Stakeholders' handbook

WP 1 – D1.2.

June 2024

Action Number: 101079310
Action Acronym: EarthBridge
Action Title: Building Bridges between Earth Observation and Environmental Sciences
Date: 28/6/2024
Version: 1.0

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Contents

1. Foreword

This deliverable is part of the output from Work Package (WP) 1 of the EarthBridge project. One of the key objectives of this WP is to engage local and regional stakeholders in the application of EO-based solutions for landscape monitoring by providing relevant information and guidance on the best practices available.

The aim of this handbook is to offer an overview of the currently available environmental-sensing data and methods that can help improve existing monitoring and reporting systems for assessing, restoring, and conserving biodiversity in both agricultural and silvicultural landscapes. To do so, the contents of this handbook are tailored to address the needs of local and regional stakeholders from different disciplines (policy-makers, decision-makers, institutions, practitioners, and private companies). This document is not intended to provide a comprehensive review of the state of the art on EO and explore all technical aspects of the mentioned methods, but rather as a guide to the available approaches that can aid the stakeholders tasked with biodiversity monitoring at different spatial, temporal, and governance scales.

The framework of this handbook has been designed with a four-fold purpose:

- to identify environmental sensing methods available to monitor biodiversity and land management practices/landscape features relevant to biodiversity conservation in both agricultural and silvicultural landscapes

- to identify actors involved and their roles and responsibilities in setting up remote sensing-based biodiversity monitoring programmes

- to suggest approaches to implementing monitoring programmes at different spatial, temporal and governance scales

- to offer a collection of practical examples of such monitoring approaches.

This document is structured in four main sections: the first section sets out basic knowledge on biodiversity monitoring and outlines the policy requirements. The second section is meant to define the target groups of the handbook. The third section is a compendium of case studies demonstrating the use of environmental sensing-based monitoring techniques and providing recommendations for setting up a monitoring campaign.

2. Why do we need biodiversity monitoring?

Biodiversity represents the variety of life on Earth and is fundamental for ecosystem functioning. The current, unprecedented increase in biodiversity loss is acknowledged to pose serious threats to human well-being and humanity as a whole. Biodiversity and agricultural and silvicultural activities are two faces of the same coin: as these activities depend heavily on various types of biodiversity (i.e., the variety and variability of animals, plants and micro-organisms, at the genetic, species and ecosystem levels), they also play a key role in conserving rural habitats and species. In rural areas, biodiversity is influenced by several factors, including the presence and variety of habitats, of which elements typically include landscape features like hedges, field margins, dry-stone walls, and isolated trees. Similarly, forests, with their complex structure and diverse plant species, significantly enhance local biodiversity by providing shelter, food resources, and breeding grounds for numerous wildlife species.

In agricultural areas, pollinators directly contribute 5-8% of global food production, valued at an estimated US$235-577 billion annually (IPBES, 2016). Soil harbours over half of the Earth's species (Anthony et al., 2023) and supports the production of over 140 million metric tons of food each year (Fonte et al., 2023). Additionally, vertebrate diversity is important in controlling pests, which can cause up to 40% of global yield losses (IPCC, 2021). The IPBES Global Assessment Report on Biodiversity and Ecosystem Services (2019) indicates that forests are vital for biodiversity, with forested areas containing approximately 80% of the world's terrestrial species. Moreover, forest ecosystems provide a number of services, including the regulation of climate and global carbon cycles (Millennium Ecosystem Assessment, 2005). Effective monitoring is critical to keep track of the dynamics and changes in biodiversity and mitigate its loss.

2.1 What is biodiversity monitoring?

Biodiversity monitoring consists of the periodic and systematic collection, analysis, and interpretation of data to assess the status and highlight trends in the various forms of biodiversity (genes, taxa, ecosystems, etc.) using standardised methods and protocols (Juergens 2009; EEA 2010). Reliable recommendations on the effects of agricultural and silvicultural practices on biodiversity require systematic monitoring capabilities (Toivonen et al., 2015). In the past decade, the biodiversity monitoring community has agreed on a set of biological state variables, referred to as Essential Biodiversity Variables (EBVs, Pereira et al., 2013; Table 1), which are key for supporting multi-purpose biodiversity information systems. EBVs enable the integration of data from diverse sources and methodologies into biodiversity indicators used for informed decision-making and fulfilling policy reporting obligations.

The process of monitoring notifies stakeholders with information on the development and results of the actions undertaken to preserve biodiversity. Its purpose is to assist decision-making, adaptive learning, planning, and management (GEO BON 2022). The specific goals of biodiversity monitoring include:

- provide a baseline and ongoing data through standardised and periodic data collection;

- systematically track the performance of actions and procedures;

- facilitate the documentation and reporting of the results.

To achieve the best results from a monitoring program, it is essential to meticulously select the survey design based on the objectives. This involves careful consideration of sampling methods, field protocols, site selection procedures, the number of sites and replicates, as well as sampling frequency (GEO BON 2022).

EBV class	EBV name
Genetic composition	Genetic diversity (richness and heterozygosity) Genetic differentiation (number of genetic units and genetic distance) Effective population size Inbreeding
Species populations	Species distributions Species abundances
Species traits	Morphology Physiology Phenology Movement Reproduction
Community composition	Community abundance Taxonomic/phylogenetic diversity Trait diversity Interaction diversity
Ecosystem functioning	Primary productivity Ecosystem phenology Ecosystem disturbances
Ecosystem structure	Live cover fraction Ecosystem distribution Ecosystem Vertical Profile

The six EBV classes and twenty-one EBV variable names as defined by GEO BON.

2.2 EU policy requirements and regulations

The relevance of biodiversity monitoring as an essential part of rural landscape management and production in Europe becomes evident when considering the European Union (EU) policy requirements and regulations. With growing concerns about the sustainability of agricultural and silvicultural practices and their impact on ecosystems, there is a pressing need to monitor biodiversity to ensure compliance with EU regulations and promote sustainable land management practices. This monitoring provides insights into the health of ecosystems, necessary for evaluating the effectiveness of conservation measures, and guides decision-making processes to enhance biodiversity conservation within rural landscapes.

The EU sets a common regulatory framework for its Member States on biodiversity legislation in rural areas, which has its backbone in the Birds (Council Directive

79/409/EEC) and Habitat (Council Directive 92/43/EEC) Directives. These directives require that agricultural activities be carried out in a way that ensures the conservation of wild birds and natural habitats, which requires protecting Natura 2000 areas. Observance of the aforementioned Directives at the farm level is ensured by the system of inspections imposed by the EU Common Agricultural Policy (CAP).

The CAP legislation seeks to ensure a sustainable future for European farmers by means of an EU-wide system of farm subsidies. The primary goal of the current CAP (2023-2027) is to enrich the diversity of species, habitats, and landscape characteristics within the farmland ecosystems of the European Union (EU) and is crucial for aligning with the objectives of the European Green Deal. The CAP represents a partnership between society and the agricultural sector to secure a stable food supply, maintain farmers' financial stability, preserve the environment, and promote vitality in rural regions. The sustainable development of rural areas is contributed by the CAP through three long-term goals: enhancing the competitiveness of agriculture and forestry, promoting the sustainable management of natural resources and climate resilience, and fostering equitable growth in rural economies and communities.

All CAP subsidy beneficiaries are subject to a “cross-compliance” system of obligations, i.e., they must respect a basic set of standards according to the EU law on environmental, public and animal health, or land management. Otherwise, the beneficiaries would have their CAP support reduced. Thus, appropriate monitoring is necessary to avoid lost time and resources and to better target actions, since policy needs evidence of the benefits and successes of legislation and its obligations.

Similarly, sustainable forest management practices are crucial for maintaining forest biodiversity, which supports essential ecosystem services for human well-being. The "EU Forest Strategy for 2030," adopted by the European Commission in 2021, aims to enhance the quantity and quality of EU forests and strengthen their protection, restoration, and resilience. This strategy advocates for the development of forest management plans that incorporate biodiversity goals and address the need for forests to adapt to changing climate conditions. Such measures are vital for forests to continue delivering their socio-economic functions and ensuring vibrant rural areas with thriving populations. To achieve these goals, it is necessary to enhance the monitoring and reporting of forest conditions and biodiversity through improved data collection and analysis (European Commission, 2021).

3. Who is this handbook for and why?

The target audience for this handbook encompasses a diverse range of stakeholders involved in environmental conservation, agricultural and silvicultural management, and policy-making. This includes researchers, scientists, practitioners, policy-makers, environmental organisations, and governmental agencies at local, regional, and national levels. The handbook aims to stimulate technical synergies that reduce redundancy and costs in biodiversity monitoring while accelerating benefits for nature conservation and stakeholders' needs. The spectrum of stakeholders encompasses all those responsible for or involved in at different levels in biodiversity conservation in rural landscapes, from the local to the national scale.

By involving stakeholders, research findings can be better tailored to fit local situations, enhancing the probability of adoption and implementation. Engagement of stakeholders with researchers fosters learning and empowerment. Stakeholders can learn from researchers and contribute to new knowledge generation and exchange, promoting learning, trust-building, and conflict resolution among participants.

Stakeholders audience

- Landowners and land managers
- Protected Area managers
- Forestry businesses
- Businesses other than agriculture/forestry
- Non-governmental organisations (NGOs) and environmental charities
- Policy-makers: community associations, local authorities, regional authorities
- Environment agencies
- Interest groups
- Professional groups (e.g., surveyors)

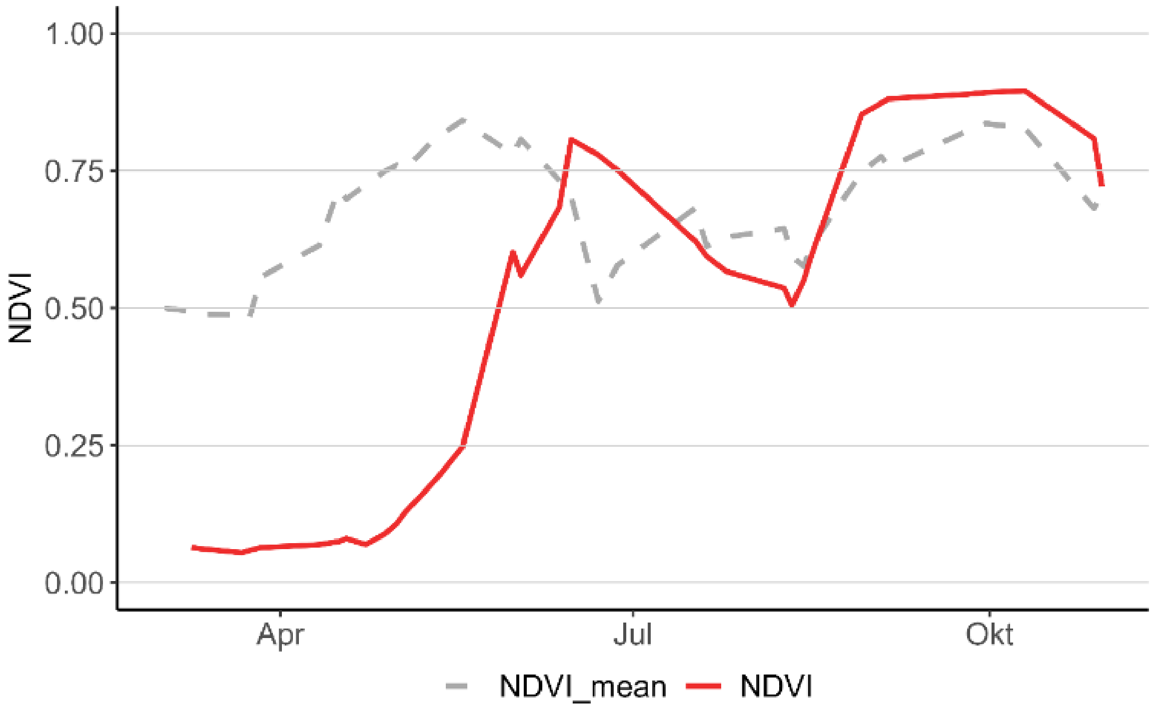
4. Case studies

4.1 Using optical satellite imagery for monitoring permanent grasslands

The current EU Common Agriculture Policy (CAP) defines 9 standards for good agricultural and environmental conditions (GAEC) that farmers are obliged to adhere to in order to receive payments. At least two of these standards focus on the maintenance of permanent grassland for which converting or ploughing is prohibited. These policies ensure that grassland ecosystems which serve as habitats for many species and thus play a vital role for biodiversity in agricultural areas, are preserved and not destroyed. In order to check if permanent grassland is illegally converted, an accurate monitoring system is key. Modern earth observation satellites provide large-scale high-resolution imagery at repeated time steps and can therefore be used to develop such a monitoring system.

The Sentinel-2 satellite mission from the Copernicus Programme of the European Union’s space programme provides optical satellite data at 10 m spatial resolution every 5 days on average (if cloud-free) to the public. From this, dense time series of different variables can be created. Potential variables can be the reflectance values of various spectral bands of the satellite (red, green, near-infrared bands for example) or useful combinations of these bands, so called spectral indices, like the NDVI (Normalised Difference Vegetation Index) that is an indicator of healthy green vegetation or the BSI (Bare Soil Index) which increases when the surface resembles soil without presence of vegetation. By comparing the variable values of one permanent grassland plot with those in its surroundings, we can see if this particular plot deviates from the usual annual progression, even taking mowing dates into account. Other more sophisticated anomaly detection methods (e.g. isolation forests or Mahalanobis distance) can be applied to identify “suspicious” grassland plots in a single time step.

Within the project 3C (Copernicus Cross Compliance) such a grassland monitoring system is currently being developed for the German state of Saxony. At the end of the project, a traffic light system will be implemented, labelling plots where conversion is suspected in red. Based on this, local agencies can streamline their inspections and costs as well as bureaucracy can be reduced.



The NDVI of one grassland plot (red solid) deviates significantly from the NDVI mean of surrounding plots (grey dashed) over the course of the year.

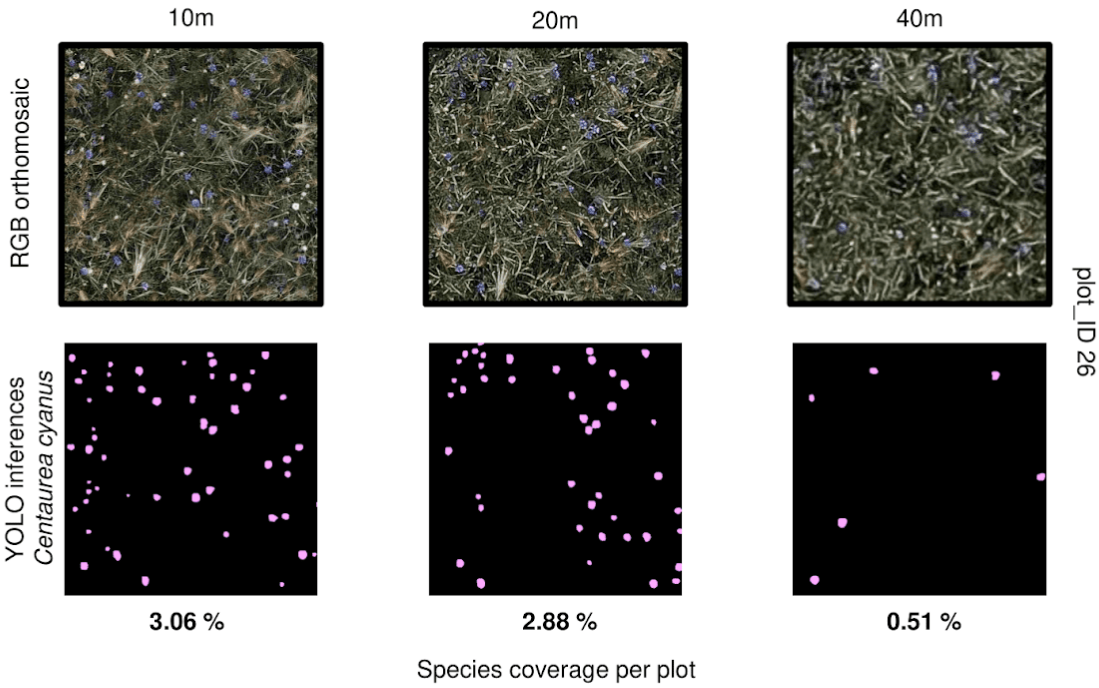
4.2 UAVs for plant biodiversity monitoring in farmland

The intensification of agriculture through the application of high fertilisation rates is leading to the decline of wild arable herbs with significant natural value (HNV). This decline, in turn, is having a series of adverse ecological consequences. One approach to encourage the preservation of HNV wild arable herbs is to implement result-based payment schemes that compensate farmers based on the observable biodiversity improvements within their fields.

However, the major obstacle facing these programs is the substantial cost and time required for biodiversity monitoring, typically carried out by field surveyors. Consequently, such initiatives are infrequently adopted within the European Union's Common Agricultural Policy. Satellite and Uncrewed Aerial Vehicle (UAV) remote sensing have already displayed promising results for biodiversity monitoring across various ecosystems. In agricultural landscapes, this task is particularly challenging due to the diminutive size of the plants and their partially overlapping spectral signatures.

A monitoring workflow was developed for multiple arable areas in a UNESCO biosphere reserve in eastern Saxony (Germany) using UAV Photogrammetry and a lightweight deep learning model called YOLO. The study collected data in June 2023 from both UAV flights at various heights and ground surveys. The study successfully mapped six species and one genus class on the high-resolution RGB images. Interestingly, the YOLO models trained on these high-resolution images were still effective when applied to images collected at higher flight heights and lower resolutions.

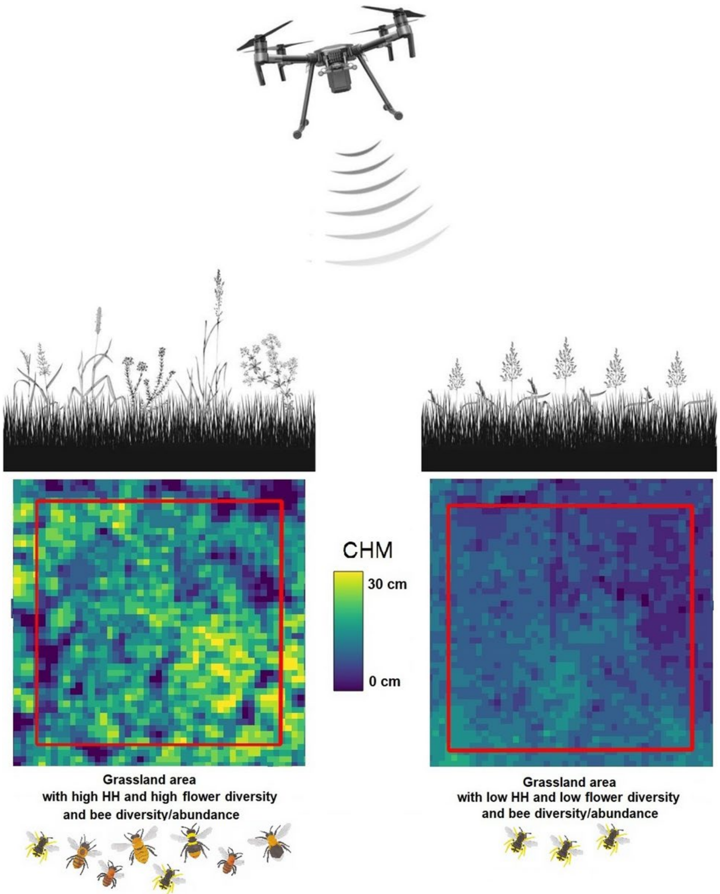
Our findings suggest that utilising commercially available UAV-based sensors and deep learning algorithms for remote sensing of segetal flora in arable fields is a feasible technology for implementing result-based payments. While our results demonstrate the potential for efficient and cost-effective monitoring on a large scale, further testing and annotation development in different regions and over multiple years is necessary to capture the variability in phenology.



Example of *Centaurea cyanus* instances inferred with YOLO, and derived species coverage in plot 26, based on RGB orthomosaics collected at 10, 20 and 40 m above-ground. In pink the predicted instances.

4.3 Using vegetation structure heterogeneity for pollinators' biodiversity monitoring

Insects, and especially bees, play a vital role in supporting agriculture and biodiversity. However, factors like habitat loss and climate change are causing a decline in bee populations. Bees are essential for maintaining wild plants, contributing to cultural ecosystem services, and impacting plant community sustainability. With an annual value exceeding 150 billion euros, bees significantly contribute to global food production. Protecting these pollinators is crucial for sustaining ecosystems and ensuring vital services. Additionally, technologies like LiDAR and Uncrewed Aerial Vehicles (UAVs) provide cost-effective ways to study biodiversity. Advances in photogrammetry and UAV imaging offer precise 3D data on vegetation structure in grasslands, showing promise for research on insect diversity.



Grassland ecosystems with high HH and, thus, with a complex vertical structure and high environmental heterogeneity are expected to have a high flower diversity and high bee diversity and abundance. On the other hand, grassland areas with low HH might have lower flower diversity and bee diversity and abundance.

This study used UAV technology to assess vegetation height heterogeneity in variously managed grasslands in the Netherlands. Counting both wild bees and honeybees using a standard method, data was collected simultaneously with field surveys in May 2021. Vegetation height heterogeneity was calculated at different resolutions, showing that it can serve as an indicator of flower and bee diversity in these grasslands. The study found no significant differences among tested spatial resolutions, suggesting that UAV-derived data is effective in assessing biodiversity in diverse grassland management scenarios.

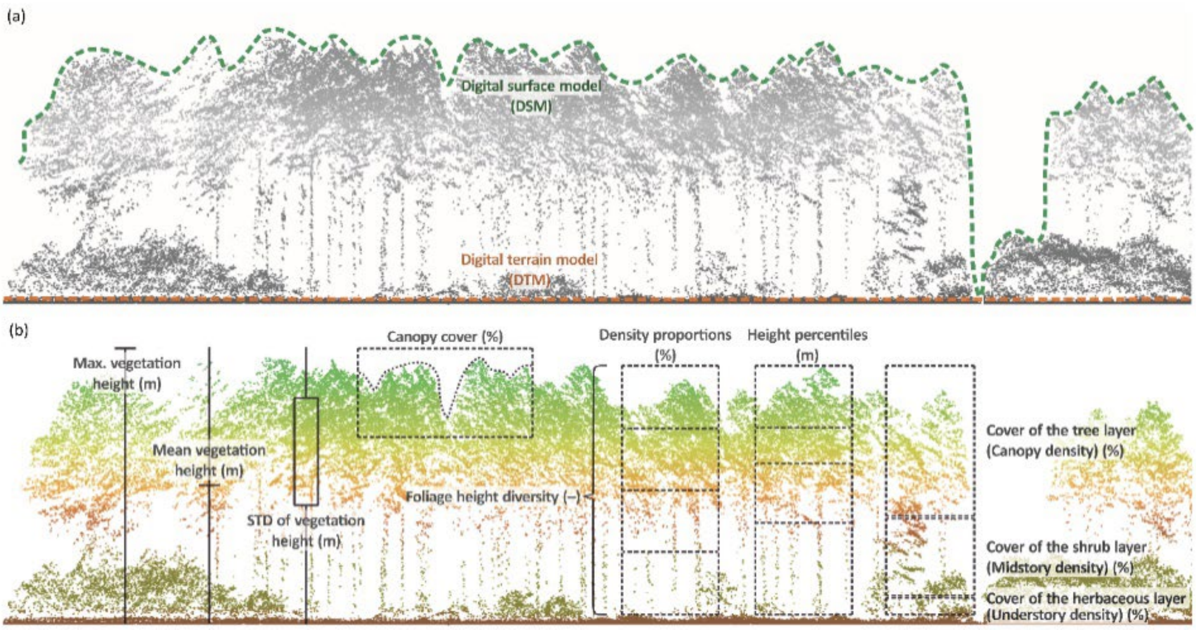
Monitoring biodiversity using height heterogeneity is resilient against challenges faced by traditional optical data methods. High-resolution UAV cameras capture detailed images, providing information on fine-scale vegetation complexity. The on-demand capability allows precise recording of vegetation stages, especially during flowering, offering insights into plant-pollinator interactions. This approach is scalable and applicable compared to data-intensive methods like machine learning. However, large-scale UAV deployment presents challenges in data processing, sensor calibration, and standardisation. Despite these challenges, the proposed approach shows promise for routine use in assessing changes in grassland structure due to various factors, including land management and ecological processes.

4.4 Deriving information on vegetation structure using open-access ALS databases

Ecosystem structure is one of the six essential biodiversity variable classes and represents a significant aspect of habitat heterogeneity. Species diversity is significantly influenced by variations in vegetation structure, showing an increase with midstorey and canopy density. Conversely, many species, especially specialists or weak competitors, favour specific habitats with relatively lower heterogeneity. For example, the occurrence of such species can be associated with early stages of spontaneous succession, which are rare in managed rural landscapes. Hence, establishing a mosaic of habitats with diverse vertical vegetation structures is crucial to preserve biodiversity. For example, in agricultural landscapes, small woodland patches and linear vegetation features, such as tree lines, hedgerows, ditches, and green lanes, serve as vital refuges and corridors for biodiversity. Preserving and restoring these features is essential for biodiversity conservation, yet detailed information on ecosystem structure is frequently lacking.

Currently, Light Detection and Ranging (LiDAR) technology, particularly Airborne Laser Scanning (ALS), is widely used for efficient collection of detailed vegetation structure information. Employed on airplanes, ALS has become the primary method for obtaining precise terrain and vegetation data across extensive areas. LiDAR, an active remote sensing technique, determines the three-dimensional positions of objects by measuring the time taken for laser beams to travel from the sensor to the target and back. One notable advantage of LiDAR is its ability to penetrate vegetation canopies, capturing multiple returns from different layers. This results in a point cloud, representing an irregular distribution of returns in three-dimensional space.

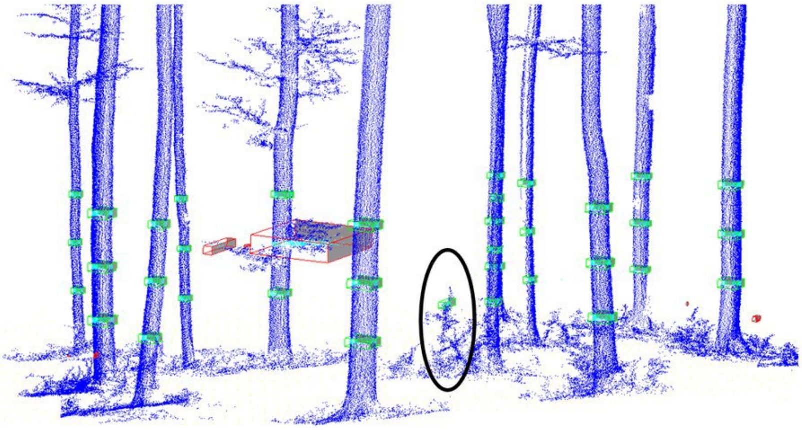
Over the last two decades, the accessibility of Airborne Laser Scanning (ALS) data has grown, particularly in Europe, where ALS point clouds and derived products are freely available from public agencies. While digital elevation models aid in assessing horizontal vegetation structure, they lack information on vertical vegetation structure. Direct work with ALS point clouds is necessary for the latter, but it involves complex data processing and remote sensing skills. ALS is often conducted in winter to achieve precise terrain data. However, this may result in a less accurate representation of deciduous tree vegetation structure.



Example of an ALS point cloud profile. The top figure (a) illustrates that digital terrain and surface models (typical raster products derived from ALS point clouds offered by the data providing authorities), can be used to derive information on vegetation height and horizontal variation in canopy cover, but do not adequately describe the vertical variability of vegetation structure. The bottom figure (b) shows suitable variables to describe the vertical structure of the vegetation.

4.5 Forest metrics and forest change from LiDAR

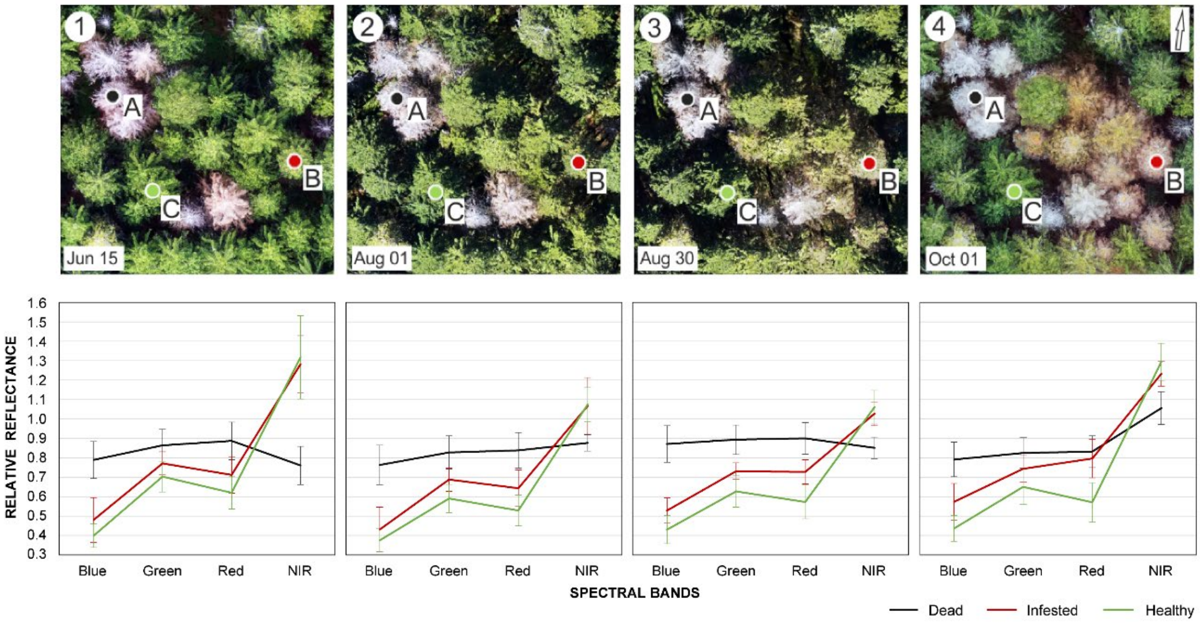
LiDAR (Light Detection and Ranging) is an active remote sensing technology to map the earth surface, which has revolutionised the assessment of forest inventory, growth, biomass and species identification and distribution. To capture LiDAR data various platforms can be used, such as UAVs (uncrewed aerial vehicles), aircraft and ground-based systems, i.e., mobile platforms, like a hiker with a backpack or mounted on cars, and terrestrial laser scanners. This offered flexibility enables a very detailed capturing of forest structure at different scales and from different perspectives. By measuring multiple return laser pulses, LiDAR distinguishes between ground and top-of-canopy returns, and therefore allows for the generation of a canopy height model (CHM) because some of the emitted laser pulses penetrate the vegetation. Resolving the vertical construction of forests can be extended, when considering full-waveform devices that enable a nearly continuous



Example for detecting individual trees and measuring the tree diameter at breast height (DBH) by segmenting in the XY plane due to the detection of circles with specific point densities and then tracing the point cloud at the found circles along the height axis (©Anne Bienert).

Colorized 3D point cloud derived from UAV-LiDAR data.

representation of the vegetation structure. Also, the understory and ground vegetation of forests can be mapped with LiDAR. LiDAR measurements result in high-resolution 3D point clouds, for which segmentation algorithms exist to automatically and efficiently detect individual trees. This information can be then used to estimate single tree heights. When combined with corresponding regression models, based on field measurements and forest parameters derived from the 3D data, the tree volume and biomass can be calculated. Additionally, LiDAR allows for the characterisation of canopy cover, gap fraction, and leaf area index approximations. At the individual tree scale, the technology enables the retrieval of various attributes such as position, height, canopy diameter, canopy area, canopy volume, and it can be used to count trees. Even the entire skeleton can be derived. Forest growth can be assessed simply by performing multi-temporal LiDAR data acquisition and calculating the differences. Such comparison aids in assessing tree height changes, estimating average expected yield, and evaluating the impact of wildfires. LiDAR data can be used to classify tree species based on the tree structure, leveraging 3D canopy information and, potentially, color information. The multifaceted approaches demonstrate the versatility and efficiency of LiDAR in advancing our understanding of forest ecosystems.



Spectral curves of the time series captured in different stages of the bark beetle infestation, showing dead (grey, A), infested (red, B), and healthy (green, C) trees throughout the season. The graphs represent mean relative reflectance values calculated from all infested (red), dead (black) and healthy (green) trees higher than 15 m in the study area at the individual dates.

4.6 UAVs for tackling bark beetle outbreak in European spruce forests

In recent decades, rising bark beetle (*Ips typographus*) activity has significantly impacted spruce forests in Central Europe, posing environmental and economic challenges for forest management. The European spruce bark beetle primarily targets recently harvested or weakened spruce trees. Timely detection of bark beetle infestation is crucial to mitigate losses, as outbreaks affect not only wood production but also vital forest ecosystem functions, including the water cycle, nutrient cycle, and carbon fixation. A bark beetle outbreak causes a significant drop in the value of wood and, even more importantly, imposes significant costs associated with its consequences and recovery. This escalating threat is a significant challenge for Europe’s forest, and will continue to be so.

As prevention is the most effective defence against bark beetle, it is necessary to focus on the deceleration of its spread. However, the spatial and temporal dynamics of the pest's disturbances are not yet fully understood. Successful measures necessitate early detection of infested trees, as visual and spectral changes occur within weeks. Remote sensing, particularly drones, can record these spectral changes with high detail, facilitating precise detection of infested trees.

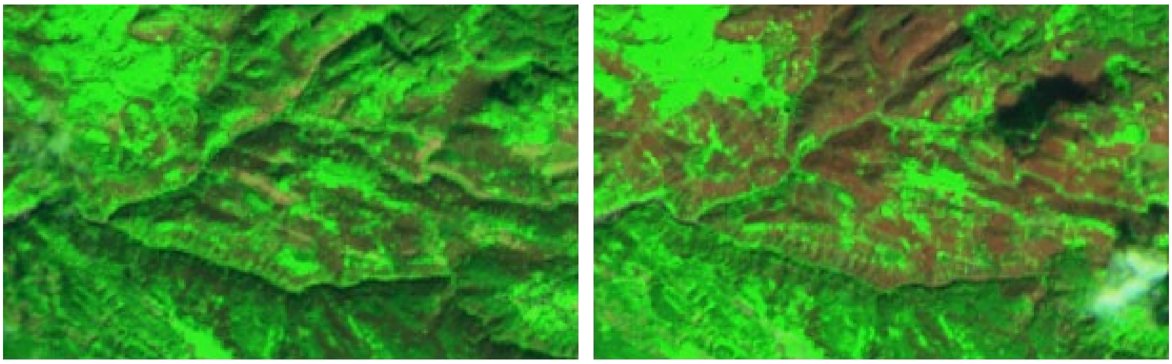
This study relied on low-cost UAV-based solutions to detect bark beetle infestation in individual trees, focusing on distinguishing their health status (dead, healthy, or infested). UAV-derived true colour ortho mosaics enabled the identification of individual treetops through automated methods. Health status classification was based on visual image interpretation and verified by a field survey. The results demonstrated precise detection of infestation, particularly in the green attack stage, with the Greenness Index showing promising outcomes. Such a study highlights the suitability of consumer-grade and customised UAV-mounted sensors for bark beetle infestation detection throughout different stages of the season, acknowledging the potential for prediction in larger-scale management.

4.7 Satellite Remote Sensing and Wildfires

Wildfires are an increasing problem in Central Europe and are set to remain so for the foreseeable future. It is therefore necessary to employ all means possible to reduce the risk of fires and their effects. Satellite remote sensing is one of the tools that can help identify and reduce wildfire risk, but it can also help understand the effects on the landscape following a fire.

Satellite-based remote sensing can be used to determine fuel characteristics such as vegetation moisture content, this information can then be used to refine/update fire danger warning levels. The use of satellite-based remote sensing of the available fuels such as trees, deadwood and litter, can provide information that can be used in forest fire models to estimate speed pf spread and direction of spread, such information is vital in protecting settlements and infrastructure, both in terms of avoiding risk and preparing for such fires.

Satellite remote sensing can be applied within the monitoring of forest fires and their effects, for instance the VIIRS (Visible Infrared Imaging Radiometer Suite) and MODIS can be used to provide information about the heat released during a fire, providing an indication of severity and combustion completeness and burnt area. However, it has the disadvantage of having a limited capability in terms of sensing forest floor fires, where the canopy restricts the ability to sense the heat released.



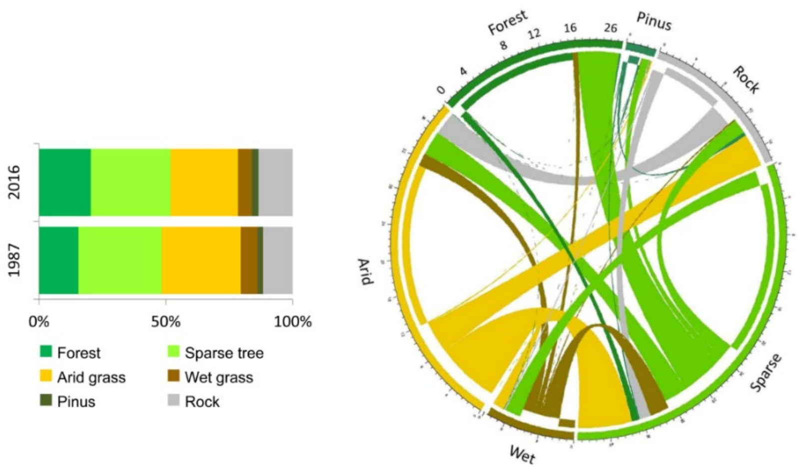
Example of shortwave infrared images (SWIR) from Sentinel-2 (left before a fire, right following a fire) (image source: Copernicus).

Understanding the severity of fire is a key element of assessing how well an ecosystem can cope with fire and thus its resilience and provides a baseline upon which recovery rates of existing species and/or pioneer species can be measured. This is a significant knowledge gap in Central Europe where recovery rates and species distribution are seldom researched or reported.

In very basic terms, the use of optical satellite-based imagery for measuring burn severity uses before and after images and provides a measure of the difference between them. The method, known as the Difference Normalised Burn Ration dNBR ,uses the shortwave infrared and near infrared parts of the electromagnetic spectrum and the different reflective properties of living, damaged and destroyed vegetation. This process, repeated on an annual basis, can aid in quantifying the recovery/colonisation by vegetation following a fire.

4.8 Dynamic Pattern Analysis: Unveiling Mediterranean Mountain Forest Transformations

This study employs Dynamic Pattern Analysis to dissect three decades of land use dynamics in the central Apennines, showcasing the potential of Dynamic Pattern Analysis as a powerful monitoring tool. Leveraging an extensive archive of freely available Landsat data, this study compares land cover maps from 1987 and 2016, revealing a significant resurgence of natural woodlands at the expense of sparse trees and arid grasslands.



Percentage of cover over time of the different land cover types and a Chord Diagram of the transition matrix (1987-2016). To show transitions, the chords without space at the endpoints indicate the source (original land cover type) and those with space at the endpoint the target (cover type to which the original changed). The internal coloured ring indicates the amount of each land cover type that remained stable over time.

The results highlight the landscape's dynamism, with 35% undergoing transformation during the study period. The trajectory analysis of forested areas unveils a nuanced relationship between forest gain and spatial pattern changes. Using sample-based metrics, spatial pattern analysis depicts an evolving forested landscape marked by increased patch density, edge density, and mean patch area.

Socio-economic factors, such as declining human populations and shifting grazing activities, set the stage for natural forest recolonisation, impacting open areas and grasslands. This study emphasises the ecological repercussions of forest resurgence and offers valuable insights into biodiversity conservation in such landscapes. Notably, Dynamic Pattern Analysis's capability to utilise an extensive archive of freely available Landsat data makes it a cost-effective tool for landscape monitoring.

The results highlight Dynamic Pattern Analysis's convenience compared to systematic in-situ data collection. By relying on citizen science, exemplified by geotagged Flickr photos, this study demonstrates a user-friendly approach to data acquisition. Overall, the study illustrates how Dynamic Pattern Analysis can unravel the socio-ecological dynamics of Mediterranean mountain ecosystems, making it an appealing tool for landscape change analysis that can also be employed in a Central European context.

4.9 Key stages when setting up a monitoring campaign

Monitoring campaigns consist of systematically collecting biodiversity data following standardised procedures. Monitoring entails conducting repetitive surveys, enabling the observation of fluctuations in the condition of the target species, community or habitat over time and facilitating the exploration of underlying causes for such variations. Effective planning is essential for the success of any monitoring campaign, ensuring that objectives are clear, methods are appropriate, and resources are efficiently utilised. A lack of strategic planning in monitoring efforts can result in an overwhelming volume of data that proves challenging to analyse and utilise promptly.

Below we outline key steps in planning a biodiversity monitoring campaign.

1. **Define objectives**: clearly define what needs to be monitored. What specific aspects of biodiversity? Are you focusing on species richness, population trends, habitat quality, or ecosystem functions? Define measurable goals and outcomes.
2. **Select indicators**: Identify scientifically sound indicators that align with the defined objectives and are feasible to measure.
3. **Design the sampling framework and choose monitoring methods**: Develop a sampling framework that determines how and where data will be collected. Define the location and boundaries of the biodiversity features to be monitored. Consider factors such as spatial scale, temporal frequency, and measurement methods. Select appropriate monitoring methods and protocols for data collection and ensure they are standardised, repeatable, and compatible with the selected indicators.
4. **Establish baselines**: Collect baseline data to establish a reference point for future comparisons. Baseline data provide essential context for interpreting changes in biodiversity over time and assessing the effectiveness of conservation interventions.
5. **Allocate resources**: Allocate resources efficiently, considering budgetary constraints, staffing requirements, and logistical considerations.
6. **Develop a data management plan**: Implement a robust data management plan to organize, store, and analyse monitoring data effectively.
7. **Pilot testing and iterative improvement**: Conduct pilot testing to validate monitoring protocols, identify potential challenges, and refine methods before full-scale implementation. Use feedback from pilot studies to refine sampling protocols, address logistical challenges, and improve data collection methods.

By following these steps, stakeholders can develop robust biodiversity monitoring campaigns that provide valuable data for informing conservation decisions and management actions. Effective planning ensures that monitoring efforts are focused, scientifically rigorous, and contribute to the understanding of biodiversity dynamics.

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