EUROPEAN PARTNERSHIP

Habitat pilot internal review

Overview of remote sensing in mapping and quality monitoring of grassland and wetland habitats

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What is Biodiversa+

The European Biodiversity Partnership, Biodiversa+, supports excellent biodiversity research with impact for policy and society. Connecting science, policy and practice for transformative change, Biodiversa+ is part of the European Biodiversity Strategy for 2030, which aims to put Europe's biodiversity on a path to recovery by 2030. Co-funded by the European Commission, Biodiversa+ brings together partners from research funding, research programming and environmental policy across European and associated countries to work on five main objectives:

1. Plan and support research and innovation on biodiversity through a shared strategy, annual joint calls for research projects, and capacity building activities.
2. Set up a network of harmonised schemes to improve monitoring of biodiversity and ecosystem services across Europe.
3. Contribute high-end knowledge for deploying Nature-based Solutions and valuing biodiversity in the private sector.
4. Ensure efficient science-based support for policy-making and implementation in Europe.
5. Strengthen the relevance and impact of pan-European research on biodiversity in a global context.

More information: https://www.biodiversa.eu/

Contents

Table of acronyms

AI	Artificial Intelligence
EEA	European Environment Agency
EO	Earth observation
GIS	Geographic Information System
LiDAR	Light detection and ranging
ML	Machine learning
UAV	Unmanned aerial vehicle
RS	Remote sensing
WG	Working Group. The group of partners who meet regularly and conduct the pilot workplan.

Executive Summary

The first module of the Biodiversa+ Habitat Pilot, conducted from January to August 2024, focused on reviewing existing methods for mapping and quality monitoring of grassland and wetland habitats across Europe. The primary aim was to identify and evaluate remote sensing (RS) technologies and other methodologies currently in use either by the project partners or other prominent RS habitat mapping and monitoring projects to establish a foundation for harmonised biodiversity monitoring across different regions in the EU.

During this module, extensive collaboration among 11 European countries led to the compilation and analysis of over 40 different habitat mapping and monitoring approaches. These were assessed for their strengths, weaknesses, and potential applicability in creating a continent-wide standard for habitat monitoring. Key activities included bi-weekly Working Group meetings and a dedicated workshop in Bolzano, Italy, where partners presented their findings and proposed methods for further testing.

The review highlighted significant variability in the approaches and technological integration levels among the participating countries. While some regions have advanced in incorporating RS and machine learning techniques, others still rely heavily on traditional field-based methods due to concerns over the accuracy and reliability of RS data. Despite these differences, a consensus was reached on a set of focal methods to be tested in the subsequent project modules.

Looking forward, Modules 2 and 3 will involve the practical application of these selected methods in pilot sites across the participating regions, aiming to validate and refine them for broader use. The outcomes from these tests will be input to the recommendations in Module 4, moving towards a more standardised and efficient approach to habitat mapping and monitoring across Europe.

1. Habitat pilot - background and overview

Biodiversa+ is a multinational partnership co-developed by the European Commission to support biodiversity goals and enhance harmonisation in data handling and research methods in the field of biodiversity assessments across Europe. To pave the way towards the harmonisation of biodiversity monitoring, the Work Package 2 in Biodiversa+ has launched several pilot studies, each focusing on different specific aspects of biodiversity monitoring. In these pilots several countries are collaborating to test or develop improved monitoring methods for biodiversity. One of the pilot studies is the Habitat Pilot, which aims to assess methods for mapping and quality monitoring of grassland and wetland habitats using remote sensing (RS) data.

1.1. Background

Globally and in Europe, ecosystems and habitats are increasingly degraded. The CBD Global Biodiversity Framework (GBF)[1] and the EU Biodiversity Strategy[2] aim to reverse this trend through restoration actions, including the EU's new Nature Restoration Law[3]. Effective planning and assessment of these actions require comprehensive mapping and monitoring of ecosystems and habitats.

However, there is a lack of harmonised methods for mapping and assessing habitat and ecosystem conditions, leading to inconsistent reporting and evaluation. This impedes effective nature conservation and management, including assessing restoration needs and preparing national restoration plans under the EU Nature Restoration Law. Therefore, transnational cooperation is needed to harmonise methods and test their applicability across different regions and scales.

Biodiversa+, the European Biodiversity Network, has recognized this need and prioritised the “habitats” topic[4], launching a pilot project to harmonise habitat mapping and monitoring methods[5] [6]. Remote sensing methods are potentially cost-effective tools for these tasks, yet despite efforts such as the EU Copernicus programme[7], their potential remains underutilised, particularly for high nature-value habitats like those listed in Annex I of the Habitats Directive[8].

The Biodiversa+ pilot aims to test and harmonise remote sensing methods for mapping and monitoring, and for evaluating global[9] and EU indicators[10] of ecosystem and habitat conditions. Since, remote sensing techniques are increasingly important, and are being developed in multiple countries, developing systematic tools during this phase is crucial for methodological harmonisation. The pilot will focus on grassland and wetland habitats, which are widely distributed across EU countries and are among the most threatened globally. “Wetlands” is also a key priority within Biodiversa+.

[1] CBD, global biodiversity framework: https://www.cbd.int/gbf
[2] EU biodiversity strategy: https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en
[3] EU nature restoration law: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1991&qid=1722240349976
[4] Biodiversa+ priorities: https://www.biodiversa.eu/biodiversity-monitoring/priorities/
[5] Biodiversa+ workplan: Mapping and monitoring of grassland and wetland habitats.
[6] Biodiversa+ on habitat pilot: https://www.biodiversa.eu/biodiversity-monitoring/pilot/#1719932439554-db6eb784-7ebb
[7] EU copernicus program: https://www.copernicus.eu/en
[8] EU habitats directive: https://environment.ec.europa.eu/topics/nature-and-biodiversity/habitats-directive_en
[9] CBD monitoring framework: https://www.cbd.int/doc/c/179e/aecb/592f67904bf07dca7d0971da/cop-15-l-26-en.pdf
[10] EU biodiversity strategy action tracker: https://dopa.jrc.ec.europa.eu/kcbd/EUBDS2030-dashboard/?version=1

1.2. Overview of the pilot

Eleven European countries and regions are participating as active partners in the Biodiversa+ Habitat Pilot, which started in the beginning of 2024 and is currently concluding its first project module. The first project module has involved (i) identifying and assessing synergies between the Habitat Pilot and other projects (e.g., EU Grassland Watch) and (ii) reviewing current practices and prior experiences in the partner countries regarding RS-based and other methods for habitat mapping and quality monitoring. During this review, the partners compiled, described, and presented over 40 different methods for habitat mapping and monitoring, including information on data sources used, spatial cover of the studies, as well as identified methodological strengths and weaknesses. Based on the review outcomes, the methods that were considered to best align with the Habitat Pilot's aim to find one or few harmonised methods applicable across the continent were discussed in more detail. The evaluation of the potential methods to be applied in the pilot was carried out in the Working Group (WG) meetings and particularly during the workshop hosted by Eurac Research in Bolzano in early June 2024. Following these discussions, a joint decision was made on which methods should be tested at field sites in the participating countries and regions.

In the following project Modules 2 and 3, over the next year and a half, the pilot partners will test the selected mapping and monitoring methods in grassland and wetland sites. In the Module 4 of the pilot, the outcomes of the mapping and monitoring studies are gathered and finally reported.

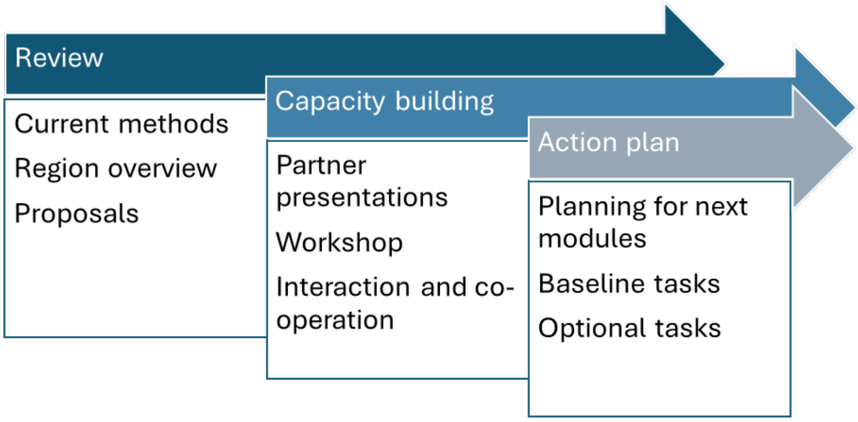
The partners/regions that participated in Module 1 as active contributors are:

- BOZEN, Autonomous Province of Bolzano
- DACC, Spain - Catalonia
- ExEA, Bulgaria
- MEPGT, Croatia
- MoE_DK, Denmark
- MoE_FI, Finland (project coordination)
- NCA CZ, Czech Republic
- NPWS, Republic of Ireland
- SAS, Slovakia
- SEPA, Sweden (project coordination)
- VL O, Belgium – Flanders

2. Module 1 - Review

The Habitat pilot, aiming at developing harmonised methods for the mapping and quality monitoring of grassland and wetland habitats using remote sensing (RS) data, is divided into four modules:

The Review carried out in Module 1 sets the framework for the subsequent modules by providing an overview of the partners' experiences in habitat mapping and quality monitoring. It also aims to collect information on current remote sensing methods that can be used across various regions, enhancing the methodological knowledge basis for habitat assessments and reporting, as well as systematic comparisons of areas. The overall aim of the Review is to form a solid foundation for harmonised analysing and monitoring of the status of European habitats. Extensive efforts have been made by the partners to revise current EO-based habitat approaches, share their experiences, and to develop proposals for the next steps in the pilot. The methodological approaches and knowhow vary notably among the pilot partners. Thus, the capacity-building component of the Habitat pilot is considered as crucial for the up-scaling of harmonised methods, facilitating the measurements of the state of our valuable habitats in a harmonised way across Europe.



Core activities in the Module 1 included a series of bi-weekly Working Group (WG) meetings with the full group, partners conducting their own reviews of habitat mapping and quality monitoring experiences, and proposals for testing some of these methods in the next modules. A workshop was held at the premises of Eurac Research (Bolzano) to evaluate, discuss and summarise these proposals, and a revised updated version of the Action Plan was developed following the outcomes of the workshop.

2.1. Current methods and experience

For the Review, each partner was requested to collect and report information on habitat mapping and quality monitoring from their respective regions. This collaborative effort aimed at establishing a comprehensive understanding of current practices, challenges, and future needs, facilitating a comparative analysis of regional experiences. The reporting was conducted using two different templates, which were developed and refined during working group meetings:

- The Excel template which included a list of various methods and projects along with the corresponding input data used.
- The Word template, see Appendix 1, where more detailed information for the selected methods were gathered.

Partner proposals for the preferred methodological approaches for EO-based mapping and monitoring were shared among all the pilot partners before the Bolzano workshop. This workflow facilitated the summarisation of the review into a format and information basis that could then be used to support the decision making for the activities to be tackled in Module 2 and 3.

2.1.1. Partners' reviews

The partner reviews for their mapping and monitoring methods are rather extensive and therefore they are included in the Appendices of this Review. They include descriptions of the experiences from earlier EO-based approaches in each country or region, research needs and future plans as well as more in-depth assessments for some of the methods/projects.

The full list of the reviewed earlier or on-going mapping and monitoring approaches and projects from the partner countries or regions can be examined here: Link to the Excel overview of methods/projects and input data. Overall, this list contains more than 40 projects and several methods.

Based on each partners' assessments, some of the EO-based mapping and monitoring approaches were considered to have more potentiality than the others. Thus, in the Review Word documents produced by each partner, these preferences can be examined from the separate country / region-based review documents. The review documents are gathered in the Appendix 1 of this report, including the following documents: BOZEN, Autonomous Province of Bolzano Review; DACC Spain - Catalonia Review; ExEA Bulgaria Review; MEPGT Croatia Review; MoE_DK Denmark Review; NCA CZ Czech Republic Review; NPWS Republic of Ireland Review; SEPA Sweden Review; MoE_FI Finland Review; VL-O Belgium - Flanders Review; SAS - Slovakia Review.

2.1.2. Summary of partner reviews

The partners' review showcases a mixture of traditional field-based methods and evolving remote sensing (RS) technologies across different regions, highlighting both commonalities and unique regional approaches.

Common Practices and Challenges

Many partners, including BOZEN (Autonomous Province of Bolzano), Catalonia, Republic of Ireland and Croatia, rely heavily on empirical in situ fieldwork for habitat mapping and monitoring due to its higher accuracy and reliability compared to RS-based approaches. In these regions extensive field surveys and manual photo interpretation have been conducted to validate and update habitat maps. Despite recognizing the potential benefits of RS technologies for upscaling and cost-efficiency, there are some concerns limiting the full integration of these methods without proven accuracy and reliability.

In contrast, partners like Denmark, Finland, and Sweden have made significant strides in integrating RS and machine learning (ML) methods into their habitat mapping practices. Denmark, for instance, is developing ML-based systems to map habitat types using a variety of data inputs, though challenges remain in validation and accuracy for certain habitat types. Finland has examined the capacity of RS-based projects in mapping of different northern habitat types, particularly in forests and wetlands, and for the monitoring of quality changes in peatlands, highlighting the complexity and need for further refinement of RS-based approaches.

Some examples on regional approaches can be drawn from the partner Reviews:

- **The Autonomous Province of Bolzano** has explored integrating RS technologies to facilitate provincial habitat mapping and monitoring in different smaller-scale projects, but the widely implemented method is still based primarily on field surveys.
- In **Catalonia, Spain**, extensive habitat mapping surveys have been conducted using high-resolution orthophotos and field validations. The wall-to-wall mappings are done using CORINE Biotopes Manual (with crosswalks to EUNIS and Habitats of the Annex I). In addition, the habitat mapping of protected natural areas at a scale of 1:10,000 is under way. Remote sensing techniques have not yet been used in the mapping surveys but some tests with remote sensing for the detection of changes in habitats have been executed.
- **Bulgaria** employs a detailed model-based approach, using both deductive and inductive models combined with extensive field verification to create comprehensive habitat maps for the Natura 2000 sites. The focus is on improving methodologies and expanding habitat mapping to cover the entire country.
- **Croatia** recently collected more than 5000 habitat observations in the field and is going to use them in modelling the new habitat map using existing data and RS.
- **Denmark** has - for some years - worked on a system for detecting Annex I habitat types country-wide using AI and different kinds of input data, among others remote sensing data. This system is still not launched, but the plan is that it will be in a short time. Also, the ministry has a program ("Digital Nature Monitoring") dedicated for developing remote sensing based solutions for monitoring Annex I nature throughout the country. Some of the first habitat condition metrics that are being worked at currently, are vegetation height, vegetation cover, grazing and mowing, that are all part of ongoing development using remote sensing.
- In **Finland**, remote sensing (RS) based approaches have recently been used together with ground truthing data in regional habitat mapping projects (particularly in Northern Lapland) and nation-wide mapping of peatland site types. Results suggest differences between habitat types in their RS based mapping accuracy, with certain wetlands, e.g. mires, showing challenges due to their structural heterogeneity. First assessments and monitoring of ecological status of mires via their hydrological conditions using RS methods and machine learning classification methods have shown a good overall accuracy but the approach needs further validation. In contrast, there are only sporadic attempts for RS-based mapping of grasslands. However, the extensive field data available from the nation-wide grassland surveys allow testing the capacity of RS based approaches in grassland mapping and quality monitoring.

- In **Slovakia**, habitat mapping has historically relied on field surveys conducted at permanent monitoring sites, and comprehensive habitat maps for the country do not currently exist. However, since the initiation of the NaturaSat project in 2020, the first remote sensing-based maps of Natura 2000 habitats have been created by Plant Science and Biodiversity Centre SAS. The habitat mapping within the NaturaSat software employs semi-automatic and automatic segmentation of habitat boundaries, automatic classification of segmented areas, and the creation of relevance maps depicting habitat distribution, utilising the deep learning method known as the Natural Numerical Network. Primarily, Sentinel-2 data is used, although airborne and UAV data can also be utilised for small-scale habitats. Habitat monitoring is facilitated through the NaturaSat software for both area and quality assessments. Looking ahead, the focus will be on testing the software and methodologies in various European countries, acquiring large training datasets for network calibration, and harmonising the methods used across the EU.
- **Sweden** has tested an integrated approach combining national programmes like National Inventories of Landscapes in Sweden (NILS) and National Wetland Inventory (VMI) with RS technologies, drones, and LiDAR for habitat mapping and quality monitoring. This multi-source data integration has a potential to provides comprehensive coverage but includes high costs and technical demands.
- In **Flanders, Belgium** the Research Institute for Nature and Forest (INBO) maintains a detailed Biological Valuation Map (BVM) which is mainly based on field-driven surveys and is exploring RS for efficient updating, particularly in urban and agricultural areas. The Flemish monitoring network for Article 17 Habitat Directive Reporting has been in place since over a decade and also using mainly in-situ vegetation data. The focus is on harmonising and validating RS methods alongside traditional approaches.
- **Republic of Ireland** conducts detailed habitat mapping and monitoring using manual field surveys, often facing challenges due to the labour-intensive nature of these methods and lack of capacity within the ecological sector. They are beginning to explore RS techniques, including LiDAR and UAVs, particularly for monitoring large and remote areas like peatlands, uplands and fens.
- **The Czech Republic** established comprehensive habitat mapping and monitoring in the early 2000s, which has since focused on continuous updating and improving its quality and reliability. The application of RS methods has been limited, but there have been attempts to integrate UAV and Sentinel data. The potential of RS methods for detecting previously overlooked areas of natural habitats and monitoring habitat changes is recognized, although expertise and resources are currently lacking.

Future directions

All partners recognize the potential of RS technologies to enhance habitat mapping and monitoring. There is a general consensus on the need for:

- **Improved Data Integration:** Advanced tools and methodologies to combine RS data with field surveys for comprehensive habitat assessments.
- **Cost-Effective Technologies:** Making high-resolution RS data more accessible for large-scale and long-term projects.
- **Capacity Building:** Training personnel in advanced RS and GIS techniques to improve data quality and accuracy.

- **Regular Updates and Monitoring:** Ensuring continuous habitat data updates to maintain relevance and respond to environmental changes.
- **Harmonisation of Methodologies:** Standardising mapping methods across regions for better data comparability and reporting.

Despite varying levels of RS integration, the partners share common goals of enhancing habitat mapping accuracy, efficiency, and coverage through technological advancements and methodological improvements. This collaborative effort highlights the importance of balancing traditional field methods with modern RS techniques to achieve effective conservation and management of Europe's diverse ecosystems.

2.1.3. Review of earlier and on-going habitat mapping and monitoring projects

In addition to the reviews conducted for habitat mapping and monitoring approaches in the partners' countries, Module 1 gathered information from a number of earlier and on-going key projects that have considered the potentiality or applied EO-based and EO-related approaches for mapping and/or monitoring habitat ranges, occurrences, habitat patch size and the changes in the habitat characteristics that describe quality. This additional information was gathered from the publications, presentations and internet pages that describe the aims and methodologies of the projects. In addition, Habitat pilot also organised joint Working Group meetings with other projects or researches involved in some key projects (e.g. EU Grassland Watch and MAMBO) where information from those projects was provided to the pilot partners via targeted presentations and associated discussions.

The main aims of these reviews were to generate understanding of the data and methodological approaches applied in the other projects to develop comparison points for the work in the Habitat pilot. The reviews provided guidelines for the technical decisions, analysis and for the potentiality to apply corresponding methods in the pilot partners' study sites in the Modules 2 and 3 of the pilot.

The projects and surveys that were included as the focal points in the review were EEA Eionet Review of Habitat Mapping Approaches in European Countries, EU Grassland Watch, The Habitat Map of Switzerland project, Guidelines for assessing and monitoring the condition of Annex I habitat types of the Directive 92/43/EC, MAMBO, and CarHab (national cartographic modelling program for natural and semi-natural habitats in France). For all these projects various presentations, evaluations and discussions about their potential usefulness for the Habitat pilot were carried out in Module 1. For some of the most relevant and promising projects and methods (Eionet Review, EU Grassland Watch, MAMBO, The Habitat Map of Switzerland project, Guidelines for assessing and monitoring the condition of Annex 1 habitat types of the Directive 92/43/EC), a detailed information overview is provided in the Appendix 2 section of this report.

In the arena of developing coordinated monitoring activities across Europe, EuropaBON (https://europabon.org/) has been one of the key projects. The biodiversity-related work in EuropaBON has targeted at identifying the data across scales to support national and EU level nature conservation legislation, strategies and initiatives, including Biodiversity Strategy for 2030, Habitats Directive, Birds Directive, Water Framework Directive, Climate Strategy and Ecosystem Restoration goals. The project has particularly examined how to successfully use Essential Biodiversity Variables (EBVs) and Essential Ecosystem Services Variables (EESVs) in different biodiversity-based assessments, identified gaps in the monitoring schemes of European biodiversity, and developed assessments how novel technologies and modelling approaches might support filling the gaps. For this, EuropaBON has carried out surveys of existing biodiversity long-term monitoring initiatives, assessed the potentiality of remote sensing and citizen science to contribute to producing comprehensive biodiversity information, and determined pathways from data collection to knowledge production to enhance the mobilisation and harmonisation of biodiversity monitoring data.

Two of the deliverables of EuropaBON dealing with the novel methods for biodiversity monitoring, including RS-based approaches, and assessing their suitability for large scale deployment across Europe were considered as useful comparison points for the Habitat pilot. They were the following:

- Deliverable 4.2 Novel technologies for biodiversity monitoring - Final Report (https://preprints.arphahub.com/article/105600/)
- D5.2 Past-to-present EBV modelled datasets and status indicator for selected terrestrial habitats in the Habitats Directive (https://preprints.arphahub.com/article/128158/)

The key points emerging from these two deliverables are described as one of the Appendices of this report (Appendix 2f).

2.2. Capacity Building

2.2.1. Working group meetings

After a few meetings, the working group (WG) decided to hold more frequent meetings with the full group. During the spring of 2024, the project had 12 regular WG meetings. Since all partners are spread across Europe, these meetings played an important role in getting to know each other and advancing the module work.

There were usually about twenty participants from various partners in these meetings. Initially, the focus was on defining what information about experiences and methods from the different regions was needed for the Review and how this should be structured. Based on this, two Review templates were developed to be filled by the partners.

Over time, the focus of the WG meetings shifted more towards sharing experiences and showcasing different techniques and insights. Consequently, discussions became more centred on the project's future modules and how best to address them. When some unclear issues emerged in the work with reviews making it challenging to assess what should be included, the questions were sharpened before the Bolzano workshop. All partners were then asked to propose methods and techniques that could be tested in Modules 2 and 3. Some of these were presented before the workshop, while others were presented in words and pictures, to be discussed during the workshop.

2.2.2. Partner presentations

Based on the review of current experiences and other findings, many partners took the opportunity to share their ideas. During the WG meetings, several presentations were given by the partners and the visiting researchers from other projects, including one from the EU Grassland Watch project, which was identified as an interesting project to follow and collaborate with. After each presentation, there was time for questions and discussions, which helped to establish a baseline for the forthcoming proposals. The exact activities plan for what to do in Modules 2 and 3 was largely left open when starting the pilot in January 2024, to be clarified and decided along the progress of the Review Module 1. The presentations provided in the WG meetings included:

- MAMBO project (22.2. by MoE_FI)
- Eionet survey on Habitat mapping approaches in European countries (29.2. by MoE_FI)
- SAS: NaturaSat (7.3.)
- VI O: Current mapping and monitoring in Flanders (7.3.)
- MoE_DK: RS based habitat condition metrics in Denmark based on airborne and drone-borne lidar (vegetation height and cover) as well as on satellite data (grazing/mowing) (7.3.)
- SEPA: Habitat quality monitoring in Sweden (7.3.)
- MoE_FI: Wetness monitoring of flarks using Sentinel-2 and SentinelHub cloud services (11.4.)
- EU Grassland Watch (25.4.)
- VL-O: Automated detection of ploughing events and mowing; Validation/training of EU-Grassland Watch indicators; Hydrological condition of wetlands (2.5.)
- MoE_DK: Biodiversity monitoring laser scanning point clouds and deep learning with detailed drone mapping (16.5.)
- SEPA (SLU): Assessment of trends in Ecological conditions in grassland and wetland polygons by time-series using Sentinel 1 & 2 sensor data (23.5.)
- SEPA (Metria): Regional calibration of wetland classes; Implement single image superresolution for Sentinel-2 data; Mapping using time series (23.5.)
- CarHab, the French methodology for mapping of Biotopes and Physionomies, France (30.5.)
- Habitat Map of Switzerland (30.5. by BOZEN)

2.2.3. Proposals

Sixteen proposals for the activities to be tackled in Modules 2 and 3 were prepared before the Bolzano workshop.

Nr	Presented by	Proposal	Method	Supporting technique
1	VL-O	Automated detection of ploughing events in (semi-) natural grassland	x	
2	VL-O	Validation/training EU-Grassland Watch indicators		x
3	VL-O	Mapping and monitoring condition of wetland habitats (and flooded grasslands?)	x	
4	MoE_FI	Showcase of mapping and quality monitoring of semi-natural grasslands - applying and testing EU Grassland Watch processes in boreal grasslands		
5	MoE_FI	Wetland hydrology - from time series data to condition indicators	x	x
6	MoE_FI	ML-classification to detect inundation in wetlands	x	
7	SEPA	Regional calibration of wetland classes		x

8	SEPA	Implement single image super resolution for Sentinel-2 data		x
9	SEPA	Mapping using time series		x
10	SEPA	*Assessment of trends in Ecological conditions in grassland and wetland polygons by time-series using Sentinel 1 & 2 sensor data.*	x	x
11	DACC	Detection of habitat changes by remote sensing and habitats mapping (Catalonia)	x	
12	BOZEN	Habitat map of Switzerland	x	
13	DACC	Addition of assessment attributes useful for monitoring to the habitats map (Catalonia)	x	
14	MoE_DK	Vegetation height and cover using UAV data		x
15	SAS	Habitat mapping and monitoring using NaturaSat approach	x	x
16	VL-O	Micro-topography detection in grassland for the detection of a specific type of ancient high nature value grassland.		x

These proposals were discussed in groups of four people during the workshop. People attending online formed one group. All groups presented their views on each proposal which generated a list of positive opinions and challenges for each proposal, see Appendix 3 Positive/challenging in the proposals.

2.2.4. Workshop

A workshop was organised in Bolzano between the 4th and 6th of June 2024, with 9 partners participating. There were 16 participants from 8 partners participating in-person, and two participants/partners online. The main goal of the workshop was to further discuss the method proposals prepared and provided by the pilot partners, and ultimately select on which methods to base the habitat mapping and quality monitoring in the pilot's second and third modules. Additionally, the workshop was an opportunity for the pilot partners to meet in person, discuss habitat indicators and the potential and limitations of remote sensing methods in general, and discuss the expected goals and outcomes of the Habitat pilot.

Before the start of the workshop, the partners had presented 16 different projects and methods, referred to as proposals, which were further discussed during the workshop in Bolzano. The presenting partner for each respective proposal provided a short text and a PowerPoint slide summarising the proposed methodology which were used during the workshop for easy overview and comparison between the differences and overlap in methodology between the proposals.

The full agenda and proposal summaries created for the workshop in Bolzano can be found here:

- Agenda for Bolzano workshop
- Proposals - Word summaries
- Proposals - Slide summaries

Workshop day 1

The workshop took place at Eurac Research in Bolzano and started on the morning of the 4th of June with a review on indicators of habitat condition, and on the 16 proposals and their respective methods. Afterwards, the participants were split into four break-out groups, with the two partners joining the workshop online forming a fifth group. In these break-out groups, the participants discussed the individual proposals more in-depth, leaving comments on the strengths and challenges of the different proposals, for the other groups to read, respond to, and elaborate on. See Appendix 3. (Positive/challenging in the proposals) for the comments provided on the respective proposals during the in-group discussions. Except for a short project presentation of HyperEcos, a project assessing the potential of using hyperspectral satellite data for classifying different grassland types, the participants' in-group discussions on the proposals continued for the majority of the first workshop day.

At the end of the first workshop day, the break-out groups presented their internal group discussions to the full group. Each partner was asked to discuss the proposals with their colleagues in their respective country or region, and prepare a short presentation for the morning of the third workshop day, on which methods they would like to move forward with in the pilot's second and third project module.

Workshop day 2

On the second workshop day, a field excursion was organised to Alpe di Siusi, a Dolomite plateau and alpine meadow area nearby Bolzano. Alpe di Siusi features both alpine meadows and pastureland of varying management intensities at around 2000 metre's altitude with parts of the area also included in the Natura 2000 area Parco Naturale dello Sciliar - Catinaccio. During the excursion, the partners visited different Annex I habitat types including Alpine and subalpine calcareous grasslands (6170), Species-rich Nardus grasslands (6230) and Mountain hay meadows (6520) and were given an introduction to the area, its current and historical management practice, and its flora by representatives from from Eurac Research and the Province of Bolzano.

Workshop day 3

The third and final day of the workshop started with each pilot partner presenting their perspectives on how the habitat pilot should move forward with the proposed methods.

The slideshows presented by the different pilot partners can be found in the following folder: Partners' perspective on the Bolzano workshop proposals.

Both in the group discussions on the first workshop day, and in the partner presentations on the third workshop day, several partners highlighted the similarity in methods between many of the proposals, and the fact that some proposals were focusing on the use of a certain supporting technique, rather than offering a standalone method (see Table under Section 2.2.3. *Proposals*). Additionally, the fact that several of the methods discussed during the workshop (e.g., proposal no. 1, 2, 4, 12) are dependent on the cooperation and delivery of models, support or expertise from an external partner was discussed. The partners therefore agreed that the testing of methods in project module two and three should make use of a combination of different methods, both by combining aspect from a different project into one method, and potentially adding supporting techniques to that protocol; however, also the option of testing several methods simultaneously was considered as a useful possibility for the partners, as long as each included method is tested in at least two or more countries.

The partners decided that the Habitat pilot Action plan will be updated to provide a more concrete plan on which specific methods should be tested in the Module 2 and 3 of the pilot and how to divide the work and responsibility between the partners. Finally, a deadline for when this updated version of the Habitat pilot Action plan would be provided to the pilot partners by the coordination team was set, and a meeting was scheduled for three days afterwards to give the pilot partners time to read through the updated version of the Action plan before the meeting.

2.3. Action Plan

The outcomes of the workshop have been incorporated into the project's Action Plan, which is a dynamic document that evolves over time. The results from Module 1 have been used for establishing the activities for Module 2: Mapping, and Module 3: Quality Monitoring. The updated version of the Action Plan is considerably explicit, outlining the tasks to be performed in these modules.

Given the varying capacities and regional differences among the partners, including differences in habitat types and quality indicators, the tasks have been categorised into:

- Baseline tasks (B): These are tasks that all partners should aim to perform (but note that for the two hydrology indicators partners can decide if they want to use moisture or inundation - or both - as indicators, based on their preferences and data availability).
- Optional tasks (O): These are tasks that are voluntary for the partners but applying them should involve at least two or three partners. Any partner that has an interest is invited to co-operate and to contribute to the optional tasks.

<table>
<tr><th></th><th colspan="2">Mapping (Module 2)</th><th colspan="2">Quality monitoring (Module 3)</th></tr>
<tr><td>Grasslands</td><td>EU grassland watch mapping procedures (B*)</td><td rowspan="2">NaturaSat (B)
Swiss mapping (O*)</td><td>EU grassland watch indicators (B*)
Mowing and/or ploughing (O**)</td><td rowspan="2">Overgrowth (shrub/tree cover) (B**)
Other indicators (O**)
Super resolution S2 images / lidar & drones (O)</td></tr>
<tr><td>Wetlands</td><td>Mapping of inundated habitats (O)</td><td>Hydrology indicators: moisture/ water table level and/or inundation (B**)</td></tr>
</table>

Note that some of the activities are common for both grasslands and wetlands, and that extent and precise format of activities for the collaboration between Habitat pilot and other projects (*) is conditional to the establishment of workable collaboration. **Includes both NaturaSat methods and project developed methods.

The revised, updated version of the Action plan can be examined here: Habitat Action plan_v1.1.docx

Appendix 1. Review documents

The review documents are produced by each partner based on earlier and on-going EO-based mapping and monitoring experiences, projects, research needs and future plans for grassland and wetland habitats in each country or region.

Template

Instructions

Summarise your experiences of methods that have been used for grassland and wetland habitat mapping and habitat quality monitoring in your country/region. Choose some of them to describe in more detail in this document. Not only the most promising methods, but also the ones we can learn from - what worked well, what did not?

We aim for finding methods for Annex 1 habitat mapping, but to see how far we can reach - all classification schemes are interesting! Work have been done in former projects which are used as input and a starting point for this review. We are here aiming at focusing on methods and try to structure the descriptions to make it possible to compare methods used in different countries.

To make further comparison possible on a large scale some generalisations can be done when describing the process for each methodology. However, it is important to understand advantages and disadvantages of the methods used and therefore several sections are intended for free text.

The review report for each partner consists of:

- *An overall summary/analysis of experience*
- *Future needs*
- *Detailed description of chosen methods [1..n]*

Contact persons for former studies are being collected and will be distributed to the relevant partners:

- *Review of Habitat Mapping Approaches in European Countries*
- *Methodologies for assessment and monitoring of annex i habitats condition overview and analysis of compiled information*
- *Habitat Grassland Watch/Mambo projects*

1 Partner

Name and contact details (in the present context)

2 Analysis of experience

Overall analysis and summary of former experiences; how you have worked with different methods (for grasslands and wetlands), experience of different methods – ½ -1 page.

Also mention rejected ideas/methods - WHY didn't it work? WHY was it removed?

At which scale (regional/local) has the technology been used?

3 Needs and Future plans

Overall needs and knowledge gaps today

How much (estimation) of existing Annex 1 habitat areas have you mapped in the country/region today? Protected areas or everything?

What need for quality assessment is there?

What about plans for habitat mapping/monitoring in short or long term in your country?

4 Methods

Description of methods for mapping and quality monitoring of grassland and wetland habitats.

Select the most relevant (according to your experience) methods, listed in the data sheet "Review" in the Excel file for a more extensive description. Please link these descriptions to this data sheet and to a GIS layer showing the coverage of methods used as well as the coverage of input data used within each reported region (country).

4.1 Method 1

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	*Link to ID in the Excel data sheet "Methods"* *(Or refer to a proposal (made in Bolzano), identify by name.)*
*** Method (Method reviewed)**	*Type of method described* *e.g. Remote sensing and lidar approach [year, coverage or something]* *Field inventory* *Aerial photo interpretation* *Combination of several methods*
***Classification system**	*e.g. Annex 1 Habitat, EUNIS, Corine LC* *For less-known systems, give a short description and a reference. If a well-known system was used with modifications, describe these.*
***Output data**	*Description of data output/quality indicators from the method*
***Owner/producer**	*Producer/owner; name and contact details*
Target group/Primary user/User needs	*The user/system /organization interested in the results from each method* *Describe shortly the target group and its needs and goals*
***Input data and data providers**	*The provider of input data which will be elaborated in this method* *A table of input data including download link or if not open access data - link to data provider.*
Data cost	*Indicate cost for data (if possible)* *If not open data, indicate cost (per km^2 or per other unit) in Euro*
***Description**	*A short narrative description of the method and products* *e.g.:* *The National Land Cover Database (NMD) is a land cover map over the entire country. The purpose of the database is to provide basic information about the landscape and any changes over time. The mapping production was conducted during 2017-2019 and will be updated every fifth year. NMD is comprised of a base map with 25 thematic classes in three hierarchical levels. The map is in a raster*

	format with 10 m resolution and a minimum mapping unit of 0,01 hectare. In addition to the base map, there are several complementary layers including: *• Object Height and Extent;* *• Productivity* *• Land Use* *• Forests in Mountainous Regions* *- revision of base information* *- feedback for future improvements (according to e.g. validation)*
Documentation	*Include links to any additional documentation*
Competence	*Competence(s) needed to use the method*
Tools	*What tools are needed?* *A list of software used or needed for production* *e.g. GIS, classification tool, Lidar Tool etc.* *Description of hardware, e.g. drones, used in the production line.*
Status	*Status of the methods* *Short summary of the status of described method. Any future plans? Is it still in use? For how long has this method been used for reporting? On-going development or research?*
Result/output/accuracy	*Mapping quality and output description* *Output resolution (geometrical/minimum mapping area/detail/repeat time)* *Mapping accuracy for different classes/levels.* *Transferability (spatial/temporal)* *For which classes is the methodology, based on input data xyz in region n, usable for?* *Usable for: class n* *But not for: Classes xyz* *Scalability*

BOZEN, Autonomous Province of Bolzano Review

1. Partner

Albin Bjärhall, BOZEN (The Autonomous Province of Bolzano / Eurac Research)

2. Analysis of experience

In the aspect of utilizing remote sensing (RS) methods, there is a large difference between *implemented* and *research* methods for mapping and monitoring grassland and wetland habitats in the Province of Bolzano. There are ongoing research projects exploring the potential of hyperspectral satellite data for classifying grassland types (see “Hyperecos”, ID: 17 in the Excel review template), and using a combination of vegetation survey and RS data for locating biodiversity-rich alpine grassland sites (see “G4B”, ID: 28 in review template). However, these projects have no, or only preliminary results to assess the functionality and accuracy of the project methods. Additionally, research projects carried out in this field in the province of Bolzano over the last couple of years have tended to be limited to one particular research study area, be dependent on their own collected ground-truth data, and often with limited accessibility of the project method and data to external partners.

On the other hand, habitat mapping is also carried out at hundreds of sites across the province by Eurac research (a private research facility in Bolzano with the Province of Bolzano as main client) and the Free University of Bolzano (UniBZ). Eurac research is carrying out habitat mapping in the context of Biodiversity Monitoring in South Tyrol (BMS), a biodiversity-monitoring program across the province conducted by Eurac where the area around each BMS-site is habitat-mapped. UniBZ, on the other hand, has been commissioned by the Nature Office at the Province of Bolzano to carry out habitat mapping of natural areas across the province. The habitat mapping of the UniBZ is mostly carried out in areas with known high ecological values and/or areas affected (or likely to be affected) by either natural or anthropogenic pressure (e.g., droughts, human development etc.). Eurac and UniBZ use the same method for their habitat mapping, although this method is based on in-field habitat delineation and classification and makes very limited use of RS methods in the mapping process.

Finally, there have been trials by Eurac and UniBZ in cooperation with the province’s Nature Office to better integrate RS methods into the mapping and monitoring of natural areas across the province. Such trials have mainly been of small format, in select areas, and have not resulted in any methods that could be scaled up and used widely in the province’s habitat mapping. Problems therein have, at least partially, been the lack of available and reliable ground-truthing data for the province. (Natura 2000-areas across the province are habitat-mapped, but the quality of the mapping, especially in the older Natura 2000-areas, is known to be poor.) Ultimately, since the accuracy and reliability from in-field habitat mapping has been higher than anything that could be performed with RS methods, the Nature Office has preferred to focus on manual and in-field methods rather than try to incorporate RS method into the provincial habitat mapping.

3. Needs and Future plans

Neither Eurac, UniBZ, nor the Nature Office have any concrete plans on changing their implemented method for habitat mapping to incorporate more RS-based methods. However, all three parties are well-aware of the potential benefits in upscaling and labor-efficiency that could be brought from RS-based habitat mapping methods. Therefore, there is a general positivity about trying out RS-based methods to complement their habitat mapping, but only if presented with viable and already-developed methods for doing so.

4. Methods

The method described below is the method used by Eurac and UniBZ in their habitat mapping, and is the only widely applied method for habitat mapping in the province. Eurac maps the habitats in the area surrounding each site in their biodiversity-monitoring program (BMS). There are a total of 320 BMS sites spread out across the province, and around each site, an area of 400 x 400 meters is habitat-mapped. UniBZ maps the habitat of natural areas on behalf of the province, focusing mainly on areas with high ecological values and/or areas likely to be affected by natural and/or anthropogenic pressures, wherefore the size of each mapped area and its location within the province depends on those two factors.

Method 1

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	16
*** Method (Method reviewed)**	Field inventory and habitat mapping by the Province of Bolzano (carried out by UniBZ, and also implemented in Eurac's BMS program)
***Classification system**	Local classification system described by Wilhalm et al. (2022). The system provides references to the Annex I classification system where applicable. The system is based on the Swiss classification system described by Delarze et al. (2015).
***Output data**	Vector data limited to the select areas that have been mapped. No wall-to wall or raster maps with classified habitats available
***Owner/producer**	Areas mapped by UniBZ are jointly owned by the Province of Bolzano and the Free University of Bolzano. Areas mapped as part of the BMS program are owned by Eurac research.
Target group/Primary user/User needs	Areas mapped by UniBZ are used by the Province of Bolzano to assess ecological values in certain natural areas, especially areas likely to be affected by natural and/or anthropogenic pressures. The maps can be used as a knowledge base when the Province plans and assesses plans for local land management and development. The long-term goal of the province is to habitat-map areas across the whole province. Areas mapped by BMS are used for research purposes and specifically in combination with other metrics collected at the respective BMS sites (i.e., inventories of seven organism groups and an assessment of soil features).
***Input data and data providers**	Orthophoto of the Province of Bolzano (1 m resolution) provided by the Province of Bolzano. The orthophoto is updated once every four years, and as of now (June 2024), the newest orthophoto is from the year 2020.
Data cost	The orthophoto used for the habitat mapping is openly available on request from the Province of Bolzano.
***Description**	When possible, a preliminary delineation of the habitat types and borders in the target area is made using the QGIS software and the provincial orthophoto as image support before visiting the site in the field. Actual habitat delineation and

	classification (or confirmation) is done by drawing habitat borders of the target area onto a print-out of the provincial orthophoto in the field. Finally, the habitat borders and classifications that have been determined in the field, are drawn out as polygons manually in QGIS after the field visit.
Documentation	Protocol description for the BMS program: https://biodiversity.eurac.edu/online-as-of-today-manual-on-the-survey-methods-of-the-bms/ Wilhalm et al. (2022) classification system: https://www.natura.museum/wp-content/uploads/2023/01/Wilhalm-et-al.-Checkliste-Lebensraeume-Suedtirol-Gredleriana_22-2022-1.pdf Information on the Provincial orthophoto used as part of the method: https://geoservices.buergernetz.bz.it/geonetwork1/srv/api/records/p_bz:Orthoimagery:Aerial-2020-RGB/formatters/xsl-view?output=pdf&language=ger
Competence	The method requires knowledge on the local habitats, and specifically the flora, for being able to classify using the Wilhalm et al. (2022) classification system. The method hardly requires any additional experience or knowledge using GIS-och RS-based methods.
Tools	Tools necessary are a print-out of the orthophoto, a GIS-software, and a description of the various local habitat types.
Status	From the side of the Eurac and BMS, the method has been applied since 2019 with currently no specific plans to change the method. From the side of UniBZ and the Province of Bolzano, the general method for habitat mapping has been used longer but the effort and quality of habitat-mapped areas have vastly improved over time. The habitat inventories of the first Natura 2000-areas conducted in early 2000s were among the first areas to be habitat-mapped in the province and the mapping quality of these early Natura 2000-areas, is known to be poor.
Result/output/mapping accuracy	The output is vector data with habitat polygons manually drawn in QGIS on the background of the provincial orthophoto. No minimum classifiable habitat size is defined in the method.

DACC Spain - Catalonia Review

1. Partner

Pau Sainz de la Maza, Catalonia (Unitat d'Informació i Coneixement, DAAC) psainz@gencat.cat

Albert Ferré Codina, Catalonia (GeoVeg, University of Barcelona) aferrecodina@ub.edu

2. Analysis of experience

In the administrative area of the Catalan government, we have habitat mapping, with the legend CORINE Biotopes Manual (with crosswalks to EUNIS and Habitats of the Annex I). Currently (2024), we have finished the third version of this cartography, which includes the entire territory. The above correspond to the years 2012 and 2003, approximately. The map contains polygons (with a minimum area of 1.5 hectares), and also points, to represent habitats that occupy small areas. The methodology is manual photo interpretation of 25 centimeter resolution orthophotos, with field work for validation.

This map incorporates a series of assessment attributes, which are of interest for management and conservation: threat, endemicity, biogeographical value, extent, aggregation, eccentricity, etc.

Another habitat mapping project is underway, the habitat map of protected natural areas, at a scale of 1:10,000. The legend is the same (CORINE Biotopes Manual), and the minimum area is 2000 square meters.

We did not use remote sensing techniques for the production of the maps. Yes, we have done some tests with remote sensing for the detection of changes in habitats between versions 2 and 3 of the cartography. See http://atzavara.bio.ub.edu/geoveg/docs/Habitats_changes_Cat_IHCantabria.pdf.

These projects are promoted by the Catalan government (UIC, DAAC), and executed by the Geobotany and Vegetation Mapping Group of the University of Barcelona.

3. Needs and Future plans

The cartography we have is complete, for all the habitats of the directive, both inside and outside the protected areas. In the short term, we have no plans to change the mapping methodology. However, we are very interested in exploring the potential of remote sensing in the detection of changes in the landscape.

Apart from the detection of changes at a landscape scale, we are also planning a habitat monitoring system, based on fixed plots on the ground. It is a program that is just now being designed.

4. Methods

We do not have a specific methodology for grasslands and wetlands, as we work simultaneously with all habitat groups.

Method 1

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	09
*** Method (Method reviewed)**	Habitats map of Catalonia. Aerial photo interpretation (25 cm) Field work
***Classification system**	CORINE Biotopes Manual, with crosswalks to EUNIS and Annex I Habitats https://mediambient.gencat.cat/ca/05_ambits_dactuacio/patrimoni_natural/sistemes_dinformacio/habitats/habitats_terrestres/documents_complementaris/docs_hc/index.html
***Output data**	Vector polygons map, and vector point map
***Owner/producer**	Owner: Unitat d'Informació i Coneixement, DAAC, psainz@gencat.cat https://mediambient.gencat.cat/ca/05_ambits_dactuacio/patrimoni_natural/sistemes_dinformacio/habitats/ Producer: GeoVeg, University of Barcelona, aferrecodina@ub.edu https://www.ub.edu/geoveg/indexen.php
Target group/Primary user/User needs	Habitat mapping is widely used by managers and researchers: management of protected areas, management of threatened fauna and flora, preparation of directive reports, research in the fields of ecology, plant biology, biology conservation, etc.
***Input data and data providers**	Orthophoto of Catalonia autonomous region (25 cm resolution). The orthophoto is updated every year by the Institut Cartogràfic i Geològic de Catalunya (ICGC). Lidar of Catalonia autonomous region https://www.icgc.cat/en
Data cost	The orthophoto and Lidar used for the habitat mapping is openly available https://www.icgc.cat/en/Data-and-products/Imatge/Conventional-orthophoto https://www.icgc.cat/en/Geoinformation-and-Maps/Data-and-products/Bessons-digitals-Elevacions/Lidar-data
***Description**	The map covers the entire territory, with the legend CORINE Biotopes Manual (with crosswalks to EUNIS and Habitats of the Annex I). Currently (2024), the third version of this cartography is available. The map contains polygons (with a minimum area of 1.5 hectares), and also points, to represent habitats that occupy small areas. The methodology is manual photo interpretation of 25 centimeter resolution orthophotos (in ArcGIS environment), with field work for validation. This map incorporates a series of assessment attributes, which are of interest for management and conservation: threat, endemicity, biogeographical value, extent, aggregation, eccentricity, etc.
Documentation	https://mediambient.gencat.cat/ca/05_ambits_dactuacio/patrimoni_natural/sistemes_dinformacio/habitats/habitats_terrestres/

	https://agricultura.gencat.cat/ca/serveis/cartografia-sig/bases-cartografiques/habitats/habitats-catalunya/index.html#cartografia-dels-habitats-d-interes-comunitari-a-catalunya--versio-2--2018- https://www.ub.edu/geoveg/en/semhaveg.php https://www.ub.edu/geoveg/en/ManualCORINE.php
Competence	The method requires knowledge on the local habitats, and specifically the flora, for being able to classify using the CORINE Biotopes Manual classification system. The method hardly requires any additional experience or knowledge using GIS.
Tools	GIS software (ArcGIS or QGis)
Status	This method, in a more rudimentary way, was implemented in 1998, although in the first years photo interpretation was not done digitally, but on paper. The work methodology has been evolving, as the resolution of the orthoimages increased, Lidar data became available, the working environment with GIS improved, etc.
Result/output/mapping accuracy	The map legend includes approximately 600 different habitats. The minimum area for polygons is 1.5 hectares.

Method 2

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	40
*** Method (Method reviewed)**	Detection of habitat changes with remote sensing
***Classification system**	CORINE Biotopes Manual, with crosswalks to EUNIS and Annex I Habitats https://mediambient.gencat.cat/ca/05_ambits_dactuacio/patrimoni_natural/sistemes_dinformacio/habitats/habitats_terrestres/documents_complementaris/docs_hc/index.html
***Output data**	Vector polygons map
***Owner/producer**	Owner: Unitat d'Informació i Coneixement, DAAC, psainz@gencat.cat https://mediambient.gencat.cat/ca/05_ambits_dactuacio/patrimoni_natural/sistemes_dinformacio/habitats/ Producer: GeoVeg, University of Barcelona, aferrecodina@ub.edu https://www.ub.edu/geoveg/indexen.php Producer: IHCantabria, University of Cantabria https://ihcantabria.com/en/
Target group/Primary user/User needs	The detection of changes in habitats is a necessary tool for management and research
***Input data and data providers**	Habitat mapping of Catalonia Sentinel satellite images Landsat satellite images

	Lidar data https://www.icgc.cat/en
Data cost	The input data is openly available https://www.icgc.cat/ca/Ambits-tematics/Observacio-de-la-Terra/COPERNICUS-i-SENTINEL-2-Geoserveis-sobre-el-territori https://www.icgc.cat/en/node/20203
***Description**	The main objective of this work is to design a methodological framework to validate the vegetation (sensu habitats) changes that have occurred in Barcelona province between the years 2010 and 2020. These changes are documented through expert-based, detailed vegetation maps of habitat types in both years. The assessment is intended to be done by means of remote sensing techniques, more specifically from data derived from Sentinel 2 time series (available monthly 2017 to 2020), Landsat 5, 7 and 8 (download from 2010 to 2020 in a yearly basis) and LiDAR PNOA datasets (available ca. for 2010 and 2020 for the entire province)..
Documentation	http://atzavara.bio.ub.edu/geoveg/docs/Habitats_changes_Cat_IHCantabria.pdf
Competence	The method hardly requires experience using remote sensing.
Tools	GIS and RS software
Status	This methodology has been tried for the first time in 2022. It remains pending improvements
Result/output/mapping accuracy	This methodology is in the trial phase. Validations are needed in order to improve the results.

ExEA Bulgaria Review

1. Partner

Executive Environment Agency (ExEA) Bulgaria

2. Analysis of experience

Habitat mapping

In Bulgaria, the mapping of the habitats was carried out only in the NATURA 2000 sites. The habitats mapped in the project (2011-2013) covered all habitat types (except marine habitats) in Natura 2000 sites, not just grasslands and wetlands. The marine habitats in Natura 2000 sites are mapped in another project (2017-2023). The initial map of the habitats was made through a deductive model that used the available input digital information (map units from the Map of Physical Blocks of Bulgaria, altitude, geological base - limestone, slope, exposure, map unit from the Bondev Vegetation Map (1991)- used only as indicative information, due to the small scale of the map (1:600000), previous field studies and the ecological characteristics of the habitat.

The final habitat distribution map was created after applying an inductive model, topological verification, and merging the graphical polygons drawn after verifying the deductive model polygons during fieldwork and the resulting inductive model polygons for the area not mapped in the field. To create an inductive model of habitat distribution, a geographically weighted regression analysis was applied, as a result of which the probability values of each polygon of the investigated dependent variable are calibrated or refined. The habitat distribution polygon layer is taken as the dependent variable, which includes: field-mapped polygons drawn by field experts with a probability value of 1, deductive model polygons not verified in the field - with a probability value of 0.2 up to 0.9 depending on the observations of the credibility of the deductive model during the fieldwork and all other polygons from the physical blocks that, according to the permanent land use, could potentially be the studied habitat - with a probability value of 0 to 0.1. As independent environmental variables of the environment, the following are considered: geological base, soil cover, permanent land use, altitude, exposure and slope of the terrain.

The inductive model is applied in the territorial scope of each NATURA 2000 site in order to avoid spatial correlation of the data with the territories outside the boundaries of the NATURA 2000 site for which there is no field data or sufficient data from other studies and projects. A re-inductive model at the national level is applied only after the final area-level habitat distribution maps have been completed, in order to examine the probability of the distribution of the habitat at the national level and to give the most accurate national estimate of the distribution of the habitat. In order to model the distribution of the habitat at the national level, all locations of the presence of the habitat within the boundaries of the protected areas and independent ecological variables of the environment - exposure, terrain slope, altitude, soil cover, geological basis, land use, average annual temperatures, average annual amount of precipitation, annual temperature and precipitation amplitudes, daily temperature amplitudes. The final habitat distribution map is created after an expert review of the result of the applied inductive model and after making corrections in the cases of implausible probability values. The final habitat distribution map is produced at the area level, at the national level and at the biogeographical level. The required accuracy is ensured by topological verification of the final polygon distribution layer against the 1:5000 scale reference layer –

the physical block map. Complete information from the phytocenological description of the trial site within the boundaries of the polygon is attached to each polygon mapped in the field.

Habitat monitoring

The habitats (except marine habitats) are monitored in the project (2018-2022). The marine habitat surveys were carried out under another project (2017-2023). A monitoring methodology has been developed for each type of habitat. The methodology includes a description of the habitat type, distribution, places for monitoring, typical species, monitoring period, monitoring parameters, indicators and technical equipment.

3. Needs and Future plans

There are 93 types of natural habitats in Bulgaria, which are mapped only in NATURA 2000 sites. Our future plans are to map the habitats of the entire country and improving mapping methodology, using new methods.

Our future plans for habitat monitoring are to continue habitat monitoring by improving monitoring methodologies and using new methods such as drones, remote sensing and others.

4. Methods

Method 1

Habitat mapping

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	**2**
*** Method (Method reviewed)**	Field inventory Combination of several methods
***Classification system**	**Annex 1 habitat types (Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora)**
***Output data**	Pixel-based Habitat type classification maps in raster format (10 x 10 m resolution). Object-based habitat boundaries in vector format. The list of indicators includes typical species for habitat identification different for different habitats. For mapping of habitats in 2012 are used Corine Land Cover 2012
***Owner/producer**	Ministry of environment and water, Bulgaria Executive Environment Agency (ExEA), Bulgaria
Target group/Primary user/User needs	The main users are Ministry of environment and water, Executive Environment Agency, Bulgarian Academy of Science, Regional inspectorate for environment and water, National park Directorate and Nature parks Directorate. Other users are Ministry of agriculture and food, Universities, Forestry enterprises and NGO's. The main type of usage is Habitat directive reporting and the assessments of threatened habitats as well as other surveys, assessments and studies. The

	maps are used as a base for develop the management plans for protected areas and NATURA 2000 sites.
***Input data and data providers**	Corine Land Cover 2012, Topographic map database and Digital Elevation Model. Data providers are Ministry of environment and water (https://www.moew.government.bg/en), Executive Environment Agency (https://eea.government.bg/en) and Geodesy, Cartography and Cadastre Agency (https://kais.cadastre.bg/en/Map).
Data cost	Some data listed above is free of charge. For part of the data is required minimal fees (Max 5 euro for usb flash memory, cd or paper). If the information is sent by e-mail it is free of charge) by Access to Public Information Act.
***Description**	The habitats mapped in the project (2011-2013) covered all habitat types (except marine habitats) in Natura 2000 sites, not just grasslands and wetlands. The marine habitats in Natura 2000 sites are mapped in another project (2017-2023). A mapping methodology has been developed for each type of habitat. The mapping methodology includes preliminary work (description of ecological characteristics, habitat identification criteria, threats, available information, national assessment, definition of habitat boundaries, creation of map material using topographic maps, orthophotos, cadastral maps) and fieldwork (surveying the territory, fixing spatial boundaries, taking geographic coordinates, sketching, photographing and determining the habitats using a specially developed "Guide for determining the habitats of European importance in Bulgaria" and the Red book of Bulgaria) and digitizing the maps.
Documentation	https://natura2000.egov.bg/EsriBg.Natura.Public.Web.App/Home/Reports?reportType=Habitats (documentation page in Bulgarian) https://eea.government.bg/bg/bio/nsmbr/prakticheskо-rakovodstvo-metodiki-za-monitoring-i-otsenka/metodiki-za-monitoring-na-mestoobitaniya-predstoi-utvarzhadavane (documentation page in Bulgarian)
Competence	The field method requires knowledge on the local habitats, and specifically the flora, for being able to classify. Experience and knowledge in GIS analysis.
Tools	Desktop GIS software for visualizations and data management. Verification on the field.
Status	The method was successfully used for habitat mapping in Bulgaria. The future plans for mapping habitats are to use remote sensing the habitats and Machine learning classifier for classifying the habitat types This method has been used for reporting from 2013.
Result/output/accuracy	Output resolution is 10 m The minimum map unit is 25 ha. Scalability is 1:25 000 to 1:100 000

Method 2

Habitat monitoring

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	**3**
*** Method (Method reviewed)**	Field inventory
***Classification system**	**Annex 1 habitat types (Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora)**
***Output data**	Object-based data from habitat monitoring in vector format. Field forms (paper and electronic) in text format. The list of indicators includes typical species for habitat different for different habitats.
***Owner/producer**	Executive Environment Agency (ExEA), Bulgaria
Target group/Primary user/User needs	The main users are Ministry of environment and water, Executive Environment Agency, Bulgarian Academy of Science, Regional inspectorate for environment and water, National park Directorate and Nature parks Directorate. Other users are Ministry of agriculture and food, Universities, Forestry enterprises and NGO's. The main type of usage is Habitat directive reporting and the assessments of threatened habitats as well as other surveys, assessments and studies. The monitoring data are used as a base for develop the management plans for protected areas and NATURA 2000 sites.
***Input data and data providers**	Executive Environment Agency (https://eea.government.bg/en)
Data cost	Some data listed above is free of charge. For part of the data is required minimal fees (Max 5 euro for usb flash memory, cd or paper). If the information is sent by e-mail it is free of charge) by Access to Public Information Act.
***Description**	A monitoring methodology has been developed for each type of habitat. The methodology includes a description of the habitat type, distribution, places for monitoring, typical species, monitoring period, monitoring parameters, indicators and technical equipment. The monitoring parameters are selected so as to allow in situ collection of the necessary data to carry out a subsequent assessment of the conservation status of the natural habitat. Places for monitoring are designated for each habitat. There are field forms to carry out monitoring in the field, in which data are filled in for the parameters defined in the methodology.
Documentation	https://eea.government.bg/bg/bio/nsmbr/praktichesko-rakovodstvo-metodiki-za-monitoring-i-otsenka/metodiki-za-monitoring-na-mestoobitaniya-predstoi-utvarzhadavane (documentation page in Bulgarian) https://eea.government.bg/bg/opos_2014-2020/opos_os3/deynosti-i-rezultati/direktivata_mestoobitaniyata (documentation page in Bulgarian)
Competence	The field method requires knowledge on the local habitats, and specifically the flora.

Tools	An information system to the national system for monitoring the state of biological diversity (Biomon - an information system specially developed for collecting data on biodiversity in Bulgaria), which contains electronic forms (identical to field forms), query capabilities and data visualization. Information system include a mobile application in which data can be entered in the field. Technical equipment (specialized mobile application when collecting data in an electronic form, camera, binoculars, measuring tape 50 (100) m long, laptop, inclinometer or protractor). Desktop GIS software for visualizations and data management.
Status	The method is successfully use for habitat monitoring in Bulgaria. Our future plans for habitat monitoring are to continue monitoring by improving monitoring methodologies and using new methods such as drones, remote sensing. This method has been used for reporting in 2019.
Result/output/accuracy	The distribution map is presented in ETRS grid 10 x 10 km and ETRS grid 1 x 1 km, corresponding to the reported under Art. 17 of the Habitats Directive. Plot size for habitat monitoring is different for each habitat type (25 m2 - 50 m2).

MEPGT Croatia Review

1. Partner

MEPGT (tamara.kirin@mingor.hr)

2. Analysis of experience

In Croatia we have so far produced two habitat maps. First one was made in 2004, using remote sensing. The data was extrapolated from Landsat ETM+ with a combination of the literature data with few field work data. MMU was 9 ha. The second one was done from 2014 to 2016, and the base map was Orthophoto. This map covered only non-forest habitats and MMU was 1,56 ha. This map was made manually drawing the polygons from the Orthophoto, manually checking whether the polygon is smaller or bigger than 1,56 ha. It took a team of around 17 photo-interpreters working three years on it. After drawing the polygons fieldwork was conducted in order to confirm the habitat determination. During these three years 64 343 of field work points were collected, which meant that 22% of polygons were checked in the field. More than 25 botanists were involved during three seasons.

Many protected areas have made their own habitat maps in the meanwhile, but since it was always covering small areas it was also not done with remote sensing methods but focusing on field work.

3. Needs and Future plans

We urgently need to produce a new habitat map. The last one included the update plan, but it was made too optimistic, planning to visit all the polygons in the field during the period of 10 years. It was too expensive and never even started.

We have recently collected over 5000 field work points describing the most important habitat types in the most relevant places. Hopefully a new habitat map is going to be done using satellite data in a combination with earlier mentioned 5000 field points as reference. The basic doubts and considerations about the old and the future map at the moment are:

- should we use the "framework" (still correct polygons) from the old map or not. It would be great to use them because these polygons were very detailed and nicely done and this would make data easier to compare. At the same time it is probably more complicated to work this way.
- The last map didn't include forest data, now we do have data also about the forest habitat type, we can include them, but that would make the layers less comparable.
- In the last map it was allowed to describe a habitat with three habitat types (in the case of mosaic habitat). This resulted in most polygons containing three habitat types and therefore even though MMU is pretty detailed, we are still not able to calculate the precise area of one habitat type in the required area. If this is to be changed, certain information will be lost, the map will be "simplified" but maybe more practical.

4. Methods

Visual interpretation of Orthophoto map 2014 in the combination with field work

Method 1

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	**6**
*** Method (Method reviewed)**	Visual interpretation of Orthophoto map 2014 in the combination with field work
***Classification system**	NHC (National habitat classification of Croatia) This is similar to EUNIS and it has pretty clear crossword to Annex 1 Habitat
***Output data**	Very detailed map with mostly correct habitat types
***Owner/producer**	Ministry,it is publicly available: https://bioportal.hr/gis/
Target group/Primary user/User needs	Everyone; it is used for Habitat directive reporting, assessment of the intervention's impact on the ecological network, research planning…
***Input data and data providers**	Data was also publicly available (Orthophoto)
Data cost	The map costed 60.000,00 euros
***Description**	Terrestrial non-forest habitat map was made from 2014-2016. It covered non-forest habitats of the whole Croatia. MMU was 1,56 ha. It was made by photo interpretation of Orthophoto map. After the preparation of a region, botanists were sent to the field to check it out and confirm the habitat determination. Botanists were using the tablets with prepared maps on them and they were able to confirm or refute the habitat type in each polygon. For certain very important but small habitats (such are bogs in Croatia) botanists had also the possibility to insert an “punctual habitat” in the map. Described method produced a very good map. It was highly detailed and during the time showed to have a high degree of correctly described habitats. However the problems were: the fact that polygons might have been associated with three different habitat types (listed in the order of their dominance) caused certain problems. In this way it was not possible to calculate the precise surface of a certain habitat type in one area. The map did not include forest areas. This fact in combination with three-habitats-rule caused some polygons to be described as dry mediterranean meadows/forest/rocky habitat. This is not very informative all together since there is a term “forest” inside the map was very expensive so it was never updated All together it was a very good map. It might be better if it included forests, however it is too expensive to be repeated.
Documentation	Final report: https://www.dropbox.com/s/nxscgka5baefe50/Konacno_izvjesce_Karta_2016.zip?dl=0&e=1&file_subpath=%2FFinal_report_of_the_project_Terrestrial_Habitat_Mapping_of_the_Republic_of_Croatia.pdf
Competence	photo-interpretation of the orthophoto pictures in GIS

Tools	GIS
Status	Too expensive
Result/output/mapping accuracy	Habitat map, 1:25 000, MMU 1,56. The map contains 322 758 polygons and 972 “point locations” . It describes 155 habitat types and during its preparation 64 343 field observations were made (which is around 22% of the polygons).

MoE_DK Denmark Review

1. Partner

Ministry of Environment - Denmark. Represented by Aarhus University.

2. Analysis of experience

In Denmark there are no remote sensing based methods currently operational for mapping or monitoring open landscape nature. In the following the known approaches to national mapping and monitoring of Annex I habitats are mentioned and discussed. At local scale visual orthophoto interpretation is used as support tool, mainly for mapping habitats.

Mapping: The Danish Agency for Nature Protection has been working on a machine learning based method to map all Annex I habitat types in Denmark using mainly remote sensing data but also other data, such as distance to coast and climate. This system currently works satisfactorily for 6 of the 43 Annex I habitat types in Denmark, but these constitute approximately 50% of the area covered with Annex I nature. It takes a wealth of different input data – several tens of features – and outputs a map in 10x10 m resolution with each pixel assigned to an Annex I habitat type. The system is currently undergoing second round of validation and attempt to improve the system is being taken. Main problems are types with little training data and types that do not depend on the vegation type, e.g. springs. Also types that are relatively small by nature are difficult to predict using this method, e.g. dune slacks. Another main problem is the validation of this system. It is hard to find the “right” reference, as field-biologists would also be in doubt about the nature types in some cases. So the risk is that one validates against data saying that a given area is a certain habitat type that is actually “wrong” or could just as well be another nature type close to the one that the field biologists have designated. In addition to this the scale of which the system should be validated is not trivial to decide. Currently, work is being done developing a method to validate it on polygons representing “a site” as that mirrors the scale at which typical management takes place.

Habitat quality: The Danish Agency for Nature Protection has initiated the development of various condition metrics that are aimed at being part of a new habitat condition assessment system. These currently count vegetation height, vegetation cover, grazing or not (binary) and mowing. These are now being validated over the next year or so and their usefulness is still quite uncertain. Issues with developing these are manifold. For vegetation height, we typically need knowledge of even quite low vegeation, e.g., < 10 cm and this is hard to get from normal remote sensing data. The development is based on both lidar and orthophotos, but the lidar has been recorded for digital terrain models and therefore mainly during leafs-off seasons, and for condition metrics one is mainly interested in leafs-on e.g. summer vegetation height. Also, we usually need information at finer scale than most remote sensing products; < 2 m resolution preferably for many of the metrics that can be derived from remote sensing. This is not possible with currently available satellite data so we are often stuck with national data sources like national lidar data campaigns having the limitations mentioned above. In addition to this, there is usually not good training and validation data as these often mismatch the time of lidar data acquisition, so gathering additional data in the field is typically required to develop systems to map several relevant habitat condition metrics, including vegetation height and cover. Mowing is easier and currently works in Denmark for agricultural fields, and possibly the validation of this metric will show it also works well in open landscape nature. Grazing is harder as this is an ongoing process and it is varying in intensity.

3. Needs and Future plans

Overall, we need better ground truth data and better input data (e.g., lidar data, and finer resolution satellite data). For satellite data – even if it is much easier than it used to be – we need easier ways of getting top-notch perfectly atmospherically corrected images and country wide mosaics from the same day. The latter is probably impossible but would likely give the best and most reliable models and results. We also need easier-to-use deep learning frameworks that can take satellite data or raw point clouds as input. Today most frameworks are made for RGB images, so one has to adjust the architectures and there are typically not networks available with pretrained weights for all image channels in a satellite image or pretrained raw-point-cloud architectures. Most likely deep learning has a lot of potential over the more traditional machine learning approaches that are currently far easier to grab and use.

In Denmark we don't know how much of the country has been mapped as we don't know all patches of each habitat type. However, we have conducted a country-wide mapping based on field data, and possibly most of the most important of each habitat type is already mapped. Today habitat quality assessment is conducted based on field work. This system works very well and we in principle don't have the need for further quality assessment in the areas. However, there is a wish to digitalize monitoring, so in that perspective the need is high, and the ministry wishes to have a habitat quality assessment system based at least in part on remote sensing as soon as possible. As written in 2, this development already takes place.

The plan for digital habitat mapping and monitoring is to have it working by the end of 2026 in a first operational version. Likely, this could then be extended with more digital approaches than in the first running version. As said, we already have mapped large parts of the Annex I nature, but this is constantly changing. We also already have a good habitat quality assessment system, but this is based only on field work.

4. Methods

Method 1

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	**32**
*** Method (Method reviewed)**	Based on UAV lidar and RGB imagery. Various machine learning approaches are taken to train a model to predict the vegetation height in open landscapes (and trees/forests for that matter). Training data are field collected.
***Classification system**	**Annex 1 Habitat**s, but not dependent on certain habitats, should work in all kinds of nature.
***Output data**	The vegetation height in very fine resolution (< 50 cm) and very high accuracy (a few cm error) for a whole area (for example used on Molslab in DK which is 130 ha)
***Owner/producer**	Department of Ecoscience, Aarhus University. Part of the MAMBO project. Made by Agata Walicka. Contact: Jesper Erenskjold Moeslund, jesper@ecos.au.dk, +45 23227111

Target group/Primary user/User needs	The target group is all landowners who wishes to monitor vegetation height on their premises, incl. states and their nature agencies or ministries. Targeted towards enabling digital monitoring for the reporting of habitat condition to the EU (article 17).
***Input data and data providers**	A lidar point cloud from an UAV borne lidar, for example the L1 or L2 systems for DJI drones. Field collected training/validation data collected using a GNSS receiver (differential GPS). 200-400 points (collected in 1 day, 2 persons). An image mosaic recorded together with the lidar data.
Data cost	Collection of data costs around 1-2 days in the field with a drone pilot and the costs of renting a drone if you don't have one. If neighbour or not too far away from Denmark, Denmark may be able to come to the area with a drone a help doing the flight. Cost of field data is 2 person days and rent of GNSS receivers if you don't have any. Denmark may be able to bring two receivers if they visit anyways. RTK corrections are needed but usually free for science. Ask if you don't know what it is. There is also a little preparation for the field work, e.g. flight campaign preparation (DK can help) but that is probably not even one full day.
***Description**	This method is made to enable fine-resolution acquisition of vegetation heights over relatively large areas. It works in both open landscapes like grasslands and wetlands but also in shrublands and probably also in more forested areas. It still needs some testing to confirm how well it works across different regions and environments. Being able to map vegetation height for a whole landscape at very fine detail enables actual monitoring of encroachment and quantification of how low and tall herbs, small and large shrubs, bare soil, bare water and trees are distributed. This can also help assessing the degree to which natural processes (e.g. natural grazing) is going on. Vegetation structure will also be one of the first parameters where one can see changes after e.g. restoration or various conservation initiatives have been initiated or completed, so this habitat condition metric is quite important and will bring a lot of information for monitoring habitats.
Documentation	Still none, but data processing scripts can be provided
Competence	Ecological knowledge is also a plus but not required. Field work experience is a plus but not required. Drone pilot is needed but could possibly be flown in from DK (see above). Experience with recording lidar points clouds is a plus, but not hard to learn. If you wish to run the analyses yourself, you need Python programming skills and preferable a background in remote sensing and lidar. Denmark can also do the analyses provided the acquired field data. Generally, DK will help in most aspects if needed.
Tools	An UAV with a lidar sensor, e.g. a DJI with an L1 or L2 lidar sensor. (could possibly be provided by DK incl. a pilot, see above) The DJI software for processing point clouds (DK has this and could do this processing for you) A GPU accelerated PC or cloud computer solution to run the modelling on. DK has this and could run the analyses for you.

Status	The method is still being developed but is approaching an end within a few months, so analyses could be run already autumn 2024 if data is recorded in summer/late summer 2024.
Result/output/accuracy	Output resolution: < 50 cm (0.5 m) Mapping area could be anything from a few hectares to some square kilometers Every time a new map or quantification of vegetation heights are needed for monitoring in the future, a new UAV campaign needs to be initiated to get updated information on the vegetation. Accuracy will be very accurate with only a few cm error. The method is likely transferable to many different areas and regions, but this is what we wish to test in the pilot. For upscaling to e.g. national levels, UAV borne points clouds for all areas in need of monitoring will be needed. Given better future airborne lidar, this method could be transferred to use airborne lidar data and orthophotos instead, but accuracy will then likely suffer depending on the point cloud quality and point density.

NCA CZ Czech Republic Review

1. Partner

Nature Conservation Agency of the Czech Republic (NCA CZ)

= Agentura ochrany přírody a krajiny ČR (AOPK ČR)

Dep. of biodiversity monitoring

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2. Analysis of experience

Comprehensive habitat mapping and subsequent monitoring was established in the Czech Republic in the early 2000s in connection with accession of the country to the European Union and establishment of the Natura 2000 network. This wall-to-wall field inventory of all areas with potential occurrences of natural habitats laid the foundation of today's habitat mapping. Since then, the focus has been on continuous updating, correcting, refining, standardising and complementing of this original resource. Its quality and reliability is steadily improving and while still being far from perfection, it is used in more and more governance-related applications (see part 4).

Taken together, high importance of this data, solid expertise in field botany among NCA CZ and its contractors, lack of expertise in remote sensing methods and general lack of personnel and resources which could facilitate any kind of radical change has resulted in a conservative approach. The application of remote sensing (RS) has been limited to using aerial photographs as basemaps on which the segments are hand-drawn, and based on which they are checked by regional supervisors.

There have been some attempts in the Czech Academia to employ remote sensing methods to aid the habitat mapping, but the results have been limited. The most recent project aimed at RS-based supplementing NCA CZ field mapping was called “Possibilities for updating map layers of NATURA 2000 biotopes using advanced remote sensing methods” (SentiMap), carried out by a group of researchers at the Czech University of Life Sciences in Prague. They explored usability of both UAV and Sentinel data and several classification techniques. While all of these methods were successful at detecting broad habitat categories (water/forest/grassland/…), none has reliably distinguished habitats in the sense of the national classification system.

ref.: ŠÍMOVÁ, P.; BARTÁK, V.; MORAVEC, D. et al. (2023). Možnosti aktualizace Vrstvy mapování biotopů s využitím dat družic Sentinel. Praha: Česká zemědělská univerzita v Praze. 128 s.

Regarding quality monitoring, see part 4.1 for a list of quality indicators recorded in the *habitat mapping* scheme. There has also been a parallel system of so-called *habitat monitoring* set up and maintained since the early 2000s. It consists of a network of several hundred standard phytosociological relevés placed in “typical” spots of the national habitat classes. They were supposed to be surveyed every 6 (non-forest habitats) or 12 (forests) years, which has been followed in many of them to the present day. The original goal was to use this data to better inform the reporting on the quality of the individual habitat types, but this potential has never been utilised. It might become useful as ground-truthing data for some RS methods.

3. Needs and Future plans

The ongoing field habitat mapping aims at covering all areas of Annex I habitats in the whole country. It is in principle hard to estimate how successful it is at fulfilling this goal, but we estimate that we are able to cover well over 90 % of most of the habitat types. But the field botanists are currently not systematically incentivised to search for new natural habitat patches in unmapped landscape, which is assumed to consist of only agricultural, urban or intensive forest plantation habitats. Such a task would be prohibitively time consuming. New additions of natural habitats are based on random encounters of the field surveyors and their local knowledge. But this is exactly where RS-based methods can be of great value - to uncover previously overlooked areas of natural habitats.

Another potential application of RS-based methods within the framework of the field habitat mapping project is detection of habitat change. Field mapping is done every 12-15 years at any given spot. This rather low frequency and high age of the data at many locations is the single biggest limit of further usability of the data. RS could detect habitat change since the last field mapping, at least detecting events such as constructions of buildings, felling of forests, planting tree plantations etc. The results could be used to directly update the habitat map, or to flag potentially outdated areas, or to target focused local field surveys.

There is currently a lack of RS expertise in habitat mapping and monitoring at NCA CZ, but we hope to change this as soon as possible.

1. Methods

Method 1

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	**18**
*** Method (Method reviewed)**	**Field inventory** (supported by aerial photographs)
***Classification system**	**National classification, almost fully compatible with Annex 1 Habitats, but more detailed for many habitat types.** CHYTRÝ, M.; KUČERA, T.; KOČÍ, M. (eds.) et al. (2010). Katalog biotopů České republiky: Habitat catalogue of the Czech Republic. 2nd edition. Praha: Agentura ochrany přírody a krajiny ČR. 445 s. ISBN 978-80-87457-03-0. Habitat catalogue - interactive: https://portal.nature.cz/seznam-biotopu#/ (under construction); pdf: https://www.sci.muni.cz/botany/chytry/Chytry_etal2010_Katalog-biotopu-CR-2.pdf
***Output data**	Vector map Species lists for individual polygons (diagnostic, typical, dominant, protected and invasive species)

	Supplementary table with polygon attributes: "Representativeness", spatial and age structure of the tree and shrub layer, deadwood abundance, habitat degradation, habitat management, regional evaluation, plant species, habitat structure and functions evaluation.
***Owner/producer**	Nature Conservation Agency of the Czech Republic (NCA CZ) = Agentura ochrany přírody a krajiny ČR (AOPK ČR) Dep. of biodiversity monitoring Interim designated contact person: Dan Leština dan.lestina@nature.cz tel.: +420 721 323 149 Kaplanova 1931/1, CZ14800 Praha 11 – Chodov
Target group/Primary user/User needs	The primary users are employees of the public sector dealing with biodiversity and landscape protection in a very broad sense. In the context of the Czech Republic, those are NCA CZ employees both at the regional offices and at the headquarters, employees of the regional government offices, national parks and the Ministry of Environment and the Ministry of Agriculture. Secondarily the data is used by NGOs, Academia and private companies and individuals dealing with environmental issues. The users require high reliability, accountability and precision of the data, compared to many other habitat monitoring schemes abroad. Obvious limit is the age of the data in some areas. This data has naturally become the basis of the Habitats Directive reporting, but it is also used in protected areas management planning, calculation of certain agricultural subsidies (grassland mowing), urban planning and zoning in some high-value areas, Environmental Impact Assessments and many others.
***Input data and data providers**	NCA CZ https://data.nature.cz/ds/21 (Available for download upon registration and agreeing to terms and conditions.) Simplified viewer app set up here.
Data cost	Free to use, terms and conditions apply.
***Description**	Habitat mapping of the Czech Republic is a long-term activity of NCA CZ. As described above, it was established in the early 2000s as one of the data foundations of the Natura 2000 network set-up. Initial wall-to-wall field inventory of all areas with potential occurrence of natural habitats involved hundreds of field botanists and produced a baseline resource. The whole country was evaluated on the basis of aerial photographs and other maps in order to exclude large continuous areas of agricultural, urban and other unnatural habitats. The whole rest of the land area of the country was mapped in the field by botanists. In the following years and all the way to the present day, the focus has been on continuous updating, correcting, refining, standardising and complementing of this original resource. The country is divided 3494 into mapping regions, with each assigned employee or contractor updating the habitat map in one or several of these regions each season. Each region should be updated every 12 years, but delays occur. Almost all areas have been updated once, and over 20 % have been updated twice or the second update is currently (summer 2024) under way.

	The quality and reliability of the product has been steadily improving over time with methodological and technological development. Other data recorded for each individual habitat patch include: "Representativeness", spatial and age structure of the tree and shrub layer, deadwood abundance, habitat degradation, habitat management, regional evaluation, plant species, habitat structure and functions evaluation.
Documentation	Methodology: https://portal23.nature.cz/publik_syst/files/metmapb_i24.pdf (in Czech, English summary available upon request) Data with documentation: https://data.nature.cz/ds/21 Habitat catalogue - interactive: https://portal.nature.cz/seznam-biotopu#/ (under construction); pdf: https://www.sci.muni.cz/botany/chytry/Chytry_etal2010_Katalog-biotopu-CR-2.pdf
Competence	Field botanists with good knowledge of diagnostic and other species, of other identifying characteristics of the habitat types and of other details of the methodology are needed. For scaling up to a larger scale, advanced GIS and IT expertise is needed to compile the data into the final product.
Tools	Field surveyors hand-draw habitat segments on printed aerial photographs and maps on the 1:10,000 and 1:5,000 scale and record other data onto prepared printed forms. Dedicated software has been developed by NCA CZ to aid the surveyors in redrawing of the field drawings into a digital form and entering all other recorded data. The software streamlines this process, providing simplified GIS tools, dedicated forms, automated error detection, automated compilation of a final report on the surveyed area and, crucially, uploading of all of the data onto a server database and merging the newly surveyed area into the final GIS layer product. It could be replaced by standard GIS software in a pilot testing, but it would be prohibitively time-consuming and error-prone on a large scale (eg. country-wide).
Status	Ongoing, constantly developing method
Result/output/accuracy	Minimum mapping area for common habitats occurring on large areas: 0,15 – 0,25 ha. Smaller patches also included for rare, EU-protected and other selected habitat types. Method is developed for the Czech Republic. Habitat catalogue and the distinguishing features would have to be expertly updated if to be used in another country; neighbouring countries would require only small additions, while a method transfer further, namely to the Mediterranean region, would mean considerable methodological preparation Scalability is limited mainly by availability of field botanists and funding.

NPWS Republic of Ireland Review

1. Partner

Domhnall Finch – domhnall.finch@npws.gov.ie. National Parks and Wildlife Service (NPWS), Republic of Ireland.

2. Analysis of experience

Wetlands

Between 2009 and 2023 dedicated habitat mapping and monitoring stop surveys have taken place at 21 upland locations in Ireland, these cover 10 Annex 1 habitat types. We have revised our methodologies between these years, e.g., IWM 48 and IWM 79 (details in Section 4.3 Method 3), to include amendments to the provisional vegetation classification and habitat assessment procedures, as well as new or expanded guidance to including descriptions and photographs of a range of habitats, and figures to illustrate certain aspects of the project methodology. These surveys are undertaken at a local scale, but data is collated to feed into a national programme. Due to the size of some of these upland sites, e.g., one survey covered over 140km^2, the monitoring stop field surveys and habitat mapping of these areas are extremely expensive to conduct and don't allow for frequent revisit. Our National Fen Survey takes a similar methodological approach of habitat mapping and monitoring stops, where sites are pre-digitised using GIS to try and break the sites up into reasonably homogenous polygons that are of a manageable size for field surveyors to work with. A field survey of each site is carried out, usually by two field surveyors, who will divide up the tasks between them. The tasks include habitat mapping (assigning percentages of each polygon to the appropriate habitat), habitat assessment plots, vegetation plots, water parameter recording (pH & EC), and peat depth recorded. All data is recorded on ruggedized tablets. These are challenging and labour-intensive surveys at a national level and demands a skilled field team. There has also been a terrible chicken-and-egg scenario of undertaking local surveys and creating national classification system for any habitat. For any national monitoring programme, e.g., National Fen Survey that is the first of its kind in Ireland, there was no classification system that could be used at the start. So, an adaptive approach had to be taking to utilise species list to develop a national classification system as the surveys were taking place. This of course could be reviewed and tweaked at the end as required. However, this does risk that good, older data are being lost; that land use data is insufficient to understand the relationship between management and vegetation; and combining these two, the risk of a shifting baseline (setting lower targets for national monitoring programmes).

For our active and degraded raised bog, vegetation mapping using detailed ground surveys has been used for c. 30 years. The method uses an ecotope classification system that has been refined over the years and used in several national raised bog monitoring programmes. High accuracy (i.e., sub-meter) handheld computers are used on the field to assess changes in vegetation boundaries. The availability of higher resolution aerial images in later years has improved the accuracy of the surveys. Additionally, in recent years several remote sensing techniques have been tested by a few universities to varying degrees of success in habitat mapping and monitoring (discussed further in Section 3 and Section 4).

Grasslands

The 2023 monitoring survey of Calaminarian grassland revisited sites previously mapped in 2018 and originally identified and assessed, but not mapped, in 2008. Mapping was undertaken of all mine spoil areas present within a site, with polygons drawn in the field using aerial photography. As Calaminarian Grassland is usually fragmentary and typically occurs as small patches on mine spoil areas, the areas of spoil were mapped as a mosaic and a percentage cover was assigned for each habitat present within a polygon. This method could perhaps be considered coarse but given the small size of most survey sites and the limited extent of most Calaminarian grassland present, it was determined to be the most useful and efficient method. Although their presence is not essential to call an area Calaminarian grassland, a suite of rare specialised metallophyte bryophytes is a key defining feature of this habitat in Ireland, so a high level of bryophyte expertise is required to survey and assess the habitat, as knowledge of the presence and abundance of the specialise species is important.

Between 2007 and 2012 the 'Irish Semi-natural Grassland Survey' (ISGS; O'Neill *et al.* 2013 – detailed methods and map viewers can be found in Section 4.5 Method 5) visited 1,192 sites across all counties in Ireland, providing a broad sample of semi-natural grasslands in Ireland. The methods used to survey, map and assess the quality of the habitats have been modified slightly in the interim but are still *largely* the same and largely in use now. Before those dates other surveys took place but were either much earlier, pre-dating digitisation or used differing methods and/or differing habitat definitions. Thus, the ISGS survey is most commonly used as a start point and reference point. Note that while it was widespread in its coverage, it was by no means comprehensive, and many areas of semi-natural grassland will have been missed, including some likely to be of excellent quality.

The key successes of the ISGS and following surveys (e.g., 'Grassland Monitoring Survey', Martin *et al.* 2018) has been the consistency of methods used in the field, allowing good comparisons of changes over time, where they are occurring. The downside is the labour-intensive methodology, requiring skilled field botanists. It would be desirable to move to a situation where all sites of interest had baseline mapping and information from field surveys, but then remote sensing could be used to help spot changes such as abandonment, agricultural improvement, afforestation, scrub/bracken spread, etc.

It must also be noted that all our habitat data and mapping is made publicly available here - https://www.npws.ie/maps-and-data

3. Needs and Future plans

Wetlands

Overall, capacity building within the Irish ecological sector is the main need and knowledge gap we are facing. Many of the experienced ecologists are retiring and we are finding that we have a significant capacity gap of skilled field surveyors within the sector. Additionally, many of our habitats cover extensive areas nationally and so the frequency of mapping and monitoring stops is dependent on staffing and resource requirements, particularly our upland habitats.

The National Fen Survey is on-going, but has, to date, mapped more than 298 ha of 7140, 228 ha of 7210 and 589 ha of 7230, the aim over the extent of the project is to map 450 sites. This survey will cover virtually all SACs for which fen is a Qualifying Interest, other SACs, and also land outside the Natura 2000 network. As this is the first national survey it is an important baseline assessment to be able to track losses in area and degradation in condition. Remote sensing (drones or high-quality satellite data) may be useful in preparing habitat/vegetation maps for fen sites in the future, at a higher resolution than possible by field workers and likely at a higher accuracy. Ground-truthing surveys and plot level data collection will still be required to produce comprehensive assessment.

Active raised bogs in the protected area network (SACs and NHAs) have been mapped to a very high degree of accuracy using the detailed ecotope mapping methods. This accounts for ca 90% of the national resource. The disadvantage of the detailed ecotope mapping methods is that they require a high amount of time and human resources. Remote sensing techniques have been trialled to varying degrees of success. For example, Bhatnagar et al. (2020) were relatively successful in mapping the higher quality areas of active raised bogs (central ecotope) but less successful in mapping the lower quality areas (sub-central ecotope). Putting this in context it should be realised that sub-central ecotope accounts for an estimated 75% of active raised bogs habitat at present in Ireland.

Going forward a remote sensing project AI2Peat (https://ai2peat.ie/) is currently working on improving remote sensing methods of mapping ecotopes. However, quality assessment is needed to ensure that the methods are indeed being improved. In the short term, ecotope mapping through fieldwork is still envisaged while possibly making more use of drone imagery to target areas of a site to survey or areas that may have changed. Stronger collaboration between field workers and those in the remote sensing field is needed to improve new mapping methods.

Grasslands

Whilst we have managed to survey the majority of locations suitable for Calaminarian grassland as part of the recent survey, there are a number of offshore islands that were not surveyed due to greater logistical, resource and staffing considerations. Although these sites are not likely to contain large areas of Calaminarian grassland, the total area of the habitat in Ireland is small, so these areas are significant in that context.

Due to the limited coverage of our other grassland surveys (Section 4.5 Method 5), we also lack comprehensive mapping at a both a local and national scale for those five Annex I habitats. This is a particular knowledge gap we are aware of and working towards filling. O'Neill *et al.* (2013) suggests that c.80% of semi-natural grassland is outside of SACs. However, due to the scale of grasslands in Ireland it is not known what the percentage is for Annex grasslands. We are currently reviewing the results from mapping and condition assessment of c.100 sites in the past three years (i.e., a monitoring survey from 2021 to 2023). This will inform our reporting on these habitats for the 2019-2025 Article 17 reporting period. Given capacity within our organisation, no other grassland surveys are currently planned, but it is envisaged that *at the least* there will be a similar monitoring survey covering c.100 sites in within the next six years to inform the next Article 17 reporting period. Similar to our raised bog remote sensing surveys we lack specialist knowledge/capacity between in house staff and external contractors/academics.

Overall, our wetland and grassland habitats will continue to be monitored in the short and long term as part of our national monitoring programmes when fund and resources are available. We hope to trial and utilise more remote sensing techniques to allow us to increase value for money whilst still collecting valuable data over large areas of our Annex 1 habitats. Additionally, all our habitat monitoring programmes undergo quality assessments as part of the official procedures. We this is as an extremely important element of any surveys, especially ground truthing remote sensing techniques.

4. Methods

Method 1

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	**43**
*** Method (Method reviewed)**	Field inventory and habitat mapping
***Classification system**	Two habitat classification systems were used: Annex 1 habitats Fossitt Habitat Classification*. While this is not a fully-developed habitat mapping scheme, it has been used in Ireland as such for broad habitat mapping. *Fossitt, J.A. (2000) A Guide to Habitats in Ireland. The Heritage Council The Irish Vegetation Classification will be applied to the vegetation plot data recorded. https://biodiversityireland.ie/projects/ivc-classification-explorer/
***Output data**	The data output will comprise GIS-based habitat maps illustrating dominant habitats present within the digitised polygons at a site level. Assessment plot data will be collected to allow an assessment of structures and functions Water parameters (pH & EC) will be recorded for sites Vegetation data will be provided in Turboveg format
***Owner/producer**	The data will be produced by BEC Consultants Ltd, 65 Holywell, Dundrum, Dublin 14 and will be owned by the National Parks and Wildlife Service, 90 King Street North, Dublin 7, D07 N7CV
Target group/Primary user/User needs	The results of the National Fen Survey will primarily be for the National Parks and Wildlife Service in completing their Habitats Directive Article 17 reporting for submission to the European Commission.
***Input data and data providers**	Input data includes orthophotography produced by Ordnance Survey Ireland and used under licence, and previously collated habitat data for the target fen habitats held by the National Parks and Wildlife Service.
Data cost	NA
***Description**	The National Fen Survey is a country-level habitat mapping survey for the Annex I fen habitats 7140, 7210 and 7230, as well as non-Annex fen habitats and other associated habitats. It is a field-based survey, with field surveyors aiming to cover approximately 450 sites across Ireland, with a good geographic spread. This is the first baseline survey of its kind for fen habitats in Ireland and is based on data gathered as part of the Article 17 reporting process by the National Parks and Wildlife Service. The National Fen Survey is being carried out at sites selected from previously identified fen sites and orthophotography analysis. The sites are pre-digitised using QGIS to break the site up into reasonably homogenous polygons that are of a manageable size for field surveyors to work with. A field survey of each site

	is carried out, usually by two field surveyors, who will divide up the tasks between them. The tasks include habitat mapping (assigning percentages of each polygon to the appropriate habitat), habitat assessment plots, vegetation plots, water parameter recording (pH & EC) and peat depth recorded. All data is recorded on ruggedized tablets. Data outputs of the project will include GIS-based maps illustrating the distribution of fen habitat in Ireland that can be used for Article 17 reporting and as a baseline for future monitoring. Assessment plot data will be used for Structures & Functions assessment, while threats and pressures recorded can be used for Future Prospects Assessment. Vegetation plot data recorded will be used to further develop the Irish Vegetation Classification System, particularly about fen vegetation communities.
Documentation	Pilot Fen Survey Report O'Neill, F.H., Perrin, P.M., Denyer, J., Martin, J.R., Brophy, J.T. & Daly, O.H. (2023). Scoping study and pilot survey of fens. Irish Wildlife Manuals, No. 143. National Parks and Wildlife Service, Department of Housing, Local Government and Heritage, Ireland. https://www.npws.ie/sites/default/files/publications/pdf/IWM143.pdf Post pilot national survey is still being undertaken and will be published on our website once complete.
Competence	The field survey requires a high level of botanical field identification skill (vascular plants and bryophytes), as well as endurance and field experience. Good data recording and data management skills are required. Basic computer and QField skills.
Tools	Ruggedized tablet with appropriate recording software Qfield/QGIS Turboveg Excel
Status	The current methodology for carrying out the National Fen Survey is similar to that for other national habitat surveys carried out by BEC Consultants for the National Parks and Wildlife Service. It is likely to be carried into the future with minor adjustments, as required, for future monitoring surveys.
Result/output/mapping accuracy	The habitats maps will be based on hand-drawn site boundaries broken down in to similarly drawn habitat polygons. The minimum mapping area is generally 400m^2.

Method 2

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	**44**
*** Method (Method reviewed)**	Field inventory and habitat mapping
***Classification system**	Two habitat classification systems were used: Annex 1 habitats

	Fossitt Habitat Classification*. While this is not a fully-developed habitat mapping scheme, it has been used in Ireland as such for broad habitat mapping. *Fossitt, J.A. (2000) A Guide to Habitats in Ireland. The Heritage Council
***Output data**	Habitat maps with polygons covering mine spoil areas containing Calaminarian grassland. For each polygon, the percentage of Calaminarian grassland and other habitats in mosaic were calculated. Occurrences of rare metallophyte species were also mapped. For each site, site reports describing the site, detailing threats and pressures acting on the site, assessing changes in the site since the previous survey and assessing the national importance of the site were produced.
***Owner/producer**	The data were produced by Des Callaghan on behalf of Nimbosa Ecology, Coolies, Muckross, Killarney, Co. Kerry and are owned by the National Parks and Wildlife Service, 90 King Street North, Dublin 7, D07 N7CV
Target group/Primary user/User needs	The results of the 2023 survey of Calaminarian grassland will primarily be for the use of the National Parks and Wildlife Service in completing their Habitats Directive Article 17 reporting for submission to the European Commission and to inform targeted conservation measures for this habitat.
***Input data and data providers**	Input data includes orthophotography produced by Ordnance Survey Ireland and used under licence, and previously collated habitat data for the target habitat held by the National Parks and Wildlife Service.
Data cost	NA
***Description**	The 2023 survey of Calaminarian grassland was carried out with the aim of assessing the condition and status of 20 Calaminarian grassland sites that were determined during the previous monitoring survey to be in unfavourable condition. The extent of Calaminarian grassland habitat was mapped at each site, as percentage of the habitat within polygons representing a mosaic of habitats and threats and pressures were noted and assessed. Specialised metallophyte bryophytes were searched for and their occurrences mapped. The overall quality of the Calaminarian grassland habitat was assessed.
Documentation	The methodology is based, with very minor modifications on: Hodd, R.L. and Hodgetts, N.G. (2018) Results of a survey to monitor the EU Annex I habitat Calaminarian grassland, 2018. Irish Wildlife Manuals, No. 105. National Parks and Wildlife Service, Department of Culture, Heritage and the Gaeltacht, Ireland. https://www.npws.ie/sites/default/files/publications/pdf/IWM%20105%20Calaminarian%20Grassland%20Monitoring%202018.pdf
Competence	In addition to skills in field data recording and management and habitat mapping, expert bryophyte identification skills are required to fully assess the quality of the habitat.
Tools	Ruggedized tablet with appropriate recording software Qfield/QGIS Turboveg Excel

	Microscopes and keys for bryophyte id
Status	The latest monitoring survey was completed in 2023, but the results are not yet published. The methods of this survey were based on a 2018 monitoring survey, with minor modifications.
Result/output/mapping accuracy	The habitat mapping is based on site boundaries determined as the extent of mine spoil present at mine sites identified as supporting Calaminarian grassland.

Method 3

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	**45**
*** Method (Method reviewed)**	Field inventory and habitat mapping
***Classification system**	Two habitat classification systems were used: Annex 1 habitats Fossitt Habitat Classification*. While this is not a fully-developed habitat mapping scheme, it has been used in Ireland as such for broad habitat mapping. *Fossitt, J.A. (2000) A Guide to Habitats in Ireland. The Heritage Council The Irish Vegetation Classification will be applied to the vegetation plot data recorded. https://biodiversityireland.ie/projects/ivc-classification-explorer/
***Output data**	The data output will comprise GIS-based habitat maps illustrating dominant habitats present within the digitised polygons at a site level. Assessment plot data will be collected to allow an assessment of structures and functions Vegetation data will be provided in Turboveg format
***Owner/producer**	Data has been collected by several NPWS staff members and ecological consultants since 2009. It is owned by the National Parks and Wildlife Service, 90 King Street North, Dublin 7, D07 N7CV
Target group/Primary user/User needs	The results of all the National Survey of Upland Habitats (NSUH) are primarily be used by the National Parks and Wildlife Service in completing their Habitats Directive Article 17 reporting for submission to the European Commission.
***Input data and data providers**	Input data includes orthophotography produced by Ordnance Survey Ireland and used under licence, and previously collated habitat data for the target habitat held by the National Parks and Wildlife Service.
Data cost	NA
***Description**	Between 2009 and 2023 dedicated surveys have taken place at 21 upland locations in Ireland, these included areas around Mweelrea, Corraun, Comeraghs, Carlingford, Nephin, Croaghaun, Brandon, Killarney, Galtees, Ox, Ben Bulben, Arroo, Cuillcagh, Slieve League, Slieve Mish, Caha, Ballyhouras, Sonnagh, Glendree, Loughatorick, and Slieve Blooms.

	Uplands form Ireland's largest expanses of semi-natural landscape and support numerous habitats of high nature conservation value that require conservation under Irish and EU law. For the purposes of the NSUH surveys upland habitats are defined as unenclosed areas of land over 150 m and contiguous areas of related habitat that extend below this altitude. The main objectives of the NSUH are to map upland habitats and vegetation and to assess the conservation status of upland habitats listed in Annex I of the EU Habitats Directive. The habitat maps and survey data generated by these surveys are required for conservation management purposes at an individual site level and for the identification of appropriate national conservation strategies, as well as to contribute data towards fulfilment of Ireland's reporting obligations to the EU Commission on conservation status of Annex I habitats. The main habitats surveyed as part of these surveys are: 4010 Northern Atlantic wet heaths with Erica tetralix 4030 European dry heaths 4060 Alpine and Boreal heaths 7130 Blanket bogs (* if active bog) 7150 Depressions on peat substrates of the Rhynchosporion 8110 Siliceous scree of the montane to snow levels (Androsacetalia alpinae and Galeopsietalia ladani) 8120 Calcareous and calcshist screes of the montane to alpine levels (Thlaspietea rotundifolii) 8210 Calcareous rocky slopes with chasmophytic vegetation 8220 Siliceous rocky slopes with chasmophytic vegetation 6230 Species-rich Nardus grasslands, on siliceous substrates in mountain areas (and submountain areas, in Continental Europe)
Documentation	Perrin, P.M., Barron, S.J., Roche, J.R. & O'Hanrahan, B. (2014). Guidelines for a national survey and conservation assessment of upland vegetation and habitats in Ireland. Version 2.0. Irish Wildlife Manuals, No. 79. National Parks and Wildlife Service, Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland. https://www.npws.ie/sites/default/files/publications/pdf/IWM79.pdf Perrin, P.M., Barron, S.J., Roche, J.R. & O'Hanrahan, B. (2010) Guidelines for a national survey and conservation assessment of upland vegetation and habitats in Ireland. Version 1.0. Irish Wildlife Manuals, No. 48. National Parks and Wildlife Service, Department of Environment, Heritage and Local Government, Dublin, Ireland. https://www.npws.ie/sites/default/files/publications/pdf/IWM48.pdf
Competence	The field survey requires a high level of botanical field identification skill (vascular plants and bryophytes), as well as endurance and field experience. Good data recording and data management skills are required. Basic computer and QField skills.
Tools	Ruggedized tablet with appropriate recording software Qfield/QGIS Turboveg Excel

Status	The current methodology for carrying out the NSUH is similar to that for other national habitat surveys carried out by National Parks and Wildlife Service. It is likely to be carried into the future with minor adjustments, as required, for future monitoring surveys.
Result/output/mapping accuracy	The habitats maps will be based on hand-drawn site boundaries broken down in to similarly drawn habitat polygons.

Method 4

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	***46***
*** Method (Method reviewed)**	Field inventory and habitat mapping
***Classification system**	Ecotope classification developed Kelly (1993) in Hydrology, Hydrochemistry and Vegetation of Two Raised Bogs in Co. Offaly project, further developed by Kelly & Schouten (2002) in the Conservation and Restoration of Raised Bogs: Geological, Hydrological and Ecological Studies and adapted by Fernandez et al. (2014). Ecotope system classifies high bog vegetation occurring on raised bogs as either Active Raised Bog in the case of central, sub-central ecotope and active flush or as non-Active Raised Bog vegetation in the case of sub-marginal, marginal ecotope, facebank, and inactive flush.
***Output data**	*Vector data limited to the select areas that have been mapped.*
***Owner/producer**	*NPWS*
Target group/Primary user/User needs	The maps are used by the NPWS to monitor raised bog sites and to aid conservation management. Data from these maps is used in developing restoration plans and in assessing impacts. Positive impacts such as restoration works can be estimated through the extent of increases in Active Raised Bog and negative impacts can be estimated through losses of Active Raised Bog.
***Input data and data providers**	Input data includes orthophotography produced by Ordnance Survey Ireland and used under licence, and previously collated habitat data for the target habitat held by the National Parks and Wildlife Service. Lidar data was also collected from a third party.
Data cost	NA
***Description**	All designated raised bogs now have an ecotope map of the high bog on the site available. Monitoring surveys update this map by uploading old map onto a tablet with ESRI software and using sub-metre GPS equipment in the field to take new ecotope points and redraw the map again assessing any changes to the previous map. Any recent and available ortho-aerial imagery is used to aid this process. Main habitats covered during these surveys: 7110 Active raised bogs 7120 Degraded raised bogs still capable of natural regeneration

	7150 Depressions on peat substrates of the Rhynchosporion
Documentation	Bhatnagar, S., Gill, L. and Ghosh, B. (2020) Drone Image Segmentation Using Machine and Deep Learning for Mapping Raised Bog Vegetation Communities. *Remote Sensing*, 12 (16). Fernandez, F., Connolly K., Crowley W., Denyer J., Duff K. & Smith G. (2014) *Raised Bog Monitoring and Assessment Survey 2013*. Irish Wildlife Manuals, No. 81. National Parks and Wildlife Service, Department of Arts, Heritage and Gaeltacht, Dublin. Kelly, L. (1993) *Hydrology, Hydrochemistry and Vegetation of Two Raised Bogs in Co. Offaly, Ph.D. Thesis.* Trinity College, Dublin. Kelly, L. & Schouten, M.G.C. (2002) Vegetation. In: M. G. C. Schouten (Ed.), *Conservation and Restoration of Raised Bogs: Geological, Hydrological and Ecological Studies*. pp.110-169, Department of Environment and Local Government, Dublin, Ireland/Staatabosbeheer, The Netherlands. Steenvoorden, J., Leestemaker, N., Kooij, D., Crowley, W., Fernandez, F., Schouten, M.G.C. and Limpens, J. (2024 Towards standardised large-scale monitoring of peatland habitats through fine-scale drone-derived vegetation mapping, *Ecological Indicators*, Vol. 166. Article 112265. Steenvoorden, J., Limpens, J., Crowley, W. and Schouten, M.G.C. (2022) There and back again: Forty years of change in vegetation patterns in Irish peatlands, *Ecological Indicators*, Vol. 145. Article 109731.
Competence	The method requires high competence in the ecotope classification system**.**
Tools	Tools necessary are a tablet that is connected to a sub-metre GPS. The tablet needs to operate GIS software such as ESRI with a data dictionary stored in the tablet to aid ecotope points being recorded in the field. Post-survey office work requires access to orthophotos and GIS software to draw the maps.
Status	An early version of the method was first used on two midland raised bog sites in the early 1990s and was expanded to be used in all designated raised bogs in the mid-1990s. The method was further refined post-2000 and has been used in a number of national raised bog monitoring programmes since then. The method is still in use but currently research (e.g., Bhatnagar *et al*. 2020; Steenvoorden *et al*., 2022, 2024) has been undertaken to identify if drone or satellite imagery can help improve efficiency.
Result/output/mapping accuracy	The output is vector data with habitat polygons manually drawn in GIS on the background of an orthophoto. Minimum mapping area is usually considered to be in the region of 0.01 to 0.05ha.

Method 5

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	***47***
*** Method (Method reviewed)**	Field inventory and habitat mapping
***Classification system**	Two habitat classification systems were used: Annex 1 habitats

	Fossitt Habitat Classification*. While this is not a fully-developed habitat mapping scheme, it has been used in Ireland as such for broad habitat mapping. *Fossitt, J.A. (2000) A Guide to Habitats in Ireland. The Heritage Council The Irish Vegetation Classification will be applied to the vegetation plot data recorded. *https://biodiversityireland.ie/projects/ivc-classification-explorer/*
***Output data**	The data output will comprise GIS-based habitat maps illustrating dominant habitats present within the digitised polygons at a site level and monitoring stop locations in point format. Assessment plot data will be collected to allow an assessment of structures and functions and typcial species lists Vegetation data will be provided in Turboveg format
***Owner/producer**	The data will be produced by BEC Consultants Ltd, 65 Holywell, Dundrum, Dublin 14 and will be owned by the National Parks and Wildlife Service, 90 King Street North, Dublin 7, D07 N7CV
Target group/Primary user/User needs	The results of our national grassland surveys will primarily be for the National Parks and Wildlife Service in completing their Habitats Directive Article 17 reporting for submission to the European Commission.
***Input data and data providers**	Input data includes orthophotography produced by Ordnance Survey Ireland and used under licence, and previously collated habitat data for the target habitat held by the National Parks and Wildlife Service.
Data cost	NA
***Description**	Section 2 ‘Methods’ in the ISGS final report (O’Neill *et al.* 2013) and the GMS report (Martin *et al.* 2018) outline methods used in detail. In short, experienced botanists visit semi-natural grassland areas, carry out 2x2m botanical relevés (incl bryos, minimum of four relevés), and assess the habitat quality against pre-agreed criteria (see pages 152 to 157 for example from ISGS). In some cases (e.g., if it is a repeat visit), the full relevés may not be completed, but only data needed for the condition assessment are recorded (e.g. indicator species, vegetation height, etc.). In addition, at each site, the habitat area is recorded using GIS polygons which are amended from previous as/if needed. Habitats covered in these surveys: 6210 Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (* important orchid sites) 6230 Species-rich Nardus grasslands, on siliceous substrates in mountain areas (and submountain areas, in Continental Europe) 6410 Molinia meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*) 6430 Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels 6510 Lowland hay meadows (*Alopecurus pratensis, Sanguisorba officinalis*)
Documentation	O’Neill, F.H., Martin, J.R., Devaney, F.M. & Perrin, P.M. (2013) The Irish semi-natural grasslands survey 2007-2012. Irish Wildlife Manuals, No. 78. National

	Parks and Wildlife Service, Department of Arts, Heritage and the Gaeltacht, Ireland. https://www.npws.ie/sites/default/files/publications/pdf/IWM-78-Irish-semi-natural-grassland-survey.pdf Martin, J.R., O'Neill, F.H. & Daly, O.H. (2018) The monitoring and assessment of three EU Habitats Directive Annex I grassland habitats. Irish Wildlife Manuals, No. 102. National Parks and Wildlife Service, Department of Culture, Heritage and the Gaeltacht, Ireland. https://npws.ie/sites/default/files/publications/pdf/IWM%20102%20Annex%201%20Grasslands.pdf Irish Semi-Natural Grassland Survey 2013 Map Viewer: https://dahg.maps.arcgis.com/apps/webappviewer/index.html?id=0cdebbb63005462192ef12d8a167431b
Competence	The method requires high competence in the ecotope classification system**.**
Tools	Tools necessary are a tablet that is connected to a sub-metre GPS. The tablet needs to operate GIS software such as ESRI with a data dictionary stored in the tablet to aid ecotope points being recorded in the field. Post-survey office work requires access to orthophotos and GIS software to draw the maps.
Status	The current methodology for carrying out the grassland surveys is similar to that for other national habitat surveys carried out by National Parks and Wildlife Service. It is likely to be carried into the future with minor adjustments, as required, for future monitoring surveys.
Result/output/mapping accuracy	In the field surveyors generally use a rule of thumb to only map habitat patches of 20x20m. But they use discretion. In general, differential GPS units are not used in these surveys, and so accuracy of points is understood to be to the nearest 3 to 10m in general. As we do not used fixed relevé locations, this is deemed sufficient.

SEPA Sweden Review

1. Partner

Swedish Environmental Protection agency (SEPA)

Mona Naeslund, Ola Inghe, Sara Wiman

2. Analysis of experience

Summary of Sweden's Experiences with Habitat Mapping of grassland and wetland habitats and quality monitoring.

Sweden has engaged in various habitat mapping projects, focusing particularly on forests, grasslands and wetlands. These initiatives aim to monitor and manage the country’s diverse ecosystems and contribute to a better understanding of environmental conservation and land-use planning. Continuous projects such as the National Land Cover Data (NMD) and NNK utilise a range of methods and technologies to achieve their objectives.

Besides the national programmes there are several research projects focusing on developing remote sensing methodologies that can help developing the strategies for mapping and quality monitoring of habitats.

The NILS inventory (National Inventory of Landscapes in Sweden) employs a field-based sampling approach to monitor changes in landscapes, including grasslands, seashore, and alpine vegetation. Field surveys assess species composition, vegetation structure, and grazing impacts, etc. However, this program uses air imagery and remote sensing to select the areas to be visited in the field, by creating maps of potential high-value habitats. These methods should be of value even where the goal is wall-to-wall mapping of habitats. While this integration provides broad coverage and detailed insights, it faces challenges such as resolution limitations of remote sensing that may miss finer-scale habitat features. Drones and LiDAR technology are particularly useful for accessing difficult terrains and detailed topographic mapping, respectively. These technologies offer precise data and comprehensive coverage but come with high costs and technical requirements.

The programme employs a systematic sampling approach, covering various landscape types and regions across Sweden to ensure comprehensive national coverage. This includes both broad-scale monitoring and detailed inventories in specific sample plots distributed throughout the country.

The National Land Cover Data (NMD) provides detailed land cover classification across Sweden, essential for environmental monitoring, spatial planning, and biodiversity conservation. The project utilizes advanced remote sensing technologies, including Sentinel 1/2, combined with ground-truthing to verify and refine classifications. GIS plays a crucial role in data integration and analysis. Despite achieving high accuracy in land cover classification, the project depends on regular updates and high-quality satellite data to maintain its relevance.

During 2023 a new vegetation map has been produced for Swedish open wetlands using a remote sensing methodology based on Sentinel-2 together with many other data sources. It is described in more detail in a Methods review, number 23.

The NNK (Natura 2000 Habitat Mapping and Wetland Mapping) project integrates data from various sources to map the Annex 1 habitats in the Habitat and species directive within Natura 2000 areas and other protected areas. NNK uses a combination of remote sensing data and extensive interpretation of aerial photography to create detailed annex 1 habitat maps. Technologies such as LiDAR for topography, drones for aerial surveys, and GIS for data integration and analysis ensure comprehensive coverage and high-resolution mapping. These methods facilitate detailed habitat assessments and effective conservation measures but involve high costs and complexity in data integration.

Sweden’s experience with habitat mapping highlights the importance of integrating multiple data sources and technologies to achieve comprehensive and accurate habitat assessments. Remote sensing technologies provide broad coverage and efficiency, while field surveys are essential for ground-truthing and capturing detailed habitat features. Moving forward, there is a need for improved data integration tools, cost-effective technologies, capacity building in advanced techniques, and regular updates to land cover and habitat data to maintain accuracy and relevance.

3. Needs and Future plans

Despite significant advancements in habitat mapping and quality indicator monitoring, there are several areas where Sweden still faces challenges. Addressing these needs and gaps is crucial for improving the accuracy, efficiency, and effectiveness of habitat conservation and management efforts.

Overall needs:

Improved Data Integration: Advanced tools and methodologies are needed for integrating data from multiple sources such as remote sensing, field surveys, and hydrological models to achieve comprehensive habitat assessments. Effective integration can enhance the accuracy of habitat maps and is crucial for understanding complex ecological patterns.

Cost-Effective Technologies: Developing and implementing cost-effective remote sensing technologies is essential to make high-resolution data more accessible, particularly for large-scale and long-term monitoring projects, allowing for better resource allocation and broader coverage.

Capacity Building: Investing in training and capacity building for personnel in advanced remote sensing, GIS, and data analysis techniques is crucial. Enhanced technical skills will improve the quality and accuracy of habitat mapping, ensuring that the latest methodologies are effectively utilized.

Regular Updates and Continuous Monitoring: Regular updates to land cover and habitat data are necessary to maintain accuracy and relevance. Continuous monitoring is vital for tracking changes over time and responding to emerging environmental challenges promptly.

Harmonization of Methodologies: Standardizing habitat mapping methodologies across different regions and projects is essential for ensuring data comparability. Harmonized methods facilitate better reporting and analysis at both national and international levels, particularly for Annex 1 habitats.

Knowledge gaps:

Detailed Habitat Features: Current remote sensing technologies often fail to capture finer-scale habitat features that are critical for specific species. Research into improving the resolution and accuracy of remote sensing data is needed to address this gap.

Integration of Traditional and Modern Methods: Finding effective ways to integrate traditional field survey methods with modern remote sensing technologies remains a challenge. Research on best practices for this integration can help maximize the strengths of both approaches.

Species-Specific Data: There is a lack of detailed species-specific data in many areas. Targeted research and monitoring efforts are needed to fill these gaps, particularly for species that are indicators of habitat quality or are of conservation concern.

4. Methods

Method 1

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	11-13
*** Method (Method reviewed)**	National Inventory of Landscapes in Sweden - NILS
***Classification system**	Annex 1
***Output data**	Maps: Detailed maps showing various habitat types, land use, and landscape features. Measurements: Quantitative data on vegetation cover, soil conditions, and biodiversity indicators. Reports: Analytical reports summarizing findings, trends, and changes in the landscape over time. Databases: Comprehensive databases containing raw and processed data for further analysis and research
***Owner/producer**	Swedish Environmental Protection Agency (SEPA) Swedish University of Agricultural Sciences (SLU)
Target group/Primary user/User needs	Data and analyses from NILS are used for a variety of purposes, including: Policy-making and Planning: Providing a basis for environmental policies, conservation strategies, and physical planning at local, regional, and national levels. Research: Supplying baseline data for scientific studies in ecology, biogeography, and environmental science. Public Information: Making information available to the public, interest organisations, and other stakeholders.
***Input data and data providers**	Swedish University of Agricultural Sciences (SLU): Responsible for field inventories and overall programme management. Remote Sensing Agencies: Providers of satellite imagery and aerial photographs. National Land Survey of Sweden (Lantmäteriet): Supplies geospatial data and maps. Local and Regional Authorities: Contribute additional data on land use and environmental conditions.
Data cost	

***Description**	The National Inventory of Landscapes in Sweden (NILS) is a national environmental monitoring programme aimed at tracking the state of Sweden's landscapes and biodiversity. The programme is managed by the Swedish University of Agricultural Sciences (SLU) and is part of the Swedish Environmental Protection Agency's national environmental monitoring system. The programme employs a systematic sampling approach, covering various landscape types and regions across Sweden to ensure comprehensive national coverage. This includes both broad-scale monitoring and detailed inventories in specific sample plots distributed throughout the country. NILS has several primary objectives: Monitoring Landscape Changes: Documenting and analysing changes in landscape structure and land use over time. Biodiversity: Mapping and monitoring biodiversity in different habitats and landscape types. Ecosystem Services: Evaluating and tracking the development of ecosystem services. Climate Change: Studying the impacts of climate change on landscapes and their ecosystems
Documentation	https://www.slu.se/en/Collaborative-Centres-and-Projects/nils/nils-alpine-mountainous-inventory/ https://www.slu.se/en/Collaborative-Centres-and-Projects/nils/nils-grassland-inventory/
Competence	
Tools	NILS employs a combination of remote sensing, field inventories, and Geographic Information Systems (GIS) to collect and analyse data. **Field Inventories:** Systematic inventories are conducted in sample plots randomly distributed across the country. These inventories include data collection on vegetation, soil conditions, landscape structure, and land use. **Remote Sensing:** Satellite images and aerial photographs are used to complement and extend field data, enabling large-scale and continuous landscape monitoring. **Geographic Information Systems (GIS):** GIS is utilised to analyse and visualise collected data, making it possible to detect patterns and trends over time and space.
Status	The National Inventory of Landscapes in Sweden (NILS) is an ongoing national environmental monitoring programme managed by the Swedish University of Agricultural Sciences (SLU). It has been in use since its inception in 2003, providing valuable data on Sweden's landscapes and biodiversity for over two decades. Ongoing development in remote sensing technologies and data analysis methods will enhance the accuracy and scope of monitoring.
Result/output/accuracy	The accuracy for major habitat types such as forests and wetlands ranges between 80-90%. More detailed and specific classes may have varying accuracies, often reported around 70-85%, depending on the complexity of the landscape and the quality of remote sensing data.

	The methodologies used in NILS are designed to be scalable and transferable, making it possible to apply them in other regions or countries with similar landscapes.

Method 2

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	***23***
*** Method (Method reviewed)**	National Land Cover Data (NMD)
***Classification system**	National
***Output data**	Raster product, 10m resolution
***Owner/producer**	Swedish Environmental Protection Agency, Producer: Metria
Target group/Primary user/User needs	The purpose of NMD is to provide a detailed and up-to-date overview of Sweden's land use and land cover. This is important for environmental monitoring, land use planning, research, and the management of natural resources. NMD is used in various fields, including: Environmental monitoring and reporting Land use planning and management Research and studies in ecology and geosciences Decision support for policy-making and environmental policies Nature conservation and biodiversity protection
***Input data and data providers**	Input data: Sentinel 1/2, Lidar, map databases (road network, buildings, arable land etc) Providers: National Land Survey, ESA
Data cost	Open access and free to use (the result, NMD)
***Description**	The National Land Cover Database (NMD) is a land cover map over the entire country. The purpose of the database is to provide basic information about the landscape and any changes over time. The mapping production was conducted during 2017-2019 and will be updated every fifth year. NMD is comprised of a base map with 25 thematic classes in three hierarchical levels. The map is in a raster format with 10 m resolution and a minimum mapping unit of 0,01 hectare. In addition to the base map, there are several complementary layers including: • Object Height and Extent; • Productivity • Land Use • Forests in Mountainous Regions The production of NMD in Sweden utilizes several tools and techniques to ensure comprehensive and accurate mapping of the country's land cover and land use. The production is based on satellite imagery, lidar data, existing map information, ground truth which all are processed, classified and combined according to a hierarchical classification scheme.

Documentation	https://www.naturvardsverket.se/en/services-and-permits/maps-and-map-services/national-land-cover-database/
Competence	
Tools	Remote sensing techniques including Machine learning, Rule-based classification Time series and change detection, GIS for processing,
Status	In 2023, work began on the updating of the National Land Cover Database. Delivery of updated data will begin in 2024.
Result/output/accuracy	

Method 3

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	***21***
*** Method (Method reviewed)**	Satellite based vegetation mapping on wetlands
***Classification system**	Similar nomenclature as in NILS. The classification system includes 16 vegetation types within open wetlands, divided into categories like "open bog" and "open wetland outside bog"
***Output data**	The output data consists of a satellite-based vegetation map of open wetlands in Sweden with a 10-meter resolution
***Owner/producer**	*Owner: SEPA, Producer: Brockmann Geomatics Sweden AB*
Target group/Primary user/User needs	National, regional, and local authorities such as Swedish environmental Protection Agency, county administrative boards, and municipalities. Other relevant users include the Swedish Forest Agency, Swedish Board of Agriculture, and Swedish Civil Contingencies Agency (MSB)
***Input data and data providers**	Satellite data (Sentinel-2), property maps, aerial photographs, soil maps, calibration data, peat type regions, Wetland Inventory (VMI), and National Land Cover Database (NMD)
Data cost	
***Description**	The methodology involves an expert-based, iterative stratified Maximum Likelihood classification of vegetation types. It includes the preparation of input data, creation of masks for peat occurrence and vegetation cover, and classification based on satellite imagery with optimal weather conditions. Time series of satellite data is used for separation of sparse and lush areas.
Documentation	https://www.naturvardsverket.se/4adb57/globalassets/media/publikationer-pdf/7100/978-91-620-7127-1.pdf (in Swedish)

Competence	The process requires high expertise in object identification and interpretation, along with knowledge in satellite imagery and weather condition analyses
Tools	General remote sensing and GIS tools
Status	Completion of the first national vegetation mapping of open wetlands.
Result/output/accuracy	Raster map, 10m resolution

Method 4

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	***23***
*** Method (Method reviewed)**	The NNK (Natura Naturtypskarteringen) process is used in Sweden to map and classify natural habitats within the Natura 2000 network. This is part of the EU's strategy to protect biodiversity. The production process involves several steps and utilizes various data sources and techniques.
***Classification system**	Annex 1, modified
***Output data**	Maps, data bases
***Owner/producer**	Swedish Environmental Protection Agency (SEPA)
Target group/Primary user/User needs	County administrative boards, governmental organisations
***Description**	The NNK (Natura Naturtypskarteringen) process is used in Sweden to map and classify natural habitats within the Natura 2000 network. This is part of the EU's strategy to protect biodiversity. The outcome of the NNK process is a series of detailed maps and databases that document the distribution and extent of natural habitats. These maps are essential for conservation planning, environmental impact assessments, and monitoring the effectiveness of habitat protection measures within the Natura 2000 framework. They provide a foundation for managing natural resources and protecting biodiversity in Sweden (För en bra livsmiljö idag och imorgon) (Skogsstyrelsen). In summary, the NNK is a critical tool in Sweden's efforts to conserve biodiversity, combining field surveys, remote sensing, and GIS techniques to produce habitat maps.

MoE_FI Finland Review

1. Partner

MoE_FI, Finnish Environment Institute (Syke)

2. Analysis of experience

Wetlands

Mapping: There have been research projects in recent years that have used remote sensing (RS) / Earth Observation (EO) approaches to develop regional habitat mapping products (method 1: Remote sensing habitats in Northern Lapland) and even national scale mapping (method 38: Mapping peatland site types of Finland). Mire types are challenging with RS-based ML-methods – classification accuracy is ok, but it might require improvements. Reasons for the accuracy uncertainties are not studied in detail but are probably related to the fine-resolution structural heterogeneity of the mire habitats.

Quality: In recent years multiple research projects have aimed at estimating hydrological conditions with satellite-based methods in Finland. OPTRAM-model (method 29 in the Review Excel table) and machine learning (ML) based classification methods (expert-based decision tree classifier; classification tree analysis, CTA; Random Forest; methods 1, 31, 41) have been employed to estimate water table level, producing results with moderate accuracy. The applied models perform best in treeless areas. Accuracy of model projections varies largely between sites, showing on average moderate accuracy (R^2 around 40%). ML-classification has been tested for monitoring waterlogged area in aapa mires (Jussila et al. 2024, method 31), with good overall accuracy but the approach needs further validation; the model training data were collected solely based on visual interpretation of aerial images and training pixel selection focussed on homogenous mire surfaces, as borderline cases may be challenging to classify and changes therein are hard to detect reliably.

Grasslands

Mapping: A nation-wide survey of the distribution and quality changes in semi-natural grasslands and other traditionally managed agricultural biotopes has been conducted at the turn of the century (Vainio et al. 2001; http://hdl.handle.net/10138/40675), followed by repeated inventories of the size and quality changes of the grasslands rated as important for biodiversity carried out primarily by regional environmental centres (ELY centres) and Metsähallitus Park & Wildlife Finland at various annual frequency. At a general level, the extent of grasslands has been mapped as part of national high-resolution land cover / land use map (Corine land cover, 2000-2018) at 20 m pixel size, for the whole country. However, the accuracy of grassland classifications in this product has not been properly validated, but based on expert review there is a lot of room for improvement (for example, better differentiation between croplands, grasslands and forest clear cuts). As regards RS-based habitat mapping, there has not been, to our knowledge, any systematic and concentrated efforts or scientific research in RS-based mapping targeting specifically Finnish grasslands, or aiming to further differentiate grassland types at any scale. One RS-based attempt to map grasslands was included in the Remote sensing of Northern Lapland habitats project (method 1). In this project, two Annex 1 grassland habitat types (Siliceous alpine and boreal grasslands, Northern boreal alluvial meadows) were mapped (see below for details) but this was the main focus, as the areas covered by these are small.

Quality: To our knowledge, there has been no efforts to monitor the condition of grassland habitats in Finland with Earth Observation methods.

3. Needs and Future plans

Wetlands

In Finland, recent detailed habitat mappings has been done mainly in (state-owned) protected areas, but there are earlier nation-wide general surveys of mires to support the conservation network planning for these ecosystems, as well as a number of local peatland mapping surveys that have provided data for land use planning at the level of municipalities and other regional planning entities. The more detailed mapping work is carried out by Parks & Wildlife Finland. Habitat conditions outside protected areas are largely unknown but they are considered to be negatively affected by forestry and other land-use, particularly large-scale ditching, that disturbs the natural hydrology of ecosystems especially in aapa mires (which are dependent on water from surrounding landscape). Wetlands, such as boreal mires, cover large areas in remote locations and thus satellite-based approaches have the potential to fill in the spatial gaps in wetland information and support the rapid and cost-effective assessments and repeated systematic monitoring of their ecological state.

Grasslands

The situation of habitat mapping for grasslands is somewhat different than the mapping of wetlands, largely due the above mentioned nation-wide survey and the fact that many of the semi-natural grasslands are located outside traditional nature conservation areas (but many are included in Natura 2000 network). However, these mappings are primarily based on the field inventories, with very little EO tools support. The quality conditions of grasslands are also monitored in-situ but this is not done systematically. In general, only 1 % of semi-natural grasslands in Finland remain from the baseline extent in the 1950. Thus, semi-natural grasslands are nationally assessed as the most threatened habitat group in Finland, with nearly all the associated habitat types being critically endangered. Without any management, this habitat type is projected to heavily further decline or even disappear from Southern Finland.

For RS-based mapping needs, a sufficient discrimination between grasslands, croplands, forest clear cuts and other similar types is a requirement, but this is challenged by the very small extent of semi-natural grasslands and lack of training and validation data. Separating the grasslands down the EUNIS hierarchy may be considered as a less essential target, as in Finland there is a very limited number of different EUNIS grassland (or Annex 1) habitat types.

Regarding the needs for monitoring grassland conditions with Earth Observation, it is important to distinguish managed from unmanaged grasslands. As an example, useful trends for quality monitoring could include the colonisation of shrubs and trees (overgrowth of open areas), which is a sign of mismanagement or total lack of management. Detecting mowing events is also important as a sign of management.

4. Methods

Method 1

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	**1**
*** Method (Method reviewed)**	"Remote sensing the habitats of Northern Lapland" project, 2020-23. The classification of the EO (Sentinel) data was done with two main methods: 1) Machine learning classifier (Random Forest) for classifying following the Finnish typology for habitat types (the system used by Parks & Wildlife Finland for National Parks and other protected areas in Finland) and 2) Expert-based decision tree classifier for classifying following the Annex I habitat types. The input data for classification used a combination of features extracted from satellite-based remote sensing (Sentinel 2 and 1 = multispectral and SAR), Very high resolution satellite images, national LiDAR data, and auxiliary GIS datasets (e.g. DEM, National topographic map database) were used. For calibration and validation of the classification models, 4 500 circular plots with 10 m radius were surveyed in the field by an ecologist during three summers 2020-2022. The field data were augmented by digitising more training areas from aerial photographs especially from areas that were hard to reach or where the classification had high uncertainty. The classified area covered nearly 3 mill. hectares of state-owned land, of which most is protected or otherwise set aside from commercial forestry. The land is managed by National Parks Finland. The habitats mapped in the project covered all natural and semi-natural habitat types, not just grasslands and wetlands.
***Classification system**	Two habitat classification systems were used: Finnish typology, "inventory class" (Parks & Wildlife Finland own system). The inventory class is not exactly same concept as habitat or vegetation type: It describes the prevailing vegetation on the bottom-most vegetation layer (mosses, lichen, fungi) and the herbaceous layer (up to 2 m height), and in wetlands it describes the vegetation at water level. Annex I habitat types
***Output data**	Pixel-based Habitat type classification maps in raster format (10 x 10 m resolution), for both classification systems. Object-based habitat boundaries in vector format, used in National Parks Finland's own SAKTI protected area compartment information system (biotooppikuviot), from where they are available to the entire environmental administration. Available as open data: https://www.syke.fi/avointieto
***Owner/producer**	Parks & Wildlife Finland (Metsähallitus, Luontopalvelut) and Finnish Environment Institute (Syke). Contact: elisa.paakko@metsa.fi, anna.tammilehto@metsa.fi, saku.anttila@syke.fi

Target group/Primary user/User needs	The main user for the developed classification using Finnish typology is Parks & Wildlife Finland (and to a lesser extent, Finnish Environmental Administration as a whole). This classification system forms the backbone of the SAKTI habitat system in Northern Lapland. Results are used for the overall management planning of the protected area network in Lapland and for monitoring the extent and condition of those habitats. The main user for the classification using Annex I Habitat types is Finnish Environmental Administration as a whole. The main type of usage is Habitat directive reporting and the assessments of threatened habitats as well as other surveys, assessments and studies, and the classification results can be also used in the implementation of the EU Biodiversity Strategy.
***Input data and data providers**	Sentinel1 and 2 data from ESA, processing done at Syke. Copernicus High resolution phenology product and Very High Resolution satellite images by Copernicus Land Monitoring Service. DEM, Topographic map database, aerial photographs and LiDAR data from National Land Survey.
Data cost	All data listed above is free of charge. Unless you want to count working time for processing data products and features for classification, and field data collection.
***Description**	See description in “method” field.
Documentation	Final report, part 1 (julkaisut.metsa.fi, in Finnish, documentation page in English) Final report, part 2 (julkaisut.metsa.fi, in Finnish, documentation page in English)
Competence	Expertise in satellite remote sensing, GIS analysis, LiDAR data processing, machine learning methods. For field work, expertise in ecology and habitat types.
Tools	- Desktop GIS software for visualizations and data management. - Remote sensing software (e.g. Erdas Imagine) for satellite data processing, but this can be replaced with open source tools (R or Python). - Sentinel-2 mosaics were created with Sentinel-2 Global Mosaic service. - Sentinel-2 index mosaics were created with CalFin processing cluster at the National Satellite Data Centre, hosted by Finnish Meteorological Institute. - For image classification, open source tools (R or Python). - For processing LiDAR data – e.g. lastools.
Status	The method was successfully used for habitat mapping in Northern Lapland with satisfactory results. No information about future plans.
Result/output/mapping accuracy	Output resolution: 10 m pixel. Class-level accuracies for grassland and wetland habitats of the Habitats dir. Annex 1 types : 6150 Siliceous alpine and boreal grasslands. UA: 0,88 PA: 0,93 F1: 0,90

	6450 Northern boreal alluvial meadows. UA: 1,0 PA: 0,24 F1: 0,38 7110 Active raised bogs. UA: 1,0 PA: 1,0 F1; 1,0 (only two of this type) 7140 Transition mires and quaking bogs. UA: 0,84 PA: 0,39 F1: 0,53 7310 Aapa mires. UA: 0,56 PA: 0,77 F1: 0,65 7320 Palsa mires. UA: 0,60 PA: 1,00 F1: 0,75 91D0 Bog woodland. UA: 0,75 PA: 0,75 F1: 0,75 UA=Users accuracy PA=Producer's accuracy F1=F1-value, harmonic mean of UA & PA **Overall accuracy of all wetland types using the Annex I class was 0,67.** --- Class-level accuracies (F1-values) for wetland habitats of the inventory class : Spruce mires (3 types) 0,40 – 0,63 Bogs and mires (3 types) 0,27 – 0,78 Other wetlands (3 types) 0,67-0,80 **Overall accuracy of all wetland types using the inventory class was 0,59.** --- **<u>Annex 1 grassland and wetland types, which were not possible to map with remote sensing methods (and why):</u>** 6270 Fennoscandian lowland species-rich dry to mesic grasslands. Coverage in study area only 30 ha, distinguishing from other seminatural grassland types requires field work. 6430 Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels. Coverage in study area only 45 ha, often small in size, distinguishing from other seminatural grassland types requires field work. 6510 Lowland hay meadows (*Alopecurus pratensis, Sanguisorba officinalis*). Coverage in study area only 2 ha, distinguishing from other seminatural grassland types requires field work. 7160 Fennoscandian mineral-rich springs and springfens. Coverage in study area 121 ha. Small in size, mapping requires field work. 7230 Alkaline fens. Coverage in study area 693 ha. Requires field work to determine eutrophy. 7240 Alpine pioneer formations of the Caricion bicoloris-atrofuscae. Small in size, field work required. Calciphilous habitat type.

Method 2

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	***31***
*** Method (Method reviewed)**	**31 Detection of wet mire surfaces.** Simple ML-based decision tree (supervised classification) to classify Sentinel-2 image pixels to two classes: pixels dominated by wet mire surfaces where water table level is very close to or above mire surface (as in flarks typically), and pixels dominated by drier conditions. Training data consisted of 1400 pixels (georeferenced to match Sentinel-2 image pixels) from 16 mires around the aapa mire zone of Finland, classified by visual interpretation from aerial images.

	Method can be applied to produce time series over large areas. Two different regional data products have been produced in Finland/Syke for all open mires in northern part of Finland, that provide an example of **approaches to produce large-scale RS time series products:** Monthly 10m-resolution classification rasters (wet/dry) over all open mires of Northern Finland with CDSE tools Statistical time series for each mire polygon with SentinelHub batch statistical API
***Classification system**	Quality indicator for hydrology of aapa mires (and possibly other wetland habitats characterised by inundated surfaces)
***Output data**	Classification raster of two classes: wet mire surface and drier mire surfaces. The method was used to produce two kinds of large-scale data products: Monthly 10m-resolution classification rasters (wet/dry) over all open mires of Northern Finland Statistical time series for each mire polygon
***Owner/producer**	Finnish Environment Institute/Tytti Jussila et al. (tytti.jussila@syke.fi)
Target group/Primary user/User needs	Provides information for assessing ecological condition of aapa mires. Useful for EU Habitat Directive reporting (by Finnish Environment Institute), restoration efforts, etc. In addition, useful for researchers assessing and upscaling greenhouse gas fluxes of mires.
***Input data and data providers**	Sentinel-2 L2 by Copernicus Polygon data of targeted mires. In Finland, open mires from the topographical database of the National Land Survey of Finland. Model does not work well in tree-covered areas and those should be treated with much caution or left out.
Data cost	For model training data requirements are not huge and do not require cloud processing. Sentinel-2 data is free. However, producing large scale outputs have processing costs in Copernicus cloud services: **Monthly rasters** produced in Copernicus Data Space Ecosystem (CDSE) with best quality and 10m resolution: 120€ per month (price 1/4 with 20m resolution) for whole aapa mire occurrence zone area of Finland (northern half of Finland = 186000km^2, clipped later to open mires) **Statistical time series** of wet surface extent produced with SentinelHub Batch Statistical API: 24€/month for total mire area of 4 476km^2 (“difficult to traverse” mires of Finnish aapa mire zone by topographical database) 0,005€/km/month

	CDSE may provide processing units (PU) for free for research purposes.
***Description**	
Documentation	*Jussila et al. (2024). Quantifying wetness variability in aapa mires with Sentinel-2: towards improved monitoring of an EU priority habitat* https://doi.org/10.1002/rse2.363 Classification tree and SentinelHub Batch Statistical API demo (statistical time series) and scripts in GitHub: https://github.com/sykefi/feo-aapa/tree/v1.0.0 Metadata of large-scale raster products: https://ckan.ymparisto.fi/dataset/vetiset-suonpinnat
Competence	**Apply model for single site and date:** with small instruction rather simple even without data skills, e.g. using Sentinel Hub EO browser online and copy-paste “custom eval script” (the classification tree coded for SentinelHub) for visualisation of S2 data. **Apply model on single site and multiple dates:** programming skills (e.g. R or python). Acquiring S2-data. Applying the decision tree model in R for S2-data is quite easy. Handling clouds in images /selecting cloudless images. **Apply model on a large scale for multiple sites and multiple dates**: programming skills and cloud computing (e.g. SentinelHub API or Google Earth Engine). Scripts of Jussila et al. openly available for SentinelHub Batch Statistical API. **Training own model with same approach**: Programming skills (e.g. R) to apply methods. Mire expertise to construct training data (classifying based on aerial images). QGIS or other program to georeference (snap spatially together) S2 images to aerial images.
Tools	Training the model: R (rpart package) – or other software capable of training decision trees (classification trees).
Status	Monthly raster time series of data has been recently published as open data by Finnish Environment Institute. We hope to get comments by data users. The classifications still lack extensive field validation. The method has not yet been used for reporting, but there is intention to possibly utilize the data for next Habitat Directive reporting (habitat quality in mires). Future research plans are open but there are multiple possible ideas: Analysing the latest updated time series extended also outside Natura-2000 areas Further validation with easily available field measurements (logger data collected in other studies), drone or aerial images Linking wet surface variability to drivers of change (ditching in landscape, climate)
Result/output/mapping accuracy	Resulting classification has a very good 93.6% overall accuracy based on cross validation with aerial image -based data.

	Classification performance is clearly weaker if applied on tree-covered areas. Performance was tested against logger data in one mire. Temporal variation of wet surface extent during summers 2017 and 2018 was compared to logger data of water table level from one point. Correlation was good (r=0.88). Based on expert visual evaluation, the results seem acceptable, but both over- and underestimation occur in certain regions, areas and parts of mires. Seasonal changes seem plausible. However, lack of actual field observations makes it difficult to thoroughly assess the reliability. Vegetation variability in time and space might affect classification results. Resolution: 10 meters, but SWIR bands actually are originally 20m. Sentinel-2 revisit time is 2-3 times per week, but in practice there are a lot of cloudy dates. Data from cloudless dates has been used as aggregated to monthly means/medians.

VL-O Belgium - Flanders Review

1. Partner

VL-O, Belgium, represented by INBO (Research Institute for Nature and Forest)

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Disclaimer: The following text is solely expressing the current knowledge and opinions of the third party partner INBO (Research Institute for Nature and Forest). This information may therefore be incomplete with regard to the current state-of-the-art research and opinions from other major organisations in Flanders and Belgium, especially the ones dealing with remote sensing research in the context of nature conservation. The views, conclusions and methods presented here do not necessarily reflect the positions of all relevant stakeholders and may not represent the full breadth of perspectives on this subject matter.

2. Analysis of experience

Mapping

Belgium has a strong history of vegetation and land cover mapping. In 1978 the ambitious Biological Valuation Map (BVM) project was initiated and aimed for a wall-to-wall vegetation and land cover map of the entire Belgian territory. Land cover classes and vegetation types are defined by an extensive list of legend units with a strong link to phytosociological ecotopes present in this region. For fast and easy interpretation these legend units are also translated into a limited number of broad classes of ecological value, allowing a straightforward interpretation at the landscape scale.

Some of the units reflect information about the land use (e.g. arable land, urban area). Most of them however describe vegetation types (e.g. dry heath, mesotrophic swamp alder wood, wet oligotrophic grassland). Their phytosociological relation is often at the level of alliances (e.g. Calthion, Caricion davallianae, Ericion tetralicis, …), but also sometimes at the level of vegetation associations (e.g. Cladietum marisci, Fago-Quercetum) or even sub-associations (e.g. Galio-Trifolietum, Betonico-Brachypodietum, …). About two-third of the number of the legend units for vegetations match a phytosociological alliance or association. The original typology, with strong phytosociological foundations, is still being used today, but underwent numerous changes in terms of details and linkage with existing international classifications (e.g. EUNIS)

The BVM is primarily a field-driven survey of land cover and natural and semi-natural vegetation. Aerial orthophotos are used as the main background in addition with historical maps, soil maps, Digital Terrain Models (DTM) and cadaster maps. Since then, it has become an important instrument in numerous applications in nature conservation research, legislation and spatial planning and is therefore still being updated in Flanders with increased detail and accuracy and decreased observer-bias effects.

The first version was completed in 1996, followed by an update of the entire territory of Flanders in 2010 in a second version. A third mapping cycle was launched in 2013 with a methodology that was adapted to novel requirements from the Natura 2000 Habitat Directive. Annex 1 habitats are since being mapped directly and independently from the BVM typology using vegetation determination keys (a.o. De Saeger et al. 2016, Vandekerkhove et al., 2016, Oosterlynck et al., 2022)

Linear and point landscape elements are also mapped separately (f.e. tree lines, fence lines, ponds, and sunken roads). Additional codes have been added to indicate dominant trees and scrub species. Furthermore, in Flanders it is not uncommon for (semi-)natural vegetation to appear in small remnants such as parcel borders or steep slopes due to extensive habitat conversion and fragmentation. Specific codes are used to indicate these situations. Consequently, the resulting geodatabase is of a high resolution (minimum mappable unit for polygons = 400m², minimum mappable unit for linear elements = 30m and no limitations for point elements) and often tailored to scale of the management level (parcels and management units).

Currently the map is up-to-date (field work no older than 10 years) for all Natura 2000 sites and an additional significant surface of natural areas outside SAC. The data for the remaining territory (urban and agricultural areas) on the contrary is often much older (10-25 years). Although the relative density of biologically valuable vegetation types is generally much lower in these parts, still a significant amount of fieldwork would be needed to update these areas. We are therefore looking for EO-based methods to increase the efficiency of the field work in these regions. Recent research with regard to these methods is up until now mostly preliminary and focuses on change detection. For a number of easy to discriminate types and change events such as orchards, standing water bodies and ploughing of grassland operational workflows are (nearly) ready. Some of the latter are described more in detail below.

Quality monitoring

Nature monitoring in Flanders is also the core business of the Research Institute for Nature and Forest. Flanders installed an extensive monitoring scheme to assess the biotic quality of its Natura 2000 habitats in order to comply with Article 17 of the Habitat Directive (see Paelinckx et al., 2019). This monitoring scheme was designed in 2012/2013, became operational in 2014 and was revised in 2021 after a first reporting cycle of 6 years. The monitoring focuses on assessing the condition of Natura 2000 habitats through the measurement of various biotic indicators, such as vegetation composition, structure, and presence of typical species. Several thousands of sampling sites were selected using a random stratified sampling approach based on the aforementioned habitat map as sampling population. Rare habitats, with a restricted distribution are monitored over their entire surface. The data from this monitoring network allows to calculate robust estimates and confidence intervals for the regional conservation status of Annex 1 habitats. In the meantime the first cycle has been completed for most of the habitats and revisits are being executed since 2022 allowing for the first time a data-driven trend analysis for the 2025 reporting period.

Sampling sites consist of a nested vegetation plot of 9m² and a circular plot of 1000m². The latter is mainly used for estimating structural indicators such as tree encroachment or presence of different successional stages within an habitat, while the vegetation relevé data allows for the calculation of so-called indicators of local conservation status (Oosterlynck et al., 2020)

Earth-observation based approaches in mapping and quality monitoring

In Flanders, no EO-methods or data have yet been fully implemented in our operational habitat mapping and monitoring workflows. Nevertheless some exploratory studies have been carried out in the past and recent research efforts have been intensified to integrate remote sensing technologies into running mapping and monitoring projects. Some of the more recent research is described in more detail below.

In the STEREO I and II programme of the Belgian Science Policy Office (BELSPO), extensive research was carried out in 2007-2011 using hyperspectral airborne imagery to map heathand habitats and heathland quality (e.g., tree and Molinia invasion) (Haest et al. 2017, Haest et al. 2011). The results were very promising, but the high costs and complex logistical requirements for the production of this type of RS data are limiting the continued implementation of this approach.

Autonomous acquisition of RS data through the use of an internal UAV equipped with specific sensors also stalled due to complications in laws and permits.

3. Needs and Future plans

Currently all Natura 2000 sites (Special Areas of Conservation, SAC) in Flanders are mapped entirely and in detail through field-surveys with a relatively recent date of origin. The revisiting frequency is set to 6 years for open habitats and 12 years for forests. Furthermore it is plausible to rate the accuracy high due to sustained efforts in and long-term experience with mapping methodology (e.g. highly experienced, specialised and permanent field staff, use of determination keys, …).

Essentially the same applies for the quality monitoring scheme where skilled field workers do vegetation relevés and indicator estimations and the methodology is described in detail in standard field protocols. A crucial benefit for the habitat monitoring design proved to be the wall-to-wall habitat map that served as a reliable sampling population. Not many regions or countries in the EU have this advantage.

Nevertheless the camping and monitoring workflows require relatively labour intensive fieldwork, even in Flanders and is dependent on a rather limited human resource, namely highly specialised botanists. Also, the comparability is hampered by seasonal variation in growth, extreme weather events, and management practices. But overall, on the level of the Flemish region, these obstacles are relatively small compared to some countries with more remote, vast or inaccessible habitat locations.

The current approach only allows for an evaluation on the whole of the Flemish region and is never representative on the local level (f.e. SAC). With new legislation in mind (i.c. the Nature Restoration Law and Standard Data Form habitat quality assessments) more data acquisition on the local level is to be expected. Deploying traditional monitoring schemes on the scale of the sites would require a 10 to 100-fold increase in workload. Consequently, even for smaller countries or on the sub-national level efficiency gains through EO-based approaches are a no-brainer. It is generally agreed upon that these methods in the future will play a complementary and facilitating role alongside the more in-situ approaches currently in place.

Vanden Borre et al. (2011) proposed some essential steps forward, more than a decade ago, but remarkably these remain important points of attention today:(1) harmonising and standardising RS and nature monitoring approaches, (2) focus on data at hand to develop readily useful products, (3) a proper validation of both traditional and remote sensing methods, and (4) an enhanced sharing and exchange of ideas and results between the different research communities involved, in other words more capacity building is needed. From our more recent experiences some additional bottlenecks can be mentioned: (1) cloud screening remains a challenge, (2) spatial resolution is often too coarse for traditional grassland and wetland quality indicators, (3) upscaling from the local to the regional level is needed in order to develop useful indicators, (4) automated and open sourced data workflows could stimulate wider application.

Although in the last decade huge advancements in RS approaches for biodiversity monitoring are being made, not in the least because of the game-changing Sentinel 2 products, operational use of remote sensing techniques in natural monitoring and mapping in Flanders is still rather limited and their potential is therefore most probably underexploited.

4. Methods

In the following description, we elaborate on projects in which EO-derived data are used in the mapping and quality monitoring workflows, since this is the focus of the Habitats Pilot. We refer to the previous chapters for a more detailed description of our long-running and more classical mapping and monitoring approaches.

Method 1

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	***4: Efficiency gains for in-situ habitat mapping through remote sensing techniques***
*** Method (Method reviewed)**	Deep learning models were used in combination with aerial imagery to delineate meadow orchards (high-stem orchards) in the entire area of Flanders. More specifically, the GitHub repository OrthoSeg was used to 1) train a segmentation model on aerial image patches (128x128m), 2) download aerial images in patches (256mx256m) from a WMS server for the whole of Flanders, and 3) apply the trained model to these image patches of Flanders. Training data was generated by manual selection of examples of orchards from recent fieldwork (2018-2023) for the Biological Valuation Map (BVM). This procedure was applied twice to aerial imagery (winter) from 2016 and 2021, resulting in two vector layers covering Flanders. Subsequent postprocessing of these layers consisted of buffering for simplification of the polygons, selecting only the polygons that are located in grassland (with land cover map by Poelmans et al. (2023)) and combining both maps (2016, 2021) to a single vector layer by only keeping the polygons of 2021 that overlap with polygons from 2016. These post-processing steps were taken to minimise false positives in the raw model output.
***Classification system**	The classification system is a binary, the two classes being high-stem orchard/other.
***Output data**	Vector layer indicating potential locations of high-stem orchards over the entire region of Flanders.
***Owner/producer**	The vector layer is created and owned by INBO (Research Institute for Nature and Forest). Contact: kato.vanpoucke@inbo.be, toon.spanhove@inbo.be, stien.heremans@inbo.be
Target group/Primary user/User needs	The vector layer will be used by INBO to update the BVM regarding high-stem orchards. Currently, a team at INBO is still working on how to implement the produced remote sensing product into the BVM. The vector layer will probably first be used to identify orchard locations that are not yet part of the BVM, in its goal to provide a region-wide update of this land cover type.

***Input data and data providers**	Orthophoto of the region of Flanders at 0.25m resolution which is flown yearly in winter. The orthophoto of 2016 and 2021 was used in this project, respectively available at link 2016 and link 2021. For the selection of suitable training locations, the latest version of the BVM was used which is available for download on this web page. In the post processing phase of the raw model output, a land cover map at 10m spatial resolution was used for the year 2022. This land cover map is updated every three years and is openly available here.
Data cost	All data listed above is freely available. Note that the training of the model and its application over the entire region, does require availability of a GPU.
***Description**	To delineate meadow orchards (high-stem orchards) across Flanders, deep learning models were employed alongside aerial imagery. Using the OrthoSeg GitHub repository, a segmentation model was trained on manually selected orchard examples from recent fieldwork (2018-2023) using 128x128m image patches. Aerial images in 256x256m patches were then downloaded for the entire region from a WMS server and segmented with the trained model. This process was repeated for aerial imagery from the winters of 2016 and 2021, creating two vector layers. To reduce false positives in the raw model output, postprocessing steps included buffering polygons for simplification, retaining only those in grassland, and merging the 2016 and 2021 data by keeping only 2021 polygons overlapping with 2016 polygons. This resulted in a refined vector layer indicating potential high-stem orchard locations across Flanders.
Documentation	No additional documentation yet, report will be available in late 2024
Competence	Knowledge of GIS, remote sensing on aerial imagery, deep learning methods, Python
Tools	Desktop with: (Q)GIS for visualisation, creating training data, analysis and postprocessing GPU for training and running of the models Data storage for storing aerial imagery locally Python, anaconda, environment with Orthoseg installed Aerial imagery, preferably available on a standard WMS server. Platform (airplane/drone) does not matter, but only 3 channels are supported in the OrthoSeg package. Ground truth data for training the model Land cover map for filtering of the raw model outputs
Status	The research method for the detection of high-stem orchards started its development in late 2023 and is still under development at the time of writing (June 2024). The objective on the longer term is to use the model for the detection of other elements that are distinguishable on aerial imagery. The same tool (OrthoSeg) has been used at INBO before in another application, i.e. for the digitisation of historical maps. More information can be found in the report of De Keersmaeker et al. (2024), of which an abstract is available in English.
Result/output/accuracy	*Output resolution*: We filtered the minimum area of a model prediction (vector layer) to be 250m², because of the application of mapping high-stem orchards.

	Repeat time is based on the frequency that new aerial imagery is available, which is yearly for winter images in the case of Flanders. *Mapping accuracy*: Based on the validation set during training, the categorical accuracy was 0.94 and the mean IOU 0.73. for the prediction on the entire region, only the user's accuracy is determined, which was >80%. No producer's accuracy is yet available for the mapping of the entire region. *Transferability*: Although not thoroughly tested, both spatial and temporal transferability most likely requires retraining of the model. Factors like differences between orthophotos and the differences between spatial resolution of aerial imagery complicate transferability between regions. Retraining for other regions is a possibility and requires the availability of aerial imagery and ground truth data. In addition to these data requirements, also the tools and competences listed above are required. Since this method was tested in the context of high-stem orchard detection, thematic transferability is also relevant here. If OrthoSeg were to be applied to tree encroachment in grasslands and wetlands, a possible approach would be to segment tree crowns from other vegetation types such as grass. From a visual exploration on orthophotos, this approach requires aerial imagery from summer with sufficient spatial resolution. A complicating factor could be the high variability of tree crowns on grassland and wetland plots. *For which classes*: delineation of trees from other vegetation types (tree encroachment) *Scalability*: Applying the trained model to Flanders (>13 500 km²) in patches of 256x256m, resulting in more than 200 000 patches, takes about three days. Orthoseg makes this scalability to larger study areas relatively easy to implement.

Method 2

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	***8: Assessing grassland restoration phases from Sentinel-2 data***
* Method (Method reviewed)	All grasslands in Flanders can be assigned to one of six 'restoration phases' of different species richness, composition and biodiversity value. In this exploratory study, we assessed how well these different phases can be distinguished using an intra-seasonal time series of Sentinel 2 satellite images. We found that the phases at the low and high extremes are very distinctive in the spectro-temporal domain of our Sentinel 2 acquisitions. The intermediate phases however are more similar spectrally, making them more difficult to discern. Most phases can however be separated at least on one acquisition date. This is an encouraging result as the long-term aim of developing a monitoring system for grassland restoration at the parcel scale seems feasible.
***Classification system**	The grassland restoration phase model has been developed by Zwaenepoel (2000) and is used in Flanders for identifying discrete successional stages in species composition of grasslands. The classification comprises 6 different classes ranging from agricultural grass monocultures over species-poor intensive and extensive grasslands to species-rich and semi-natural

	grasslands. Since the classification relates directly with species composition (dominant species, monocultures, herb/grass ratios, etc…) the outcome of this research is also relevant for other grassland classifications.
***Output data**	Output data merely consists of calculated separability indices (M-statistics) between the different grassland phases for the different study areas on different acquisition dates and for different Sentinel2-bands. Further research is needed to derive indicators or a classification model.
***Owner/producer**	KULeuven, Research Institute for Nature and Forest Research. Contact: Stien Heremans (stien.heremans@kuleuven.be; stien.heremans@inbo.be)
Target group/Primary user/User needs	Primary users are RS-researchers and ecologists. End-users are NGOs, government, landowners and farmers with management contracts. Although grassland phase assessments in the field are currently rather scarce it is clear that having up-to-date and frequently updated information on species composition at the level of the individual management parcel is a major benefit.
***Input data and data providers**	Atmospherically corrected Sentinel-2 multispectral imagery downloaded from the VITO server (March 2017- October 2017): 13 bands, cloud masks, shadow masks, scene classification map Polygon data of targeted grassland phases: 50 (100) per study site
Data cost	Use of Sentinel 2 data is free of cost, processing costs and costs of field collection of validation data are unknown
***Description**	This method aims at testing if different restoration phases in grasslands can be distinguished based on multispectral Sentinel-2 imagery. Restoration phases are a concept developed by Zwaenepoel (2000) defining 6 successional grassland stages (0-5) starting from mono-specific grass crop fields (phase 0) over two species poor stages (1-2) to 3 types (3-5) of species-rich to semi-natural grassland types. Types 0-5 show increasing biodiversity value. Currently, assessment of a parcel's restoration stage is based on field surveys because of the strong emphasis on species composition. Different grassland stages should be allocated spectrally and temporally, and linked to biophysical properties present in the field (e.g. dominant species, number of species, etc…). Therefore the restoration stage in a number (50-100) of grassland sites was determined in the field in 3 study areas, covering a wide range of grassland types. A first exploration of the Sentinel-2 imagery revealed that the spectral signatures of the grassland parcels of interest show large variation between different parcels and throughout the growing season. Difficulties were encountered in differentiating management influences from differences between the restoration phases. A separability analysis on individual Sentinel-2 bands showed that the red-edge and NIR spectral regions have a good potential for differentiating between different sets of restoration stages. This indicates the potential suitability of Sentinel-2, with a relatively high density of bands in those regions, for this kind of application. In a second part of analyses, information on vegetation biomass, water and nitrogen content was included. Those biophysical variables are derived from

	analysis of biomass samples collected in the field. Subsequently a set of spectral vegetation indices (VIs) was screened for their potential to upscale the limited information of the biomass samples to the full area of studied grasslands. However, no VI could be identified to meaningfully retrieve biophysical variables from the imagery. The same set of VIs was used as the input for a new separability analysis. The results indicate that spectral regions linked to vegetation water content and pigmentation have good potential for differentiating between restoration phases. The hypothesis that separability between phases increases for phases lying further apart could only be confirmed partially. The hypothesis that the very homogenous ryegrass meadows (phase 0) appear more distinct than the very diverse nutrient-poor meadows (phase 5) could not be confirmed, at least partially because of the limited number of available phase 5 parcels.
Documentation	Heremans S., Hillen R., Vanierschot L., Somers B.., 2018. Assessing the Ecological Value of Grasslands from Sentinel 2: A Case Study in Flanders. IGARSS 2018 Conference paper (DOI: 10.1109/IGARSS.2018.8518398)
Competence	Expertise in satellite remote sensing data handling, GIS analysis, Sentinel 2 data processing, statistical data analysis For field work and training data (general) expertise in grassland typology and botany
Tools	RStudio (rgdal and raster packages for Sentinel data transformation, FactoMineR and factoextra packages to perform PCA analysis) QGIS for field data preparation
Status	There are currently no follow-up plans
Result/output/ accuracy	The Sentinel 2-bands used have a spatial resolution of 10-20 meters resulting in a few pixels per typical grassland parcel in Flanders. Potential for analysing within parcel variability is therefore rather low. Transferability (spatial/temporal) is unknown but the results show consistent separability within the different study areas for bands B06, B07, B8A, B11 and B12. B06,B07 and B8A appear to have the highest separability potential overall. May, the customary moment of field survey-based phase assessment, has shown to be a suitable moment for remote-sensing based phase assessment, next to March and August. The separability analysis, based on calculating Separability Index (SI) values on groups of pixel values corresponding to the same restoration phase, has shown to be a valuable approach in allocating spectral differences temporally and spectrally. However, it also showed drawbacks of autocorrelation and poorly handling differences in the area covered by different restoration phases. The methodology could prove useful in the further development of a grassland quality indicator based on species composition/richness but also maybe in the development of mapping/identifying high biodiversity value grasslands.

Method 3

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	***39:*** Automated detection of ploughing events in ancient grassland
*** Method (Method reviewed)**	The ploughing detection model is using Sentinel2-NDVI and Sentinel2-FAPAR indices to detect bare soil and subsequently discern ploughing from mowing events. A training set based on field polygon data is used to calibrate a threshold based model.
***Classification system**	The classification system is essentially binary, the two classes being ploughed/unploughed with an additional indication of the probability
***Output data**	A GIS layer of the target population with a probability indication of a ploughing event on the individual parcel level
***Owner/producer**	VITO (Vlaams Instituut voor Technologisch Onderzoek) is the owner and producer
Target group/Primary user/User needs	Primary user today is the Flemish government for surveillance and enforcement of nature legislation on conversion of historical grassland. The model is run on a regular basis and parcels that are flagged are inspected manually using aerial imagery and field visits.
***Input data and data providers**	The model is currently applied in Flanders and was trained using ploughed and unploughed grassland parcels of the target type. Additional training data is probably necessary if the model is to be transferred to other regions with f.e. different edaphic and climatic conditions.
Data cost	unknown
***Description**	The VITO model for detection of ploughing events in semi-natural grasslands is a fully operational workflow used for the surveillance and enforcement of legal obligations within Flemish Nature Conservation legislation. The entire historical grassland surface of Flanders is processed on a monthly or 3-monthly basis for detection of illegal grassland conversions through ploughing. The model is using NDVI and FAPAR from Sentinel-2 sensors to detect parameter drops beneath certain threshold values. Confusion with mowing events is omitted to a large extent. Extreme drought events and flooding are impairing accuracy and are therefore excluded from the evaluation. Firstly, a dynamic vegetation climax value is calculated as the 85 percentile value of the actually measured NDVI values. This is then used to determine the climax vegetation threshold value (which is set to be 10% lower than the vegetation climax value) and the mowing event threshold value (which is set to be 20% lower than the vegetation climax value). The static vegetation threshold value (0.48) and the bare soil threshold value (0.36) were determined empirically. Some regional fine-tuning with regard to these thresholds will be a necessary step if the method is to be transferred to other EU-member states. In order to make an accurate decision on a ploughing event, ten parameters per plot are derived from the NDVI and FAPAR time series: (1)the number of bare soil events, (2,3) the bare soil dip for NDVI and FAPAR, (4,5) the bare soil observation ratio for NDVI and FAPAR, (6,7) the bare soil area ratio for NDVI and FAPAR, (8) the event transition ratio, (9) the numbers of transition events,

	(10) the number of real bare soil observations. These parameters are then used to calculate the probability a plot was ploughed at a certain time.
Documentation	No published documentation available to our knowledge
Competence	Expertise in satellite remote sensing data handling with Python, GIS analysis, Sentinel 2 data processing, statistical data analysis.
Tools	Python in a Jupyter Notebook environment, (Q)GIS
Status	The method is currently in use and run on demand of the Vlaamse Overheid by VITO. Future plans are unknown
Result/output/accuracy	The output resolution is at the scale of individual grassland parcels with a minimal area of 0.5ha The method is generally perceived as satisfactory by the end-user. The model is not working accurately during the winter period due to confusion with flooded parcels. Transferability has not been tested to our knowledge but it is expected to be achievable if the decision algorithm can be fine-tuned to local conditions by means of additional training data

Method 4

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	***42: Micro-ditch detection in grasslands***
*** Method (Method reviewed)**	The model detects micro-ditch rich grasslands based on digital elevation model data
***Classification system**	No typical landuse/landcover classification system is used The classification in binary and discriminates ‘micro-ditch’ parcels vs ‘non-micro-ditch parcels’
***Output data**	Primary output is a map with a shapefile of micro-ditches. Secondary output (to be further developed) is a map with indication whether a parcel corresponds with the definition of a ‘micro-ditch’ parcel.
***Owner/producer**	Method developed by VITO, as requested by INBO (VL-O)
Target group/Primary user/User needs	The method is developed within the framework of the Biological Valuation Map of Flanders, in which grasslands with micro-ditches are a specific category on its own (hpr or hpr*; respectively species poor and species rich grasslands in valleys with a lot of micro-topography). Depending on the destination on zonal plans, these parcels are protected under the Flemish Nature Decree. The Biological Valuation Maps is an instrument used in law enforcement with respect to enforce this legislation
***Input data and data providers**	A detailed DHM-raster (raster size 0.25m) is used . This dataset was obtained in the periode 2013-2015. The data are freely available. More info on https://www.vlaanderen.be/digitaal-vlaanderen/onze-oplossingen/earth-observation-data-science-eodas/het-digitaal-hoogtemodel Training of the model is based on a dataset with examples of manually delineated polygons of micro-ditches. This dataset was prepared by VITO.

Data cost	The DHM data for Flanders are freely available, but at the moment only one detailed DHM layer is available and is already somehow outdated Although there are intentions to obtain a new DHM for Flanders, the high costs associated with the acquisition and processing hinders the update of the dataset.
***Description**	The micro-ditch detection based on a AI method - methodological details to be completed The postprocessing involves a rule-based decision tree to determine micro-ditch rich parcels, based on patterns / number of micro-ditches in a parcel. Details to be completed
Documentation	Not available yet
Competence	Experience with AI tools is an advantage. Competence/licence to be agreed.
Tools	To be completed
Status	The method is still under development
Result/output/accuracy	The method is still under development - results are expected by the end of 2024.

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SAS - Slovakia Review

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2. Analysis of experience

Remote sensing has emerged as a vital method for efficiently and directly gathering information about the Earth's surface. When combined with standardized plots and regular in situ measurements, remote sensing serves as a powerful monitoring engine, playing an irreplaceable role in data acquisition and fulfilling its potential as a key tool for evaluating and implementing environmental policy. In a rapidly changing world, marked by increasing pressure on natural resources, land cover maps and monitoring have gained significant importance for spatial planning and resource management.

There is an urgent need for competent planning and decision-making in biodiversity conservation, ecosystem restoration, and sustainable development. Remote sensing data, coupled with ecological models, can play a crucial role in addressing this need and protecting our natural assets. The robustness and complexity of data obtained through remote sensing reflect their multi-source, multi-scale, high-dimensional, and dynamic-state characteristics. However, existing techniques and methods often fall short in addressing many challenges associated with big data, such as efficiently processing and analyzing vast datasets, identifying the relevant data for specific tasks, and uncovering meaningful structures within the information. Despite initiatives within the Copernicus programme and other programmes, remote sensing (RS) methods remain underutilized for mapping and monitoring high nature-value lands, such as the habitat types outlined in Annex I of the Habitats Directive. While RS methods may not address every requirement, they hold significant untapped potential to enhance a cohesive and efficient mapping and monitoring system for European habitats.

Nature conservation is becoming increasingly vital as humanity grapples with two conflicting challenges: societal development and sustainable environmental protection. It is essential to clearly delineate areas designated for development from those of high conservation value. A profound understanding of habitats—the fundamental building blocks of nature—is crucial for navigating this complex task. Not only is habitat identification important, but also the assessment of their spatio-temporal changes in area and quality, along with their biodiversity significance. Addressing these challenges surpasses the capabilities of traditional field research and monitoring, necessitating the adoption of cutting-edge methods and technologies. The absence of EU-wide harmonization in the methods used to assess habitat quality results in inconsistent reporting across the EU, complicating the understanding of overall habitat conditions. This inconsistency hampers effective nature conservation and management, including the evaluation of restoration needs and the preparation of national restoration plans under the proposed EU Nature Restoration Law (NRL).

Traditionally, the workflow for habitat mapping and monitoring involved multiple steps across different software platforms, leading to outcomes heavily reliant on the subjective judgments of field experts. Consequently, the quality of results varied significantly among stakeholders engaged in this work.

From our experience, there was a gap in software system that effectively meets the diverse needs of habitat mapping and monitoring aimed at creating precise habitat maps across the expansive habitat types (Natura 2000 network - the largest nature protection network in the world, included). NaturaSat software (Mikula et al. 2021) stands out by catering to the requirements of vegetation scientists, field experts, and nature conservation managers, including those who may not possess advanced GIS skills. Its unique combination of vegetation plot data processing, direct access to multispectral remote sensing data through the software interface, highly accurate segmentation methods, and capabilities for spatio-temporal monitoring and classification make NaturaSat an indispensable tool for a wide range of stakeholders in the field of nature conservation.

Habitat mapping

For assessing habitat distribution, two different approaches are commonly used— object-based and pixel-based approaches—and NaturaSat software supports both. The object-based approach is represented by segmentation methods where exact habitat boundaries are found semi-automatically by expert or automatically, starting from the georeferenced phytosociological relevé (Mikula et al. 2021).

NaturaSat image segmentation methods are based on evolving planar curves (Kass et al. 1987, Caselles et al. 1997, Kichenassamy et al. 1996, Mikula & Ševčovič 2001) and they are efficient and robust segmentation tools when an "initial estimate" of the desired area is available. This is the case in Natura 2000 habitat segmentation where the point-wise estimate of habitat occurrence is available in botanical/phytosociological databases. Software tools thus allow to focus the Sentinel-2, aerial or UAV image to the selected habitat occurrence indicating point and then allow user to perform either semi-automatic or fully-automatic segmentation by evolving the initial curve, either in form of straight line (semi-automatic segmentation) or in form of small circle (fully-automatic segmentation). The segmentation curve is evolving by a general mathematical model in the form of evolutionary partial differential equation.

For automatic habitat classification, a new approach for supervised deep learning data classification - Natural Numerical Networks - is implemented in the NaturaSat software. It is based on numerical solution of the nonlinear forward-backward diffusion (FBD) equation on a complete graph. The output of classification is so-called relevancy map for each habitat. It is created as a novel tool for validation of the classification, study relation of the habitat classification with the habitat species composition and for finding a new Natura 2000 habitat appearances.

Habitat monitoring

Our Natura 2000 habitat-monitoring approaches are based on semi-automatic and automatic segmentation algorithms used to monitor habitat quality and area evolution, respectively.

Habitat Quality Monitoring

The quality monitoring of habitats is based on comparing optical band values (mean, maximal, minimal, standard deviation, NDVI and Graph Laplacian (Mikula et al. 2021, Ožvat et al. 2024); in case of wetlands also NDWI, NDPI, and Turbidity index) inside the same segmented area on different dates of Sentinel-2 datasets. However, any kind of georeferences base data such as UAV or aerial photos with appropriate quality and various bands' values (Infrared, near infrared ,etc) can be used. Newly discovered indexes (based on satellite data) for quality assessment, or water saturation, etc. can be easily added to the software.

Spatio-Temporal Change Monitoring

The method developed for dynamic area change monitoring in Sentinel-2 dynamic data (or in repeated UAV/aerial datasets) is based on the automatic segmentation method provided in different time periods. The segmentation model parameters are tuned to get the best possible area segmentation in the older dataset. Then the same model parameters for the segmentation are used to get a segmentation of the area of the same habitat in the updated data. These two segmentations can be quantitatively compared by means of Hausdorff distance, perimeter, area, and isoperimetric ratio (shape index) values (Mikula et al. 2021).

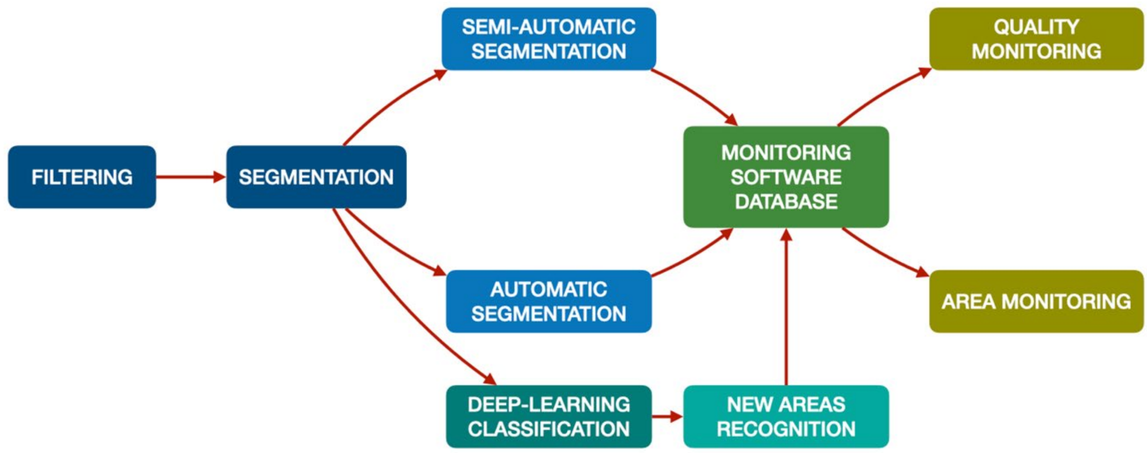

Fig. 1. Used workflow when using the NaturaSat software.

3. Needs and Future plans

There is an increasing demand for improved classification and monitoring of NATURA 2000 habitats, as well as other landscape and habitat classification systems, utilizing advanced Earth observation data. To meet this demand, we plan to continuously develop and test the NaturaSat software in the future.

This software will enable the localization, classification, and dynamic spatio-temporal segmentation and tracking of habitats, primarily utilizing Sentinel-2 multispectral imaging data. However, it will also be adaptable to incorporate various georeferenced data sources, such as aerial photographs, drone (UAV) imagery, and historical maps.

The goal is to produce highly accurate habitat maps with pixel-level resolution and efficient segmentation processes. The scale of these mapping efforts will depend on the data utilized; for larger habitats like forests and grasslands, Sentinel-2 data will be ideal, while smaller habitats such as wetlands, peatlands, and salt marshes will require orthophoto or UAV data for optimal results.

Majority of NaturaSat tools were successfully tested in the territory of Slovakia, and surrounding countries. However, habitats that occur in whole Europe have large geographical variability, and one of the biggest challenges for the future is to test the software tools in different European regions, as well as to train the network for automatic identification of habitats with their internal variability at whole European level.

Looking ahead, we anticipate implementing automatic classification using Neural Networks, aiming for 95% accuracy during the training phase and at least 90% accuracy in the final relevance maps. By developing these capabilities, we aim to significantly improve habitat monitoring and management, ultimately contributing to more effective conservation strategies and sustainable development practices.

Recent studies have predominantly utilized satellite data for large-scale vegetation mapping at higher hierarchical levels, often overlooking the specific identification of Natura 2000 habitats. In many cases, distinguishing particular habitat types has only been feasible with aerial photographs. However, our approach offers a significant advancement by enabling the segmentation of habitat boundaries within the pixel accuracy of Sentinel-2 data (10m), allowing for the recognition of individual habitats directly from satellite imagery. This capability is particularly valuable for differentiating various forest types that typically exhibit a mosaic pattern in the field—an aspect that has not been effectively addressed by previous methods.

Given that updated satellite data is now more accessible than aerial imagery and is available across all regions of Europe, our approach presents a more practical and scalable solution for habitat monitoring.

Our plans within Biodiversa+ project focus on:

Habitat mapping

- Creation of precise habitat maps for partner institutions
- Preparation of relevancy maps for target habitats in other European countries

Habitat monitoring

- Monitoring water regimes in periodic wetlands, oxbows, and river branches, with a focus on water macrophytes and muddy bank vegetation in Slovakia (optionally in partners localities).
- Tracking area changes in Natura 2000 habitats following revitalization activities to evaluate the effectiveness of restoration efforts in Slovakia.

By implementing these strategies, we aim to enhance our understanding of habitat dynamics and contribute to more effective conservation efforts across Europe.

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4. Methods

Method 1

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	**Habitat mapping with NaturaSat software**
*** Method (Method reviewed)**	Semi-automatic and automatic segmentation of habitats borders, with combination with field research
***Classification system**	Annex I habitat types Slovak habitat catalogue classification
***Output data**	Map of habitat types of the Biskupické luhy protected area (available at http://sbs.sav.sk/SBS1/bulletins/abs/bull44_1.htm#08)
***Owner/producer**	Plant Science and Biodiversity Center SAS, State Nature Conservancy of Slovak Republic (SNC SR)
Target group/Primary user/User needs	National Parks services, Protected landscape areas services, Slovak Environmental Agency
***Input data and data providers**	Sentinel-2 datasets, vegetation plots from the Slovak Vegetation Database
Data cost	Data are free of charge
***Description**	See description in “method” field.
Documentation	http://sbs.sav.sk/SBS1/bulletins/abs/bull44_1.htm#08
Competence	Expertise in botany and habitat types.
Tools	- NaturaSat software, Desktop GIS software, Turboveg (database program for vegetation databases)

Status	The map was published, the future plans are to continue with mapping of other Natura 2000 protected areas with the same methodology.
Result/output/mapping accuracy	Accuracy of habitat borders reached pixel accuracy of Sentinel-2 data (10x10 m)

Method 2

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	**Relevancy maps of 8 wetland habitats for Slovakia**
*** Method (Method reviewed)**	Natural Numerical Network (within NaturaSat software)
***Classification system**	Annex I habitat types
***Output data**	Relevancy maps (rasters) for the territory of Slovakia for following wetland habitats: 1340 Inland salt meadows 1530 Pannonic salt steppes 3230 Alpine rivers and their ligneous vegetation with Myricaria germanica 3240 Alpine rivers and their ligneous vegetation with Salix elaeagnos 3270 Rivers with muddy banks with Chenopodion rubri pp and Bidention pp vegetation 6440 Alluvial meadows of river valleys of the Cnidion dubii 91E0 Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae) 91F0 Riparian mixed forests of Quercus robur, Ulmus laevis and Ulmus minor, Fraxinus excelsior or Fraxinus angustifolia, along the great rivers (Ulmenion minoris)
***Owner/producer**	Ministry of Environment SR/ Plant Science and Biodiversity Center SAS, Geobotany research center, Algoritmy:SK, Slovak University of Technology
Target group/Primary user/User needs	WWF Slovakia, National Parks services, Protected landscape areas services, Slovak Environmental Agency, State Nature Conservancy of Slovak Republic (SNC SR), municipalities, Slovak water management company (SVP), NGO's, public
***Input data and data providers**	Sentinel-2 datasets, vegetation plots from the Slovak Vegetation Database/Providers: Plant Science and Biodiversity Center SAS, Geobotany research center, State Nature Conservancy of Slovak Republic (SNC SR)
Data cost	Data are free of charge
***Description**	Large training dataset will be obtained from Slovak Vegetation Database, Permanent Monitoring Localities (PML) database of SNC SR, and vegetation databases of Geobotany research center. Training phase and parameter optimization will be done in naturaSat software, until the success rate in training phase will reach 95%. Then relevancy maps for each habitat will be created and published.

Documentation	Internal documents - Deliverables for ESA. Documentation will be available at webpages of PSBC SAS, Algoritmy:SK and Geobotany research center in December 2024.
Competence	Expertise in botany, habitat types, skills with NaturaSat software and Mathematica software.
Tools	- NaturaSat software, Desktop GIS software, Turboveg (database program for vegetation databases)
Status	On-going activity, the maps will be finished in December 2024, and verified in the field until November 2025.
Result/output/mapping accuracy	Pixel accuracy of relevancy maps will be the same as Sentinel-2 data (10x10 m) Success rate of habitat identification shall be at least 90%, but the results will be available in 2025.

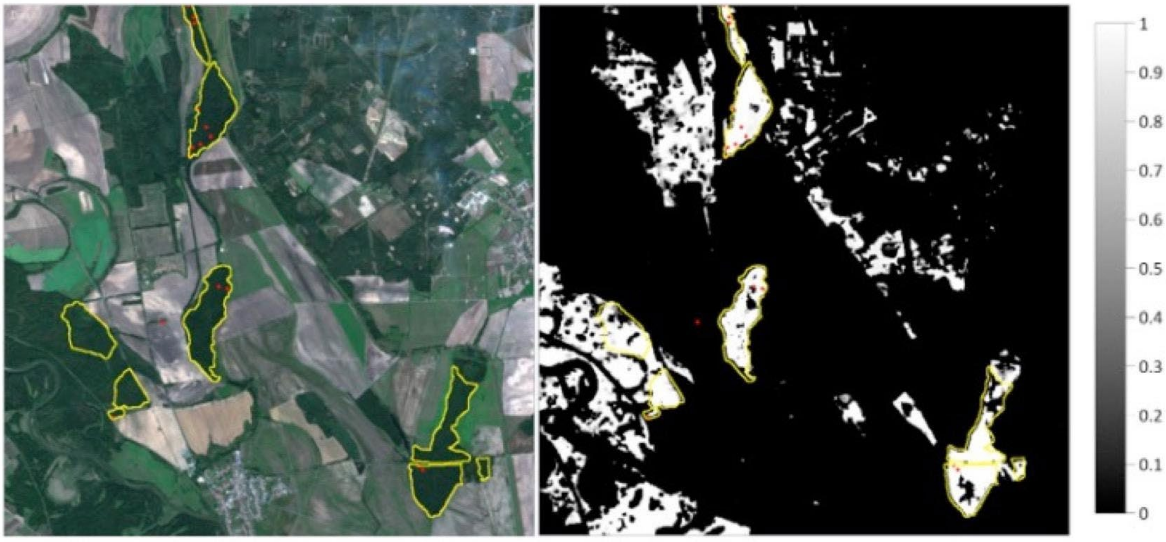

Fig. 2. Result of Natural Numerical Network classification - relevancy map of hardwood floodplain forests (91F0)

Method 3

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	**Maps of small-scale wetland habitats in Natura 2000 protected site Čiližské močiare wetlands**
*** Method (Method reviewed)**	Semi-automatic and automatic segmentation of habitats borders, with combination with field research, Natural Numerical Network (within NaturaSat software)
***Classification system**	Annex I habitat types Habitat types according to the Habitat catalogue of Slovakia (habitats of national interest)
***Output data**	Relevancy maps (rasters) for the territory of Slovakia for following wetland habitats:

	3150 Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation 3130 Oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and/or of the Isoeto-Nanojuncetea Lk10 Large Carex beds Lk11 Reed beds 6440 Alluvial meadows of river valleys of the Cnidion dubii
***Owner/producer**	BROZ conservation association / Plant Science and Biodiversity Center SAS, Geobotany research center, Algoritmy:SK, Slovak University of Technology
Target group/Primary user/User needs	BROZ, Protected landscape areas services, Slovak Environmental Agency, State Nature Conservancy of Slovak Republic (SNC SR), public
***Input data and data providers**	UAV data, vegetation plots, DTM model of area /Providers: Geobotany research center, BROZ
Data cost	Data are owned by BROZ and Geobotany, they are free of charge for scientific use (after request).
***Description**	Validated segmentation polygons database for studied wetland habitats was obtained in 2023. Trained Natural Numerical Network will be prepared for loading into NaturaSat-Wetlands software service and relevancy maps will be prepared. Cnsequently, precise map f wetland habitats in Čiližské močiare protected area will be prepared.
Documentation	Internal documents - Deliverables for ESA. Documentation will be available at webpages of Geobotany research center in December 2024.
Competence	Expertise in botany, habitat types, skills with NaturaSat software and Mathematica software. UAV licence and skills with Pix4Dcapture PRO
Tools	- NaturaSat software, Pix4Dcapture PRO (for drone operation), Turboveg (database program for vegetation databases)
Status	On-going activity, the maps will be finished in 2025.
Result/output/mapping accuracy	Pixel accuracy of relevancy maps will be the same as UAV data (20 x 20 cm). Success rate of habitat identification shall be at least 90%, but the results will be available in 2025.

Fig. 3. Example of semi-automatic segmentation (UAV data) from Čiližská močiare swamps.

Method 4

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	**Monitoring of wetland habitats before and after revitalization projects**
*** Method (Method reviewed)**	Semi-automatic and automatic segmentation of habitats borders, computation of Sentinel-2 band values statistics and indexes (NDVI, NDWI, TI, Graph Laplacian)
***Classification system**	Annex I habitat types Habitat types according to the Habitat catalogue of Slovakia (habitats of national interest)
***Output data**	Relevancy maps (rasters) for the territory of Slovakia for following wetland habitats: 3150 Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation 3130 Oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and/or of the Isoeto-Nanojuncetea Lk10 Large Carex beds Lk11 Reed beds 6440 Alluvial meadows of river valleys of the Cnidion dubii
***Owner/producer**	BROZ conservation association / Plant Science and Biodiversity Center SAS, Geobotany research center, Algoritmy:SK, Slovak University of Technology

Target group/Primary user/User needs	BROZ, Protected landscape areas services, Slovak Environmental Agency, State Nature Conservancy of Slovak Republic (SNC SR), public
***Input data and data providers**	Habitat maps created in previous project (see Method 3), Sentinel-2 time series, vegetation data/Providers: Geobotany research center, Plant Science and Biodiversity Center SAS
Data cost	Data are owned by BROZ and Geobotany, they are free of charge for scientific use (after request).
***Description**	For wetland habitat polygons, datasets of Sentinel-2 time series will be obtained from two years before and two years after conservation action (restoration of water regime). The characteristics as NDVI, NDWI and Graph Laplacian indexes will be compared.
Documentation	Internal documents - Deliverables for ESA. Documentation will be available at webpages of Geobotany research center in December 2024.
Competence	Expertise in botany, habitat types, NaturaSat software
Tools	- NaturaSat software
Status	On-going activity, the monitoring reports will be prepared in 2024 and 2025.
Result/output/mapping accuracy	

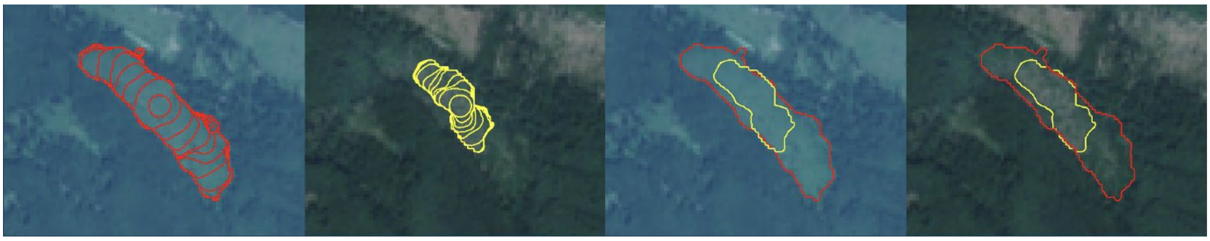

Fig. 4. Area monitoring

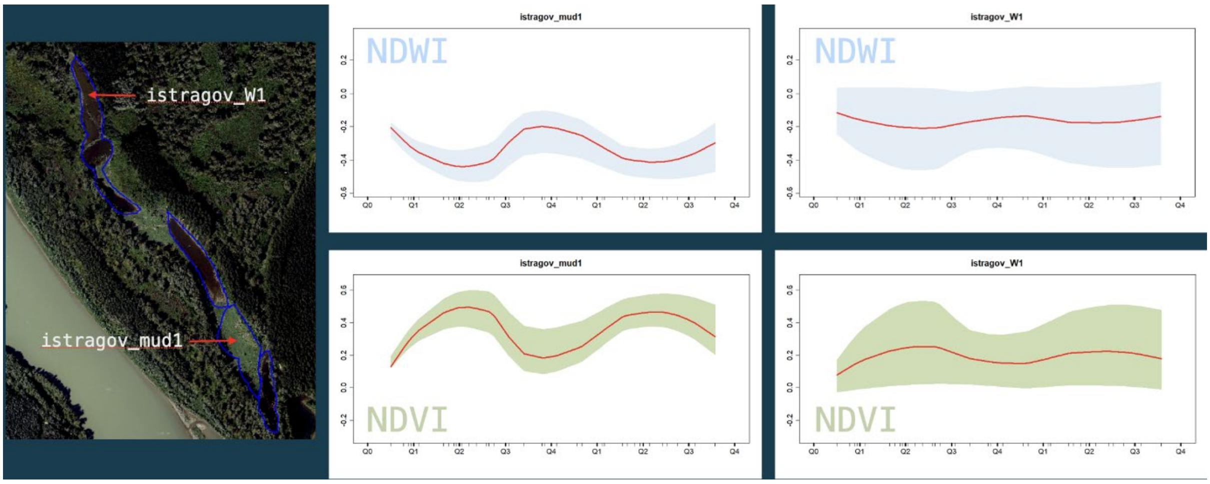

Fig. 5. Quality monitoring

Method 5

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	**Permanent monitoring localities (PML)**
*** Method (Method reviewed)**	Field based monitoring. Permanent monitoring plots (PML) were established in the whole territory of Slovakia, covering all habitat types. Plots were selected by local experts, and the polygons representing each PML were delineated in GIS or Google Earth environment.
***Classification system**	Annex I habitat types Slovak habitat catalogue classification
***Output data**	www.biomonitoring.sk
***Owner/producer**	State Nature Conservancy of Slovak Republic (SNC SR)
Target group/Primary user/User needs	National Parks services, Protected landscape areas services, Slovak Environmental Agency
***Input data and data providers**	Initial lists of species, boundary of each permanent monitoring plot (data provider SNC SR)
Data cost	Data are free of charge for registered users, usually those who also contributed to the mapping.
***Description**	See description in “method” field.
Documentation	www.biomonitoring.sk
Competence	For field work, expertise in botany, phytosociology and habitat types.
Tools	- Desktop GIS software, Google Earth software for visualizations of PML’s borders, if they had changed
Status	No information about future plans, however data could serve for monitoring purposes and as a source of information.
Result/output/mapping accuracy	Not applicable (no remote sensing methods were used)

Method 6

Review of performed methods for mapping and monitoring of grassland and wetland habitats	
*** ID**	***Habitat Catalogue of Slovakia***
***Method (Method reviewed)**	Expert based analyses
***Classification system**	Slovak habitat catalogue classification (with a link to Annex I habitat types)
***Output data**	A book and PDF format with habitat characteristics and basic maps of habitat occurrence at the level of squares.
***Owner/producer**	State Nature Conservancy of Slovak Republic (SNC SR)

Target group/Primary user/User needs	Practitioners, nature conservationists, researchers, public
***Input data and data providers**	Slovak Vegetation Database (owned by Plant Science and biodiversity Center SAS), database of PML's. These databases were checked by experts who are co-authors of the Catalogue, and the maps were prepared according to verified habitat occurences.
Data cost	PDF is freely available at: http://www.biomonitoring.sk/CMS/Publication/Detail/40
***Description**	
Documentation	PDF is freely available at:
Competence	Not applicable
Tools	Turboveg and Juice softwares (specialized softwares for handling and analyzing of phytosociological data)
Status	Finished
Result/output/mapping accuracy	Revised and accurate maps of habitat occurrence are important, but there may be gaps in information for certain habitats, and new localities can still be discovered. A map of the recorded occurrence of the habitats in Slovakia in the geographical network of the Central European mapping of flora and fauna with the boundaries of the Alpine and Pannonian bioregions are shown. Phytosociological records, data from the Comprehensive Information and Monitoring System including monitoring areas, layers from habitat reporting for the European Commission were used as a data source.

Appendix 2. Reviews of the selected earlier and on-going (EO-based) projects on habitat and/or grassland and wetland mapping and monitoring

Appendix 2a. Review of Habitat Mapping Approaches in European Countries – Summary of a survey by the European Environment Agency and its Partners

Overview of the survey

The European Environment Agency (EEA) conducted a survey within the Eionet network from December 2022 to January 2023 to gather information on current habitat mapping approaches in European countries. The survey focused on habitat mapping methods, emphasising the integration of traditional field-based techniques with remote sensing methods such as satellite data and aerial imagery. Variety of topics were covered, including current methods, data sources, digital capabilities, priorities for mapping, coverage, habitat classification systems, maturity of RS-based applications, validation, challenges and bottlenecks, and recommendations for using RS methods. Answers were received from 17 countries: Austria, Bulgaria, Czech Republic, Denmark, Estonia, Finland, France, Germany, Iceland, Italy, Kosovo, Latvia, Netherlands, Norway, Serbia, Spain, and Sweden, including many of the countries participating in the Habitat pilot. The survey was carried out in Excel format and was complemented with interviews. At the time of writing of this report, the survey results were not yet published.

Key findings: current status of habitat mapping

Based on the survey findings, traditional field-based mapping is currently the dominant main approach for habitat mapping, applied by the majority (n=13) of the countries. Field mapping is supported by use of aerial imagery in seven of the countries. Some rely on land cover and other maps for habitat mapping. Only a few (Iceland, Sweden, Finland) have integrated satellite data in their current mapping procedures, and only one country (Iceland) had full-coverage automated satellite-based mapping product in active use. Finland has produced a satellite-based complete habitat mapping for its northern Lapland region. Majority of other countries as well, however, had pilot projects running for utilising satellite data and automated processes in habitat mapping, and many of the rest were also advancing in implementing digital methods in mapping. Current methods for mapping and monitoring cover typically only protected areas or some share of the country. With new methods the countries hope to achieve better spatial and temporal coverage for mapping and to enhance the efficiency of the mapping process. Highlights from countries other than active Habitat pilot partners, along with Iceland’s full wall-to-wall satellite-derived habitat map, include semi-automated mapping pilots in Germany and Latvia. Germany has multiple projects with Copernicus data started in 2023, focusing on natural and semi-natural grasslands, and in peatlands on raised bogs, mires and fens. Latvia mentioned multiple projects: “Remote sensing and machine learning for surveillance of mire habitats” (PurvEO, completed), “Automated identification of mires and peatlands using multi-temporal satellite data” (MireClass, ongoing) and a project developing methodology for detecting changes in the area of habitats by applying RS data.

Key findings: challenges and recommendations for the use of RS methods

Based on experiences in the countries, also several challenges and limitations were pointed out. Differentiating between habitat types remains difficult, with significant uncertainty surrounding many habitat categories. The usability of satellite data varies widely depending on the habitat type being studied. In some cases, manual corrections are necessary to address data inaccuracies, as noted in Iceland. Expert knowledge is crucial to avoid misinterpretation of RS data and to understand its limitations. There is ongoing discussion about the role of remote sensing in habitat mapping, with a need to clearly define its benefits and restrictions. Building trust among map users is also a challenge, as officials may be sceptical about new methods. Compatibility between habitat classification systems and RS approaches poses another challenge. Identifying the appropriate system or hierarchy levels where RS methods are sufficiently reliable is crucial. RS has potential applications in prioritising fieldwork by identifying potential habitat areas or regions needing further ground truth data collection. A major bottleneck is the availability of ground truth data, as machine learning algorithms require extensive field data for training and validation. The time gap between field observations and satellite data collection can also affect accuracy. Additionally, cloud-free time series data is essential for reliable mapping and is pointed out as a common challenge. The role of unmanned aerial vehicles (UAVs) in national-level mapping remains uncertain. Resource limitations, including financial constraints, insufficient human resources, and inadequate data and methods, further complicate the implementation of RS-based habitat mapping. Addressing these challenges will be key to advancing the use of remote sensing in habitat monitoring and management. Despite these issues, RS-based maps have proven useful in several projects, such as those in Iceland and Finnish Lapland.

Relevance for the Habitat Pilot

The survey results highlight the timely need for developing harmonised habitat mapping approaches, as countries are currently exploring and refining their methods. There is a clear and shared need for automated and comprehensive habitat information, which remote sensing (RS) methods and satellite data could potentially provide. A positive aspect for harmonisation is that most countries have adopted standardised habitat classification systems, such as the EU Annex I or EUNIS, or have developed crosswalk tables to align with these frameworks. However, also several challenges were identified regarding the use of RS data in mapping. These, together with recommendations provided in the survey, can be considered in pilot work.

The survey's focus on general habitat mapping constrained the depth of information regarding specific methodologies for different habitat types, which is understandable given the extensiveness of the topic. The methods and developmental stage of RS applications vary depending on habitat type, as was implied in some survey answers. While the survey provides valuable background information on habitat mapping in Europe generally, it does not offer detailed insights into the status and methods used specifically for grassland and wetland habitats, which are central to the Habitat Pilot. The review conducted in Module 1 of the pilot successfully addresses this gap, offering in-depth information on the current status and methodologies used for mapping and monitoring these two habitat types.

Appendix 2b. EU Grassland Watch - A review based on information available on the project internet pages as well as the workshop and other EU Grassland Watch representation material provided kindly to Biodiversa+ Habitat pilot.

Project partners

Copernicus for Natura 2000 - EU Grassland Watch (EU GW) is a project team that consists of nine partners: Space4environment (project leader), Gisat, Bilbomãtica, VITO Remote Sensing, JOANNEUM RESEARCH, ALSO Space, Specto Natura, SLU Artdatabanken, Birdlife International and Institute of Landscape Ecology, Slovak Academy of Sciences.

Overview of aims and project development process

EU Grassland Watch and its forerunner project COP4N2K (Copernicus for Natura 2000) were contracted by the European Commission to develop a service system to enable the assessment and monitoring of the status and management of grassland-dominated Natura 2000 sites. The key target was to support the development of a service portal prototype for N2000 grasslands (https://ec.europa.eu/eu-grassland-watch/) to be generated by the EU GW project team. In September 2023, EU GW launched its second main phase, including producing methodological updates and improvements of the contents of the EU GW portal, as well as increasing the number of N2000 sites covered, ultimately aiming at developing an operational service to deliver timely information on the status, changes and pressures for the grassland-dominated N2000 sites between the years 1994 – 2026.

At the core of EU GW is the satellite image data extracted from the Copernicus system - European programme for monitoring the Earth from space using different EO and in-situ sensors producing freely available reliable and up-to-date environmental information. Based on Copernicus data, EU GW portal currently provides information for the grasslands situated in 3 689 Natura 2000 areas occurring in 27 EU Member States, mapped using the framework of Copernicus Land Monitoring Service. The changes in the status and area of the focal N2000 grasslands has been assessed starting from the year 1994 until today using the harmonised satellite information extracted for the first time slice (1994 – 2015) from Landsat and, since 2016 from Copernicus Sentinel 1 and 2, images. This harmonised EO-based information allows exploring the changes in grassland cover, and the indicators derived therefrom, at different spatial resolutions, including separate Natura 2000 sites, regional and national levels.

An overall aim of EU GW is to provide information to various stakeholders on the evolution and conservation status of specific natural habitat types such as grasslands and their biodiversity, as well as the ecological trends and health of Natura 2000 network sites in Europe, and to raise awareness of activities causing degradation of habitats and engage citizens in the protection of N2000 sites. For the EU level nature conservation targets, the outputs of EU GW aim to provide essential support for the Article 17 reporting via the provision of systematic spatial quantitative data on grassland habitats.

It is important to acknowledge that the EUGW project is the successor to COP4N2K project which represented a “EP Pilot project” providing the first step towards developing consistent and effective Natura 2000 monitoring services for grasslands.This resulted in the development of an EO-data processing workflow, map products and indicators accessible via the prototype platform service of

COP4N2K which are now being actively further developed and expanded in EU Grassland Watch project. The updated platform service will include certain improvements, including (i) a stronger stakeholder engagement; (ii) additional Natura 2000 sites and more thematic details; (iii) more flexibility for incorporating new sites and managing the site boundaries; (iv) more readily interpretable information extracted from technical indices providing insights to grassland sites.

Methods – site selection and characterisation

By definition, COP4N2K project focussed on grasslands that occur in the Natura 2000 sites. When developing a prototype of the service system to assess the changes in grassland dominated N2000 (NK2) areas between the years 1994 - 2022, particular attention was paid to the technical feasibility, especially EO data processing and database storage for the information.

For the prototype, COP4N2K project selected 3 689 grassland-dominated N2000 sites out of > 24 000 sites available. The selection of the focal sites was done based on the land cover information derived from Copernicus Land Monitoring Service (CLMS) information for the N2000 sites (https://land.copernicus.eu/en/products/n2k).

In summary, N2K Land Cover/Land Use provides vector data on the land cover and land use for the 55 thematic classes measured by six years' interval and a Minimum Mapping Unit of 0.5 ha and a Minimum Mapping Width of 10 m. Based on the N2K habitat information for the N2000 sites, and following the Mapping Europe's ecosystems (MAES) Level 4 nomenclature, the cover of grasslands was determined and used to guide the site selection. For the selected 3 689 N2000 sites information was generated based on EO data and complementary GIS data for developing land cover maps, information on grassland indicators (their extent and spatial changes) and biophysical parameters (e.g. mowing, bare soil).

Starting from 2023, EU GW project works on enhanced provision of an operational service for delivering the information on the status, changes and pressures for the grassland-dominated N2000 sites covering the years 1994 – 2026. The aim is to provide more complete coverage by including more sites, with a target set at 16 430 sites, as well as more thematic details for these sites. In addition to EUNIS classification of grassland habitats used in COP4N2K, cover and status information in relation to Annex 1 grassland habitats will be provided via the EU GW portal.

Methods – EO and other data

Earth Observation technology and data provides a massive capacity for long-term systematic monitoring of different habitat types, including grasslands, across Europe. In the EU, the EU Copernicus programme plays an essential role. Thus, the analytical processes of EU Grassland Watch have been based on freely available high-resolution EO data derived from Copernicus. These data include both optical RS data from Copernicus Sentinel 2A & 2B (12 optical bands, spatial resolution 10/20/60 m, re-visit time: 5 days, data from 2015 onwards) and optical and thermal data from Landsat (7 optical bands, 2 thermal bands, spatial resolution 30 m, re-visit time: 8 days, data from 1984 onwards), as well as radar data from Copernicus Sentinel 1A, 1B and 1C (VH, VV polarization, spatial resolution 10/20 m, re-visit time: 12 days, data from 2014 onwards).

Optical data has been used in EU GW to capture land surface images in different spectral bands (visible, infrared) and features hidden to human eyes but are limited by clouds and shadows. In contrast, radar data have no limitation to clouds, shadows or daytime, and can be used to complement optical data.

Supportive datasets used in habitat definition or qualitative assessments of EU GW include:

- CLMS HR-VPP: raw vegetation indices, seasonal vegetation trajectories and vegetation phenological and productivity parameters
- CLMS EU-DEM: digital surface and elevation model
- CLMS HRL Forest: dominant leaf type, tree cover density, forest type, tree type
- CLMS HRL SWF: small woody features
- CLMS HRL VLCC: characteristics of vegetated land cover
- CLMS N2K:land cover/land use (LC/LU) status and change maps tailored to the needs of biodiversity monitoring in Natura 2000
- CLMS CLC+BB: land cover map
- Open Street Map: roads
- Urban and EU-Mountain regions

The four main components of the EU GW approach

At present, the activities of EU Grassland Watch are organised under four main components: Land Cover, Grassland Type, Grassland Management and Grassland Productivity Components.

The main aims of these components are as follows:

- **Land Cover Component:** Grassland identification and Land Cover change assessment
- **Grassland Type Component:** Characterisation of grasslands from biological / habitat perspective
- **Grassland Management Component:** Characterisation of grasslands from the perspective of management intensity
- **Grassland Productivity Component:** Characterisation of grasslands from the perspective of productivity trend, state and performance

The activities in **Land Cover Component** primarily target the grassland (LC4) identification part of the EU GW workflow, but include also consideration of other land cover classes. In total, 11 different main land cover (LC) classes are used in EU GW Land Cover Component:

- LC1 – Urban/Built-up areas
- LC2 – Arable land
- LC3 – Permanent crops
- LC4 – Grassland
- LC5 – Broadleaved dominated forest
- LC6 – Coniferous dominated forest
- LC7 – Heathland, bushland, shrubs
- LC8 – Wetland
- LC9 – Bare and sparsely vegetated areas
- LC10 – Glaciers and perpetual snow
- LC11 – Water

The LC4 Grassland class in the prototype COP4N2K project was divided into class 41 Intensively Managed Grassland and class 42 Extensively Managed Grassland, and the class 42 further on into subclass 421 Extensively Managed Grassland and subclass 422 Alpine and subalpine Grassland (see Mišurec et al. 2023; Workshop on Review of the nomenclature -section below).

Determining the cover and occurrences of the main land use classes in the Nature 2000 areas provides essential information to assess the potential changes of grassland to another land cover type, or vice versa, as such changes may take place also in N2000 areas. Specifically for grasslands, these analyses enable assessing the age of N2000 grasslands, i.e. how long a certain grassland polygon can be observed in a certain spot. Furthermore, these analyses provide the basis for calculating spatio-temporal trends for the changes in grassland habitats' area at different scales, ranging from individual N2000 sites to local, regional, national and EU wide assessments.

The main target in the grassland identification step is delimitation of the areas considered as grassland. This allows generating the grassland mask for consequent steps in the workflow, i.e. a binary mask of grassland areas that will be used as input for the characterization of the N2000 grasslands. The primary data sources in grassland identification are airborne orthophotos (background layer), EO optical and SAR data and land cover classification data on raster level but also supportive datasets listed above may be used.

In the second main component, **Grassland Type Component**, characterisation of grasslands sorted out in the grassland identification step will be classified into different grassland types from biological and habitat perspective and using machine learning (ML) techniques. Here, characterisation of grasslands follows EUNIS level 2 nomenclature that is slightly modified for the purposes of EU GW:

- GT1: Dry grassland
- GT2: Mesic grassland
- GT3: Wet and seasonally wet grassland
- GT4: Alpine and sub-alpine grassland
- GT5: Forest clearings
- GT6: Inland salt steppes
- GT7: Sparsely wooded grassland

The classification into different grassland types utilises data on the spatial and temporal patterns in (i) grassland biophysics, i.e. green biomass (assessed by NDVI), canopy water (NMDI), and leaf pigments (TCARI); (ii) phenology and productivity (HRVPP); (iii) SAR Backscatter data, and (iv) topography (DEM), including elevation, slope, aspect, Topographic Position Index (TPI) and Topographic Wetness Index (TWI).

Grassland Management Component: This component deals with characterisation of grasslands from the perspective of management intensity. The key attributes considered include (i) grassland mowing and developing means for the indication of possible mowing events using especially NDVI temporal profile data, and (ii) grassland ploughing and degradation, i.e. the detection of local anomalies with sudden occurrence of bare soil within grassland area.

The guidelines used for the characterisation of grasslands based on management intensity include the following principles:

- The relationship between management intensity and grassland naturalness is not straightforward but sometimes complex
- A three-fold division to be applied: Natural vs. semi-natural vs. managed grasslands (i.e. CLMS N2K product)
- Even natural areas need specific conditions (high altitude / latitude) or disturbances (grazing by wind / semi-domestic/ domestic animals) to remain as open grassland
- Nomenclature must follow only one of these aspects: naturalness or management intensity

Consequently, grasslands in EU GW are assigned from the perspective of management into the following classes:

- GM1: Permanent grasslands with no management
- GM2: Permanent grasslands with extensive management
- GM3: Permanent grasslands with intensive management
- GM4: Temporary grasslands with intensive management
- GM5: Other grasslands

The quantification of management intensity relies heavily on the temporal profiles of NDVI. Based on NDVI data, identification of significant features that can correspond to management events is carried out. Features that are potentially useful here include total and monthly statistics of detected events and their categorisation, the first and last timing of events, and the relative indices developed from NDVI data, indicating grassland productivity and dynamics.

In the **Grassland Productivity Component,** the characterisation of grasslands based on biomass productivity is based on mean productivity level of the last 5 years; this is considered recommendable to avoid temporary issues such as drought conditions. Here, the grasslands can be assigned into two categories:

- GP1: High productivity grasslands: grasslands with high productivity level most likely corresponding to agricultural production (hay production, intensive grazing)
- GP2: Low productivity grasslands: grasslands with low productivity level most likely corresponding to either no or extensive human management.

From the annual /seasonal productivity data, also short-term productivity trends can be calculated across the 6-years EU reporting periods to describe the slope (‘intensity’) of the trend. Also the statistical significance of the trends can be examined, as well as their long-term amplitudes starting from 1994.

Analytical details of Land cover classification, Grassland identification and Grassland management characterization

The workflow of EU GW concentrates on 1) robust grassland areas identification and 2) grassland area characterisation using EO-based parameters. The identified grassland areas are entered into the ‘Grassland Characterization’ component for further characterisation using both biological and management perspectives.

For Land cover classification and Grassland Identification steps, there are several steps in the process and various types of data are - or can be - used. An overall aim in Grassland Identification is reliable mapping of grassland extent using a Land Cover classification approach resulting in a temporally harmonised sequence of land cover thematic rasters. To reach this, multitemporal spectral composites of optical satellite imagery (Sentinel-2 – monthly, Landsat - quarterly), multitemporal statistical composites of the Normalized Difference Vegetation Index (NDVI), and multitemporal SAR composites, i.e. temporal aggregation of SAR backscatter extracted from the Sentinel-1 are used in grassland delineations.

Grassland characterization step starts from the perspective of biological characteristics, where variables related to grassland phenology, productivity and biophysics are analysed for the grassland sites. At the core here is the HR-VPP dataset from Sentinel providing altogether 13 variables related to vegetation phenology and productivity.

These variables describe. e,g., start of season, end of season, peak of season, length of season, and productivity, and can be used to differentiate grassland types from a biological perspective. In addition, vegetation indices reflecting certain biophysical variables such as biomass amount, leaf area index, chlorophyll content and water content can be used for grassland characterization. These include Normalized Difference Vegetation Index (NDVI), Normalized difference Water Index (NDWI), Normalized Multi-band Drought Index (NMDI) and Transformed Chlorophyll Absorption Index (TCARI). Using these indices together with phenological characteristics enables discriminating the main grassland types such as dry grasslands, mesic grasslands, and wet grasslands.

Additional variables to be used include, for example, HRL Forest which when used together with Copernicus-DEM elevation and European Mountain Regions layer allows identifying alpine grasslands, and HRL Small Woody Features (SWF) which can be used as a supportive input for detection of occurrence of scattered woody vegetation on grassland areas (for more details see Mišurec et al. 2023).

The other element in grassland characterization is the Grassland Management assessment. Here, grasslands can be characterised from the perspective of management intensity, i.e. based on the activities such as mowing, ploughing and grazing. The features of main interest in EU GW are grassland persistence, which expresses the length of the period during which grass cover at the given location is observed, and ploughing and degradation, i.e. appearance of sudden occurrences of bare soil representing a local anomaly caused either by direct ploughing of grassland area or degradation due to intensive grazing. Technically, the detection of ploughing or severe degradation is based on analysing spatial and temporal patterns of two indices extracted from Sentinel-2 data: NDVI and BSI (Bare Soil Index), and combined where required with analysing SAR backscatter. In some areas, detected anomalies with bare soil may be caused by more natural processes (drought, flooding, …) than ploughing especially in grasslands under notably dry climatic conditions (e.g. Mediterranean environments).

Detection of mowing using EO data is carried out in EU GW using a combined processing of temporal profiles of SAR coherence data (extracted from Sentinel-1) and NDVI data (extracted from Sentinel-2). With this combination, a binary mask indicating occurrence of a mowing event can be constructed and temporally aggregated to assess the number of seasonal mowing events. In contrast, detection of grazing is considered more demanding due to the lack reliable tools or workflow for direct grazing detection based on EO data processing.

Characterisation of grasslands using Grassland indicators

In the COP4N2K project a very high number, i.e. 43, indicators were produced and made available in the service portal. This initial list of COP4N2K indicators was considered not fully optimal in delivering relevant and easy-to-adopt information for different stakeholders (i.e., mainly ‘technical’ indices for experts and not easily accessible to the non-expert). Thus EU GW is currently going through a phase of revising and redefining the focal set of indicators for assessing the status and changes, intensification, abandonment, ecosystem condition of the N2000 grasslands.

In the COP4N2K project, the work on indicators focused on (i) the provision of general indicators on grassland composition and configuration, and (ii) combining general indicators with external auxiliary data to develop more complex indicators to derive more elaborate information. Overall aim was to develop specific indicators allowing a better understanding and monitoring of grassland abandonment and intensification and providing information for sustainable land use and the implementation of EU Habitats Directive. The indicators largely focussed on the metrics for the absolute and relative surface areas of the grasslands in N2000 areas, their cover changes and grassland class diversity. The assessments in COP4N2K were subdivided into (i) all grasslands, (ii) intensively and (ii) extensively used grasslands, and the metrics were generated for local, regional and national levels.

One of the thematic workshops organised by EU GW focused on the revised selection and relevance to stakeholders assessment of the indicators: the report of that workshop (Gregor et al. 2024: Reflections on the EU GW indicators. Background material for the indicator user workshop and conclusions from the discussions. 14.03.2024) is available to the Biodiversa+ Habitat pilot partners in the pilots' Google folders. At general level, the aim of the workshop was to allow users of the EU GW portal to bring their expertise and their real-life requirements and expectations for the EU GW service in terms of policy-relevant robust indicators.

Current focal point in the indicator development in EU GW is to, in addition to the indicators reflecting land cover composition and changes, the project will progress the construction of indicators related to grassland intensification and abandonment as well as ecosystem conditions of grasslands. One underlying cornerstone for this is the theoretical ecological foundations of grassland intensification and abandonment adopted in EU GW, where grasslands are assigned into three main groups: natural, semi-natural, and intensively used grasslands.

Similarly as in COP4N2K, grazing was considered more difficult to map on the basis of satellite data as it may require in situ knowledge of the target area to distinguish different intensities in grazing, as well as separate it from mowing based on EO. Thus mowing and ploughing are more important as indicators of intensification processes on grasslands, executing also a dual function by supporting the assessment of land abandonment by indicating disruption or discontinuation of agricultural management. Grassland ploughing can be used as an indicator for proper management of grasslands. Specifically, when it is applied in extensive, semi-natural grasslands, it is an indication that the sites are undergoing intensification and if not followed by grassland re-establishment, this means conversion to arable land and removal of grassland habitat.

The current aim in grassland quality indicator revision thus is to use EO-derived products, especially the Copernicus vegetation data sets (e.g. VPP) as ancillary EO data input, to support following developments:

- Development of a method to accurately map added value information at the pixel level, such as ploughing events; mowing events; annual biomass (extracted from HR-VPP); or other biophysical parameters which cannot be derived from HR-VPP, e.g., TCARI, NDWI or NDVI.
- Derivation of specific characteristics and indicators, such as number of events (ploughing, mowing); area of ploughing/mowing; timing of events; annual change in biomass; or number of ploughing events in last 5 years (to identify permanent from semi-permanent/natural).

- Development of a method to group several of those indicators into single composite indicator on intensification and abandonment.

Dedicated thematic workshops

EU Grassland Watch has arranged and will also organise further thematic workshops for the project partners and different grassland-associated stakeholders and other projects' researchers. The four planned workshops focus on (i) Review of the nomenclature, (ii) Indicator selection (see section 7), (iii) Platform functionality, and (iv) Use cases. The first two workshops have been organised already and they included a large amount of useful information for the grassland habitat classification and the different elements in their qualitative monitoring. The materials of the two workshops have been compiled into two workshop reports by the EU GW personnel, and these two reports (Gregor et al. 2024; Mišurec et al. 2023) are available to Biodiversa+ Habitat pilot partners in the pilots' Google folders.

The workshop on nomenclature examined how the different types of grassland are defined in currently used habitat classification systems, and how the information of grassland habitats may be transferred between different classification systems. The addressed typologies included Corine Land Cover systems, Natura 2000 Land Cover/Land Use categories, EUNIS Habitat types, and land cover types in COP4N2K (level-4 classification). For all the typologies and habitat classification systems considered and grassland habitat types included in them, the review provides an in-depth description of the criteria that can be used to identify different grassland habitat types (see Mišurec et al. 2023).

The *EUNIS habitat classification system* that include Level-2 categories Dry grasslands (R1), Mesic grasslands (R2), Seasonally wet and wet grasslands (R2), Alpine and subalpine grasslands (R4), and Forest fringes and clearings and tall forb stands (R5), has been in a central position in the definition of grassland types in the initial COP4N2K project and in currently on-going revisions in EU GW. The land cover classification used in COP4N2K included nine Level-1 main categories, Grasslands (4) being one of them. This classification system was designed to correspond to the nomenclature used in the CLMS N2000 product but also to guarantee the maximal suitability of the habitat typology in relation to EO data used in the project. For the grasslands, the terms 'managed grasslands' and 'natural and semi-natural grasslands' were replaced by 'intensively managed grasslands' and 'extensively managed grasslands', and alpine grasslands were identified using a combination of DEM and forest line mask.

The nomenclature and monitoring concept used in EU Grassland Watch is an upgraded version of that used in COP4N2K. A major difference is that in EU GW the thematic products derived from satellite imagery as well as other supportive layers are directly used as inputs for characterising the identified grasslands. The current EU GW nomenclature for grassland characterization from biological/habitat perspective was outlined based on EUNIS Habitat classification as follows:

- GT1 – Dry grassland
- GT2 – Mesic grassland
- GT3 – Wet and seasonally wet grassland
- GT4 – Alpine and sub-alpine grassland:
- GT5 – Forest clearings stands:
- GT6 – Inland salt steppes and salt marshes:
- GT7 – Sparsely wooded grassland:

Character descriptions for these grassland types are described in Mišurec et al. (2023).

References

Gregor, M., Kleeschulte. S., Watson, M., Toräng, P., Halada, L. 2024. Reflections on the EUGW indicators. Background material for the indicator user workshop and conclusions from the discussions. Version: 1.1. Last update: 14.03.2024.

Jan Mišurec, J., Kleeschulte. S., Gregor, M., Toräng. P., Halada. L., Gallaun. H., Watson, M. 2023. EU Grassland Watch. Proposal on land cover and grassland nomenclature. Materials for the nomenclature user workshop. Version: 1.1. Last update: 06.11.2023. 58 pp.

Appendix 2c. Review of the habitat mapping project of Switzerland.

Project lead and purpose

The Habitat Map of Switzerland is a start-to-finish habitat mapping method developed by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) to create a wall-to-wall vector map of the habitats of Switzerland. The method uses a combination of remote sensing (RS) data and field survey data as input, and several processing models to create classified vector and raster maps. The RS data used as part of the method is both satellite data (Sentinel 1 & 2) and nationally available data including e.g., orthophotos, DEMs, soil and climate maps, etc. The processing models used in the method are both already-existing Swiss species distribution models, as well as habitat distribution models specifically developed for the method. The field survey data used in the method are point locations to sites that have been previously habitat-mapped in field surveys compiled from different national field inventorying efforts. The method is based on the Swiss habitat classification system described by Delarze et al. (2015), also referred to as the TypoCH-system.

Aims of the Habitat pilot

The potential, and the subsequent aims of testing the Swiss habitat map method in the Habitat pilot is largely dependent on our contact with the development team at WSL, and our access to internal models, training datasets and support. As part of the general workflow of creating the Habitat Map of Switzerland, the team at the WSL have developed habitat models used for generating distribution maps of different grass-dominated habitat types across Switzerland. These habitat models use different sets of pre-selection of predictors, based primarily on Sentinel 1 & 2 indices and other types of RS data (see fig. 1). The details on which specific types of RS data (including for example spectral information and temporal period for satellite data) was selected for modelling the distribution of what grassland habitat types is listed in the supporting information of the Huber et al. (2022) article. The primary aim of the habitat pilot will be to use the different sets of pre-selected RS-based predictors to try to classify the pilot partners' selected grass-dominated test sites. Additionally, if possible, these RS-based predictors would be tested in combination with vegetation survey data from the partners, and together with some of the processing models described by Huber et al. (2022).

Summary of the method

The Swiss method uses the software eCognition in combination with a topographic landscape model, various habitat models, and a vegetation height model to segment and classify an orthographic image and produce a wall-to-wall vector map of Switzerland's habitats based on the TypoCH classification system (as described by Delarze et al., 2015). The main goal of the Habitat pilot will be to specifically test the sets of pre-selected RS-based predictors used in the grassland habitat models (marked red in fig. 1) incorporated into the Swiss habitat map method.

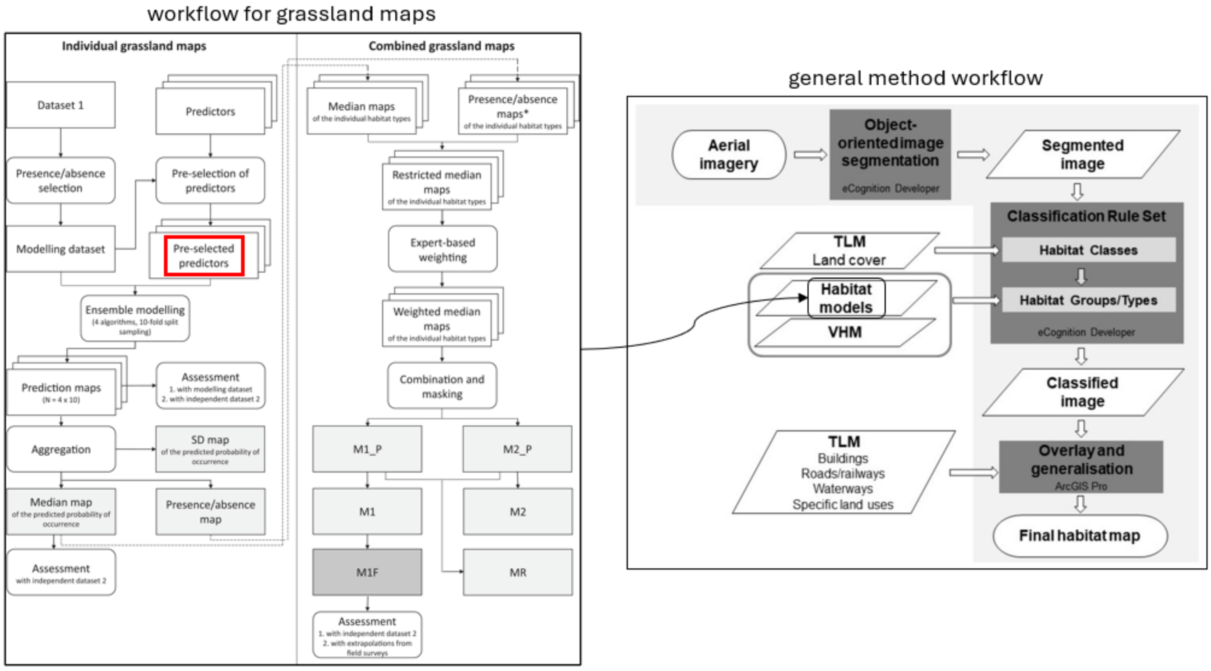

Fig. 1: Workflows describing the general process of creating the Habitat map of Switzerland (right, from Price et al., 2023), and for generating the distribution maps of different grass-dominated habitat types (left, from Huber et al., 2022). The main goal of the Habitat pilot will be testing the pre-selected RS-based predictors used for generating the grassland maps (marked red in the left workflow).

Types of data used

The RS-based predictors in the Swiss method use Sentinel 1 & 2 spectral indices in combination with soil ecological indicators (e.g., soil pH, soil moisture), terrain attributes (e.g., slope, aspect) and climatic predictors (e.g., temperatures, precipitation patterns). These RS-based predictors are, in turn, combined with national vegetation survey data to model habitat distribution maps for the Swiss habitat map. The main focus of the Habitat pilot will be to test the RS-based predictors that are based on data widely available for all pilot partners (e.g., Sentinel 1 & 2 indices, DEM-based attributes, climatic predictors). Secondarily, these RS-based predictors would be tested in combination with the pilot partners' vegetation survey data, additional RS-data (e.g., soil quality maps, orthophotos, species distribution models), and processing models from the Swiss method.

Method accuracy

The classification of non-arable, grass-dominated habitat types (including both grassland habitats and grass-dominated wetland habitats, and jointly referred to as *permanent grassland* in the Swiss method) has been a focal point of the Swiss habitat map wherefore the level of detail and mapping accuracy of grass-dominated habitats is relatively high compared to other habitat types. Remaining challenges highlighted by the WSL include the "influence of regional conditions on the habitat assignment" (i.e., wet habitat types tend to be overestimated in wet regions, and wet habitat types are similarly difficult to identify in dry regions). Certain transition zones, both between low- and high-nutrient grasslands, and transition zones to non-modelled habitat types (e.g., vegetated banks or naturally non-vegetated habitats) are difficult to model. However, as the Habitat Pilot aims to test primarily the RS-based predictors used in the

Swiss habitat method, rather than the method itself, it is uncertain how the method's general accuracy and reliability will translate into the tests of the Habitat pilot.

Method applicability

The method uses both national and global RS data in combination with national vegetation survey data based on a national classification system. The parts of the method that are based on global, and widely available RS data should be easily applicable on new areas. Other parts, such as implementing local habitat and species distribution models, and combining them with local vegetation survey datasets (collected using e.g., different protocols and classification systems) would be less straight-forward. For this reason, the Habitat pilot aims to focus on testing the predictors in the method that are based on satellite (or otherwise widely available RS-based) data.

Potential posterior usage of the project outcomes

As previously noted, the outcomes and posterior usage of the Habitat pilot's testing of the Swiss habitat mapping method will be dependent on the level of contact and participation of the team from WSL. If granted access and ability to test the sets of pre-selected RS-based indicators in the Swiss methods, these indicators could easily be implemented into other habitat classification models (in e.g., the NaturaSat software or other processing models). If, additionally, we gain access to some processing models used in the Swiss mapping method, these models could also be used directly and independently to classify grassland-dominated test sites provided by the pilot partners.

Project information sources

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Appendix 2d. Review of the Guidelines for assessing and monitoring the condition of Annex I habitat types of the Directive 92/43/EC project.

Project objectives

Article 11 of the Habitats Directive (92/43/EEC) requires monitoring of the conservation status of habitat types listed in Annex I, to be carried out by the Member States of the European Union (EU27). This monitoring provides the foundation for the National Reporting on the measures implemented and their effectiveness (Art. 17), which Member States have to submit to the European Commission every six years. After several cycles of reporting it has become clear that progress amongst the Member States in the development and implementation of monitoring programmes tailored to the reporting obligations move at a very different pace and that very different approaches are considered (Ellwanger et al., 2018).

The project “Guidelines for assessing and monitoring the condition of Annex I habitat types of the Directive 92/43/EC” therefore aims to develop guidelines for the assessment and monitoring of the condition of Annex I habitat types, also referred to as the “structure & functions (including typical species)” parameter within the Art.17 monitoring of the Habitat Directive. The overarching objective is to achieve improved quality, quantity, comparability and harmonisation of the monitoring data gathered by Member States across the EU. The project should support the EU 27 Member States to produce more harmonised and comparable assessments of conservation status of Annex I habitat types. An important subtask within this project is the compilation and analysis of existing information on different methodologies applied by the EU 27 Member States. The second main subtask consists of elaborating guidelines for different clusters of habitat types that will allow a more harmonised approach towards habitat condition assessment and monitoring throughout the EU.

Project governance

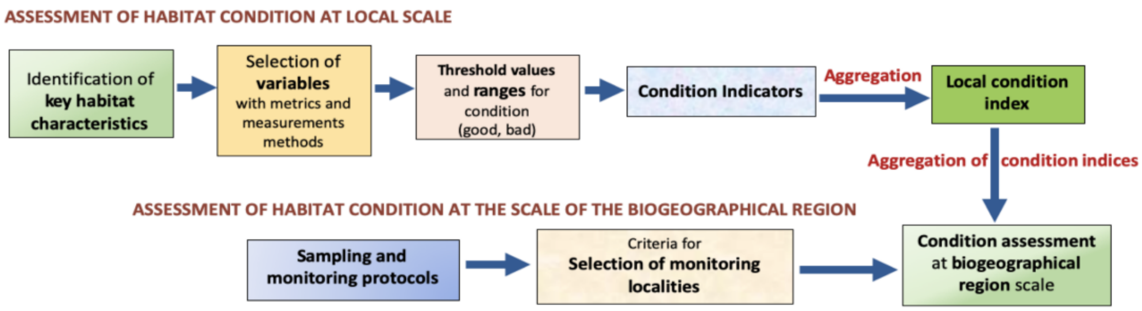
The project, running from the end of 2022 until the end of 2024, is carried out by the consortium Atecma (Asesores tecnicos de medio ambiente) and Daphne (Institut aplikovanej ekologie), and IEEP (Institute European Environmental Policy) as a subcontractor. The project is led by Concha Almeda from Atecma and Viera Sefferova Stanova from Daphne. For the different habitat clusters a multidisciplinary team of scientific experts (botany, geomorphology, terrestrial and aquatic ecology, etc) is drafting specific guidelines. An ad-hoc group of additional experts,from member states administrations (BE, BG, DK, FI, FR, GR, HR, IE, IT, LV, PL, SE) and topical expertise organisations (ETC-BE, EuropaBON, EC, EEA) was installed and is consulted every semester to provide feedback on the proposed methodological guidelines.

Project output (status August 2024)

First of all an extensive inventory of all relevant published and unpublished handbooks, reports and documents with guidelines and protocols for the assessment and monitoring of the condition of Annex 1 habitats was carried out through consulting with the responsible authorities at the national level. In a next step all this information was screened by means of strict criteria and imported in a living database allowing to classify and output the data in a structured manner for an extensive number of elements :

- variables and indicators used including the measurement units and methods
- availability of monitoring protocols and procedures
- indications on the application status
- level of application: habitat group, habitat type, subtype, etc
- methods used (field survey, remote sensing, modelling, etc.)
- evaluation techniques (integration of indicators, random sampling, reference values, etc)
- Monitoring sites selection procedures
- Use of existing data sources

The second main part of the project, still work in progress at the time of writing this report, consists of drafting guidelines for a more harmonised methodology on the assessment and monitoring habitat condition methods. Therefore a standardised clustering of habitat groups is proposed: marine habitats, coastal habitats, dunes, lakes, rivers, heathland and scrubs, grassland, bogs and mires and fens, rocky habitats and caves and forests. Next, a team of 14 experts develops guideline documents for each specific group of habitats based on comparison of current best practices and proposed key methodologies such as the global statistical standard on ecosystem accounts (UN SEEA-EA framework) (Vallecillo et al., 2022). During this process the following workflow is adopted:



Relevance of the project for the Habitat Pilot

Although the Habitat Pilot focuses on the aspects where remote sensing techniques can assist in habitat mapping and habitat quality assessment and monitoring this project is important in delivering an up-to-date inventory of currently applied methods for Article 11 and 17 monitoring of Annex 1 habitats. It also provides an extensive overview of the indicators and protocols that are in use by the different Member States. Knowledge gaps as well as commonalities and differences in approaches were identified during the process. Together with other international harmonisation initiatives such as EuropaBON or the Water Framework Directive, guidelines are developed, facilitating f.e. the selection of priority indicators per habitat type or group or harmonising the integration of different criteria into an overall evaluation score. The work done in this project confirms the more general idea that remote sensing methods seem rather underexploited in most of the currently adopted workflows. Comparable with the findings of the EIONET review on mapping techniques (see Appendix 2a) traditional field-based methods are currently the main approach for nation-wide habitat monitoring in Europe. On the other hand a number of very promising case-studies with RS derived indicators for quality assessment and monitoring of water bodies are also mentioned, f.e. chlorophyll content, total suspended particles and water transparency (Doña et al. 2014), hydrological patterns of temporary lakes, water coverage in permanent and temporary shallow lakes and wetlands (Doña et al., 2016), lagoon vegetation (Camacho et al., 2019). Typically these applications are generally only developed and tested on thelocal scale, f.e. one or a few study-areas. This confirms the need for more upscaling and testing transferability of RS-methods in future research projects.

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Appendix 2e. MAMBO (Modern Approaches to the Monitoring of Biodiversity)

MAMBO - A summary of the MAMBO project constructed based on the RIO article introducing the project (Høye et al. 2023, Research Ideas and Outcomes 9: e116951. https://doi.org/10.3897/rio.9.e116951), information available on the project internet pages and the two presentations provided in the Habitat pilots' Working Group meetings (Høye: MAMBO objectives; Agata Walicka & Jesper E. Moeslund: Biodiversity monitoring using laser scanning point clouds and deep learning).

Project funding and partners

MAMBO is a European Union's Horizon Europe research and innovation programme project (grant agreement No.101060639), funded via the research call HORIZON-CL6-2021-BIODIV-01-02 "Data and technologies for the inventory, fast identification and monitoring of endangered wildlife and other species groups". The consortium includes 10 partners: Aarhus University (AU), The Helmholtz Centre for Environmental Research – UFZ, Institut National de Recherche en Informatique et Automatique (Inria), The University of Amsterdam (UvA), The French Agricultural Research Centre for International Development (CIRAD), Naturalis Biodiversity Centre (Naturalis), Pensoft Publishers, Ecostack Innovations Limited (EcoINN), The University of Reading (UREAD, Associated partner), The UK Centre for Ecology & Hydrology (UKCEH, Associated partner).

Overview of the project aims and research landscape

A major goal of MAMBO is to generate modern methodologies for supporting standardisation of EU wide nature monitoring and for aiding the development of EU nature conservation policy and biodiversity strategies. To do this, the MAMBO project will develop, test and implement monitoring tools for mapping and for assessing the conservation status and environment-driven changes of species and habitats. MAMBO will integrate expertise from multiple fields including computer sciences, remote sensing, human-technology interactions, environmental economy, and species ecology and conservation. As the baseline to the project, policy needs for biodiversity monitoring are determined across various users via extensive stakeholder engagement and knowledge exchange. The overall aim of the MAMBO project is to realise the huge potential of cutting-edge technology for biodiversity monitoring by advancing and integrating the knowhow for sensor development, deep learning, computer vision, acoustics, ecology, remote sensing, biodiversity monitoring, citizen science, data pipelines and ecological modelling.

Specifically for the species and habitat monitoring, MAMBO aims to develop monitoring methods based on the integration of novel monitoring technologies (including proximal sensors, remote sensing, and crowd sources) with existing research infrastructures. For this, the project will test, evaluate, and demonstrate the new tools for biodiversity monitoring which then can be used in setting novel standards for species and habitat monitoring across the EU. A key element in developing improved methods for habitat monitoring is the high spatial resolution remote sensing data from the Copernicus satellite Earth observation programme and other data sources such as drones and airborne LiDAR. These data sources can provide important new opportunities for habitat extent and condition assessments.

The new tools will be tested and validated at several demonstration sites distributed across Europe to assess their potential for upscaling. This enables identifying potential shortcomings of the methods and of the key data sources and their management. It also enables identifying best practices for integrating data streams and upscaling the monitoring applications, and assessing the cost-effectiveness of different tools. The expected technical breakthroughs will provide guidelines for outlining the future ecological monitoring schemes, especially how automated systems can be effectively and trustfully used to complement biodiversity monitoring carried out by traditional approaches. Such new integrated monitoring systems combining in situ monitoring with sensor-based approaches can provide scalable and cost-effective tools especially for monitoring biodiversity changes in data-sparse remote locations.

To facilitate effective dissemination and exploitation of the project results, MAMBO investigates the need and possibilities for setting up a virtual lab to automate workflow deployment and efficient computing of the large data streams. Putting together the outcomes from different work packages and tasks of MAMBO, the project aims to provide significant methodological improvements for biodiversity monitoring activities across Europe, supporting the design of more cost-effective monitoring schemes for species and habitats with novel technologies and the future conservation planning and management of biodiversity.

Data resources and links to other projects

MAMBO will extract and utilise the large data sources available for environmental and biodiversity research, ranging from various remote sensing and species data archives to biodiversity data gathered via various citizen science applications and campaigns. These data are applied for selected species and habitat monitoring exercises during the project by integrating them into the novel tools developed in MAMBO. Both the monitoring approaches and their applications with accompanying biodiversity data provide outcomes that can be used as the basis for developing different public and private new technologies for e.g. spatial biodiversity mapping and management, green growth planning and monitoring the impact of different land use activities.

Specifically for the remote sensing applications, MAMBO include a wide range of RS data that can be acquired and are available for mapping and monitoring land cover, the status and dynamical changes in land use, as well as RS-based data on different landscape features. In the RS-based habitat type classification and mapping exercises, the central data to be employed comes from the Copernicus Sentinel-2 mission and the 10-20m resolution multi-spectral satellite imagery data gathered at 5-day frequency starting from 2015. Together with the data from Landsat satellite missions, they provide the core data source for national, continental and global scale land cover mapping and monitoring.

Other main types of RS data to be used in MAMBO are airborne LiDAR data that are available in different parts of Europe. Such data are increasingly used in several EU countries in environmental mapping and monitoring applications, including nationwide or regional airborne surveys with light detection and ranging (LiDAR) technology. Such airborne RS applications can be used to produce essential information for habitat monitoring in meter-scale resolution, such as terrain and vegetation structure and other land cover features. Some countries (including MAMBO partner countries Denmark and the Netherlands) have conducted repeated surveys which provide useful multi-temporal LiDAR data for monitoring biodiversity and habitat change. MAMBO will derive data from these repositories for the habitat quality monitoring exercises and methodological improvement tasks of the project.

The third RS data source - also used for habitat quality metrics development - in MAMBO is data from drones. The rapidly improving drone sensor technology enables gathering environmental information at very high spatial resolution (mm to cm) which may bring significant new elements to local-scale monitoring surveys. MAMBO will focus on the most prolifically used multirotor drones with red, green, blue and near infrared cameras which can deliver fine-resolution images with 3-dimensional point clouds that are very similar to LiDAR point clouds. Also, drones equipped with a lidar sensor are used to gather very high quality high-density point clouds in test-areas. In all the MAMBO tools and data generated during the project, the FAIR principles are followed so that the tools and data developed will contribute to the digital literacy of Europe.

The MAMBO project has numerous links to earlier and on-going other international, European and national projects and initiatives. Some MAMBO researchers are involved in these projects which enables the derivation of supportive technical knowledge and comparison points for the MAMBO products. The most important other projects to be linked with MAMBO include ARISE (involvement by Naturalis and UvA), BIOSCAN-Europe (Naturalis), DECIDE (UKCEH), DISSCO-EU (Naturalis), Easy RIDER (UKCEH), ECOSTACK (AU), EU PI (all MAMBO partners), EuropaBON (UvA), LifeWatch (UvA), ORBIT (UREAD), Safeguard (UREAD), SPRING (UFZ) and STING (UREAD).

Moreover, to guarantee successful integration of social sciences into the project, MAMBO will apply social science methods throughout the project as the basis for wide-ranging assessment of user needs. This will allow productive engagement with national and international stakeholders, and exploration of how actors interact. Moreover, it enables the project to develop best practices for integrating qualitative research into the testing of novel technologies, and thereby identifying opportunities that would be missed by technical assessments alone.

Project structure

The MAMBO project includes eight work packages which are all except WP8 (Project management and administration) located in one of the three pillars of activities (Fig. 1). The themes of the three pillars are: Co-creation and infrastructure, Tools and technologies, Implementation and impact. The starting point is the two WPs in the Co-creation and infrastructure pillar where the project will identify existing tools, approaches and research infrastructures and user needs. In the second pillar, Tools and technologies, MAMBO will enhance existing tools and develop new tools based on cutting edge technology to facilitate the upgraded mapping and monitoring of species (WP3) and habitats (WP4). In the third pillar, Implementation and impact, the project will test and demonstrate the implementation potential of the developed novel monitoring tools to the key user groups in the EU, identify best practices for required data streams, integrate and disseminate the outcomes, and assess their pros and cons and relevance to EU policy.

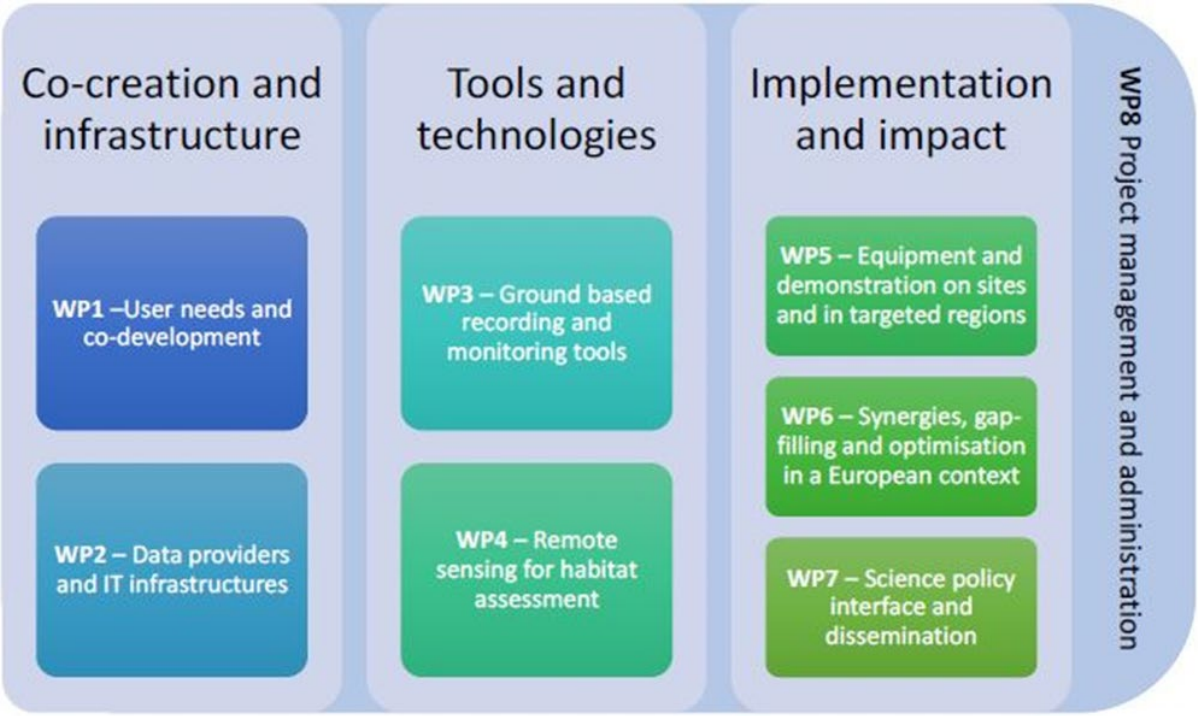

Fig. 1. The three main pillars of activity in MAMBO and the distribution of work packages within the pillars. Source: Høye et al. (2023), Research Ideas and Outcomes 9: e116951. https://doi.org/10.3897/rio.9.e116951.

In the next section(s) here below, the main focus will be given to the planned activities in MAMBO WP4, Remote sensing for habitat assessment, as this WP is most intimately linked with Biodiversa- Habitat pilot and the actions planned therein.

Remote sensing-based habitat analysis

The core concept underlying all activities of MAMBO is that new technology will bring the highest value when the development of modern methodological approaches includes linkages to existing research infrastructures and products and the long-term sustainability of their use is supported across various end-users. Following this concept, MAMBO aims to build and refine novel tools for mapping and quality monitoring of habitats based on cutting edge remote sensing technologies. The key targets include the following issues:

- Developing standardised calculation and automated retrieval of habitat metrics using in-situ observations, deep learning and remote sensing.
- Implementation of a cost-efficient system for habitat (and species) monitoring across the EU that maximises the automation, extent and resolution of biodiversity monitoring.
- Developing, testing and delivering RS-based high-resolution extent maps for EU Directive habitat types for different regions and sites (e.g. Nature 2000 sites), and consistent assessments of habitat condition metrics using airborne LiDAR and drone data.

The activities in MAMBO towards these aims are organised both under different work packages and various project objectives. For RS-based habitat activities, the first objective deals with habitat type classification and mapping. For this objective, the mantra is that modern deep learning techniques, such as convolutional neural networks (CNN), has much potential for recognizing habitats and describing complex structures of the environment and landscape. Recognising the spatial limitation of CNNs to overfit to the data locally introducing limited general value, MAMBO will also explore the performance of new deep learning model transformers (Dosovitskiy and al. 2020). Models based on transformers can exploit longer-term spatial dependencies in pixel-based habitat and land cover data and thus they hold much promise for providing general applicability. In essence, they allow segmenting habitats using high-resolution satellite (e.g. Sentinel 2) data coupled with environmental rasters in a much more efficient manner than current methods and do not require expensive field surveys. These models will be pre-trained in MAMBO on large data volumes and then fine-tuned on supervised data to produce habitat type maps under the EUNIS typology. As validation, model outputs will be coupled with spatial plant species occurrence data with particular attention to characteristic plant species for EUNIS habitat types.

The second objective in RS-based habitat activities deals with accurate assessments of habitat conditions. This is a key requirement in nature management. However, it is complicated due to a variety of condition indicators ranging from indicator species data to multidimensional vegetation structures and vegetation dynamics, leaving insufficient consistency on measurements of habitat condition across Europe. Some habitat metrics (plant height, % bare ground, % woody cover etc.) are well suited for a remote sensing (RS) approach. However, other condition assessments have been limited due to insufficient spatial detail in satellite data or limited temporal frequency and cover of finer-resolution drone and airborne or commercial satellite data. Further limitations emerge from the requirements for the storage, access and processing of large data volumes; the lack of easily accessible and standardised computational infrastructure is a particular obstacle for the use of LiDAR and drone data.

For developing habitat condition metrics, MAMBO will focus on airborne LiDAR and drone data which offer the high spatial detail required for condition assessment and which can deliver relevant habitat metrics. The findings from detailed evaluation of barriers to airborne LiDAR and drone data use in habitat condition assessments are shared to corresponding stakeholder groups. To support including LiDAR and drone data among other habitat data types (e.g. satellite, in situ) and processing of condition metrics through a cloud-based virtual lab for biodiversity monitoring, MAMBO will convert the developed scripts into interactive computing and automated workflows. This will allow processing pipelines for developing LiDAR and/or drone data metrics that are consistent across the EU.

The two central methodological questions tackled in this upscaling deal with the best practices for pre-processing airborne LiDAR repository: (1) developing a software tool for re-retiling huge las/laz files without loading the whole data into main memory, and (2) developing a software tool for clipping las/laz file with respect to a polygon of a shapefile format.

Overall, the habitat condition metrics work in MAMBO will apply current state-of-the-art methods, but also develop new methods that can better exploit the large data volumes to derive the condition metrics from LiDAR and drone data. Specifically, the project applies deep learning directly to raw LiDAR point clouds and pre-processed drone data (RGB, multi-spectral, point clouds) to avoid losing important data details, which is particularly relevant for metrics reliant on feature identification (e.g. drainage, erosion features, individual indicator plants). Moreover, the UAV LiDAR work in MAMBO aims to develop enhanced practices for the point cloud classification and vegetation height monitoring. This helps developing a semantic segmentation model that will enable to classify each point in the point cloud as belonging to shrubs, grass, trees, bare ground, or other surfaces, allowing calculating metrics to describe biodiversity conditions in the target area or habitat.

Exploitation of project outcomes

In order to enforce exploitation of the project results and ensure their maximal dissemination among a wide variety of end users, MAMBO will make use of various Open Science tools and platforms, as well as social media and scientific facilities enhancing the projects' impact on the EU nature conservation arena. One key channel is EC's Horizon Result Platform (HRP) which provides a tool for projects to announce important exploitable results widely across different stakeholders. MAMBO will use this platform to publish the project's Key Exploitable Results (KERs). Moreover, MAMBO aims to use the services of the Horizon Results Booster (HRB) to better disseminate the projects' outcomes.

Considering the monitoring methodological innovations developed in MAMBO, the project will boost their spread and exploitation potential among the remote sensing and biodiversity communities and in the national and EU-wide monitoring schemes by making the new tools widely available. One key element in reaching this goal is the establishment of an open-access internet hub for biodiversity monitoring virtual labs (Fig. 2). The hub allows developers to increase the technology readiness levels (TRLs) of their products and services and where the innovative tools developed in MAMBO are available to be examined and exploited.

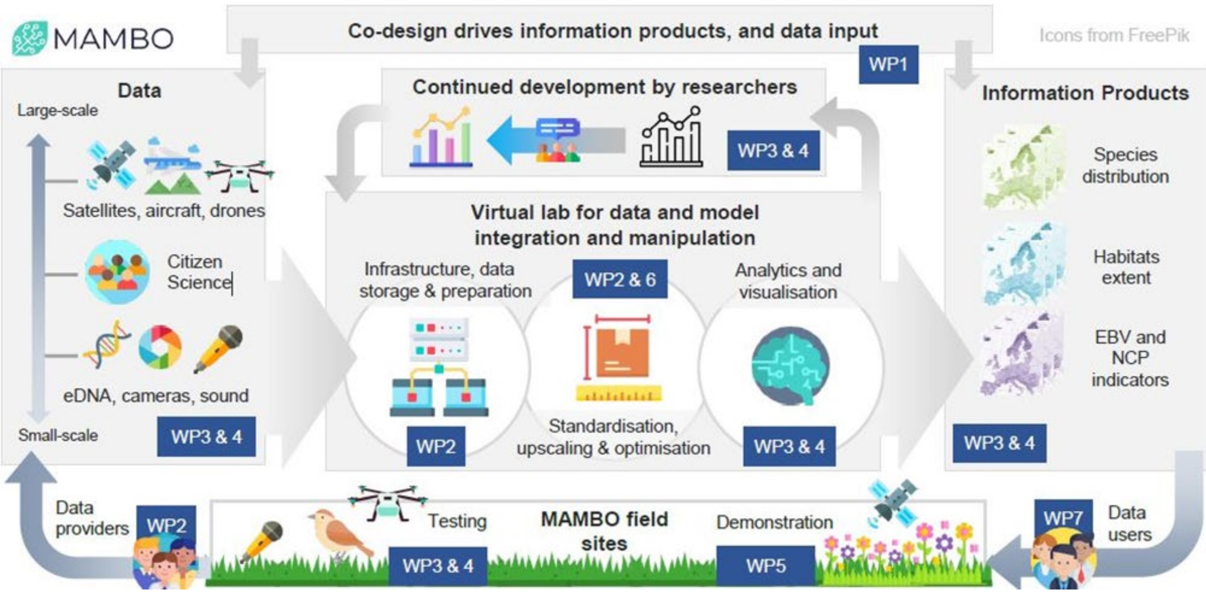

Fig. 2. Illustration of MAMBO contributions towards a cloud based virtual lab solution for biodiversity assessment and monitoring. Source: Høye et al. (2023) Research Ideas and Outcomes 9: e116951. https://doi.org/10.3897/rio.9.e116951.

The wide exploitation of MAMBO outcomes will provide tools to facilitate the integration, accessing and promoting standardised, open and FAIR biodiversity data, as well as knowledge and models for improving conservation status and ecological requirements of species and habitats. The upgraded tools can then be used to inform EU policy (e.g. the Birds and Habitats Directives, EU biodiversity strategy 2030) and other sectors more frequently than earlier about biodiversity status and trends and emerging threats. These tools will also facilitate improved planning of ecological restoration as they make monitoring of species and habitats easier and more accurate, thereby providing decision-support for nature conservation and nature restoration.

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Appendix 2f. Summary of the key findings of two EuropaBON deliverables addressing novel technologies for biodiversity monitoring

Deliverable 1

4.2 Novel technologies for biodiversity monitoring - Final Report (Deliverable 4.2 Novel technologies for biodiversity monitoring - Final Report (arphahub.com))

- The described EBVs do not link directly with the mapping (habitats) and monitoring (hydrology/ management) variables we want to address in the Habitats Pilot

  We do nature mapping but not biodiversity mapping directly!!
- The EBV level 1 classes that fit best are:
  - Community composition
  - Ecosystem functioning
  - Ecosystem structure
- The mapping approaches in the Habitats Pilot are situated more at the level of the target habitat (the step before assessing the actual EBVs)
- Total of 282 novel methods (or method components) identified
  - most were linked to data collection
  - 64 were remote sensing methods
  - majority were meant for species distribution and abundance
- remote sensing methods had a technological readiness level mainly between 5 and 7 but spanning the whole range from 2 to 9
- **for plants (taxa), remote sensing was a dominant method suggested by experts**
  - LiDAR has the highest technology readiness level
- for birds remote sensing was mentioned
  - weather radar
  - bioacoustics
- remote sensing spans more EBV classes than any other novel method type; and one of its main advantages is its scalability
- most validation examples come from vegetation remote sensing
- but remote sensing mainly focuses on top canopy, understory vegetation is understudied
- the need for standardization is one of the most emphasized general needs in EBV monitoring
  - especially data collection needs to be more standardized across member states
- there is also a strong need for data storage and computation power

- the lack of (centralized) reference data was also mentioned as a major factor impeding the application of many methods
- the main reasons against innovation in monitoring were:
  - methods not ready to be deployed at scale
  - methods lacking validation
- general consensus that novel approaches should complement rather than replace in-situ observations

Deliverable 2

D5.2 Past-to-present EBV modelled datasets and status indicator for selected terrestrial habitats in the Habitats Directive (D5.2 Past-to-present EBV modelled datasets and status indicator for selected terrestrial habitats in the Habitats Directive (arphahub.com))

- **remote sensing plays a pivotal role** in advancing cross-cutting (environmental) policies in Europe. It is essential for:
  - assessing the effectiveness of protected areas
  - facilitating habitat restoration
  - informing land use planning
  - enhancing ecosystem service provision
  - monitoring land use changes
- there is a **wealth of information present in vegetation surveys** that should be integrated into European habitat monitoring
- but only a **very limited amount of comparable data** from vegetation plots across countries is available
- **accurate habitat maps are crucial for EU environmental policy and biodiversity targets**

  BUT current mapping is incomplete, a unified conceptual framework and critical inputs are missing and there are insufficient human resources for large-scale mapping at high resolution

  "Recent advances in ground-based field surveys and species measurements, detailed land cover classifications, remote sensing data collections, and promising new technologies and analytical methods are emerging to enhance and upgrade the EU's habitat mapping accuracy, reliability, and efficiency"
- there is a **significant lack of geospatial data for Annex 1 habitats outside Natura2000 sites**. Time series are particularly rare and recurrence is insufficient to get reliable trend information.
- the **definitions of the habitats are inconsistent across different countries**, especially wrt the lists of typical species (they are mainly typical for the country where they are included)

- in-situ systematic monitoring across environmental gradients in combination with remote sensing techniques can improve our ability to characterize the full diversity of EU biomes (and habitats).

  focusing on under-sampled regions can improve the inputs for habitat distribution models and can also help fill the existing data gaps for these regions.
- a crucial aspect of the reporting for the habitats directive is **habitat structure**
- **standardized habitat classification** is needed!
  - best results obtained with EUNIS classification scheme
  - A hierarchical classification approach was tested only for the Cantabrian mountains in Northern Spain
    - 154 features were tested:
      - 8 LiDAR-based,
      - 25 'scalar' features (climate, soil, phenology, distance to water, inundation , population density & LAI)
      - 150 remote sensing features (Sen-1 & Sen-2)
      - 16 contextual features (based on CNN)
    - model = CatBoost
    - best features per level were selected
    - overall accuracies between 80 and 95 for most classes
    - evergreen forest type classification was most difficult
- coordinated efforts are needed to collect the necessary field observations and remote sensing data across the EU
- **training programs and knowledge exchange networks should be set up** to expand expertise in geospatial and habitat disciplines
- detailed guidelines are needed to promote compatible mapping practices across Europe
- **Making good in-situ datasets publicly available** is needed to ensure reproducibility of remote sensing approaches and adoption on a broader scale

Appendix 3. Positive/challenging in the proposals

Team work during the workshop, all groups discussing the proposals and presenting their comments on each proposal.

No	Positive	Challenges
1	**Automated detection of ploughing events in (semi-) natural grassland**	
	• Time series - changes in last 10 years • Interesting approach • Established method • Available data • Promising complementary method • Rather straightforward applicable • Feeds into mapping as well as quality monitoring • Add arable land to the model - similarity checking	• detecting ploughing might not be relevant for all countries • needs in-situ data on ploughing events (polygons) for calibration and validation • relevant problem only in some areas • method relevant only for specific issue • only peripherally relevant for Annex I habitats • would benefit of linking with grazing and mowing occasion monitoring
2	**Validation/training EU-Grassland Watch indicators**	
	• Realistic approach and doable • Similarities with Finnish proposal on grasslands • Input data openly available for all • Builds on existing map data • Cooperating with EU-GW • Several relevant factors • Data synergy landsat and sentinel → longer history	• Realistic approach and doable • Similarities with Finnish proposal on grasslands • Input data openly available for all • Builds on existing map data • Cooperating with EU-GW • Several relevant factors • Data synergy landsat and sentinel → longer history
3	**Mapping and monitoring condition of wetland habitats (and flooded grasslands?)**	
	• Good clear proposal, monitoring condition and transferring Tytti's approach to other wetlands types in Europe • Input data openly available for all • parallel with … (*illegible*) wetland habitats • there are a lot of studies on indicators • Sweden: wetness map • Overlap/synergy with proposal: 5, 6, 7, 9, 14	• Good clear proposal, monitoring condition and transferring Tytti's approach to other wetlands types in Europe • Input data openly available for all • parallel with … (*illegible*) wetland habitats • there are a lot of studies on indicators • Sweden: wetness map • Overlap/synergy with proposal: 5, 6, 7, 9, 14
4	**Showcase of mapping and quality monitoring of semi-natural grasslands - applying and testing EU Grassland Watch processes in boreal grasslands**	
	• Mapping new grassland types with "own approach" • Monitoring condition with EUGW approach • Input data openly available for all • The service is ready (if it is?) • Solid approach not from the scratch • Availability of calibration sites, reference areas • we can provide validation • several partners available • relevant parameters • Similar to proposal 2 and 4	• Very few grassland sites and small in size • historical management data (years?) • Spatial explicit information (this can vary across consortium) • We need to check if the service (methods) are available • connection with vegetation diversity • calibration datasets (Belgium, Slovakia) • Interaction with partners - tuning the model • How is it done? Regional model-tuning? • Selecting the one point-cloud–density level for LiDAR comparisons and characteristics

	• Overlap with proposals 9 and 10	• Lots of different input-data - requires skill-diversity and time (but SYKE will help with some of it)
5	**Wetland hydrology - from time series data to condition indicators**	
	• Similar to proposal 3 and 6 • It is scalable • Great interest of other partners • combining of reference data • Available data (Sentinel) • Sentinel-based - both optical and radar source • Both grassland and wetland • This fits the purpose of the Biodiversa pilot perfectly	• Same as proposal 3 • Requires cloud computing skills and credit • Indicators have to be defined • Reference data • Regional variation of wetlands • Output is dynamic • Hydrological data across consortium • Training of the PU is not easy (INBO is crucial)
6	**ML-classification to detect inundation in wetlands**	
	• Good proposal • Scalable • Interest of other partners • Could be one of the indicators in a wetland condition approach (Proposal number 3) • This case might add knowledge of trade offs spatial vs. time • Using all kind of data (satellite, aerial, drones) • Already tested in two different settings (France and Finland) • Connect with proposal number 5 and 3?	• Requires cloud computing skills and credit • Wetlands not in all countries • Model might need regional fine-tuning • Analysis/Computing environment → partner's possibilities (R/OpenEO/Py) • Bottom-up approach vs. top-down in terms of workflow • Challenging in forest areas with closed canopies and partly vegetated surface water?
7	**Regional calibration of wetland classes**	
	• Simple straightforward method • Support to other projects - one of the indicators • Available calibration data • Simple and straightforward • Similar data available also for e.g., Finland	• Calculation of wetness index from a single image? How are annual wetness variations accounted for? • it is unclear what is the aim of the calibration (is there a need to do calibration of wetness when we want to know the condition of the vegetation or map the vegetation) • calibration to different countries different vegetation response • Ellenberg values - central Europe → you can use (& Swedish + Hills IUS) European values • We need experts to land this • Connection with NDWI? • Calculation of wetness index from a single image? How are annual wetness variations accounted for? • Itis unclear what is the aim of the calibration (is there a need to do calibration of wetness when we want to know the condition of the vegetation or map the vegetation?) • Provides data for wetness conditions on a snapshot perspective, unclear the usability to assess changes • Using … … … … since they use expert … and could not reflect fine degrees in certain habitats regarding wetness/humidity (*certain words illegible*)
8	**Implement single image super resolution for Sentinel-2 data**	

	• Interesting and novel method • Having all Sentinel-2 bands in 1 meter resolution is tempting idea • Appropriate for mapping fine structures • Provides a useful comparison point for other fine-resolution data products, e.g., LiDAR and orthophotos • Comparison to Sentinel • Input to other methods (pre-processing) • Scalable throughout Europe • Very nice extra add-on	• What is the real advantage of this - why not use aerial photographs • Too demanding approach, code is not open? • Can do only for one image at a time • we should focus on simpler and widespread problems • reliability & accuracy-testing may be needed for more complicated fine-resolution mosaic habitat types (e.g., aapa-mires, certain grassland types) • Requires some methodological development to actually have a habitat condition/mapping method to test? • Some partner with operational method should provide data
9	**Mapping using time series**	
	• Potential - has also mowing and overgrowth (and grazing & flooding), not only ploughing • Scalable approach when using Copernicus data • Similar to EU Grassland Watch and case 1 & 4 • Might be relatively readily applied by the partners • Focuses on mapping • Include ideas from this proposal into combined 1 & 4-proposal?	• Are these habitat specific? • Potential extrapolation to vicarious types of vegetation • Expanded result (mapping events outside known ones) may need sharpening or expansion • What are the differences between habitat changes in time vs. habitat mapping using time series? • Time series and seasonal variation or long-term variation?
10	**Assessment of trends in Ecological conditions in grassland and wetland polygons by time-series using Sentinel 1 & 2 sensor data.**	
	• Large-scale interpretation vs. small study areas • Identifying previously relevant indicators • identifying costs • exchange expertise between partners/approaches • Focus on change-indicators compared to proposal 9 • For grasslands, overlaps with proposal 2 & 4 • Overlapping with proposal 5, 6, 3 of wetlands. also applicable for grassland habitats indicators (e.g., wetness) • Overlap with proposal 9 • Include ideas from this into other proposals	• Not clear how this differs from case 9 • In-situ monitoring temporal data to relate to Sentinel 2 Fine-series metrics • Range in habitat condition • Robustness and accuracy of Sentinel-based metrics need very likely testing to determine potential limitations
11	**Detection of habitat changes by remote sensing and habitats mapping (Catalonia)**	
	• Important to validate habitat changes • The overall target of detecting changes • Validation of major changes by aerial photographs • Might provide a useful dataset for comparison with other methods (e.g., NaturaSat)	• Not clear method • Atmospheric correction of satellite images is out of scope in this pilot • Expert-based validation and need for habitat boundaries from two time periods (=not scalable) • Uncertainties stemming from comparing landsat vs. Seinel-based image products • Could perhaps be made more reliable by using landsat-Sentinel harmonized data?

	• Not many studies of LiDAR data → show the advantages with this method for the future • Interesting for focusing fieldwork (based on probable change) → “early warning”	• Possibly works only on more broadly-defined habitat types • Direction of the change detected and its ecological meaning may be difficult to interpret from the RS-data based metrics only → needs validation with aerial photos • applicability and upgradability to areas with different climates and environments • LiDAR data not available for all? • Only for broad-scale monitoring? • Calibrating and validating “change” is a challenge
12	**Habitat map of Switzerland**	
	• Very ambitious and comprehensive work, certain parts can be applied in our pilots (e.g. important features for grassland characterization) • Creating relatively fine & accurate habitat maps • in a methodological perspective, highly sophisticated approach • Building on developed system • All countries will likely have to aim in this direction. Useful to identify challenges and useful to move a bit forward in this direction • Control over the process • you may use any data in the process (format, resolution etc.)	• In the mapping part they used image segmentation with eCognition software, which is commercial (not sure how open source segmentation methods work) • (ArcGIS and) eCognition not freeware • Multiple predictors used, needs selecting focal set of predictors • Needs extensive ground-truthing data? • Possibility to interact/have contact with project/experts? • Classification system needs to be standardized? • How to validate the boundaries? • A lot of work (Transferability?)
13	**Addition of assessment attributes useful for monitoring to the habitats map (Catalonia)**	
	• Tool for comparison and evaluation of of habitats when they are mapped • very simple tool for comparing different areas • post-processing	• Not clear method, needs more elaboration • relevance a bit unclear to habitat pilot targets • need a priori habitat classification and habitat map layers • indicator based on several indicators - connection to Directive-reporting quality monitoring uncertain • interesting indicator/method. Perhaps suggesting for the indicator group (2.1.2)? Good for management & restoration planning. Not perfect match for habitat pilot objectives. • To achieve the same maps for different countries
14	**Vegetation height and cover using UAV data**	
	• Nice software with impressive features • Ready to test • Many topics covered • Already multi-source data implemented (UAV, S2, Airborne images) • Good to test different resolutions/spectras • Test-version available for partners • Possibility for partners to test the mapping & quality change predictions for their focal study sites compared to Proposal 4 • Overlap with flooding/Upscaling proposals	• Commercial software? - not sustainable • Accessibility? • Planet basemaps? • Is it feasible to test the approach within a two-year project? • Testing of the accuracy of the classification algorithm on-going → possibilities for intriguing comparisons against commonly used RS-data classification methods • Transferable to other ms/Regions • Upscaling local vs. regional possible?
15	**Habitat mapping and monitoring using NaturaSat approach**	

	• Clear and interesting approach but only doable for small areas • EBV:s - which ones? • relation with RGB orthoimagery • Calibration with/of satellite-derived indicators • Might be useful to compare with results from other fine-resolution products e.g., super-S2 or Rapideye • Very promising and effective field tool for accurate monitoring even in very rugged terrain • Authors are willing to help in person in the field (→transferability and capacity-building)	• For monitoring you need time-series data • Accuracy might be even too high for everybody's needs? • Needs UAV and expertise to use it • Not all partners can participate (budget, time, data-handling, drone) • Current focus on LiDAR data → possibilities to expand?
16	**Micro-topography detection in grassland for the detection of a specific type of ancient high nature value grassland.**	
	• Very interesting, micro-ditches important for BD • Potential test-bed for comparing super-S2 high-resolution images with LiDAR-based images • Test-case for testing if micro-scale landscape features can be detected • The approach may provide structural features useful for persistence capacity of ecologically important habitat-features • mainly for wetland • potential indicator for wetland condition	• Limitation is availability of high resolution DEM • Not relevant for all grasslands in Europe? (Finland, Sweden, Czechia, Slovakia) • Dependence on LiDAR? • If airborne: Different LiDAR-specs from different areas/countries • Indicator quality to some extent limited - not indicator for monitoring quality changes? • Up-scalability and generality? • You need to know what you're looking for