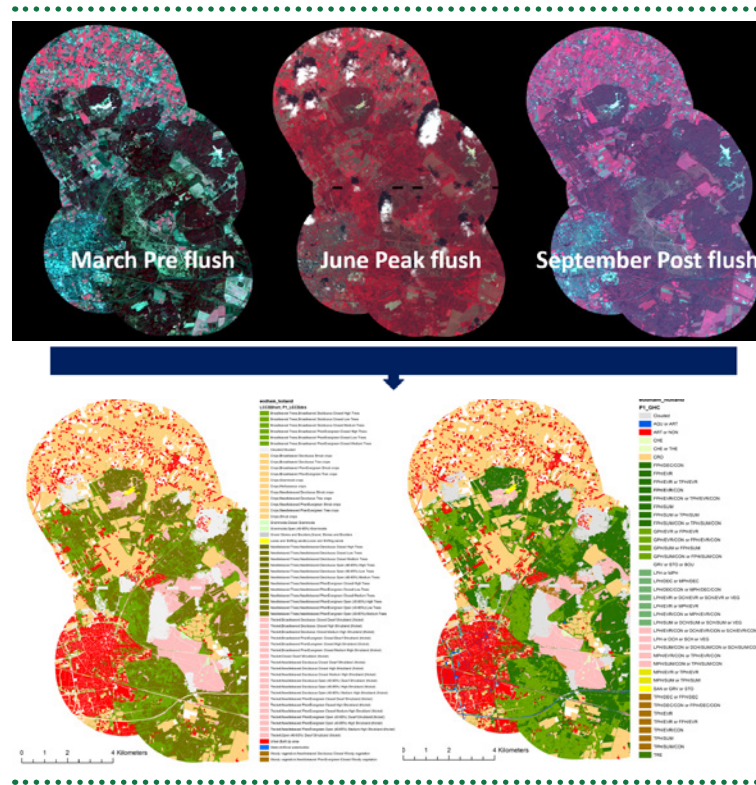
To support decisions related to the use and conservation of protected areas and surrounds, the EU-funded BIO SOS project has developed the Earth Observation Data for HABitat Monitoring (EODHaM) system for consistent mapping and monitoring of biodiversity. The EODHaM approach has adopted the Food and Agriculture Organization Land Cover Classification System (LCCS) taxonomy and translates mapped classes to General Habitat Categories (GHCs) from which Annex I habitats (EU Habitats Directive) can be defined (Lucas *et al.*, 2015).

Although LCCS focusses on land cover and GHC on habitats, both LCCS and GHC categories have height information of the canopy as essential information. Input data sources for EODHaM are very high resolution (VHR) images, height information from LiDAR data, and ancillary information such as topographical maps (Mücher *et al.*, 2015). The EODHaM system uses decision rules to derive GHC classes on the basis of spectral and height information (Mücher *et al.*, 2015), see also Figure II.5 as an example.

#### Mapping and monitoring habitat quality

##### a. Remote sensing-enabled Essential Biodiversity Variables (RS-EBVs)

Essential Biodiversity Variables (EBVs) were proposed in 2013 by the biodiversity community to improve harmonization of biodiversity data into meaningful metrics (see [chapter A.III Access to data and Information](#)). The proposed EBVs have been grouped into six classes: genetic composition (not able yet with remote sensing data), species populations, species traits, community composition, ecosystem structure, and ecosystem function (see Figure II.6). This concept has taken root within wide segments of the theoretical and applied ecology communities. Furthermore, the idea behind the original EBV concept was that at least one EBV per class should be monitored, while keeping the set of EBVs limited is necessary to assure the usefulness of the EBV concept. Possible EBVs that capture biodiversity change on the ground and can be monitored from space range from leaf nitrogen and chlorophyll content to seasonal changes in floods and fires (Skidmore *et al.*, 2015).



**Figure II.6**

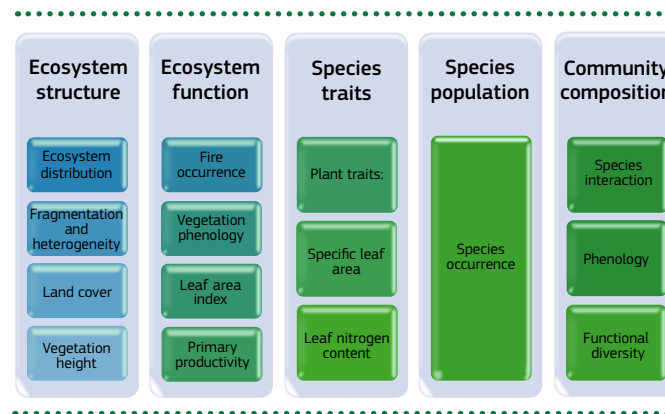
Results of EODHaM for a part of the Veluwe in the Netherlands. On the left the land cover classification at level 4 of FAO LCCS. In the right the habitat classification in terms of General Habitat Categories (Mücher *et al.*, 2015).

The RS-enabled EBVs can play a role in the monitoring of the quality of the habitats, next to the mapping and monitoring of habitat types. Nevertheless, much effort still has to be put in place to translate these remote sensing variables into useful information for ecologists in terms of habitat quality.

For example, *Vaz et al. (2015)* collected field data on five habitat quality indicators in vegetation plots from woodland habitats of a landscape undergoing agricultural abandonment. Their findings strongly suggest that some features of habitat quality, such as structure and habitat composition, can be effectively monitored from EO data combined with field campaigns as part of an integrative monitoring framework for habitat status assessment.

### b. Mapping quality of heathland areas in terms of grass encroachment

*Mücher et al. (2013)* focused on the use of continuous fraction images for habitat quality assessment in a heathland site in the Netherlands (see Figure II.7). This combined application of techniques on hyperspectral imagery demonstrates the usefulness for mapping grass abundance (*Molinia caerulea*) in heathlands. It provides a better basis to monitor large areas for processes such as grass encroachment that largely determine the conservation status of Natura 2000 heathland areas. Timely, accurate and up-to-date spatial information on the encroachment of mosses, grasses, shrubs or trees (dominant species) can help conservation managers to take better decisions and to better evaluate the effect of taken measures.



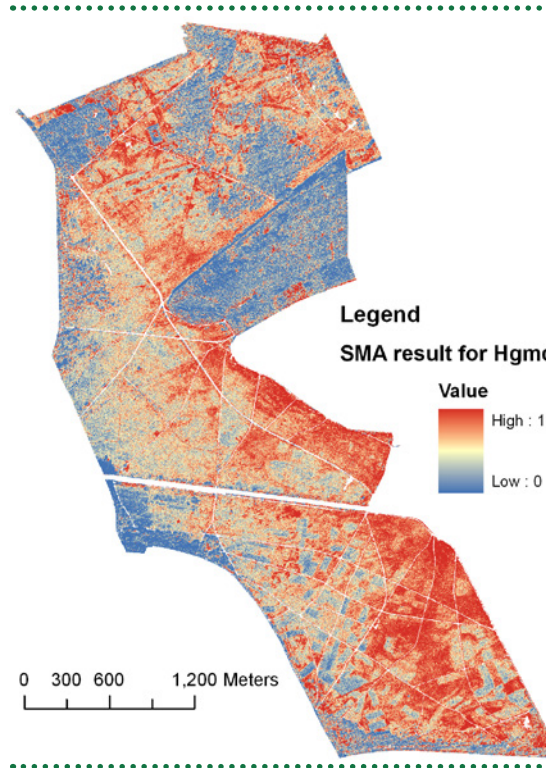
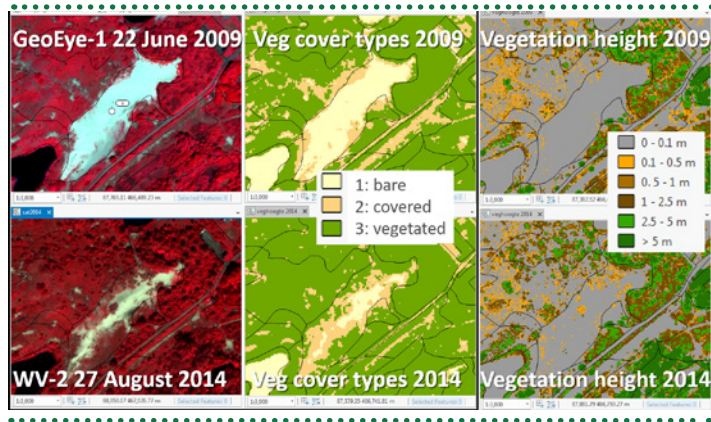
**Figure II.7**

A selection of proposed RS-Enabled Essential Biodiversity Variables (RS-EBVs) – Modified by E.Neinavaz from *Skidmore et al. (2015)*.

### c. Monitoring shrub encroachment

Regular mapping of vegetation structure is of importance for biodiversity monitoring (*Mücher et al., 2017a*). In the Netherlands, vegetation structure mapping is in most cases still done in a traditional way based on field surveys in combination with visual interpretation of aerial photographs. This procedure is time consuming and often limited in its consistency and efficiency to cover large areas. Meanwhile space and airborne imagery are increasingly becoming available at affordable costs and with a high spatial resolution of approximately 50cm (*Mücher et al., 2017a*). Therefore, commonly shared Dutch open LiDAR-data such as AHN (LiDAR derived terrain models) in combination with commercially available very high resolution satellite data were used to develop methodologies that can help to increase the updating frequency of vegetation structure maps, based on respectively vegetation height and vegetation cover. LiDAR-data from AHN2 (2008) and AHN3 (2014) was combined with very high resolution satellite imagery from the similar time period in order to detect changes in vegetation structure at 1 metre spatial resolution

(see Figure II.8). The existing habitat map was used to develop a protocol to find Grey Dunes (H2130) that showed significant changes in vegetation structure between 2008 and 2014 (see Figure II.9 as example). The Remote Sensing method can also be used for other vegetation structure – or habitat types but requires other specific decision rules in relation to vegetation height and/or vegetation cover which have to be agreed upon by the nature conservation community. Therefore, the developed Remote Sensing monitoring method for vegetation structure is only a start to enable national wide operational monitoring of the vegetation structure of all habitat types (Mücher *et al.*, 2017a).



**Figure II.8 (right)**

Thematic fraction image for grass encroachment of heathlands concerning the *Molinia* dominated heathland (Hgmd), obtained by spectral mixture analysis (SMA) on an AHS hyperspectral image of October 2007. Red means almost 100% coverage with *Molinia* or other grasses, and blue means almost 0% coverage with *Molinia*, so it's good quality Heathland.

**Figure II.9 (left)**

An example of the monitoring of changes in vegetation structure for the Grey Dunes in the Netherlands, based on changes in vegetation cover and vegetation height (Mücher *et al.*, 2017a).

## II.2.2 Recent developments

### New high resolution satellite sensors and drones

**A lot of remote sensing data sources with much higher spatial and temporal resolution have become available that can support Natura 2000 monitoring.**

The observations from the different platforms are often integrated for upscaling and downscaling of the measurements and derived information (Figure II.10). In particular, the use of UAVs, better known as drones, is increasing rapidly for biodiversity monitoring, with spectral, spatial and temporal resolution often adjustable flexibly, but with limited coverage compared to other platforms.

The spatial resolution of most current multispectral spaceborne sensors is insufficient (~2–250m) to detect the presence of individual plants. However, most airborne sensors have a sufficiently high spatial resolution (pixels of 0.5–5m) to register small-scale variation in the vegetation. Spaceborne systems have the advantage of coming over at fixed intervals (ranging from a few days to a few weeks). This means that a new recording can be made regularly, so that the phenology can be visualized.

### Three types of sensor platforms

Remote sensing is the science of obtaining information about an object, an area, or phenomenon

- 1 **spaceborne** platforms, read satellites.
- 2 **airborne** platforms (including aircraft, helicopter, balloon or Unmanned Airborne Vehicles (UAV), and
- 3 **Ground-based** platforms, where the sensor is mounted on a mast or is held manually above the ground

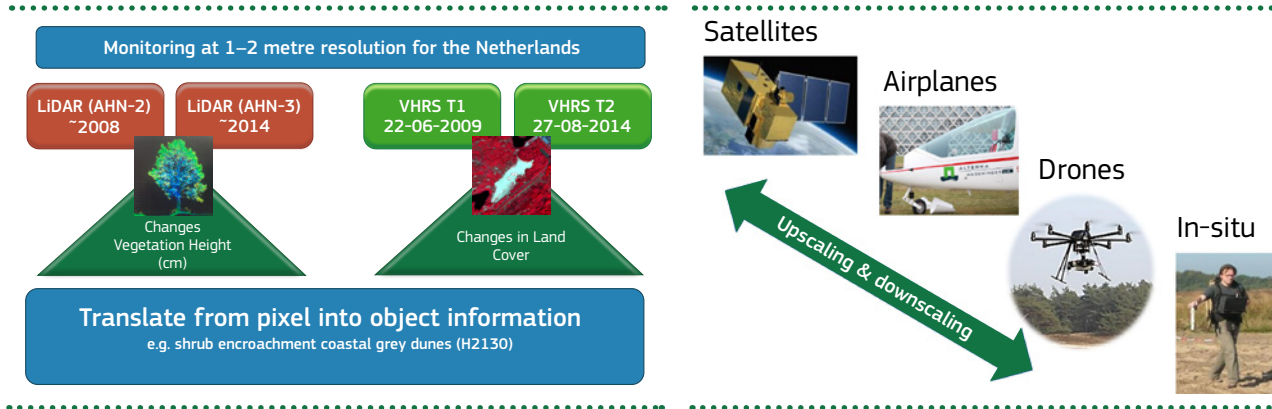


Figure II.10 (left)

Overview of the vegetation structure monitoring system based on the exploitation of LiDAR data and very high resolution satellite imagery (VHRs) (Mücher *et al.*, 2017a).

Figure II.11 (right)

Multi-scale sensing approach with different remote sensing platforms: spaceborne, airborne and ground-based (Source: presentation Mucher).

An even higher spatial and temporal resolution than with airborne or spaceborne systems can be achieved with the use of UAVs. However, this also depends on the type of camera used. Different types of UAVs exist like multicopters and fixed wing airplanes having different capacities (camera load, flight time, easiness to maneuver) (Figure II.14). They can be equipped with different sensors (passive and active). The use of unmanned airborne vehicles (UAVs) or so-called drones that can carry a LiDAR camera is a recent development. Recently, the use and adoption of UAVs as a flexible sensor platform for monitoring has evolved rapidly. Potential application domains are e.g. agriculture (phenotyping of individual plants), coastal monitoring, archaeology, corridor mapping (power lines, railway tracks, pipeline inspection), topography, geomorphology, and construction site monitoring (surveying urban environments), next to forestry and vegetation monitoring. Until recently it was not possible to have a LiDAR camera on a UAV since the cameras were too heavy to be carried by a UAV.



Figure II.12

Multicopter with hyperspectral camera and a fixed wing drone with RGB camera (source presentation Mucher).



The detail of the recorded images also depends on the height that is flown. Table II.2 gives an overview of the possible pixel size and width of the recording at different heights. Another advantage of UAVs is that it can be flown completely autonomously.

Height (m)	Pixel size hyperspectral camera (cm)	Pixel size RGB camera (cm)
20	5.3	0.52
40	11	1.0
60	16	1.6
80	21	2.1
100	27	2.6
120	32	3.1

### Mapping and monitoring vegetation structure

Mapping and monitoring vegetation height can not only help to distinguish the different plant lifeforms but can also help to identify processes such as shrub and tree encroachment (Mücher *et al.*, 2017b). Vegetation height is as such an important component of the structural aspect of ecological complexity. Bunce *et al.* (2013) emphasises the importance of habitat/vegetation structure in the development of biodiversity policies in their own right and also demonstrates that there are strong links between vegetation structure and occurrence of species. Only a very small part of all species can be monitored. Vegetation height is an important indicator as well in the definition of an ecosystem or habitat type. To enable the measurement of vegetation height, remote sensing can play a crucial role and can become an important information source.

New developments in remote sensing such as the use of very high resolution (VHR) satellite imagery and LiDAR (Light Detection And Ranging) techniques, next to the use of UAV platforms, can help to speed up the process of vegetation mapping and monitoring. Nevertheless, some of these methods are relatively new and require ecologists and remote sensing experts to collaborate closely and review the newest methods and technologies. Therefore this section discusses the potential use of passive optical sensors, RADAR and LiDAR technology for measuring vegetation height to support the monitoring of vegetation structure or in other words the EBV 'ecosystem structure' (Mücher *et al.*, 2017b).

#### a. Passive sensor technology

Several studies have employed passive satellite sensor data to estimate vegetation height. A wide variety of features have been extracted from passive sensors of spatial resolutions ranging from several centimetres to some tens of metres. Donoghue and Watt (2006) approximated mean vegetation height for plots of 0.02ha using directly the mean reflectance values from spectral bands of Landsat Enhanced Thematic Mapper Plus (ETM+) and IKONOS images (Mücher *et al.*, 2017b).

**Table II.2**

Examples of varying pixel resolution and image width with flight height for a hyperspectral and RGB camera.

### Sensor technologies for mapping and monitoring vegetation structure

- » Passive sensor technologies
- » Radar technology
- » LiDAR technology
  - UAV LiDAR (drones)
  - Airborne LiDAR
  - Spaceborne LiDAR

## b. RADAR technology

RADAR (Radio Detection And Ranging) is an important tool for detecting the structure and height of vegetation because of its ability to penetrate clouds, to provide a signal from the geometric properties of the vegetation and to generate images over large areas. The RADAR signal, backscatter and interferometric phase, depends on the physical structure and dielectric properties allowing an indirect measurement of vegetation structure. Since the early 1990s several studies have demonstrated the relationship between RADAR backscatter and vegetation structure and height (e.g. *Dobson et al., 1995, Joshi et al., 2015*). Interferometric SAR (InSAR) allows a more direct estimation of height and the vertical distribution of vegetation (*Florian et al., 2006, Papatthanassiou et al., 2008, Treuhaft and Sinqueira, 2004*).

## c. LiDAR technology

The following subsections deal with LiDAR technology from different platforms that all have their own merits for surveying, they concern respectively airborne and spaceborne LiDAR scanning.

### Airborne LiDAR

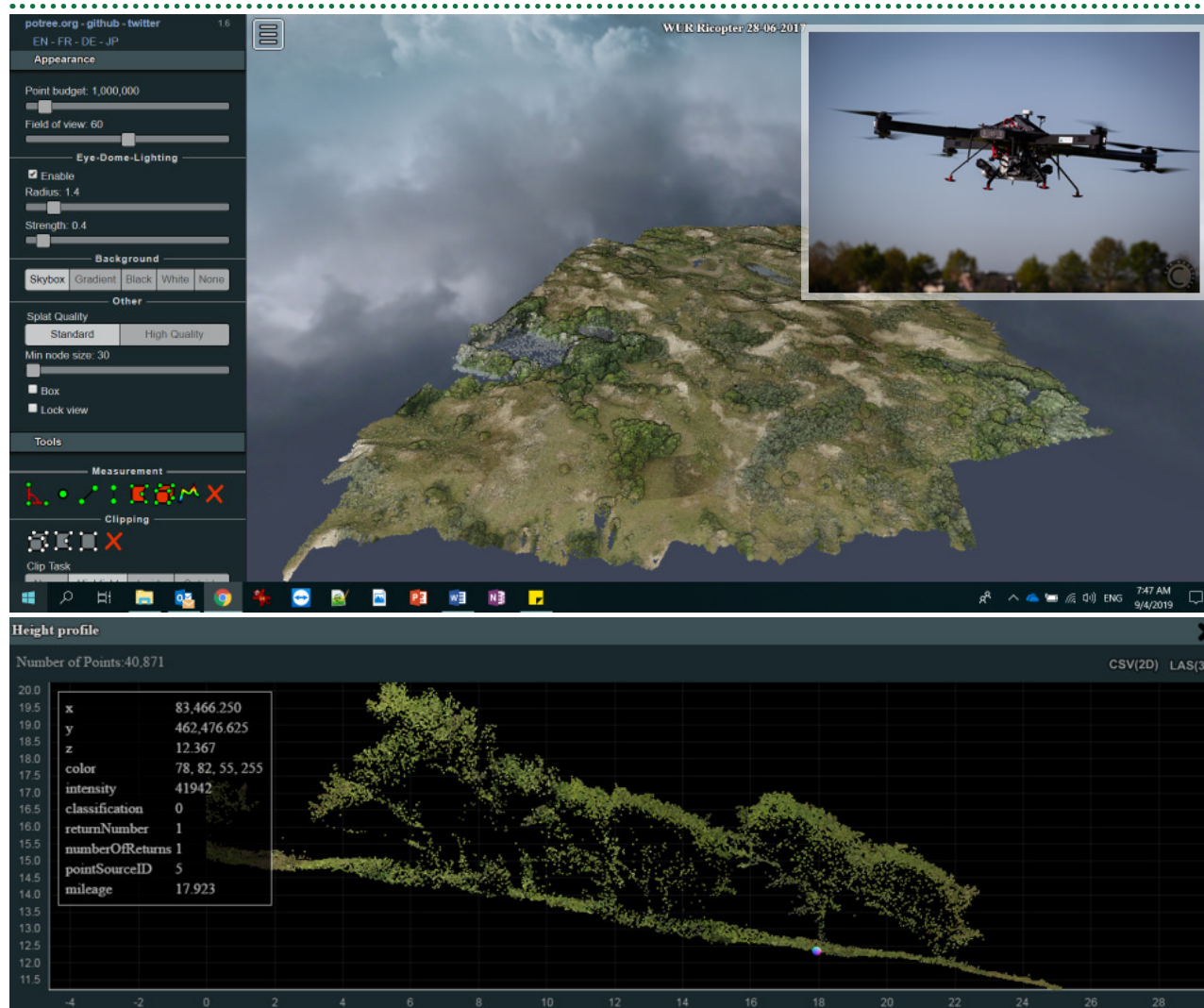
From the perspective of ecological research, LiDAR can be considered as a relatively new technology (*Carson et al., 2004*). LiDAR was originally introduced to generate more accurate digital elevation models (DEMs) (*Evans et al., 2006*) but has recently become an effective tool for natural resources applications (*Akay et al., 2008*). [Scopus](#) presents very well the steep increase in publications per year between 2000 and 2015, respectively from around 10 in 2000 to 400 publications in 2015 (search “LiDAR AND vegetation”).

Airborne LiDAR offers the possibility to collect structural information over larger spatial extents than could be obtained by field surveys (*Bradbury et al., 2005*). LiDAR, in contrast to optical remote sensing techniques, can be expected to bridge the gap in 3D structural information, including canopy shape, number of vegetation layers and individual tree identification at the landscape scale (*Graf et al., 2009*).

### UAV LiDAR (drones)

Before, LiDAR measurements were made only from manned helicopters or airplanes. Attaching a LiDAR sensor to a moving UAV platform allows 3D mapping of larger surface areas (*Mücher et al., 2017b*). The big advantage of the use of a UAV is its flexibility to be used in space and time. The major limitation compared to manned airborne laser scanning is still limited in its areal coverage, not only due to the technological capabilities but also due to aviation regulations which does not allow in most cases to fly beyond line of sight. The use of unmanned LiDAR Scanning (ULS) certainly has advantages compared to the more static terrestrial laser scanning (TLS) or large-scale systems using manned platforms (*Mücher et al., 2017b*): UAV is more flexible in its use, but LiDAR allows a larger area to be covered, and better timing of (repeated) data acquisition.





**Figure II.13**

Example of a line transect through a LiDAR point cloud, visualized in 3D, as taken by an UAV LiDAR camera (Acquired with VUX-SYS camera mounted on RiCopter).

However only a limited number of manufacturers can provide at the moment such integrated UAV-LiDAR systems (Mücher *et al.*, 2017b). See Figure II.13 as an example of ULS.

### Spaceborne LiDAR

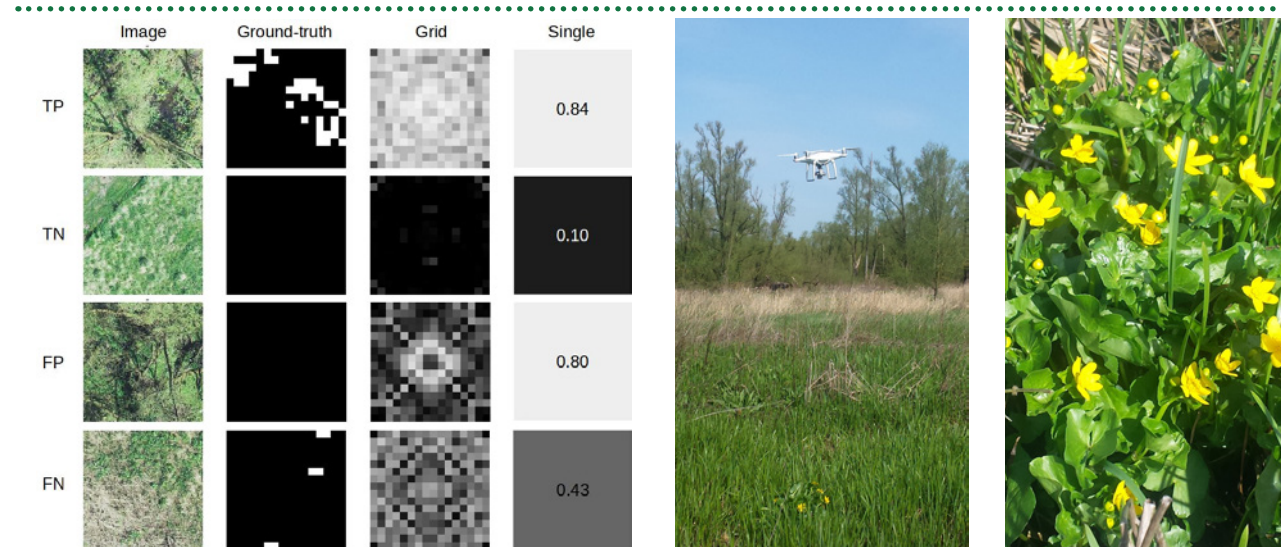
NASA's GLAS instrument (Geoscience Laser Altimeter System) on the spaceborn ICESat platform (Ice, Cloud, and land Elevation satellite), launched on 12 January 2003, is a good example of a promising technique from space. Although the main objective of the GLAS instrument was to

measure ice sheet elevations and changes in elevation through time, it was also very successful in measuring forest height. Amongst others *Hayashia et al. (2013)* showed that ICESat/GLAS data provides useful information on forest canopy height with an accuracy RMSE of 2.8m. New advanced sensors to be launched in the next couple of years will provide increasingly accurate information on traits such as vegetation height and plant-species characteristics. These include the NASA Global Ecosystem Dynamics Investigation Lidar (GEDI), successfully launched in 2018 from Cape Canaveral.

### Use of machine learning to map individual species

The exploitation of machine learning or artificial intelligence has improved with the increase in computational power, and provides the basis for more complicated image classifications that enables the recognition of objects such as human individuals but provides also opportunities to map individual plant species (in case of larger plants with distinct features). In general, machine learning explores patterns and regularities within the data in order to make predictions on new data based on what is learnt by analysing available known data. Since the accuracy can be improved with experience, machine learning performs the best when it can incorporate large training datasets.

Below is an example of a deep learning approach to identifying marsh marigold (*Caltha palustris*) from RGB drone imagery over the wetland forest Biesbosch National Park in the Netherlands (Figure II.14). The study (*Alkema, 2019*) attempts for species recognition from UAV images, to potentially assist or replace field inventories. The bright yellow flowers of marsh marigold and reflective leaves allow for relatively easy recognition in the field, and as an indicator species its presence or absence gives insight in the status of the surrounding swampy habitat.



**Figure II.14**

Examples of correct and false predictions of the grid (3rd column) and single prediction models (4th column). True positive (TP), true negative (TN), false positive (FP) and false negative (FN) outputs are depicted next to the corresponding UAV images and ground-truth masks, given a threshold of 0.5 (*Alkema, 2019*).

## II.3 Key findings and recommendations

The purpose of this report is the provision of services to advise the Commission, Member State authorities and other stakeholders on the better use of scientific knowledge and scientific networks in support of the implementation of the nature directives with a specific focus on evidence-based improvements in the Birds and Habitats Directives (BHD) implementation. Evidence-based improvements can be supported to a large extent by remotely sensed observations, and concerns this chapter. **Remote Sensing holds promise as a supporting technique for Natura 2000 habitat monitoring** (Mücher *et al.* 2013; Vanden Borre *et al.* 2011b), in many cases in terms of changes in habitat area and in some cases in terms of changes in habitat quality. But at the same time, the accuracy of remote sensing products vary a lot depending on the habitat type and its size, making the RS products not always useful. RS definitely provides a powerful tool for detecting land use changes (Feranec *et al.* 2016; Hazeu *et al.* 2014; Hazeu *et al.* 2002; Van der Zanden *et al.* 2013).

**Remote sensing has a strong, yet underexploited potential to assist in the monitoring of protected areas.** However, the data generated need to be utilized more effectively to enable better management of the condition of protected areas and their surroundings, prepare for climate change, and assist planning for future landscape management (Nagendra *et al.* 2013). More interaction between the remote sensing and conservation community is needed to fine-tune the site managers needs in terms of remote sensing products. This interaction is also needed because most RS products are not perfect and need to be exploited in the appropriate manner by ecologists and terrain managers. The RS community needs to simplify access to the original imagery and derived products to make the full potential of RS available for the TM community (Geller *et al.* in Walters and Scholes, 2017).

**Remote sensing is generally most useful when combined with in situ observations and ecological knowledge.** The in-situ observations are needed as ground-truth to enable training of the classifications and for assessing RS accuracy. RS can provide excellent synoptic spatial and temporal coverage, for example, though its usefulness may be limited by pixel size which may be too coarse for some applications. On the other hand, in-situ measurements are made at very fine spatial scales but tend to be sparse and infrequent, as well as difficult and relatively expensive to collect. Combining RS and in-situ observations takes advantage of their complementary features (Geller *et al.* in Walters and Scholes, 2017). Finally, remote sensing data can also be collected from terrains where in-situ measurements are difficult.

**Remote sensing plays a major role in mapping and understanding (terrestrial) biodiversity.** It is the basis of most land cover/land use maps, provides much of the environmental data used in species distribution modelling, can characterise ecosystem functioning, assists in ecosystem service assessment, and is beginning to be used in genetic analyses. RS data are usually combined with physical data such as elevation or climate (which in fact may be derived from RS data) and, increasingly, with socio-economic data (Geller *et al.* in Walters and Scholes, 2017).

### Key findings

- » Remote Sensing holds promise as a supporting technique for Natura 2000 habitat monitoring
- » Remote sensing has a strong, yet underexploited potential to assist in the monitoring of protected areas.
- » Remote sensing is generally most useful when combined with in situ observations and ecological knowledge
- » Remote sensing plays a major role in mapping and understanding (terrestrial) biodiversity

Early applications pertained to the stereoscopic visual interpretation of aerial photography and were a great step forward in vegetation monitoring. More recently, satellite imagery with a large range of spatial and temporal resolutions is available and enables applications for entire ecosystems. Traditional vegetation mapping methods that use visual interpretation of aerial photography in combination with field surveys are, and have always been, working very well. But they are often also labour intensive and temporal frequencies are low, while policies are currently demanding higher temporal monitoring frequencies. Therefore, terrain and nature managers are looking for alternatives that can support the mapping and monitoring of vegetation in more efficient ways.

### 11.3.1 Current limitations

#### Mutual understanding and technical skills

An important barrier for site or terrain managers (TM) to use RS products is dealing with the **“unknown” of RS products**. A lot of people are still reluctant to use these tools (scepticism about technological innovation) which is slowing down their take-up for nature conservation management. For them RS techniques are mainly related to scientific purposes. For others, there is just an over-expectation of their results. So overall, there is a lack of understanding on the utility of these RS products/tools. Therefore it is needed to engage terrain managers in using RS products so they understand the possibilities and limitations of the RS products and tools. Why change your daily work routine if it works as you do now? It is often not (directly) clear what it could mean in their daily work. A huge difference exists between what can be done versus what is needed/expected by terrain managers (TM). Communication and mutual understanding between TM and RS community is of utmost importance. In order to resolve misunderstandings and perceived mismatches, increased cooperation and communication between producers and final users is needed. On the one hand, this can be achieved by setting up facilities for an enhanced sharing of ideas and results. On the other hand, end-users need to get involved in the development of remote sensing products as early as possible (*Vanden Borre et al., 2011b*).

Next to these barriers of mutual understanding there are **limitations of more technical nature**. The products are sometimes too complex and not easy to understand as the huge amount of data make it not easy to analyse the data and recognize the patterns. Remote sensing, as a science, is a very diverse field. For site managers mostly unfamiliar with the large variety of imagery and methodologies that are available, it will be impossible for them to find the most suitable method for their needs. Next to that, the specific requirements and applications in the field of habitat monitoring are equally diverse. Standardised RS products will therefore rarely suit the specific requirements (*Vanden Borre et al., 2011b*). Furthermore, the RS products need to be interpreted for which specific skills (or training) are needed. Also the liability of image availability is often questioned, and the necessity to work with and to buy new (complex) software and hardware is also often seen as an obstacle.

#### Current limitations

- » Mutual understanding and technical skills
- » Costs of remote sensing products
- » Products mismatching expectations

## Costs

RS needs to be combined with field visit to train your classification and/or verify your products. This is one of the reasons why it is difficult to say if RS products are cheaper than field visits. Detailed cost-effectiveness studies in this area were not found. RS cannot completely replace field visits. Also RS products can be used to fill the data gaps between specific moments in which field visits took place.

The cost of RS products is nowadays mainly related to setting-up the IT infrastructure for storage and processing, the interpretation and calibration of the products.

Next to the costs discussion, RS products sometimes cannot be replaced by field visits. RS products can look back into time, i.e. show the historical situation if RS imagery is available, while field visits show only the current situation.

## Products mismatching expectations

Operational RS products at the regional/national scale are often focused on land cover/land use. The mapping and monitoring of the extent and quality of habitats in N2000 sites is limited compared to land cover and land use classifications. Moreover, legal regulations can hamper the use of remote sensing. For example, in the Netherlands habitat maps have to be derived from conventional vegetation maps, meaning that remote sensing is not allowed to replace traditional field surveys. On the other hand, remote sensing is still able to make more frequent updates in between the traditional updates implemented approximately once in 12 years. At the site level more examples are available regarding the added value of RS in habitat mapping. However, at e.g. plant species level (rare species) RS products are insufficient. In general it can be stated that large scale (and dynamic) habitats are more suitable for mapping by RS. The spatial resolution of the RS product must meet a certain 'intrinsic scale' that characterizes a specific habitat. This 'intrinsic scale' is habitat dependent (*Vanden Borre et al., 2011b*). As there are no standards defining spatial reference sizes for habitat mapping this knowledge gap makes standardisation of monitoring methodologies difficult. Matching appropriate RS observations to ecological processes or species distributions often requires a multi-scale approach where one spatial and temporal scale provides information on a portion of an ecological process or species' life-history while other scales are required to observe another portion (*Geller et al. in Walters and Scholes, 2017*). Another source for a mismatch of expectations mentioned by *Vanden Borre et al. (2011b)* is that habitat typologies are not harmonised making data compatibility and integration difficult. A standard habitat typology with a biotic and abiotic description could be of help to interchange remote sensing methods and products.



In *Corbane et al. (2015)* it is stated that the immense versatility of remote sensing technique and products has led to numerous potential approaches, but all of them are to a great extent affected by a series of potential flaws (*Grillo and Venora, 2011*):

- » the large variability in the quality of input variables in terms of their semantic, thematic and geometrical accuracy;
- » the possible variability of the spectral, spatial and temporal resolutions of the input datasets used across different studies;
- » the (non-) availability of remote sensing data and ancillary data, with standardized metadata formats and pre-processing protocols, which are a prerequisite for the transferability of the methods between the sites;
- » the (non-)availability of ground truth data in a suitable format for remote sensing applications (which differs from purely vegetation-based field mapping).

The difficulty of habitats mapping, in addition to the issues described above, is related to the following (see *Corbane et al., 2015*):

- » the mismatch between the tremendous progress in RS applications to habitat mapping and the capabilities of Thematic Mapper,
- » the difficulty to standardise monitoring methodologies due to the lack of typical surface area range in which most patches of a given habitat occur (see 'intrinsic scale'),
- » the broad definition of habitats or lack of a standardised typology (co-occurrence in mosaic patterns, based on descriptive information, heterogeneity (number of species involved)), and
- » the missing link between land cover and habitats.

Furthermore, it is recognised that small scale sites can be better mapped by field observations. Increasing the level of detail in which habitats are described/defined the more difficult they can be mapped by RS. Also RS products cannot fulfill the needs for habitat modelling.

A risk exists that excitement over the RS technologies, encouraged by donors keen to show their support for innovation, may lead to practitioners deciding on which tools to use before they have decided on what they want to measure. **Remote sensing therefore needs to be applied only when appropriate to the local situation and when it can be used to answer specific monitoring questions** (*Stephenson, 2019*). The decision to use technology should also be based on project objectives and the availability of appropriate budgets and technical skills (*Schmeller et al., 2017*).

### Summary of potential future developments for new other products

- » Increase of update frequency of products due to developments in processing and availability of imagery
- » Complete integration of remote sensing products with in-situ data (e.g. vegetation relevés, species presence)
- » Integrated camera systems (e.g. LiDAR and hyper-spectral)
- » Pocket drones with integrated camera systems that can do instantaneous habitat mapping
- » Non-disturbing drones
- » 'Everybody' has their own drone
- » Good & light batteries for drones
- » Toolboxes & apps with free available high resolution RS products (e.g. temperature, flooding, soil moisture, vegetation structure, land cover, etc.) accessible, and all in one projection
- » All RS products downloadable for own (further) processing



### II.3.2 Future outlook

At the moment RS products and/or tools are mostly used by site managers for comparing sites, transferring knowledge across sites, early warning of effects of change in/outside the N2000 sites etc. For this they most commonly use aerial photos. To enhance the integration of remote sensing and habitat monitoring *Vanden Borre et al. (2011)* mentioned harmonisation and standardisation of approaches, development of readily useful products, and a fair validation of traditional and remote sensing products. Most importantly though, there is a need for a more active involvement from both parties, especially the monitoring community, in order to develop products that really suit the needs of their future users.

In the realisation of these potential products cloud processing/storage, better viewing tools and the application of machine learning (ML) will play a significant role.

## II.4 References

- Akay, A.E., H. Oğuz, et al. (2008). Using LiDAR technology in forestry activities. *Environmental Monitoring and Assessment*: 1–9.
- Alkema (2019). Aerial Plant Recognition Through Machine Learning; A deep learning approach to identifying marsh marigold (*Caltha palustris*) from UAV imagery in Biesbosch National Park, the Netherlands. Thesis Report GIRS-2019-24, Wageningen University, Wageningen.
- Bengio, Y., Simard, P. & Frasconi, P. (1994). Learning long-term dependencies with gradient descent is difficult. *IEEE Transactions on Neural Networks*. Volume 5 Issue 2, March 1994, Pages 157–166.
- Bradbury, R.B., Hill, R.A., Mason, D.C., Hinsley, S.A., Wilson, J.D., Baltzer, H., Anderson, G.Q.A., Whittingham, M.J., Davenport, I.J. & Bellamy, P.E. (2015). Modelling relationships between birds and vegetation structure using airborne LiDAR data: a review with case studies from agricultural and woodland environments. *IBIS* 147 (3).
- Bunce, R.G.H., Bogers M.M.B., Evans, D., Halada, L., Jongman, R.H.G., Mucher, C.A., Bauch, B., de Blust, G., Parr T.W. & Ols-vig-Whittaker L. (2013). The significance of habitats as indicators of biodiversity and their links to species. *Ecological Indicators*, Special Issue: Biodiversity Monitoring, Vol. 33 (2013) 19–25.
- Carson, W. W., H. E. Andersen, et al. (2004). LiDAR applications in forestry – An overview, Denver, Colorado.
- Christian, B. & Krishnappa, N.S.R. (2009). Classification of tropical trees growing in a sanctuary using Hyperion (EO-1) and SAM algorithm. *Current Science*, 96, 1601–1607.
- Corbane, C., Lang, S., Pipkins, K., Alleaume, S., Deshayes, M., García Millán, V.E., Strasser, T., Vanden Borre, J., Spanhove, T. & Förster, M. (2015). Remote sensing for mapping natural habitats and their conservation status – New opportunities and challenges. *International Journal of Applied Earth Observation and Geoinformation* 37 (2015) 7–16.
- Dobson, M.C., et al. (1995). Estimation of forest biophysical characteristics in northern Michigan with SIR-C/X-SAR, *IEEE Trans. Geosci. Remote Sens.*, 33, 877–895, doi:10.1109/36.406674
- Donoghue, D.N.M. & Watt, P.J. (2006). Using LiDAR to compare forest height estimates from IKONOS and Landsat ETM+ data in Sitka spruce plantation forests. *Int. J. Remote Sens.* 27(11): 2161–2175.
- EC (1979). Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds. Document 31979L0409.
- EC (1992). The Habitats Directive, Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.

### Possible new products in the near future having different opportunities for realization

- » Remote sensing based habitat maps for most Annex I habitat types (Natura 2000)
- » Habitat maps every 6 years from RS (with 10m resolution)
- » Species mapping with drones
- » RS measures of abiotic site conditions (soil moisture, temperature, trophic levels, salinity)
- » High resolution LiDAR products for vegetation structure everywhere including individual trees, height and diameter trees, and dead wood
- » RS derived alert services
- » Copernicus products linked to ecosystem and climate services

- EC (2009). The Birds Directive , Directive 2009/147/EC on the conservation of wild birds.
- EC (2005).
- ETC-BD (2018).
- Evans, D.L., Roberts, S.D., et al. (2006). LiDAR – A new tool for forest measurements? *Forestry Chronicle* 82(2): 211–218.
- Feranec, J., Soukup, T., Hazeu, G. & Jaffrain, G. (2016). *European Landscape Dynamics: CORINE Land Cover Data*. CRC Press, Boca Raton, 337 Pages – 52 Color & 45 B/W Illustrations, ISBN 9781482244663
- Florian, K., Kostas, P. P. Irena, H. & Dirk, H. (2006). Forest height estimation in tropical rain forest using Pol-InSAR techniques, paper presented at International Conference on Geoscience and Remote Sensing Symposium, IEEE, Denver.
- Gerard, F., Thompson, A., Manchester, S., Smith, G., Wadsworth, R., Swetnam, S., Petit, S., Gregor, M., Luque, S., Huitu, H., Köhler, R., Olschofsky, K., Hazeu, G., Múcher, C.A., Halada, L., Bugár, G. & Pino, J. (2006). Land Cover Change in Europe from the 1950's to 2000. Aerial photo interpretation and derived statistics from 59 samples distributed across Europe. Edited by Raul Köhler, Konstantin Olschofsky and France Gerard.. Book published by University of Hamburg, World Forestry Institute, Germany. ISBN 80- 89088-46-5, 364 pp.
- Gerard, F., Petit, S., Smith, G., Thomson, A., Brown, N., Manchester, S., Wadsworth, R., Bugar, G., Halada, L., Bezák, P., Boltziar, M., Badts, E., Gregor, M., Hazeu, G., Múcher, C.A., Wachowicz, M., Huitu, Tuominen, S., Köhler, R., Olschofsky, K., Ziese, H., Kolar, J., Sustera, J., Luque, S., Pino, J., Pons, X., Roda, F., Roscher, M. & Feranec, J. (2010). Land cover change in Europe between 1950 to 2000 determined employing aerial photography. *Progress in Physical Geography*, Vol. 34(2), 2010, pp. 183–205.
- Graf, R.F., Mathys, L., et al. (2009). Habitat assessment for forest dwelling species using LiDAR remote sensing: Capercaillie in the Alps. *Forest Ecology and Management* 257(1): 160–167.
- Grillo, O. & Venora, G. (2011). Biodiversity Loss in a Changing Planet, URL <http://www.intechweb.org/books/show/title/biodiversity-loss-in-a-changing-planet>.
- Hayashia, M., Saigusaa, N., Ogumab, H. & Yamagata, Y. (2013). Forest canopy height estimation using ICESat/GLAS data and error factor analysis in Hokkaido, Japan. *ISPRS Journal of Photogrammetry and Remote Sensing* 81, 12–18.
- Hazeu, G.W., J.A. Klijjn, W. Knol & E.J. Lammerts (2002). Een eiland in beweging; veranderingen in het Terschellinger landschap over anderhalve eeuw aan de hand van oude topografische kaarten en luchtfoto's. Wageningen, Alterra. Alterra-rapport 501, 72 blz, 19 fig.; 5 tab; 31 ref.
- Hazeu, G.W., Milenov, P., Pedroli, B., Samoungi, V., van Eupen, M. & Vassilev, V. (2014). High Nature Value farmland identification from satellite imagery, a comparison of two methodological approaches. *International Journal of Applied Earth Observations and Geoinformation* 30, 98–112.
- He, K.S., Rocchini, D., Neteler, M. & Nagendra, H. (2011). Benefits of hyperspectral remote sensing for tracking plant invasions. *Diversity and Distributions*, 17, 381–392.
- Hestir, E.L., Khanna, S., Andrew, M.E., Santos, M.J., Viers, J.H., Greenberg, J.A., Rajapakse, S.S. & Ustin, S.L. (2008). Identification of invasive vegetation using hyperspectral remote sensing in the California Delta ecosystem. *Remote Sensing of Environment*, 112, 4034–4047.
- Heymann, Y., Steenmans, C., Croisille, G. & Bossard, M. (1993). *CORINE land cover project: technical guide*. Luxembourg: European Commission, Environment, Nuclear Safety and Civil Protection.
- Jongman, R.H.G., Bunce, R.G.H., Metzger, M.J., Múcher, C.A., Howard, D.C. & Mateus, V.L. (2006). Objectives and applications of a statistical environmental stratification of Europe. *Landsc. Ecol.* 21, 409–419.
- Joshi, N.P., Mitchard, E.T.A., Schumacher, J., Johannsen, V.K., Saatchi, S. & Fensholt, R. (2015). L-Band SAR Backscatter Related to Forest Cover, Height and Aboveground Biomass at Multiple Spatial Scales across Denmark. *Remote Sens.*, 2015, 7, 4442-4472.
- Kennedy, R. E., Townsend, P. A., Gross, J. E., Cohen, W. B., Bolstad, P., Wang, Y. Q., et al. (2009). Remote sensing change detection tools for natural resource managers: Understanding concepts and tradeoffs in the design of landscape monitoring projects. *Remote Sensing of Environment*, 113, 1382–1396.

- Kerr, J. T. & Ostrovsky, M. (2003). From space to species: Ecological applications for remote sensing. *Trends in Ecology and Evolution*, 18, 299–305.
- Lengyel, S., Déri, E., Varga, Z., Horváth, R., Tóthmérész, B., Henry, P.-Y., Kobler, A., Kutnar, L., Babij, V., Seliškar, A., Christia, C., Papastergiadou, E., Gruber, B. & Henle, K. (2008). Habitat monitoring in Europe: a description of current practices. *Biodivers. Conserv.* 17, 3327–3339.
- Lillesand, T.M., Kiefer, R.W. & Chipman, J.W. (2015). *Remote sensing and image interpretation*. Seventh edn. Hoboken, N.J.: John Wiley & Sons.
- Lu, S., Shimizu, Y., Ishii, J., Funakoshi, S., Washitani, I. & Omasa, K. (2009). Estimation of abundance and distribution of two moist tall grasses in the Watarase wetland, Japan, using hyperspectral imagery. *ISPRS Journal of Photogrammetry and Remote Sensing*, 64, 674–682.
- Lucas, R.M., Blonda, P., Bunting, P.F., Jones, G., Inglada, J., Arias, M., Kosmidou, V., Petrou, Z., Manakos, I., Adamo, M., Charnock, R., Tarantino, C., Múcher, C.A., Kramer, H., Jongman, R., Honrado, J. & Mairota, P. (2015). The Earth Observation Data for Habitat Monitoring (EODHaM) System. *International Journal of Applied Earth Observation and Geoinformation* 37 (2015) 17–28.
- Mallet, C. & Bretar, F. (2009). Full-waveform topographic lidar: State-of-the-art. *ISPRS Journal of Photogrammetry and Remote Sensing*, 64 (1), 1–16.
- Mora, B., Wulder, M.A., White, J.C. & Hobart, G. (2013). Modeling Stand Height, Volume, and Biomass from Very High Spatial Resolution Satellite Imagery and Samples of Airborne LiDAR. *Remote Sens.* 2013, 5, 2308–2326.
- Múcher, C.A., Kramer, H., van der Wijngaart, R. & Huiskes, R. (2017a). Ontwikkelen Remote Sensing monitoringssystematiek voor vegetatiestructuur. Pilot studie: detectie verruiging Grijze Duinen (H2130) voor het Natura 2000-gebied Meijendel-Berkheide. Wageningen, Wageningen Environmental Research, Rapport 2838, 46 pp.
- Múcher, C.A., Calders, K., Zisis, I.S. & Reiche, J. (2017b). Ecosystem Structure. Chapter 2.5 of Biodiversity Sourcebook. In: *GOFC-GOLD (2017) A Sourcebook of Methods and Procedures for Monitoring Essential Biodiversity Variables in Tropical Forests with Remote Sensing*. Eds: GOFC-GOLD & GEO BON. Report version UNCBD COP-13, GOFC-GOLD Land Cover Project Office, Wageningen University, The Netherlands. ISSN: 2542–6729.
- Múcher, C.A., Roupioz, L., Kramer, H., Bogers, M.M.B., Jongman, R.H.G., Lucas, R.M., Petrou, Z., Kosmidou, V.E., Manakos, I., Padoa-Schioppa, E., Adamo, M. & Blonda, P. (2015). Synergy of Airborne LiDAR and Worldview-2 satellite imagery for land cover and habitat mapping: a BIO\_SOS-EODHaM case study for the Netherlands. *International Journal of Applied Earth Observation and Geoinformation* 37 (2015) 48–55.
- Múcher, C.A., Kooistra, L., Vermeulen, M., Vanden Borre, J., Haest, B. & Haveman, R. (2013). Quantifying structure and function of Natura 2000 heathland habitats using spectral mixture analysis and segmentation techniques on hyperspectral imagery. *Ecological Indicators*, Special Issue: Biodiversity Monitoring, Vol. 33 (2013) 71–81.
- Múcher, C. A. (2009). *Geo-spatial modelling and monitoring of European landscapes and habitats using remote sensing and field surveys*. Ph.D. thesis, Wageningen University.
- Múcher, C. A., Steinnocher, K. T., Kressler, F. P. & Heunks, C. (2000). Land cover characterization and change detection for environmental monitoring of pan-Europe. *International Journal of Remote Sensing*, 21, 1159–1181.
- Nagendra, H., Lucas, R., Honrado, J. P., Jongman, R. H. G., Tarantino, C., Adamo, M. & Mairota, P. (2013). Remote Sensing for Conservation Monitoring: Assessing Protected Areas, Habitat Extent, Habitat Condition, Species Diversity, and Threats. *Ecological Indicators* 33 (2013).
- Papathanassiou, K.P., Kugler, F., Lee, S., Marotti, L. & Hajnsek, I. (2008). Recent advances in Polarimetric SAR Interferometry for forest parameter estimation, paper presented at Radar Conference 2008, IEEE, Rome.
- Petros Patias, Natalia Verde, Maria Tassopoulou, Charalampos Georgiadis & Dimitris Kaimaris (2019). Essential Variables: Describing the context, progress and opportunities for the Remote Sensing Community. *Proceedings Volume 11174, Seventh International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2019); 111740C (2019)*, <https://doi.org/10.1117/12.2533604>. Event: Seventh International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2019), 2019, Paphos, Cyprus.
- Rosso, P.H., Ustin, S.L. & Hastings, A. (2005). Mapping marshland vegetation of San Francisco Bay, California, using hyperspectral data. *International Journal of Remote Sensing*, 26, 5169–5191.

- Schmeller, D.S. (2008). European species and habitat monitoring: where are we now? *Biodivers. Conserv.* 17, 3321–3326.
- Schmeller, D.S., Böhm, M., Arvanitidis, C., Barber-Meyer, S., Brummitt, N., Chandler, M. et al. (2017). Building capacity in biodiversity monitoring at the global scale. *Biodiversity and Conservation* 26: 2765–2790.
- Skidmore, A.K., Pettorelli, N., Coops, N.C., Geller, G.N., Hansen, M., Lucas, R., Múcher, C.A., O'Connor, B., Paganini, M., Pereira, H.M., Schaepman, M.E., Turner, W., Wang, T. & Wegmann, M. (2015). Agree on biodiversity metrics to track from space. *NATURE*, 23 July 2015, Vol. 523, pp 403–405.
- Stephenson, P.J. (2019). Integrating Remote Sensing into Wildlife Monitoring for Conservation. *Environmental Conservation*.
- St-Onge, B., Vepakomma, U., Hu, Y., Wulder, M., Wynne, R. & Nelson, R.F. (2005). Mapping above ground forest biomass using lidar data and multispectral images.
- Srivastava, R.K., Greff, K. & Schmidhuber, J. (2015). Training very deep networks. *International Conference on Learning Representations*.
- Swain, Ph. H. & Davis, S.M. (Eds) (1978). *Remote Sensing: The Quantitative Approach*. NewYork: McGraw-Hill, 396pp.
- Treuhaft, R.N. & Siqueira, P.R. (2000). The vertical structure of vegetated land surfaces from interferometric and polarimetric radar. *Radio Science* 25, 141–177.
- Turner, W., Spector, S., Gardiner, N., Fladeland, M., Sterling, E. & Steininger, M. (2003). Remote sensing for biodiversity science and conservation. *Trends in Ecology and Evolution*, 18, 306–314.
- Ustin, S.L., Roberts, D.A., Gamon, J.A., Asner, G.P. & Green, R.O. (2004). Using Imaging Spectroscopy to Study Ecosystem Processes and Properties. *BioScience*, 54.
- Vanden Borre, J., Haest, B., Lang, S., Spanhove, T., Förster, M. & Sifakis, N. I., (2011a). Towards a wider uptake of remote sensing in Natura 2000 monitoring: Streamlining remote sensing products with users' needs and expectations.
- Vanden Borre, J., Paelinckx, D., Múcher, C. A., Kooistra, L., Haest, B., De Blust, G. & Schmidt, A. M. ( 2011b). Integrating remote sensing in Natura 2000 habitat monitoring: Prospects on the way forward. *Journal for Nature Conservation*, 19(2), 116–25. doi:10.1016/j.jnc.2010.07.003.
- Van der Zanden, E.H., Verburg, P.H. & Múcher, C.A. (2013). Modelling the spatial distribution of linear landscape elements in Europe. *Ecological Indicators* 27, 125–136.
- Vaz, A.S., Marcos, B., Goncalves, J., Monteiro, A., Alves, P., Civantos, E. & Honrado, J.P. (2015). Can we predict habitat quality from space? A multi-indicator assessment based on an automated knowledge-driven system. *International Journal of Applied Earth Observation and Geoinformation*, 37, 106–113. doi:10.1016/j.jag.2014.10.014
- Walsh, S.J., Mcclary, A.L., Mena, C.F., Shao, Y., Tuttle, J.P., Gonzalez, A. & Atkinson, R. (2008). QuickBird and Hyperion data analysis of an invasive plant species in the Galapagos Islands of Ecuador: Implications for control and land use management. *Remote Sensing of Environment*, 112, 1927–1941.
- Walters, M. & Scholtes R.J. (eds.) (2017). *The GEO Handbook on Biodiversity Observation Networks*.
- Weis and Banko (2018). *Ecosystem Type Map v3.1 – Terrestrial and marine ecosystems*. Technical paper N° 11/2018, EEA, European Topic Centre on Biological Diversity.

## Annex I: Examples of useful satellite imagery

Satellite sensor	Launch	Number of bands	Spatial resolution [m]	Revisit time (days)	Biophysical parameters
<b>WorldView-2</b>	2009	8 (B,G,R,coastal, yellow,NIR,Red-Edge, NIR2)	0.46 (pan) 1.8 (ms)	1.1	Reflection, NDVI, LAI, leaf chlorophyll (and nitrogen) concentration Classification
<b>WorldView-3</b>	2014	8 (B,G,R,coastal, yellow,NIR, RedEdge,NIR2) 8 SWIR 12 CAVIS	0.31 (pan) 1.24 (ms) 3.7 (short wave IR)	<1	Reflection, NDVI, LAI, leaf chlorophyll (and nitrogen) concentration Classification
<b>QuickBird</b>	2001	4 (B,G,R,NIR)	0.65 (pan) 2.6 (ms)	1-3.5	Reflection, NDVI, LAI Classification
<b>GeoEye-1</b>	2008	4 (B,G,R,NIR)	0.4 (pan)	~3	Reflection, NDVI, LAI
<b>GeoEye-2 (WorldView-4)</b>	2016		0.3 (pan) 1.2 (ms)	<3	Reflection, NDVI, LAI, leaf chlorophyll (and nitrogen) concentration Classification
<b>Ikonos</b>	1999	4 (B,G,R,NIR)	1 (pan) 4 (ms)		Reflection, NDVI, LAI Classification
<b>RapidEye (5 satellite constellation)</b>	2008	5 (B,G,R,NIR, RedEdge)	5 (ms)	1	Reflection, NDVI, LAI, leaf chlorophyll (and nitrogen) concentration Classification
<b>Pleiades-1A &amp; B (2 satellite constellation)</b>	2011/2012	4 (B,G,R,NIR)	0.5 (pan) 2 (ms)	1	Reflection, NDVI, LAI Classification
<b>SkySat-1 &amp; 2</b>	2013/2014	4 (B,G,R,NIR)	0.9 (pan) 2 (ms)		
<b>SPOT-6 &amp; 7 constellation</b>	2012/2014	4 (B,G,R,NIR)	1.5 (pan) 8 (ms)	1	
<b>Landsat-8</b>	2013	11 (VNIR,SWIR,TIR)	15 (pan) 30m (ms) 100m (TIR)	16	Reflection, NDVI, LAI, temperature Classification
<b>Aster</b>	1999	3, 6, 5 (VNIR,SWIR,TIR)	15 (VNIR) 30 (SWIR) 90 (TIR)		
<b>Sentinel-2A &amp; B (2 satellite constellation)</b>	2015/2016	13 (VNIR, NIR, SWIR)	10, 20, 60	< 5	Reflection, NDVI, LAI, leaf chlorophyll (and nitrogen) concentration Classification

*B: blue; G: green; R: red; NIR: near infrared; pan: panchromatic; ms: multi-spectral; VNIR: visible and near infrared; SWIR: shortwave infrared; TIR: thermal-infrared*

Different satellite sensors are acquiring information with different spectral, temporal and spatial resolution making them suitable for monitoring specific biophysical parameters.



CHAPTER A.III.

# Access to data and information

Anne Schmidt, Chris van Swaay, Rene Henkens and Peter Verweij

## III.1 Introduction

*Biodiversity information is based on data that is gathered by a mixed, large group of people. Professionals and nature enthusiasts observe and record nature, either using protocols in field studies, [remote sensing](#) and [monitoring schemes](#), or via opportunistic sightings. Despite this seeming abundance in data availability, decision- and policy-makers are constrained by the lack of targeted data and indicators, mostly as a result of barriers preventing existing data from being found and accessed, or by missing forms of presentation that answer questions of policy makers and practitioners (Verweij et al., 2019; Geijzendorffer et al., 2016; Addison, 2015; Wetzel et al., 2015; Proença et al., 2017).*

### III.1.3 Different types of data and information sources

There is a wide range of data and information sources available, including citizen-science data collections, monitoring data collections and networks, GIS-data repositories, research infrastructures for open data, synthesis of scientific knowledge and community interfacing platforms aspiring to bring the science and policy-making communities closer together. The variety of sources can be categorized in three main categories (see Box "Types of data and information sources").

### III.1.4 Barriers to sharing of biodiversity data and information

The World Conservation Monitoring Centre (WCMC) of the United Nations Environmental Programme (UNEP) conducted a review on the barriers to sharing of biodiversity data and information and made recommendations for eliminating them (UNEP, 2012). Although progress has been made since 2012, most of the barriers identified by the WCMC of UNEP still exist, namely:

- » **Psychological and behavioural barriers**, which range from unwillingness to share for commercial reasons to barriers resulting from concerns over how data, information and knowledge might be used, as well as legal barriers.
- » **Barriers related to describing information and data**, which range from a lack of widely agreed classification systems for some types of biodiversity, to insufficient use of contextual and explanatory information linked to datasets.
- » **Practical barriers**, which range from knowing how to make data, information and knowledge you hold available in meaningful ways, to locating the information that you need from amongst plethora of data, information and knowledge available.

#### Definition of data, information and indicators

Biodiversity **data** are pieces of information collected through observations or generated via modelling. More technically, data is a set of numerical or qualitative values to describe variables about an individual, or object, including space and time. Data become **information** when the values get a meaning in some context for the receiver.

**Indicators** summarize or simplify relevant information and play an important role in communicating on the status and trends of nature in such a way that these are useful for decision making, e.g. by relating them to specific management goals and policy targets (Gallopín, 1996).

#### Types of data and information sources

There is a wide range of data and information sources available which can largely be grouped in **(1) data lakes** (contains raw, non-harmonised data), **(2) data platforms** (a system that enables integration of harmonised data in other similar datasets and uses a quality checked, sometimes open-access, data repository, to which, preferably, peer-reviewed articles are attached for proof of data quality) and **(3) indicator catalogues**. Data lakes and data platforms target data analysts. Indicators catalogues aim to provide condensed information in the form of indicators with accompanying narratives and references.

- » **Inadequate strategies and resources** that result in data, information and knowledge often being made available in an opportunistic manner rather than being focused on need, often without sufficient resources being made available.

There are different types of solutions to remove these barriers and actions need to be taken by different stakeholders. Governments need to provide funding for information resources and maintenance of infrastructures and develop open data and research policies. Publishers should increase open access to publications and encourage the publication of data papers. Knowledge brokers should develop information infrastructures or repositories for ensuring long term access to data, information and knowledge and further promote the use of common vocabularies, classification systems and standards. The academic world should promote and create incentives to increase access to data and information. Donors and others providing support should ensure that each funded project provides appropriate access to the data and information and promote longer-term investment in the maintenance of data and information resources and funding of knowledge management and dissemination.

**In some cases the access to data and information is not the problem, but the willingness to use the available data and information. There might be different reasons for this amongst others the scepticism towards using data collected by volunteers.**

### III.1.5 Data and information needed for the implementation of the Birds and Habitats Directive

For the implementation of the Birds and Habitats Directive data and information are needed on the species and the habitat types targeted by these directives. This concerns data and information on the distribution and population size of species, the area and quality of the habitat for species and, the distribution, area and structure and function (quality) of habitat types. In addition, data and information are needed on the impact of pressures and threats and the effects of mitigation and restoration measures [\[see chapter B.I. Guidance and tools for effective restoration measures for species and habitats\]](#).

The data and information serve different purposes, amongst others the selection and designation of Natura 2000 sites, the management of Natura 2000 sites, appropriate assessments for permitting procedures and conservation status assessments for reporting. This **means data and information is needed on different spatial scale levels ranging from local level to Natura site level, Natura 2000 network, biogeographical, national and European level**. The user requirements e.g. in terms of the spatial-temporal coverage and resolution of the data differ depending on the purpose. Where management plans need information in detailed maps almost at the square meter, the species and habitat distribution maps for the Article 17 reporting only needs to be done in squares of 10x10km. **The idea to collect data on multiple scale levels for multiple purposes seems logical, but in practice this is not always feasible as each monitoring objective requires a specific sampling strategy** [\[see chapter A.I. Monitoring\]](#). Due to budget constraints priorities need to be set.

**Opportunistic data collected by volunteers seem very attractive as the costs of collecting this type of data are low. Nevertheless, a lot of time and effort is spent on validating and harmonizing these data** (Dobson *et al.*, 2016). Even in successful online web portals, as iNaturalist.org and observation.org, recorders tend to go to the same places and sometimes it even gets crowded with volunteers at a well-known spot, where similar spots in the surroundings are missed. **It requires active participation from experts to try and direct ('lure') recorders into visiting unvisited places.** At the end this also requires time and money, which should not be ignored when setting up such systems or using existing ones.

## III.2 Strategies, approaches and practical examples to improve data and information access

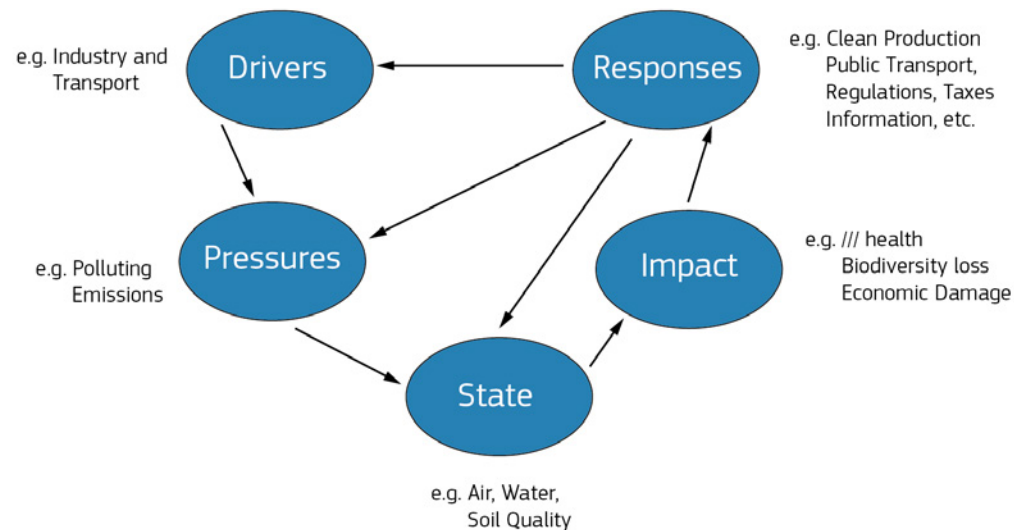
### III.2.1 Frameworks, common vocabularies and classification systems

**In order to facilitate the exchange of biodiversity data and information there should be a common understanding on the type of data and information that are needed by the different users (policy makers, practitioners and scientists).** The Birds and Habitats Directives are important instruments to preserve and restore European biodiversity, but there is more to it than that. The Convention on Biological Diversity and the European Biodiversity Strategy have a broader perspective on biodiversity including for example ecosystem services. In the following paragraphs some examples are given of frameworks and classification systems to define and describe the data and information with this broader perspective in mind.

#### DPSIR framework: drivers, pressures, states, impacts and responses

The DPSIR model (see Figure III.1) adopted by the European Environmental Agency is a causal framework for describing the interactions between society and the environment. **The DPSIR framework serves as a starting point for the development of indicators to evaluate environmental policies such as the Birds and Habitats Directives.**

**The way the conservation status of species and habitats is assessed fits into the DPSIR framework.** Conservation status is being assessed based on several state variables (e.g. the distribution and population size of species), that are influenced by pressures resulting from different drivers (e.g. pollution from agriculture) and by policy and management responses acting upon them (e.g. measures to reduce pollution from agriculture). State indicators ideally are derived from observational data, whereas the impact of pressures and the effects of conservation measures – in most cases – are assessed based on directed research or expert judgement.



**Figure III.1**

DPSIR framework of the European Environmental Agency.

Source: [www.eea.europa.eu/publications/92-9167-059-6-sum/page002.html](http://www.eea.europa.eu/publications/92-9167-059-6-sum/page002.html)

### The concept of biodiversity

**In order to collect, exchange and/or integrate data from multiple sources it is important as well to develop a common vocabulary and unified classification systems, starting with the concept of biodiversity.** *Noss (1990)* distinguishes different components (composition, structure and function) and different levels of biodiversity (genes, species populations, communities, ecosystems and landscapes), see Figure III.2. **The components and levels of biodiversity to be addressed depend on the research, policy or management questions that need to be answered.**

**The Birds Directive and Habitats Directive are targeted on the level of ecosystems and communities (habitat types) and species populations (species).** Different components are being addressed on these levels for example the population structure of species and the structure and function of habitat types. Nevertheless for the implementation of the directives the other levels of biodiversity are relevant as well, for example genetic diversity is important for setting favourable reference values on population size of species.

### Essential Biodiversity Variables (EBVs)

The GEOBON network (<https://geobon.org/>) are developing the so called **Essential Biodiversity Variables (EBVs)**, that to a large extent are based on the hierarchical approach of monitoring biodiversity proposed by *Noss (1990)*. **The EBVs provide the first level of abstraction between low-level primary observations and high-level indicators of biodiversity** (see Figure III.3). There are 6 EBV classes with 21 EBV candidates (see Figure III.4).



The EBVs serve different purposes. They are applied to integrate data coming from different sources e.g. in-situ (field surveys and monitoring schemes) and ex-situ (remote sensing) measurements and to transform these data into biodiversity indicators relevant for biodiversity assessments and reporting. They might become the window into the biodiversity observation systems upon which researchers, managers and decision makers at different levels can better interact while they do their jobs. As illustrated in Figure III.3 EBVs concern state variables sensitive to change depending on drives, pressures and policy and management responses, that act upon them.

The EBV classes that are relevant for the Birds and Habitat Directives are species populations (e.g. species distribution and population abundance), ecosystem function (e.g. disturbance regime) and ecosystem structure (habitat structure, ecosystem extent and fragmentation). Whereas the monitoring of trends in distribution and population size of species seems quite well developed, the monitoring of the distribution and area of habitat types is quite challenging and even more the monitoring and assessment of the 'quality of the habitat for species' and the 'structure and function of habitat types' [see chapter A.I. Monitoring]. The further development of EBVs might be of help to harmonize the monitoring and assessment methods applied by different EU member states for the purpose of the implementation of the BD and HD.

## Identification and classification systems (code lists)

### a. Taxonomy: species identification and classification

Taxonomy is a scientific discipline that has provided the universal naming and classification system of biodiversity for centuries and continues effectively to accommodate new knowledge (Thomson *et al.*, 2018). The assumption that species are fixed entities underpins every international agreement on biodiversity conservation,

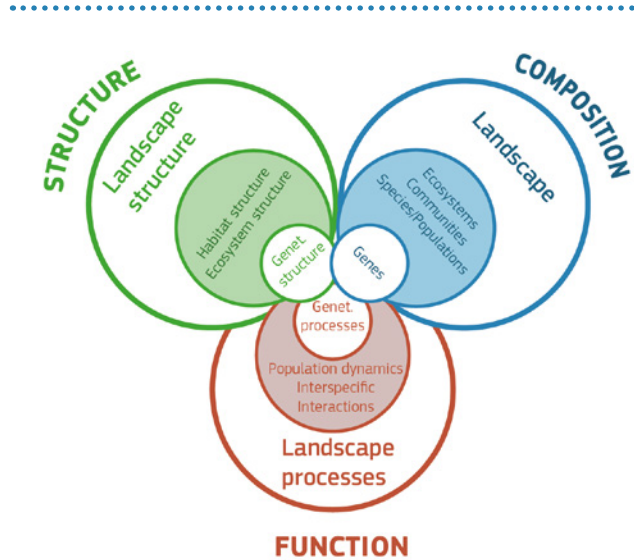


Figure III.2

Schematic visualisation of major biodiversity components (structure, composition, function) with hierarchical nested levels in each case (adapted after *Noss, 1990*). The coloured areas highlight the most feasible level, the level of diversity in species (species richness), within ecosystems and in population interactions.

Source: [www.researchgate.net/figure/Schematic-visualisation-of-major-biodiversity-components-structure-composition\\_fig1\\_281586657](http://www.researchgate.net/figure/Schematic-visualisation-of-major-biodiversity-components-structure-composition_fig1_281586657)

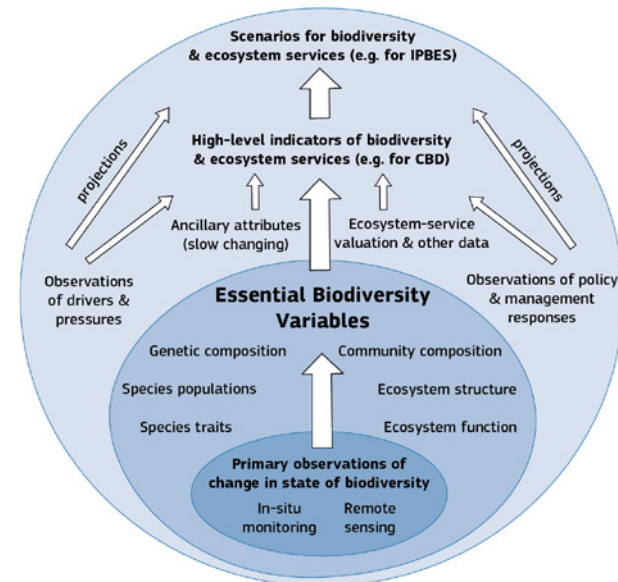


Figure III.3

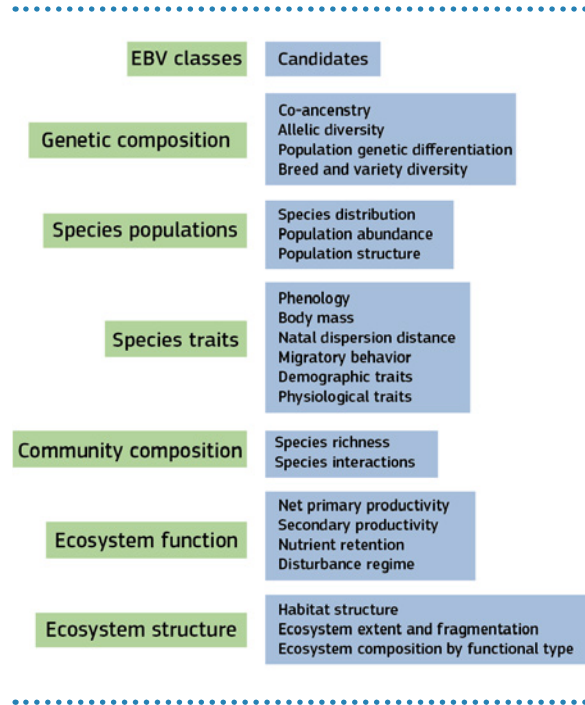
Essential Biodiversity Variables.

Source: [geobon.org/ebvs/what-are-ebvs](http://geobon.org/ebvs/what-are-ebvs)

all national environmental legislation and the efforts of many individuals and organizations to safeguard plants and animals (*Garnett and Christidis, 2017*). **New knowledge, sometimes caused by new techniques, can lead to a change in taxonomy.** Because of this species get split, lumped with other species, or are moved to another genus. This also applies to the species in the Annexes of the Habitats Directive, where e.g. *Hypodryas maturna* (see Figure III.5) from the original list was moved to the genus *Euphydryas*, and *Polyommatus eroides* is now considered a subspecies of the Alpine *Polyommatus eros*.

**To keep legislation in line with new knowledge in taxonomy, a decent backbone is needed describing the most up-to-date taxonomy. Users need standardised and continuously harmonised taxonomic reference systems, as well as high-quality and complete taxonomic data sets** (*De Jong et al. 2015*). Several initiatives have been launched to provide this:

- » **The Pan-European Species-directories Infrastructure (PESI)** provides a mechanism to deliver an integrated, annotated checklist of the species occurring in 'geographic Europe', aiming to cover the Western Palearctic biogeographic region. At the core of EU-nomen are five community networks, with common nomenclatures or systems designations: Zoology, Botany, Marine Biota, Mycology and Phycology (*De Jong et al., 2015*). The present status of PESI is unclear, as recent searches on the website ([www.eu-nomen.eu/pesi](http://www.eu-nomen.eu/pesi)) did not give decent results to all queries, also not for Habitat Directive species.
- » **EUNIS** ([eunis.eea.europa.eu/species.jsp](http://eunis.eea.europa.eu/species.jsp)) provides a website with information targeted at accessing information about species in Europe, particularly species mentioned in legal texts. However many species names appear not to be updated to the latest taxonomy.
- » **Fauna Europaea** ([fauna-eu.org](http://fauna-eu.org)) was supposed to become Europe's main zoological taxonomic index, also feeding into PESI (see above). However, due to financial constraints the information is not up-to-date anymore.
- » **EuroMed Plantbase** ([www.emplantbase.org/home.html](http://www.emplantbase.org/home.html)): The Euro+Med PlantBase provides an on-line database and information system for the vascular plants of Europe and the Mediterranean region, against an up-to-date and critically evaluated consensus taxonomic core of the species concerned. The Euro+Med PlantBase is part of the Pan-European Species directories Infrastructure (PESI), funded by the European Union under the Framework 7 Capacities Work Programme.



**Figure III.4**

EBV's classes and candidates.

Source: [www.earthobservations.org/uploads/438\\_2\\_essential\\_biodiversity\\_variable\\_strategy\\_v1.pdf](http://www.earthobservations.org/uploads/438_2_essential_biodiversity_variable_strategy_v1.pdf)



Figure III.5

*Euphydryas maturna*. Photo: Chris van Swaay from the Dutch Butterfly Foundation.

- » **WORMS** (World Register of Marine Species: the main taxonomic reference system for marine environment ([www.marinespecies.org](http://www.marinespecies.org)))
- » **Catalogue of Life** ([www.catalogueoflife.org](http://www.catalogueoflife.org)): The Catalogue of Life is the most comprehensive and authoritative global index of species currently available. It consists of a single integrated species checklist and taxonomic hierarchy. The Catalogue holds essential information on the names, relationships and distributions of over 1.8 million species. This figure continues to rise as information is compiled from diverse sources around the world. For Catalogue of Life a new infrastructure is currently being developed in the CoL+ project ([www.dissco.eu/catalogue-of-life](http://www.dissco.eu/catalogue-of-life)).

It is obvious from the above mentioned initiatives, that users will find it difficult to find their way in all these websites.

The **Darwin Core Standard (DwC)** offers a stable, straightforward and flexible framework for compiling biodiversity data from varied and variable sources. Originally developed by the Biodiversity Information Standards (TDWG) community, Darwin Core is 'an evolving community-developed biodiversity data standard. It plays fundamental role in the sharing, use and reuse of open-access biodiversity data ([www.gbif.org/darwin-core](http://www.gbif.org/darwin-core)). One of the cores is a Taxon core, which lists a set of species, typically coming from the same region or sharing common characteristics. This is an open-source way of standardizing taxa, used e.g. in GBIF ([gbif.org](http://gbif.org)).

## b. Ecosystem typologies: habitat identification and classification

Many ecosystem and habitat typologies exist ranging from local to global level. In the following paragraph some of the main typologies used on EU level are shortly described to start with the EU Habitat Directive Annex 1 habitat types. Translations are being made between these different typologies.

### EU Habitats Directive Annex I habitat types

The Habitat Directive Annex I lists today 233 European natural habitat types, including 71 priority (i.e. habitat types in danger of disappearance and whose natural range mainly falls within the territory of the European Union). Annex I was initially based on the hierarchical classification of European habitats developed by the CORINE Biotopes project since that was the only existing classification at European level. An Interpretation Manual describes the habitats but there is often variation between Member States in how they interpret the habitat types, sometimes there is variation between regions in the same country. There is a specific code list for identification of the habitat types, described as well for the Habitats Directive Article 17 reporting.



Figure III.6

Slovenia, Osrednjeslovenska, Brezovica 5, *Saxifraga-Hans Dekker*. Source: [www.freenatureimages.eu](http://www.freenatureimages.eu)

### EUNIS habitat classification

The EUNIS habitat classification is a comprehensive pan-European system for habitat identification. **The EUNIS habitat classification covers both natural and artificial pan-European habitats and groups them into 11 broad categories:**

- 1 Marine habitats
- 2 Coastal habitats
- 3 Inland surface waters
- 4 Mires, bogs and fens
- 5 Grasslands and lands dominated by forbs, mosses or lichens
- 6 Heathland, shrub and tundra
- 7 Woodland, forest and other wooded land
- 8 Inland unvegetated or sparsely vegetated habitats
- 9 Regularly or recently cultivated agricultural, horticultural and domestic habitats
- 10 Constructed, industrial and other artificial habitats
- 11 Habitat complexes

The habitat types are identified by specific codes, names and descriptions.



### The MAES ecosystem typology

The MAES project (MAES: Mapping and Assessment of Ecosystem and their Services) has proposed a typology that distinguishes 12 main ecosystem types based on the higher levels of the EUNIS Habitat Classification.

**The interpretation of ecosystem typologies is often complicated and even more so the mapping and monitoring of habitats** [\[see chapter A.I Monitoring of species and habitats\]](#). **Member States may use the same codes, but the interpretation and the mapping / monitoring and assessment methods differ leading to inconsistencies in the data and information being reported.**

### c. Classification systems for drivers, pressures, impact and responses

For the purpose of reporting the EC proposes classification systems and code lists are prescribed for the identification of pressures and threats and conservation measures. These classification systems are based on former classification systems such as proposed by *Salafsky et al. (2007)*. Differences exist between the classification systems and code lists of different directives, such as the Birds and Habitats Directives, the Water Framework Directive and Marine Strategy Framework Directive.

**Although unified classification systems for drivers, pressures, impact and responses (e.g. mitigation and conservation measures) exist, data and information are often lacking or inaccessible. The reporting formats of the Birds and Habitats Directives don't request evidence on pressures and threats in terms of quantitative data (e.g. trends).**

## III.2.2 Data portals and services

**A data portal on the internet acts as a 'gateway' to a series of other websites that deal with the same subject.** In some countries, national level web portals exist, which provide the ability to customise local projects to suit the needs and interests of key stakeholders at the same time as feeding into larger databases using standardised data collection and curation protocols. Examples include [Artportalen](#) in Sweden, the [Norwegian Biodiversity Information Centre](#), [waarneming.nl](#) and [telmee.nl](#) in the Netherlands and the [National Biodiversity Network](#) in the UK. These portals create a bridge between the needs of large Biodiversity Observation Networks and the needs of local stakeholders by reducing many of the barriers that hinder data flows. These portals provide many of the tools, systems access to expertise, feedback and other resources that otherwise make connecting local projects to global programs challenging (Chandler et al., 2017).

Next to these national gateways, [iNaturalist.org](#) and [observation.org](#) provide international data portals, making it possible for everyone in the world to enter any living organism in the world. Part of this data is uploaded to GBIF.



In the following paragraphs some examples are presented of global and European data portals and services, that are or might become of importance for the implementation of the Birds and Habitats Directives.

### GBIF – Global Biodiversity Information Facility

GBIF ([www.gbif.org](http://www.gbif.org)) is an **international network and research infrastructure** funded by the world's governments and aimed at providing anyone, anywhere, open access to data about all types of life on Earth.

The GBIF network of participating countries and organizations, provides data-holding institutions around the world with common standards and open-source tools that enable them to share information about where and when species have been recorded. This knowledge derives from many sources, including everything from museum specimens collected in the 18<sup>th</sup> and 19<sup>th</sup> century to geotagged smartphone photos shared by amateur naturalists in recent days and weeks.

The GBIF network draws all these sources together through the use of data standards, such as Darwin Core (DwC is meant to provide a stable standard reference for sharing information on biological diversity, *Wieczorek et al., 2012*), which forms the basis for the bulk of GBIF.org's index of 1,5 billion of species occurrence records. GBIF covers for instance over 500 million species occurrences for the participating countries in Europe. Publishers provide open access to their datasets using machine-readable [Creative Commons licence designations](#), allowing scientists, researchers and others to apply the data in hundreds of peer-reviewed publications and policy papers each year. Many of these analyses—which cover topics from the impacts of climate change and the spread of invasive and alien pests to priorities for conservation and protected areas, food security and human health—would not be possible without this. Currently, more than two peer-reviewed articles that use data discovered and accessed through GBIF are published every day of the year ([www.gbif.org/literature-tracking](http://www.gbif.org/literature-tracking)).

### The National Biodiversity Network UK

The National Biodiversity Network NBN ([nbn.org.uk](http://nbn.org.uk)) is a collaborative partnership created to exchange biodiversity information (see Figure III.7). The NBN Trust, the charity which oversees and facilitates the development of the Network, has a membership including many UK wild-life conservation organisations, government, country agencies, environmental agencies, local environmental records centres and many voluntary groups. Different tools are made available to record, share and explore data.



Figure III.7

NBN Data Flow Pathway. Source: [nbn.org.uk/wp-content/uploads/2015/10/Data-flow-pathway-headings-only.jpg](http://nbn.org.uk/wp-content/uploads/2015/10/Data-flow-pathway-headings-only.jpg).

## EVA – European Vegetation Archive

The European Vegetation Archive (EVA – [euroveg.org/eva-database](http://euroveg.org/eva-database)) is **an initiative of European Vegetation Survey aimed at establishing and maintaining a single data repository of vegetation-plot observations** (i.e. records of plant taxon co-occurrence at particular sites, also called phytosociological relevés) from Europe and adjacent areas and to facilitate the use of these data for non-commercial purposes, mainly academic research and applications in nature conservation and ecological restoration. The initiative follows the EVA Data Property and Governance Rules. It closely cooperates with the Global Index of Vegetation-Plot Databases (GIVD), the Global Vegetation Database (sPlot) and the Plant Trait Database (TRY).

EVA stores copies of national and regional vegetation-plot databases on a single software platform. By 30 June 2015, 61 databases from all European regions have joined EVA, contributing in total 1.027.376 vegetation plots, 82% of them with geographic coordinates, from 57 countries. EVA provides a unique data source for large-scale analyses of European vegetation diversity both for fundamental research and nature conservation applications (*Chytrý et al., 2016*).

## Copernicus

Copernicus ([www.copernicus.eu/en/services](http://www.copernicus.eu/en/services)) is the largest space data provider in the world, currently producing 12 terabytes per day. Copernicus is a **European Union Programme aimed at developing European information services based on satellite Earth Observation and in situ (non-space) data**. The Programme is coordinated and managed by the European Commission and implemented in partnership with the Member States, the European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for Medium Range Weather Forecasts (ECMWF), EU Agencies and Mercator Océan.

Vast amounts of global data from satellites and from ground based, airborne and seaborne measurement systems are being used to provide information to help service providers, public authorities and international organisations. The vast majority of data and information delivered by Copernicus are made available and accessible to any citizen and any organisation around the world on a free, full and open access basis.

**Copernicus analyses the data in a way that generates indicators useful for policy makers and end users, providing information on past, present and future trends.** They can analyse, for example, the air quality in our cities and detect visible and noticeable increases in air pollution (smoke, dust, smog) or analyse the rise in global sea levels.

## Monitoring portals

With the monitoring of more and more taxa spreading over Europe, there are now portals bringing together data and results for use at a higher level. So far the main portals are for birds (Pan-European Common Bird Monitoring Scheme: [pecbms.info](http://pecbms.info)) and butterflies (European Butterfly Monitoring Scheme: [butterfly-monitoring.net](http://butterfly-monitoring.net)). They summarize pan-European as well as EU-trends and indicators, providing a background for trends in Member States. In most cases the underlying data is also used by the member states for biodiversity reporting.

### III.2.3 Open data principles, policies and practices

As described by the WCMC some people and organisations are unwilling to share biodiversity data for various reasons, but there is a rising awareness that sharing data helps to improve the knowledge on the environment and may increase as well the effectiveness of human interventions to protect and preserve the environment. From the academic world there are different initiatives – often community driven – to improve access to data. Governments are developing and implementing policies for open data and research whereas the funding organisations demand the appropriate access to the data being collected in research projects. These initiatives and policies are contributing as well to improve the access to data and information (and knowledge) for the implementation of the Birds and Habitats Directives. In the next paragraphs some of these initiatives are presented.

#### GO FAIR

**GO FAIR is a bottom-up, stakeholder-driven and self-governed initiative that aims to implement the FAIR data principles ([www.go-fair.org/fair-principles](http://www.go-fair.org/fair-principles)), making data Findable, Accessible, Interoperable and Reusable (FAIR).** It offers an open and inclusive ecosystem for individuals, institutions and organisations working together through Implementation Networks (INs). The INs are active in three activity pillars: GO CHANGE, GO TRAIN and GO BUILD. The principles emphasise **machine-actionability (i.e., the capacity of computational systems to find, access, interoperate, and reuse data with none or minimal human intervention)** because humans increasingly rely on computational support to deal with data as a result of the increase in volume, complexity, and creation speed of data (*Wilkinson et al., 2016*).

#### Research Data Alliance (RDA)

**The Research Data Alliance ([www.rd-alliance.org](http://www.rd-alliance.org)) was launched as a community-driven initiative in 2013 by the European Commission, the US Government's National Science Foundation and National Institute of Standards and Technology, and the Australian Government's Department of Innovation with the goal of building the social and technical infrastructure to enable open sharing and re-use of data.**

RDA wants researchers and innovators to openly share data across technologies, disciplines, and countries to address the grand challenges of society. RDA's mission is to build the social and technical bridges that enable open sharing and re-use of data.

#### Open Data Directive

The Directive on open data and the re-use of public sector information, also known as the 'Open Data Directive' ([Directive \(EU\) 2019/1024](https://eur-lex.europa.eu/eli/dir/2019/1024/oj)) entered into force on 16 July 2019. Once fully transposed on the national level, the new rules will:

- » Stimulate the publishing of dynamic data and the uptake of **Application Programme Interfaces (APIs)**.

Network coherence is often addressed on the basis of:

- » assessment of landscape fragmentation, through indices
- » assessment of functionality of the landscape for particular species or ecosystems
- » assessment of corridors

- » Limit the exceptions which currently allow public bodies to charge more than the marginal costs of dissemination for the re-use of their data.
- » Enlarge the scope of the Directive to:
  - **data held by public undertakings**, under a specific set of rules. In principle, the Directive will only apply to data which the undertakings make available for re-use. Charges for the re-use of such data can be above marginal costs for dissemination;
  - **research data resulting from public funding** – Member States will be asked to develop policies for open access to publicly funded research data. New rules will also facilitate the re-usability of research data that is already contained in open repositories.
- » Strengthen the transparency requirements for public–private agreements involving public sector information, avoiding exclusive arrangements.

In addition, the Open Data Directive requires the adoption by the Commission (via a future implementing act) of a **list of high-value datasets to be provided free of charge**. These datasets, to be identified within a thematic range described in the Annex to the Directive, have a high commercial potential and can speed up the emergence of value-added EU-wide information products. They will also serve as key data sources for the development of Artificial Intelligence. Member States have to transpose Directive (EU) 2019/1024 by 16 July 2021.

### III.2.4 Information systems

Information systems bring together data and information from different sources and disseminate this information in a structured way for different types of users. They are oriented to a specific domain such as biodiversity and organised around certain user communities (governmental officials and/or scientists). In the next paragraphs some examples on global and European level are described.

#### EUNIS – European Nature Information System

The European Nature information System, EUNIS ([eunis.eea.europa.eu/index.jsp](http://eunis.eea.europa.eu/index.jsp)), **brings together European data from several databases and organisations into three interlinked modules on sites, species and habitat types**. The EUNIS information system is part of the European Biodiversity Centre and it is a contribution to the knowledge base for implementing the EU and global biodiversity strategies and the 7<sup>th</sup> Action Programme. **The EUNIS information system provides access to the publicly available data in the EUNIS database.**

#### BISE – Biodiversity Information System of Europe

Biodiversity Information System of Europe, BISE ([biodiversity.europa.eu](http://biodiversity.europa.eu)) is a **single entry point for data and information on biodiversity supporting the implementation of the EU strategy and the Aichi targets in Europe**. Bringing together facts and figures on biodiversity

A number of examples based on LIFE or Interreg projects are presented on how measures were prepared for improvement of the coherence of habitats, as well as for specific species:

- » Boreal Baltic coastal meadows (1630\*)
- » Alpine rivers and their ligneous vegetation with *Myricaria germanica* (3230)
- » Temporary Mediterranean ponds (3170\*)
- » European sturgeon/Beluga (*Huso Huso*) (HD App. V)
- » Large copper (*Lycaena dispar*) (HD App. II, IV)
- » Eurasian lynx (*Lynx lynx*) (HD App. II, IV)
- » Stag beetle (*Lucanus cervus*) (HD App. II)

The flora of Baltic coastal meadows is very rich, e.g. in Estonia a total of 390 plants species have been found, which is 26% of all Estonian species. More than 20 protected species grow on coastal meadows, including many orchids: *Dactylorhiza ruthei*, Frog orchid (*Coeloglossum viride*), Fen orchid (*Liparis loeselii*), Baltic orchid (*Dactylorhiza baltica*), Blood-red dactylorhiza (*Dactylorhiza incarnata ssp. cruenta*), Early marsh orchid (*Dactylorhiza incarnata*), Musk orchid (*Hermium monorchis*), Marsh helleborine (*Epipactis palustris*), Early-purple orchid (*Orchis mascula*), Common spotted orchid (*Dactylorhiza fuchsii*), Military orchid (*Orchis militaris*), Fly orchid (*Ophrys insectifera*) and Fragrant orchid (*Gymnadenia conopsea*).

Other decorative species in coastal meadows are: *Gladiolus imbricatus*, *Armeria maritima*, *Tetragolobus maritimus*, large pink *Dianthus superbus* and Red kidney vetch *Anthyllis vulneraria var. coccinea* (Anonymous, 2011).

and ecosystem services, it links to related policies, environmental data centres, assessments and research findings from various sources. **It is being developed to strengthen the knowledge base in support of the implementation of the EU biodiversity strategy e.g. Birds and Habitats Directives** and the assessment of progress in achieving the 2020 targets.

### OBIS – Ocean Biographic Information System

OBIS ([www.obis.org](http://www.obis.org)) is a **global alliance that collaborates with scientific communities to facilitate free and open access to, and application of, biodiversity and biogeographic data and information on marine life**. To date more than 20 OBIS nodes around the world have been established, which facilitate the connection of data sources in their region to the master OBIS data network and also increasingly provide specialised services or views of OBIS data to users in their particular region. The OBIS nodes connect over 500 institutions from 56 countries. Collectively, they have provided over 45 million observations of nearly 120.000 marine species, from Bacteria to Whales, from the surface to 10.900 meters depth, and from the Tropics to the Poles. The datasets are integrated so you can search and map them all seamlessly by species name, higher taxonomic level, geographic area, depth, time and environmental parameters.

## III.2.5 Knowledge networks

Knowledge networks are collections of individuals and teams who come together across organizational, spatial and disciplinary boundaries to invent and share a body of knowledge. The focus of such networks is usually on **developing, distributing and applying knowledge**. Just as information systems knowledge networks are often focussed on certain domains. In the next paragraphs some good examples are presented.

### The Natura 2000 Biogeographical Process

The EU Biodiversity Strategy calls for significant improvements in the conservation status of species and habitats protected under the EU Birds and Habitats Directives by 2020. To help meeting this target, the European Commission launched in 2012 the Natura 2000 Biogeographical Process, a **multi-stakeholders' co-operation process at the biogeographical level**, including seminars, workshops and cooperation activities **to enhance effective implementation, management, monitoring, financing and reporting of the Natura 2000 network**.

### OBN network

In The Netherlands there is a knowledge network called 'OBN' with researchers, conservation site managers, universities, consultancies, NGO's and governmental bodies, such as provinces and water boards, closely cooperating to restore ecosystems and nature reserves. In this network, knowledge and practice intermingle, and science and nature management jointly look for the most effective approaches to enhance sustainable conservation of important ecosystems in the Dutch landscapes [[see chapter B.I. Guidance and tools for effective restoration measures for species and habitats](#)].



## III.3 Key findings and recommendations

There are many initiatives to improve access to data and information on different scale levels (from local to global level), but often with a much broader scope than the implementation of the Bird and Habitat Directives. The challenge is to explore/exploit these initiatives for the purpose of a better implementation of the Birds and Habitats Directives. Obviously a combination of different approaches is needed to remove the barriers as identified by the WCMC.

### III.3.1 Frameworks, common vocabulary and classification systems

#### **A broader perspective than the Birds and Habitats Directives is needed to improve access to biodiversity data and information**

When defining the data and information needs and developing classification systems for the purpose of streamlining data flows, it is important to look from a broader perspective than just the Birds and Habitats Directives, as there is a strong relation and overlap with other EU directives (e.g. the Water Framework Directive, the Marine Strategy Framework Directive), biodiversity conventions and agreements (e.g. the Convention on Biological Diversity). Harmonisation of classification systems used by these directives is recommendable.

#### **The DPSIR framework is a good starting point for defining common indicators**

The DPSIR framework is useful as a starting point to define the data and information needs and develop indicators. The assessments for the purpose of the implementation of the Birds and Habitats Directives (e.g. conservation status assessment and proper assessments) fit into this framework. State indicators such as (trends in) population size of species form the basis of these assessments, but indicators for drivers, pressures, impacts and responses are important as well, specifically when addressing the impact of transitions of economic sectors on biodiversity.

#### **The Essential Biodiversity Variables are a useful concept for harmonising monitoring and assessments**

The EBVs offer opportunities to harmonise (not necessarily standardise) the monitoring and assessment methods of different Member States as they can serve as a window for observation networks and facilitate the integration of data coming from different sources. The challenge will be to define common state indicators – useful for the implementation of the Birds and Habitats Directives – based on the EBVs, and to operationalise these indicators with the help of observation data coming from different sources. In addition to state indicators other type of indicators of the DPSIR framework (drivers, pressures, impacts and responses etc.) should be defined.

#### **Identification and classification systems need to be maintained**

There is obviously a need for unified identification and classification systems, that are maintained on the long term. Many initiatives such as PESI are no longer maintained and therefore not useful anymore.

### III.3.2 Data portals and services

#### Linking data portals on different scale levels

There are several good examples of data portals and services making data accessible for different stakeholders and for multiple purposes operating on different scales (from local to global). The challenge is to have more and more organisations and networks contributing to these portals and to streamline the data flows from local to global and vice versa. Available funding on a long term basis and the contribution of certain communities (often out of idealistic motives) determines the success of these portals. In Figure III.8 the number records of the observations on macro moths from GBIF are presented to illustrate that there is quite some difference between the Member States in terms of data availability.

#### Better use of the potential of opportunistic data

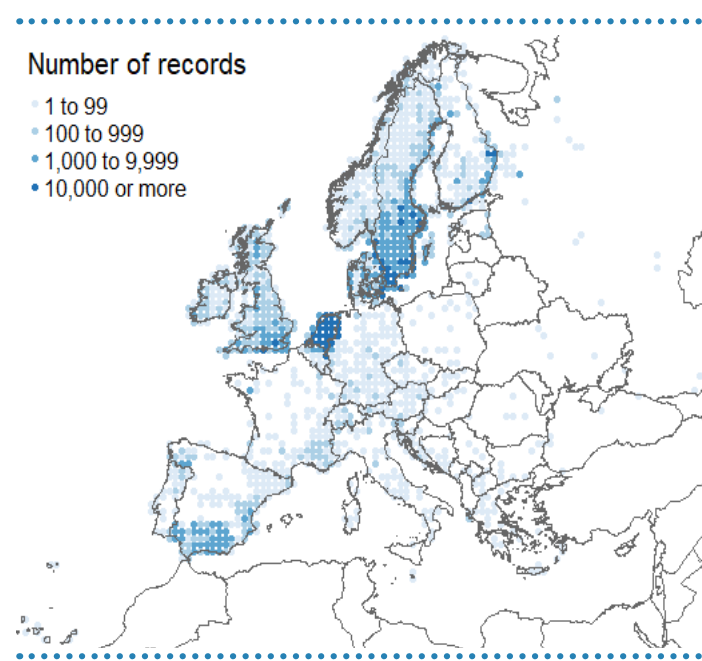
The efficient use of the widely collected opportunistic data requires active participation of leading scientists and conservationists. They can bind volunteer recorders and steer them to active investigation of 'empty' areas.

#### Better use of the potential of remote sensing data

The use of remote sensing has not yet been fully assimilated into standard biodiversity conservation practices. The remote sensing community needs to continue to reach out to the broader conservation community and to simplify access to images and the derived products that the broader community need (link with remote sensing chapter). These actions will facilitate greater use and integration and increase the return on the huge investment in remote sensing infrastructure. As more and different types of sensors become available and as coordination with that broader community continues to increase, remote sensing will play an ever-increasing role, providing global, periodic data that can improve our understanding of change as well as how society responds (*Geller et al., 2017*).

### III.3.3 Open data and research principles, policies and practices

The FAIR principles are important to improve data and information access. By means of open data policies these principles can be put in practice. Data portals play an important role, making it easier for data custodians to register their data.



**Figure III.8**

Number of records of observations on macro moths from GBIF data, 10<sup>th</sup> of March 2020, [doi.org/10.15468/dl.w1aafk](https://doi.org/10.15468/dl.w1aafk)

### III.3.4 Information systems

Many information systems are being developed that serve different purposes. The maintenance of these systems can be problematic due to lack of long-term funding and governance.

### III.3.5 Knowledge networks

Knowledge networks of e.g. scientists and practitioners are very valuable as long as they stay in place for a long period of time.

## III.4 References

- Adamec, M., Álvares, F., Anders, O., Andrén, H., Balčiauskas, L., Balys, V., . . . Boitani, L. (2012). Status, management and distribution of large carnivores – bear, lynx, wolf & wolverine – in Europe.
- Addison, P.F.E., et al. (2015). Are we missing the boat? Current uses of long-term biological monitoring data in the evaluation and management of marine protected areas. *Journal of Environmental Management* 149: 148–156.
- Chandler, M., et al. (2017). Contribution of citizen science towards international biodiversity monitoring. *Biological Conservation* 213: 280–294.
- Chytrý M., et al. (2016). European Vegetation Archive (EVA): an integrated database of European vegetation plots. *Applied Vegetation Science* 19: 173–180. [onlinelibrary.wiley.com/doi/full/10.1111/avsc.12191](https://onlinelibrary.wiley.com/doi/full/10.1111/avsc.12191)
- Dobson, A.D.M., Milner-Gulland, E.J., Aebischer, N.J., Beale, C.M., Brozovic, R., Coals, P., Critchlow, R., Dancer, A., Greve, M., Hinsley, A., Ibbett, H., Johnston, A., Kuiper, T., Le Comber, S., Mahood, S.P., Moore, J.F., Nilsen, E.B., Pocock, M.J.O., Quinn, A., Travers, H., Wilfred, P., Wright, J., Keane, A. (2016). Making Messy Data Work for Conservation, *One Earth*, Volume 2, Issue 5, 2020, Pages 455–465, ISSN 2590-3322, [doi.org/10.1016/j.oneear.2020.04.012](https://doi.org/10.1016/j.oneear.2020.04.012)
- Gallopin, G. (1996). Environmental and sustainability indicators and the concept of situational indicators. A systems approach. *Environmental Modeling and Assessment* 1: 101–117.
- Garnett S.T., Christidis L. (2017). Taxonomy anarchy hampers conservation. *Nature*. 546(7656): 25–27. [doi.org/10.1038/546025a](https://doi.org/10.1038/546025a) PMID: 28569833
- Geijzendorffer, I.R., Regan, E.C., Pereira, H.M., Brotons, L., Brummitt, N., Gavish, Y., Haase, P., Martin, C.S., Mihoub, J.-B., Secades, C., Schmeller, D.S., Stoll, S., Wetzel, F.T. and Walters, M. (2016). Bridging the gap between biodiversity data and policy reporting needs: An Essential Biodiversity Variables perspective. *J Appl Ecol*, 53: 1341–1350. [doi:10.1111/1365-2664.12417](https://doi.org/10.1111/1365-2664.12417)
- Geller, G.N. et al. (2017). Remote Sensing for Biodiversity. In: *The GEO Handbook on Biodiversity Observation Networks*. Michele Walters and Robert J. Scholes (eds.). 330p.
- De Jong Y., Kouwenberg J., Boumans L., Hussey C., Hyam R., Nicolson N., Kirk P., Paton A., Michel E., Guiry M., Boegh P., Pedersen H., Enghoff H., von Raab-Straube E., Güntsch A., Geoffroy M., Müller A., Kohlbecker A., Berendsohn W., Appeltans W., Arvanitidis C., Vanhoorne B., Declerck J., Vandepitte L., Hernandez F., Nash R., Costello M., Ouvrard D., Bezard-Falgas P., Bourgoin T., Wetzel F., Glöckler F., Korb G., Ring C., Hagedorn G., Häuser C., Aktaç N., Asan A., Ardelean A., Borges P., Dhoora D., Khachatryan H., Malicky M., Ibrahimov S., Tuzikov A., De Wever A., Moncheva S., Spassov N., Chobot K., Popov A., Boršič I., Sfenthourakis S., Kõljalg U., Uotila P., Olivier G., Dauvin J., Tarkhnishvili D., Chaladze G., Tuerkay M., Legakis A., Peregovits L., Gudmundsson G., Ólafsson E., Lysaght L., Galil B., Raimondo F., Domina G., Stoch F., Minelli A., Spungis V., Budrys E., Olenin S., Turpel A., Walisch T., Krpach V., Gambin M., Ungureanu L., Karaman G., Kleukers R., Stur E., Aagaard K., Valland N., Moen T., Bogdanowicz W., Tykarski P., Węśławski J., Kędra M., M. de Frias Martins A., Abreu A., Silva R., Medvedev S., Ryss A., Šimić S., Marhold K., Stloukal E., Tome D., Ramos M., Valdés B., Pina F., Kullander S., Telenius A., Gonseth Y., Tschudin P., Sergejeva O., Vladymyrov V., Rizun V., Raper C., Lear D., Stoev P., Penev L., Rubio A., Backeljau T., Saarenmaa H., Ulenberg S. (2015) PESI – a taxonomic backbone for Europe. *Biodiversity Data Journal* 3: e5848. [doi.org/10.3897/BDJ.3.e5848](https://doi.org/10.3897/BDJ.3.e5848)

- Noss, R.F. (1990). Indicators for Monitoring Biodiversity: A Hierarchical Approach. *Conservation Biology*, 4: 355–364. [doi:10.1111/j.1523-1739.1990.tb00309.x](https://doi.org/10.1111/j.1523-1739.1990.tb00309.x)
- Proença, V., et al. (2017). Global biodiversity monitoring: From data sources to Essential Biodiversity Variables. *Biological Conservation* 213: 256–263.
- Salafsky, N., Salzer, D., Statterfield, A.J., Hilton-Taylor, C., Neugarten, R., Butchart, S.H.M., Collen, B., Cox, N., Master, L.L., O'Connors, S. and Wilkie, D. (2008). A Standard Lexicon for Biodiversity Conservation: Unified Classifications of Threats and Actions. *Conservation Biology*, 22: 897–911. [doi:10.1111/j.1523-1739.2008.00937.x](https://doi.org/10.1111/j.1523-1739.2008.00937.x)
- Scholes R.J., Gill M.J., Costello M.J., Sarantakos G., Walters M. (2017). Working in Networks to Make Biodiversity Data More Available. In: Walters M, Scholes RJ, editors. *Handbook on Biodiversity Observation Networks*. Springer Open, 2017. pp. 1–18. [doi: 10.1007/978-3-319-27288-7\\_1](https://doi.org/10.1007/978-3-319-27288-7_1)
- Thomson S.A., Pyle R.L., Ahjong S.T., Alonso-Zarazaga M., Ammirati J., Araya J.F., et al. (2018). Taxonomy based on science is necessary for global conservation. *PLoS Biol* 16(3): e2005075. [doi.org/10.1371/journal.pbio.2005075](https://doi.org/10.1371/journal.pbio.2005075)
- UNEP (2012). A review of barriers to the sharing of biodiversity data and information, with recommendations for eliminating them. Prepared by the UNEP World Conservation Monitoring Centre. 30p.
- Verweij, P., Cormont, A., Hoetjes, P., de Meyer, K., van Bussel, T., Roosenschoon, O., Henkens, R., Schmidt, A., Janssen, S. (2019). Co-designing a data platform to impact nature policy and management: experiences from the Dutch Caribbean. *Environmental Science & Policy*, 100, pp. 13–20.
- Wetzel, F.T., et al. (2015). The roles and contributions of Biodiversity Observation Networks (BONs) in better tracking progress to 2020 biodiversity targets: a European case study. *Biodiversity* 16(2-3): 137–149.
- Wieczorek, J., Bloom, D., Guralnick, R., Blum, S., Döring, M., De Giovanni, R., Robertson, T., Vieglais, D. (2012). Darwin Core: An Evolving Community-developed Biodiversity Data Standard. *PLoS ONE*. 7 (1): e29715.
- Wilkinson, M., Dumontier, M., Aalbersberg, I. et al. (2016) The FAIR Guiding Principles for scientific data management and stewardship. *Sci Data* 3, 160018. [doi.org/10.1038/sdata.2016.18](https://doi.org/10.1038/sdata.2016.18)

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Events and forums on which the project was presented:

- » 4<sup>th</sup> NATURA 2000 monitoring workshop: remote sensing group (Doñana, 9–11<sup>th</sup> of April 2019): Carlos Sunyer, Clive Hurford, Alan Brown, Kristijan Civic, Bruno Combal, Sander Mucher, Ellen Meulman, and all other participants.
- » ESP-Conference, science-policy interface (Hannover, Leibniz University Hannover, 21<sup>st</sup> of October 2019): EBIND – The contribution of Ecosystem Services science to policy: are we addressing the right questions? Marta Perez-Soba, Leon Braat, Theo van der Sluis.
- » E-BIND Focus Group meeting 'Evidence-based improvements in the Birds and Habitats Directives (BHD) implementation: systematic review' (Brussels, June 2019).

### Complete list of organizations consulted along the project

European Environment Agency- Natural capital and Ecosystems, Helmholtz-Centre for Environmental Research (Germany), Spanish Ministry for Ecological Transition, European Bird Census Council (EuroBird Portal), German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Foundation for the research on Ethology and Biodiversity (Spain), European Commission: DG Environment, DG Research and Innovation & Joint Research Centre, Swedish University of Agricultural Sciences, University of Cantabria: Environmental Hydraulics Institute (Spain), Technical University of Denmark: National Institute of Aquatic Resources, EUROSITE, University of Twente (Netherlands), Justus-Liebig University Gießen, Universiteit Antwerp (Belgium), Natuurmonumenten (Netherlands), Bulgarian Biodiversity Foundation, University of Patras: Department of Environmental And Natural Resources Management (Greece), Infrastructure and Ecology Network Europe, IMMERSE H2020 Project (Improving Models for Marine Environment Services), Catalan Ornithological Institute (Spain), BirdLife Europe, EURAC Research Centre (Italy), Flora & Fauna International, Conservatoires D 'Espaces Naturels (France), Research Institute for Nature & Forest (Belgium).

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