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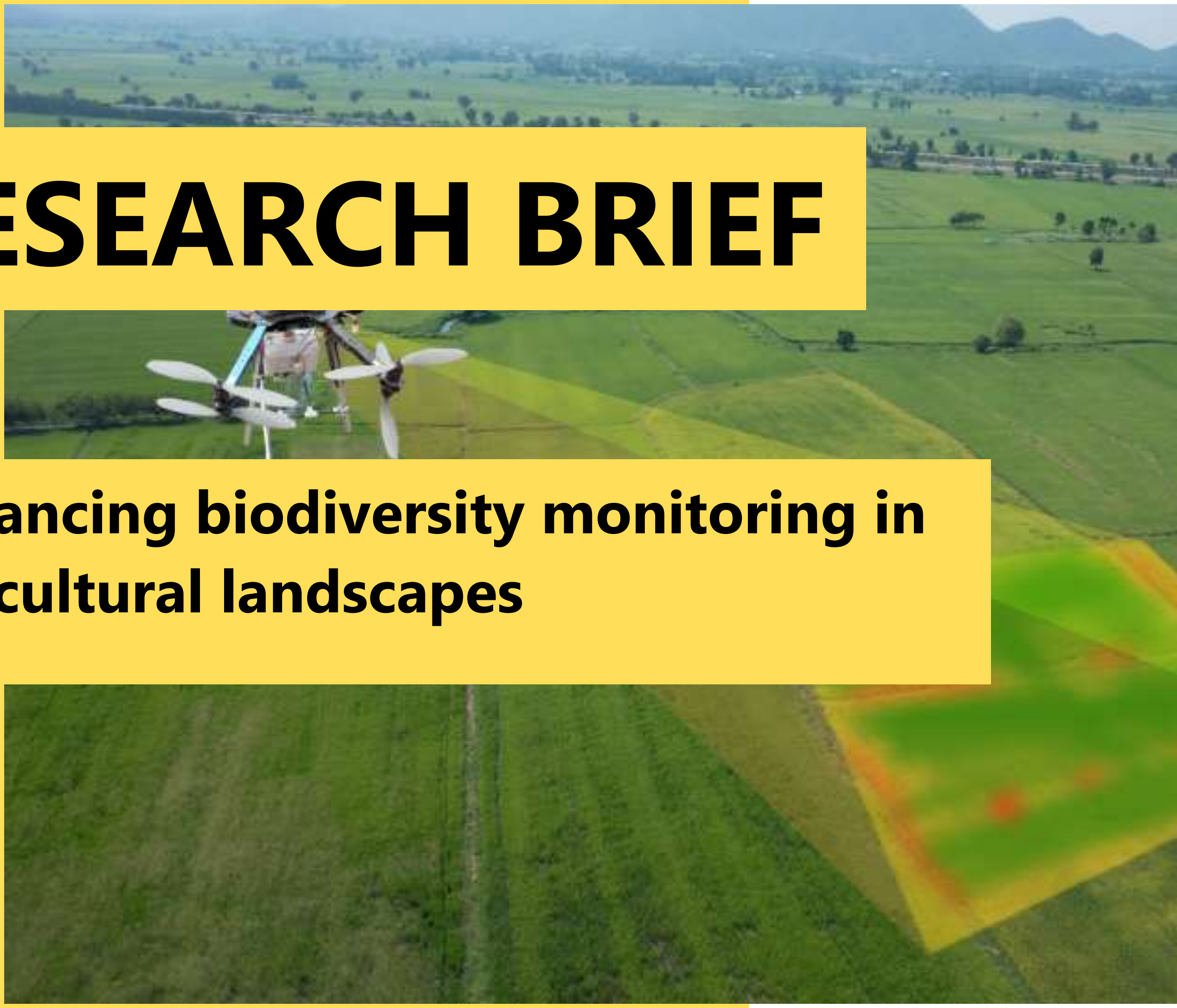

RESEARCH BRIEF

Advancing biodiversity monitoring in agricultural landscapes

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The European Sustainable Agriculture Dialogue (ESAD) is a multi-stakeholder platform created in 2019 that brings together key actors from across society – including industry, civil society, universities, and research centres – to discuss key topics, exchange our views and standpoints, and ultimately shape decisions towards sustainable agriculture. The brief was developed in consultation with ESAD members and the authors took their inputs into account in the drafting process. The paper does not reflect the views and opinions of single ESAD members. As such, their contribution is not to be interpreted as an endorsement of the final paper.

CONTENTS

EXECUTIVE SUMMARY

This briefing gives an overview of innovations in biodiversity monitoring in agricultural landscapes and discusses some advantages and limitations of how new techniques can inform policy. Rapid progress is generating much larger biodiversity data sets, with higher frequency, scope, and detail than just a few years ago. Some methods are already used effectively to inform policy or are currently being integrated. Others still require development to become a reliable standard. Inequities in access and capacity and lack of standardisation generate a lack of trust, hindering adoption in policy. There is a need for better and more used shared data management tools. Attention needs to be paid to fairness and individual's access to review if decisions are made based on these types of data. These techniques can improve the monitoring quality in payment schemes and other incentive programmes and thereby strengthen trust and adoption of result-based schemes, as well as enabling private credits and certification markets. A key step is the European Commission's pilot for a European Biodiversity Observation Coordination Centre to improve the availability, quality, coherence, timeliness, and access to biodiversity data for EU policy.

Key messages

- Technologies are being rapidly developed, and many are now readily available - but some need improvements and **validation of reliability** before committing to monitoring programmes.
- Technologies **supplement rather than replace** in situ observations and taxonomic expertise.
- Automatic recognition systems need **training and verification** against datasets – and **expert taxonomy checks and auditing** – to avoid locking in taxonomic errors.
- Technologies can strengthen and verify **citizen science approaches** with untrained volunteers and farmers and increase understanding and engagement with biodiversity friendly land management. They can improve the monitoring quality in payment schemes and other incentive programmes and thereby **strengthen trust and adoption of result-based schemes**, as well as enabling private **credits and certification** markets.
- Where publicly funded payments or sanctions are linked to measurements made with remote sensing or other automatic technologies, the contractors or recipients of such payment schemes or inspections should have **access to a channel to question and ask for a review of decisions, a means of submitting alternative evidence, and access to justice**.
- **Equality of access issues** need to be addressed: governments, agencies, and individuals vary greatly in their ability to access and pay. For the public sector, there is the challenge of paying the costs on a long-term basis.
- More work is needed to encourage biodiversity **data sharing and interoperability** and to develop international databases and metadata standards.
- The European Commission is about to launch a pilot for a **European Biodiversity Observation Coordination Centre** - to improve the availability, quality, coherence, timeliness, and access to biodiversity data for EU policy.

1. MEASURING BIODIVERSITY IN AGRICULTURAL LANDSCAPES

1.1 Why monitor biodiversity in agricultural landscapes?

Agriculture is the dominant land use in Europe, and much of Europe's biodiversity has evolved to co-exist with traditional low intensity agricultural landscapes, so that it is possible to identify 'farmland biodiversity'. Intensive agriculture is now a major driver of farmland biodiversity loss, along with land use change and agricultural land abandonment. At the same time, agriculture is highly dependent on the ecosystem services provided by biodiversity, in other words, by habitats and species and ecosystems.

We need to monitor and detect protected species and indicators of biodiversity on agricultural land for several reasons:

- to track trends in abundance and occurrence of protected species populations and habitats so that we know what to protect and whether protection is working;
- to know where and how to implement legal protection rules;
- and to assess and improve policies, rules, and support actions and incentives to conserve and restore biodiversity in agricultural landscapes.

New technologies are making it possible to monitor over larger areas and more frequently, which allows the evaluation of status and trends to better inform decision making. High quality biodiversity monitoring is essential for measuring progress towards the Union wide targets and international biodiversity commitments of the European Union. Effective monitoring can provide the necessary data and insights to inform policy decisions to protect biodiversity.

Biodiversity monitoring and data can also support the development of sustainable agricultural practices. For example, soil biodiversity monitoring can help detect the impacts of land-use change and land management practices on ecosystem health and functionality (BioMonitor4CAP, 2023). Monitoring of protected species on farmland in real time can make it easier for farmers to comply with the protection rules and for policy makers to see what measures work best for both the species and the farm.

1.2 What is biodiversity on farmland?

Farmland biodiversity or agrobiodiversity includes both wild and domesticated species and organisms and genes. It includes the species and genetic diversity and landscape features that the farmer has chosen to directly or indirectly support agricultural production (like crop types, livestock breeds, planted trees), or that people have added to that land in the past (like hedges and ditches). Farming landscapes also hold pockets of habitats and wild species that co-exist with or alongside agriculture and food production, species and organisms not actively chosen by farmers but that contribute ecosystem services (like wild pollinators and soil microorganisms) or that are a priority because they are declining (like many farmland birds).

The diversity of soil microorganisms, plant and animal populations, and ecosystem structures and functions make biodiversity monitoring complex. To ease standardisation, biodiversity has been broken down into a set of variables or groups of linked variables that express one aspect of the state of biodiversity, known as **Essential Biodiversity Variables (EBVs)** (see Table 1). Standardised approaches to biodiversity monitoring of EBVs would quantify the rate and direction of change of all EBVs over time and across space and time and harmonise EBV assessment at any scale from local to global.

In practice, the only EBVs that have been used on a regular basis in biodiversity monitoring until recently have been the area and condition of habitats of conservation interest (community composition) and species distribution and abundance – particularly breeding birds and butterflies, the most widely monitored groups of species. New technologies and methods are now making possible the measurement of more EBVs and many more species and functional groups, such as soil biodiversity and beneficial insects.

Table 1: Essential Biodiversity Variables: examples of EBVs on agricultural land

Sources: GEOBON https://geobon.org/ebvs/what-are-ebvs/ and own compilation

EBV class	**Variables**	**Examples on agricultural land**
Ecosystem structure	Live cover fraction Ecosystem distribution Ecosystem vertical profile	Permanent grassland cover Peatland and wetland cover Peat and organic soil mapping Landscape features mapping and coverage – e.g. small woody features
Ecosystem functioning	Primary productivity Ecosystem phenology Ecosystem disturbances	Permanent grassland productivity & management intensity Soil organic matter / carbon – stock and changes Grassland mowing frequency Hedge cutting – timing and frequency Drainage – changes (e.g. ditch blocking or excavation), effects on water table
Community composition	Community abundance Taxonomic/phylogenetic diversity Trait diversity Interaction diversity	EU Habitats Directive Annex I grassland habitat types – areas, condition and fragmentation Grassland plant species richness and presence of plant species indicative of conservation value of grassland Abundance and taxonomic diversity of grassland butterflies Trends in abundance of farmland bird populations Soil biodiversity – functional diversity
Species traits	Morphology Physiology Phenology Movement or mobility Reproduction	breeding / nesting seasons of farmland bird species Pollinator-flower phenological overlaps or asynchronies
Species populations	Species distributions Species abundances	Distribution and population size of specific farmland bird species (making up farmland bird index) Distribution and population size of a threatened and protected species in a specific area (e.g. Curlew population in western Ireland)

		Presence or coverage of invasive alien plant species on farmland (e.g. Ambrosia spp) or of invasive alien animal species on farmland (e.g. Muskrat)
Genetic composition	Genetic diversity (richness and heterozygosity) Genetic differentiation (number of genetic units and genetic distance) Effective population size Inbreeding	Genetic diversity of wild crop relatives or threatened crop varieties Genetic diversity and health (avoiding inbreeding) of rare livestock breeds Genetic identity of large carnivore individuals and packs living in/near agricultural areas

2. POLICY NEEDS FOR BIODIVERSITY DATA IN AGRICULTURAL LANDSCAPES

Biodiversity monitoring on agricultural land is required under several EU laws and policies, and some recent EU initiatives are upscaling monitoring for the achievement of EU biodiversity targets.

EU policies requiring monitoring and reporting of biodiversity in farmland

The **Birds Directive and Habitats Directive** require regular monitoring and six-yearly reporting of the status and trends of species and habitats under the scope of the directives (known as species and habitats of Community interest) since 2001 (for habitats and non-bird species) or 2014 (for the birds).

- The Habitats Directive protects a list of semi-natural grasslands, wooded grasslands, coastal and wetland habitats (known as **Annex I habitats**) that have some kind of agricultural activity, generally low intensity grazing and/or cutting of vegetation (for hay or bedding). These habitats should be managed and restored so that each habitat area reaches good condition, and the combination of all existing habitat areas plus re-created habitat patches (to compensate for past losses) reaches favourable conservation status.
- The directives protect certain **species** living and breeding or nesting on agricultural land (such as grassland-nesting birds), and the **species' habitats** (for feeding, breeding and resting). The Birds Directive covers all wild native birds in Europe, including the birds that breed and forage on farmland (known as farmland birds), whilst the Habitats Directive protects a subset of other wild native animals and plants that occur on farmland, including for example the European Hamster (*Cricetus cricetus*).

The monitoring must include:

- Habitat areas and fragmentation
- Habitat condition: structure and functions (for example species richness and presence of indicator species, intactness of hydrology, appropriateness of management including mowing frequency or grazing intensity)
- Species populations and abundance
- Species habitats: area, conditions, location (e.g. with regard to climate change or other factors influencing the species)

The monitoring should also measure or assess:

- pressures and threats, e.g. eutrophication due to fertiliser use, overgrazing, ploughing or other soil disturbance, drainage or other damage to hydrology, mowing that is too early or too late or too frequent or absent.
- management measures and restoration needs.

The **Invasive Alien Species Regulation** requires the tracking and reporting of any invasive alien species of Union Concern found on farmland since 2016.

The **Nature Restoration Regulation** requires the monitoring and reporting of the area and condition of habitats and species covered by the nature directives (as above) and the mapping of suitable areas for the re-creation of habitat patches that have been lost. With respect to agricultural areas, the regulation makes the requirements of the nature directives more specific (for example, the mapping and identification of species habitats) and timebound (for example, the requirements to fill knowledge gaps by deadlines).

The Nature Restoration Regulation, which came into force in August 2024, is a major step forward for biodiversity monitoring in Europe, as it establishes a legal requirement for two EU wide monitoring schemes (and their biodiversity indicators and indices) that until now were based entirely on voluntary inputs, and it establishes an additional new EU wide monitoring scheme and indicators. These are:

- Pan European Common Bird Monitoring Scheme (PECBMS)
- European Butterfly Monitoring Scheme (eBMS)
- European Pollinator Monitoring Scheme (PoMS)

The regulation therefore requires each of the following at the national level:

- the national common farmland bird index (derived from common bird breeding surveys),
- the grassland butterflies index (derived from butterfly monitoring transects),
- pollinator populations (measured by the European Pollinator Monitoring Scheme), and
- high diversity landscape features, according to the EU monitoring method and any additional methods the member state chooses to apply.

The **Common Agricultural Policy (CAP)** monitoring framework uses two impact indicators as a measure of the impact of the policy on biodiversity. These currently are:

  - farmland birds index (impact indicator no. 19)
  - percentage of species and habitats of Community interest related to agriculture with stable or increasing trends (impact indicator no. 20)
- another impact indicator relevant for biodiversity is:
  - agricultural land covered with landscape features (impact indicator no. 21)

The proposed **EU Soil Monitoring Directive** includes an obligatory soil biodiversity indicator: soil basal respiration (mm3 O2 g-1 hr-1) in dry soil. Member States may also select other optional soil descriptors for biodiversity such as: metabarcoding of bacteria, fungi, protists and animals; abundance and diversity of nematodes; microbial biomass; abundance and diversity of earthworms (in cropland); invasive alien species and plant pests.

Issues with biodiversity monitoring on agricultural land under EU policies

There are currently gaps across biodiversity indicators and variations in methodology and data quality between EU countries that make it difficult to compare and assess progress in implementation of the EU laws and policies.

For the monitoring and reporting under the Birds and Habitats Directives, more than half of EU countries struggle with poor data quality and completeness (Ellwanger et al, 2018). Very few Member States have established large-scale national biodiversity monitoring schemes (Schmidt and van der Sluis, 2021). The raw data is not easily traceable or accessible, since some national agencies rely partly on expert judgement, and the federally structured countries often have access only to regionally aggregated assessments of species and ecosystems supplied by their regional nature agencies. EU countries may struggle with lack of guidance in identifying monitoring priorities, lack of standardized monitoring protocols, a reluctance to change existing monitoring practices, and limited in-house knowledge and technical infrastructure to adequately mobilise and access biodiversity data (Kühl et al, 2020; Moersberger et al, 2024; Schmidt and van der Sluis, 2021). Monitoring efforts are often single sourced and single domained, which limits spatiotemporal and taxonomic coverage due to limited funding (usually from public budgets or NGO funding) (Kühl et al, 2020).

In a 2024 review of more than 274 biodiversity monitoring programs currently conducted by EU countries and agency, the EUROPABON project showed that 55% of the use of biodiversity data in policy was related to the Habitats Directive and the Birds Directive, with national applications for species policies and management (Moersberger et al, 2024). Meanwhile, biodiversity data are seldom used for land-use management planning.

3. INNOVATIONS IN BIODIVERSITY MONITORING TECHNOLOGIES

3.1 Recent advances in technologies

In this section, we give an overview of recent innovations in technologies and techniques for biodiversity monitoring in agricultural landscapes, and some advantages and limitations of the developments.

Rapid developments in technologies (and the supporting data, information technology and processing capacity) mean that biodiversity monitoring no longer relies primarily on labour-intensive work by experts on the ground. Their increasingly affordable and practical use promises to save time and labour and roll out monitoring at much larger scales, increasing frequency, and wider scope. More and higher-quality monitoring can better inform policy decisions to promote biodiversity conservation efforts in agriculture.

This brief reviews recent developments of these techniques and technologies. Some are in the research phase, some are being used in pilots, and some are already used in agricultural landscapes. The tools used to measure range from satellites, unmanned aerial vehicles (UAVs) or drones, and different types of sensors and robotics used in the field. The technology development is matched with developments in the automation of large data management, the use of machine learning and artificial intelligence.

- **Remote sensing, LiDAR and RADAR** allow large-scale data collection at frequent intervals that provides efficient and cost-effective monitoring.
- **Unmanned aerial vehicles or drones** can carry monitoring technology – but are limited by cost, skills, and access.
- **Automated robotics, sensors, image and sound recognition (bioacoustics)** enable real-time species identification from images or sound with machine learning algorithms and can be used to track animal presence, movements and activity. There is also a rapid development of AI-based analysis methods of the data. They can be used in fixed or mobile wildlife observation posts or units and in mobile applications with camera and microphone, such as smart phones or tablets. With these methods, un-skilled labour or volunteers can do fieldwork, and large numbers of data points can be gathered through citizen campaigns using smart-phone apps.

- **DNA-based sampling methods,** known as (environmental) eDNA, combined up with metabarcoding, are used for assessments of species distribution, size of populations, and genetic diversity. eDNA can be extracted from water, air or soil samples without disturbing the species or the habitat. The methods are widely used for measuring species presence but limited by the availability of reference DNA databases and standardised approaches.

- Low tech **citizen science methods** such as farmer-led measurements using indicators and scorecards increase understanding and motivate improvement. They can be verified and strengthened with information from aerial imagery or automated monitoring and accompanied by the use of smart phone applications with image recognition for identification of indicator plants or insects.

3.2 Remote sensing – earth observation data

Remote sensing refers to the use of a geospatial (or airborne) technology to extract information about the environment without physical contact from a large distance by measuring reflected or emitted electromagnetic radiation, on a recurrent basis. Remote sensing technologies have reached a high degree of development, with recent developments in a variety of applications in ecology and conservation.

Remote sensing techniques can be divided into active (with emission) and passive (detection only) sensing (Wang and Gamon, 2019). Both approaches can be applied across the radiation spectrum (visible, infrared and microwave). Passive sensors are deployed in satellites, including multispectral sensors and imaging spectrometers.

Scope of application: Satellite data can be used for mapping land cover, ecosystems and land cover heterogeneity, vegetation characteristics, land uses and land cover change. The relevance of remote sensing is determined by the spatial resolution (which determines the amount of information in a given image), spectral resolution (ability to differentiate between species and traits), and temporal resolution (revisit frequency). The scale at which remote sensing data measure attributes of land cover and vegetation varies with the sensor being used. Satellite data can be divided into the following categories:

- Low resolution: optical Satellite Data: >= 1km spatial resolution using multi-spectral sensors
- Medium Resolution Optical Satellite Data: 80–500m spatial resolution using multi-spectral sensors like MODIS, Landsat MSS

- High Resolution Optical Satellite Data: 5–30m spatial resolution using panchromatic or multi-spectral sensors or analogue camera systems such as Sentinel-2, Landsat
- Very High Resolution (VHR) Optical Satellite Data: 1–4m spatial resolution by panchromatic or multi-spectral sensors, e.g. Worldview-2 and Quickbird

Copernicus, the Earth observation component of the European Union's Space programme, offers data on land cover and land use, croplands, grasslands, small woody features.

Availability and cost: The European Space Agency (ESA) has five missions called Sentinels specifically for the operational needs of the European GMES programme. Sentinel data comes from dedicated satellites (Sentinel-1, -2, -3 and -6) and instruments onboard EUMETSAT's weather satellites (Sentinel-4 and -5). Open access products derived from EU satellite remote sensing in the Copernicus platform include:

- CORINE land cover data and land cover change
- Copernicus high resolution layers

Advantages: Remote sensing technologies allow extensive spatial coverage. Remote sensing technologies provide opportunity to improve and automate data collection. They are cost-effective in areas where traditional methods are expensive (e.g. monitoring of nocturnal species), work at various scales (up to 1500 ha) and in remote areas. Using a mixture of remote sensing and field methods seems to deliver the best results, and the combination of satellite data with ecosystem modelling is a promising field.

Limitations: Remote sensing data is technically complex to process, analyse and interpret. Satellite imagery needs to be calibrated, analysed and validated with reference to field-based information. Vegetation surveyors and terrain managers often lack the skills to apply these new methods, so successful use depends on them being able to communicate and work with technicians trained in such methods. This need for close collaboration between ecologists, modellers and remote sensing experts to derive meaningful information can be a challenge.

One of the challenges associated with remote sensing data are the time periods between the revisits of the satellites.

Policy relevance: The strength of remote sensing is its ability to deliver quantitative measures of land cover and parameters in a standardised manner with full coverage over very large areas, whereas field surveys can only deliver this through point sample measurements and subsequent interpolation. The provision of such data by remote sensing may open new ways of looking at the quality of European protected habitats (Annex I habitats) and the Natura 2000 network of protected areas.

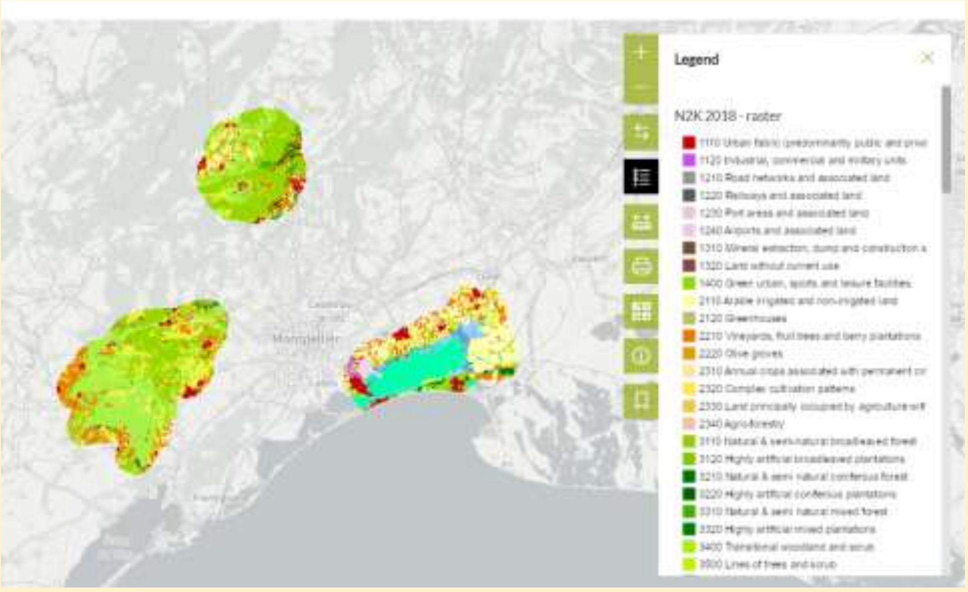
EU Grassland Watch: Monitoring Natura 2000 with Copernicus High Resolution Layers

Project: EU Grassland Watch is a grassland monitoring initiative which applies Earth Observation-based techniques to assess grassland degradation in grassland-dominated Natura 2000 sites. It leverages Copernicus CLMS data such as the High-Resolution Vegetation Phenology and Productivity Parameters (HR-VPP). Copernicus products include CORINE Land Cover (CLC) High Resolution Layers layers based on very high-resolution imagery (2.5 x 2.5m pixels) combined with other available datasets (high and medium resolution images) over the pan-European area. HRL layers are available for the following land cover characteristics: impervious (sealed) surfaces (e.g. roads and built-up areas), forest areas, grasslands, water & wetlands, and small woody features.

Data sets: The high-resolution grassland layer maps the location and size of all kinds of permanent grasslands: managed grassland, semi-natural grassland and natural grassy vegetation. permanent and temporary grasslands. The grassland data are available with a minimum mapping unit of 0.3 ha applied for the reference years 2015 and yearly since 2017. Since 2017 the Grassland Mowing products provide yearly the number and the starting dates of mowing events for all managed grassland, semi-natural grassland and natural grassy vegetation areas with a minimum mapping unit of 0.25 ha. The N2K data set allows users to monitor the status of land cover in Natura 2000 sites, including how they are changing over time, which is essential for informing conservation decisions, creating policy, and increasing accountability for land managers.

Further developments: Copernicus is a key resource for the Nature Restoration Regulation by providing freely available, standardised datasets which cover the entire European Union at high spatial resolution. The successful implementation of the NRR will benefit from continued advancements in remote sensing technologies, data accessibility, and national-level monitoring capacity.

Source: https://land.copernicus.eu/en/products/n2k and https://www.copernicus.eu/en/news/news/observer-copernicus-land-stands-ready-support-nature-restoration-regulation



Source of image: Copernicus webviewer https://land.copernicus.eu/en/map-viewer?dataset=85ecc3a6ad894d96adb302932977b0e9

3.4 Active remote sensing – RADAR, LiDAR

Active sensors include RADAR and Light Detection and Ranging (LiDAR). RADAR and LiDAR measure patterns of ecosystem structure, like tree height and allow visualizations of spatial-temporal changes and development of biotic and abiotic threats to species ("threat maps") (Reddy, 2021).

RADAR systems use radio waves and have been used in ecological research for decades, but improved classification algorithms and technical advances as well as data-sharing have greatly broadened the range of applications (Bauer, Tielens and Haest, 2024). For example, radar monitoring can detect insects in the airspace.

Light detection and ranging (LiDAR) is a widely recognized technology, especially the airborne laser scanner (ALS), which focuses on the emission and receipt of laser pulses. LiDAR produces a 3D point cloud of the structure of terrain and the vegetation above it (Melin, Shapiro and Glover-Kapfer, 2017).

Scope of application: Active remote sensing (LiDAR and RADAR) can be used to estimate biomass, monitor crop plant health and stress, detect pest or pathogen infestations, monitor soil fertility and target patches of high weed or invasive plant pressure, map flower resources from flower strips or set aside areas (Librán-Embid et al, 2020). Vertically looking radar has been used to quantify high-altitude insect migrations (van Klink et al 2022). Vertical photography and LiDAR can show insect biomass fluxes at closer ranges.

Availability and cost: The cost of LiDAR data is high (although costs decrease per unit area as total surveyed area increases). Both techniques require the aeroplanes to be able to fly, which may not be the case in areas of conflict, or in extreme weather conditions.

3.5 UAV monitoring

Use of unmanned aerial vehicles (UAVs), better known as drones, is increasing rapidly for biodiversity monitoring. They can carry airborne sensors with spatial resolutions between 40cm and 1cm.

Scope of application: UAVs have developed drastically over the last 10 years, with progressive development of types and applications. UAVs can carry many different types of sensors, including multispectral cameras, LiDAR, and thermal imaging systems.

Availability and usability: UAVs have become much more affordable and cost-efficient. UAVs are now being used by various private and public groups, including NGOs, state organizations, researchers and practitioners. However, they are not at the stage of being widely and systematically used for monitoring in agricultural landscapes (Librán-Embid et al, 2020).

Advantages: They allow quick mapping of a targeted area with increased temporal and spatial resolution in comparison to satellite imagery (especially at small scale). Provide in-situ sensing imagery, which can complement satellite-based observations. UAVs that can fly at any requested time and spatial resolution and are not affected by cloud cover, can speed up the process of vegetation mapping and monitoring.

Limitations: The use of UAVs in the field requires training and skill and is subject to regulations and restrictions to protect privacy and ensure safety.

Using drones to monitor flower density as a proxy indicator for pollinator diversity in the Showcase Horizon project

Project: SHOWCASing synergies between agriculture, biodiversity and Ecosystem services to help farmers capitalising on native biodiversity (Horizon project, 2020-2025). The project is reviewing and testing the effectiveness of economic and societal incentives to implement biodiversity management in farming operations and examined farmer and public acceptance, including the testing of new monitoring methods.

Monitoring methods: The project tested the measurement of yellow flower coverage using drone images as a proxy indicator for the abundance of bee pollinators (Torresani et al, 2023). The study measured yellow flower cover in 30 grasslands in the Netherlands using pictures taken with unmanned aerial vehicles (UAVs) and compared with surveys of bees and flowering plants using traditional monitoring methods on the same survey sites. Different machine-learning methods were used to assess remote-sensing images.

Results: The analysis found a high correlation between the estimates of yellow flower cover and bee abundance and diversity from the different methods of data collection, indicating that the drone-measured yellow flower coverage was a good indicator of pollinator abundance.

Further developments: The project will operationalise the approach and examine its reproducibility, further refine the methodology for using drones (determining what height is the most efficient to monitor flowers in grasslands) and standardise the method to obtain imagery from large areas and translate them automatically in flower cover data. A first conclusion was that although expert monitoring is currently the lowest-cost monitoring approach, cost developments in the future will likely render UAV-assisted monitoring more cost-effective (Schöttker et al 2023). Currently, higher computation post-processing costs of UAV outweigh the reduced field-labour efforts. However, as a reduction of technology-related costs is expected, and as the lower unitary costs per area compared to field sampling allow economies of scale in the case of large-area monitoring, there is likely a relevant future potential for UAV monitoring.

Source: Schöttker et al (2023), Torresani et al (2023)

Projects using similar monitoring methods: UAVs, in combination with remote sensing technology (Sentinel-2) have been used by to provide information required for farmers to receive compensation from crop losses in the Ebro Delta, in Spain, caused by a protected species - the Western Swamphen (*Porphyrio porphyrio*) (Pla et al 2019). The UAV images allowed the estimation of damages in rice crops at 10cm pixel definition.

3.7 Image recognition with AI-based analysis methods

Fixed cameras and camera traps have become widely used as the camera technology has become increasingly affordable, robust, and sensitive, and image data storage and transmission through the internet has become possible even with large quantities of data. This has necessitated a parallel development of tools to analyse those images. Similar developments have occurred in other sensors (see below for discussion of acoustic sensors). The ubiquity of smartphones with high-quality cameras and internet access has led to the development of smartphone apps that identify species in the field.

With recent technological advances in relations to computer power and deep learning, machines have become significantly more intelligent and reliable than ever. The recent development of computer vision-based species identification tools has enabled the automation of the analysis of large volumes of evidence from the field (Elvekjaer et al, 2024). Deep learning allows an automated capability for machines to recognise, classify, and detect images, sounds, and behaviour of animals, plants, and even humans (Bjerge et al, 2023a).

- **Scope of application**: Image recognition can be used to measure species richness, track the presence of specific species (for example invasive alien species), monitor pollinator-plant interactions, and much more.
- **Cost and availability**: A high level of expertise is needed to develop the application, but there are already several free or low-cost identification apps for smartphones. Cameras with image recognition are commercially available at a range of prices.

The Danish start-up FaunaPhotonics uses sensors to monitor the wing flutter pattern of in-sects visiting crops. A machine-learning algorithm associates the flutter with the insects' species, which is then reported to the farmer. This method allows the collection of data on insect abundance, activity, diversity and biomass.

Advantages: Automated imaging and species recognition can massively increase spatial sampling effort, with no or minimal disturbances to wildlife or sensitive habitats, processing large amounts of data, avoiding surveyor bias, and reducing labour costs in the context of a reduction in taxonomic expertise availability. Automated data collection and the possibility to analyse large data quantities solves the issue of the limited spatial/temporal cover of traditional surveying methods and allows the extension of the temporal and spatial monitoring scale (with revisits during the growing season) (Elvekjaer et al, 2024).

Camera traps can work with AI based methods to assist citizen science monitoring efforts when there are not enough volunteers to process images (Willi et al, 2019).

Limitations: Image recognition tools require the existence of a precise and representative training dataset. Comprehensive centralised reference databases are a missing piece for data analysis and powering automation and interpretation potential (Dornelas et al, 2023). The deployment of capable computers or capture devices to perform intensive computing in remote areas is challenging. Images collected by untrained users, for example in citizen science initiatives, suffer from a high variability in data quality.

Policy relevance: Smartphone image recognition apps are already being used for policy, for example evidence related to agri-environmental measures in the CAP framework. For example, farmers in Germany can use a plant species identification app to prove the occurrences of indicator plant species to receive payments for maintaining biodiverse grasslands (Elvekjaer et al, 2024; Mäder et al, 2021). The technology offers the opportunity to upscale pollinator monitoring efforts.

Use of image recognition approaches in the Mambo Horizon project

Project: Modern Approaches to the Monitoring of Biodiversity (Mambo) (Horizon project, 2022-2026). The project is developing novel monitoring methods for biodiversity, including image and sound recognition-based artificial intelligence approaches, high spatial resolution remote sensing (drone imagery, airborne LiDAR) coupled with deep learning and automated identification tools based on multimedia content. MAMBO aims to increase knowledge and advance tools for monitoring species and their habitats more comprehensively. The project also intends to build a new global community of practice for the development and application of the monitoring technologies.

Results: The project developed an open machine learning challenge dataset comprising 5 million plant species observations distributed across Europe and covering most of its flora, high-resolution rasters, land cover, elevation, and coarse-resolution data. The aim is to evaluate the models' ability to predict the species composition in 22,000 small plots based on standardized surveys.

Image recognition-based AI approaches using camera trap images (Bjerge et al, 2023a). This study used a dataset consisting of 29,960 annotated insects (including bees, hoverflies, butterflies and beetles taxa) across more than two million images. Authors used the dataset to train and compare the performance of deep learning algorithms (called "You Only Look Once - YOLO"). The highest performing models were able to detect and classify small insects in complex scenes with "unprecedented accuracy".

Evaluation of AI models for the identification and prediction of birds, plants, snakes and fungi using LifeCLEF virtual lab (Joly et al, 2023). Several methods for image identification were tested.

- Convolutional neural networks, which use three-dimensional data for image classifi-cation and object recognition, were found to be the most powerful method for im-age and sound processing.
- Automated global plant species identification based on deep learning using partici-patory sciences data (Bonnet et al, 2023).
- Hierarchical classification of insects with deep learning: A method for automated classification of live insects with camera-based systems (Bjerge et al, 2023b). The da-taset comprised 41,731 images of insects, combining images from time-lapse moni-toring of floral scenes with images from the Global Biodiversity Information Facility (GBIF). The algorithm correctly classified new insect species at higher taxonomic ranks, while classification was uncertain at lower taxonomic ranks. Moreover, auto-mated Anomaly detection could effectively flag novel taxa that were visually distinct from species in the training data.

Sources: Project webpage on cordis: https://cordis.europa.eu/project/id/101090273 and project website: https://www.mambo-project.eu/library?type=3&search=

3.9 Sound recognition (acoustic monitoring)

Acoustic monitoring technologies are based on measuring and distinguishing the sounds that animals produce for communication and navigation (Browning et al, 2017). Sound recognition can be used to study and track animals, for example, bats, birds or bees, either with static sensors or with drones (Mutanu et al, 2022).

Scope of application: Sensors can be placed in the field to get information on species distributions, behaviour and population, to build up a picture of communities of vocalising animals in a survey area, and to understand the relationship between animals and their acoustic environment (the 'soundscape') (Browning et al, 2017). The popularity of the method within ecological and conservation research has increased, with the development of various applications.

Cost and availability: The technology has rapidly developed over the last few years with advances in consumer technology (like smartphones) allowing drastic cost reduction. In parallel, developments in machine learning and computer vision allow automatic extraction of useful ecological information from many hours of sound recordings (Browning et al, 2017). Acoustic sensors are already being marketed by SMEs and used by private businesses, such as farming businesses, as well as in conservation research.

The cost and effort of bird monitoring based on passive acoustic recording was shown to be more expensive than human observation for 'normal' daytime monitoring, but acoustic monitoring has a cost advantage in cases of monitoring of rare species that require more field trips or nighttime sampling (Markova-Nenova et al. 2023).

Policy relevance: Acoustic monitoring devices are already being used by private businesses to measure their environmental impact and improve their management. They are also being used to monitor bird and bat populations, two groups that are good indicators of the biodiversity value of farmland.

Agrisound start-up – AI acoustic insects monitoring devices. Companies in the UK food industry, including Tesco, M&S and Innocent, are using the AI acoustic monitoring technology with their farmer producers to collect data that to collect data on in-field targeted interventions and to inform their environmental reporting. Examples are the monitoring of pollinator visits to fruit crops and remote beehive management.

Advantages: Sound recording devices can be deployed in the observation terrain for an extended period, either delivering data directly if the sensor is directly connected, or storing data for periodic collection, with-out causing disturbance to wildlife.

Limitations: Acoustic index values must be calibrated against ecological community data collected by other means, such as traditional ecological survey data, so the method cannot be used on its own. The acoustic indices of many habitat and taxonomic groups are still poorly understood, and some acoustic indices are still sensitive to background noise (although recent AI developments are providing solutions to this challenge). Obtaining a degree of standardisation between studies to ensure comparability and repeatability is challenging (there are many methods to process data from monitoring).

Projects using similar monitoring methods:

Developing passive acoustic monitoring for birds and pollinators

The EU BIOMON project (Horizon project, 2022-2024) developed passive acoustic monitoring (PAM) approaches using machine learning techniques to survey bird communities in agricultural farmlands across Europe. PAM allows monitoring to be done in places that are difficult to access and facilitates the targeting of nocturnal, rare or hard-to-detect species.

The research compared acoustic indices for measuring bird species richness in biodiverse sites in Cyprus, China, and Australia (Mammides et al, 2025). The use of indices addresses the challenge associated with species' overlapping vocalisations. Acoustic indices are mathematical equations designed to summarise the temporal and/or spectral distribution of acoustic energy. They offer proxies for species richness and composition.

The project also investigated the potential for extended use of Large Language Models (LLMs, such as Gemini and ChatGPt) to integrate multidisciplinary expertise in research projects (Mammides and Papadopoulos, 2024).

The project Bioacoustic AI 'machine listening' for wildlife monitoring (2023-2027) is building up on the BIOMON project and investigating artificial intelligence enhanced acoustic tools for wildlife monitoring. The project is establishing a network of professionals (BioacAI) to develop new AI methods for acoustic wildlife monitoring, using devices from leading European bioacoustics companies.

Acoustic monitoring of pollinators on solar farms: Led by the renewable energy company Low Carbon in partnership with Lancaster University and the UKRI Engineering and Physical Sciences Research Council. The study investigates how microclimatic variations within solar farms impact bees, hoverflies, and other invertebrates.

Automated moth monitoring in the UK: The UK Centre for Ecology and Hydrology developed an automated monitoring device that captures images of trapped moths and classifies them to species using automated workflows such as the AMI system Data Companion. Moths are trapped using UV and white lights. In the future, the pilot aims to integrate audible and ultrasound recording to increase the taxonomic coverage to include birds, bats, and Orthoptera. The device will be deployed in UK farms as part of the Agzero+, a five-year research programme supporting the transition towards sustainable agriculture.

Diopsis is a network of automated camera traps placed in fields paired with AI species identification in the Netherlands. The system consists of an intelligent camera in front of a yellow screen that is attractive to insects. Photos are sent via a data connection to a central server.

3.10 DNA-based methods

Environmental DNA (E-DNA) is a novel technology using genetic material (skin cells, scales, hair, faeces, etc.) shed by animals in their environment to monitor species diversity (WWF 2022). Genetic material is extracted from a sample of soil, water, air, or snow, for example from soil particulate matter, or pollen sampling in the air (WWF 2022). The DNA fragments are amplified and sequenced in the lab using molecular techniques to detect species presence or absence, each sample containing the genetic information of dozens to hundreds of animals (Sahu et al, 2023).

DNA metabarcoding allows the mapping out of multiple taxa within the same DNA sample with a high taxonomic resolution (Nørgaard et al, 2021). The results can be used to investigate how the measured biodiversity relates to functional diversity, and therefore how it influences the provision of multiple ecosystem functions, for example how soil bacterial and fungal functional diversity corresponds to key components of soil health.

Scope of application: E-DNA is useful for monitoring species distribution across taxa groups (Dornelas et al, 2023) and identifying species (Nørgaard et al, 2021). eDNA can be extracted from water, air or soil samples without disturbing the occurring species (Duley et al, 2023). It is a potent tool in freshwater and marine eco-systems for identifying amphibians, aquatic invertebrates and macrofauna without using damaging sampling methods (Dornelas et al, 2023; Sahu et al, 2023). E-DNA can be sampled in media such as soil where it is very difficult to impossible to extract and identify intact organisms through manual methods.

Molecular methods are being used to examine species interactions with their environment and to quantify the ecosystem services they are providing. For example, the analysis of insects' faeces, gut contents, or parasite presence to identify their predators, food, and foraging sites (including flower visitation) (van Klink et al 2022). DNA metabarcoding of the collected pollen on bees shows which flowers they have visited and how far and where they forage.

Users and usability: Molecular biology expertise is needed to perform and interpret results. With the right sampling kit, sampling can be conducted by individuals with limited expertise (Sahu et al, 2023). Access to DNA databases can be a barrier and a cost factor.

Availability: E-DNA is a relatively mature technology compared to other novel monitoring techniques (Dornelas et al, 2023). To encourage collaboration and interoperability, data needs to be stored and retrieved in online repositories throughout Europe with explicit quality check policies. The Genomic Observatories Meta-Database (GEOME) captures the who, what, where and when biological samples were collected, which ensures the interoperability and reusability of biological samples.

E-DNA already has commercial uses, with companies like Oxford Nanopore and NatureMetrics offering services (Dornelas et al, 2023; NatureMetrics 2024).

Advantages: E-DNA is a relevant tool to study species distribution and monitor target species, even at low abundance. Individual species can be singled out and monitored with this technology (WWF 2022). It enables rapid monitoring and detection of species when traditional monitoring or taxonomic expertise is not possible or available. It is a non-invasive method for identifying amphibians and fish in aquatic ecosystems. E-DNA is fast to implement and reduces processing labour, chiefly for taxonomic error and resolution (Dornelas et al, 2023; Sahu et al, 2023).

Limitations: Comprehensive reference databases are a missing piece for data analysis. E-DNA monitoring is not yet able to measure species or community abundance, and genetic diversity, because not enough DNA databases are available for comprehensive community level analyses (Dornelas et al, 2023).

Policy relevance: The method is relevant for water quality monitoring (Water Framework Directive), soil quality monitoring (CAP, Soil Monitoring Law), monitoring of invasive alien species (IAS regulation), and other environmental legislation requirements.

EU LUCAS soil survey: soil DNA metabarcoding

Monitoring and analysis method: The EU Land Use/Cover Area frame statistical Survey carries out a systematic soil sampling across the EU every two years. Sampling locations cover both semi-natural and highly-managed environments, with six vegetation cover types subjected to an increasing land-use perturbation gradient, including extensively- and intensively-managed grasslands, and permanent and non-permanent croplands. The 2022 sampling survey took 1 410 fresh samples that were analysed for their bacterial and fungal biodiversity through a DNA metabarcoding approach. Bacteria are assessed in zero-radius operational taxonomic units (zOTUs) and fungi as operational taxonomic units (OTUs). Functional databases offer a fast-functional screening of microbial data. In the 2018 samples, bacterial zOTU assignments were done based on 16S, a conserved DNA region that can discriminate bacteria at the finest taxonomic level (i.e. strain). For bacteria, the results were calculated as bacterial observed zOTU richness and Shannon diversity index. The results were compared in the context of the other survey results on ecosystem functions (primary production, enzymatic activity, soil respiration, etc.), soil properties and climatic data.

Results: The analysis of the 2018 survey showed that highly-managed habitats (e.g. croplands) represent a distinct soil biodiversity pool from less-disturbed sites such as natural or semi-natural systems (Labouyrie et al 2023). The analysis found that highly-disturbed environments contain significantly more bacterial chemoheterotrophs, harbour a higher proportion of fungal plant pathogens and saprotrophs, and have less beneficial fungal plant symbionts compared to woodlands and extensively-managed grasslands.

Further developments: The researchers conclude that the analysis would benefit from additional experimental works like (i) metagenomics, metatranscriptomics and metaproteomics to quality-check the predicted functional annotation (metagenomic) and assess the functionally active communities (metatranscriptomics and metaproteomics), (ii) metabolomics to better understand community functional potential by quantifying the presence of functional products (i.e. metabolites) in the environment, and (iii) a cause-effect analysis (e.g. linking the occurrence of putative plant pathogens to detrimental plant growth and reduced yield in agricultural fields) (Labouyrie et al 2023).

Source: Labouyrie et al (2023); JRC ESDAC https://esdac.jrc.ec.europa.eu/content/lucas-2022-topsoil-data

3.11 Citizen science – scorecards and indicator transects

Farmers and their advisors use simple scoring systems or indicator transects in the field to monitor biodiversity - a form of citizen science. The methods are used to score the condition of the parcel according to fixed thresholds. The scheme supports the maintenance (or restoration) of the good condition of certain habitats in agricultural land. The payment is determined by the condition, with a minimum threshold condition below which the parcel is not eligible for the payment. The scoring thresholds may be based solely on the occurrence of plant species that are good indicators of the habitat quality, or on a range of indicators, that are determined from ecological knowledge.

Scope of application: The method is mainly used for grazing land or meadows that are Annex I habitats protected by the Habitats Directive, either inside or outside Natura 2000 protected areas. The ecological integrity of the field or patch is assessed based on the presence of indicator species and/or indicators of positive or negative management.

Availability and cost: Methods are provided to both farmers and advisors or data collectors at no cost by the agricultural payment agency. In some schemes, the farmer or the farmer and advisor together fill out a form providing information and submit it to the agency. In other schemes, the farmer (after training) does the monitoring alone and submits the result. A proportion of the results are then verified independently by experts. The assessment methods are simple so that farmers can readily learn and do the checking within a few hours. The method is available on paper, as an Excel file, or as a phone application. In some cases, the farmer submits the data directly, in others the farm advisor does it.

Advantages: Very simple to use and understand and enables farmers to engage in biodiversity monitoring and preservation. The methods increase farmers' understanding and motivation. The scoring method enables farmers to see where they can improve their score in the next season or to verify if their management of the fields is maintaining their biodiversity value.

Limitations: The schemes do not generate biodiversity data that can be directly fed into wider biodiversity monitoring programmes, as not all farmers with such habitats enter their fields into the schemes, but the results can be used to track trends over time on the agricultural areas that are under the schemes.

Policy relevance: Payments to farmers under the Common Agricultural Policy are increasingly using a result-based set-up, where the payment is conditional to the achievement of a precise environmental result. These types of payment schemes are in place in Ireland, France, Germany, and other countries. In Germany, a national eco-scheme and regional agri-environment schemes offer payments for hay meadows based on maintaining a minimum presence of indicator plant species in the meadow, measured by the farmer every summer using an indicator sheet on a transect. The ACRES scorecard system has been established as the method for payment of the Irish Collective Agri-environment programme (ACRES) in the Irish CAP strategic plan 2023-2027. Farmers receive payments by results based on the scoring of their field (positive and negative indicators, and assessment of threats and pressures).

Species-rich grassland agri-environment scheme in Germany

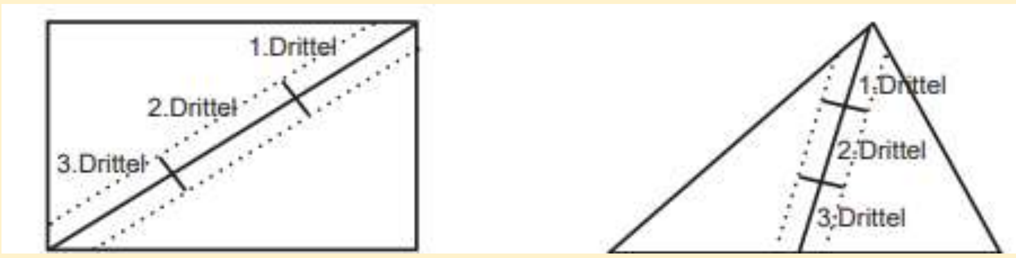
Policy measure: Species-rich grassland (Artenreiches Dauergrünland) - Baden-Württemberg -Eco-Scheme 5 and FAKT II programme implementation.

Description: This agri-environment scheme in Southwest Germany pays farmers managing species-rich grassland (both meadows and pastures) containing at least 4 or 6 key plant species. A regional catalogue for Baden-Württemberg lists 30 key species that farmers must look for, with pictures to make recognition easier. The catalogue of indicators includes highly visible plant species or groups (genera) flowering reliably in spring. Farmers also must record when they mow, pasture or fertilise their land, but there are no obligations concerning what they can or cannot do. Farmers are paid €230 per hectare for the field parcels in which 4 indicator species are found in each of the transect thirds and €260 per hectare for fields with 6 indicator species.

Monitoring methods: The farmer walks through a diagonal transect across their field during the flowering season (usually between mid-May and mid-June) and must observe at least 4 or 6 species from the catalogue in each third of the transect to meet the payment conditions. The plant species catalogue in Baden-Wurttemberg is built to be user-friendly, so that species can easily be recognized, and their presence registered by ticking off a box in the list.

Project results: This scheme exists since 2000. Around 4 800 farmers are today enrolled in the scheme, with 44 000 ha of grassland, which amounts to 10% of all grassland in the federal state. Farmer uptake of the scheme has been challenged by the greater attractiveness of growing biomass for local bioenergy plants.

Diagram of the walk patterns



Example of the form farmers must fill out

Muster# für die Dokumentation der gefundenen Kennarten

Kennarten und Kennartengruppen / Drittel	Beispiel 33/1 Heuwiese 3.6.2023 1.	2.	3.	1.	2.	3.
Augentrost-Arten (1) Wiesen- u. Steifer A.*						
Baldrian-Arten (2) Kleiner u. Arznei Baldrian						
Bärwurz (3)						
Gewöhnliches Zittergras (4)		X	X			
Kohl-Kratzdistel (5)						
Margerite-Arten* (6)		X	X			
Blutwurz (7)						
Echtes Labkraut (8)						
Flügelginster (9)						
Gelbblütige Kleearten (10) Gewöhnl. u. Sumpf-Hornklee, Hopfenklee, Gewöhnl. Wundklee, Gewöhnl. Hufeisenklee		X				
Wiesenbocksbart-Arten* (11)		X	X			
Klappertopf-Arten (12) Zottiger, Kleiner u. Schmalblättriger K.	X	X	X			
Kleine Habichtskräuter (13) Kleines u. Öhrchen-H.						
Milch- und Ferkelkräuter (14) Steifhaariges u. Herbst-M., Gewöhnl. F.						
Pippau-Arten (15) Grüner, Sumpf-, Wiesen- u. Weichhaariger P.	X					
Schlüsselblumen (16) Große u. Arznei-S.						
Sumpfdotterblume (17)						
Bach-Nelkenwurz (18)						
Flockenblumen (19) Berg-, Perücken-, Wiesen- u. Schwarze F.	X		X			
Futter-Esparsette (20)						
Kartäuser-Nelke (21)						
Lichtnelken (22) Tag- u. Kuckucks-L.		X				
Rotklee (23)	X	X	X			
Storchschnabel-Arten (24) Wiesen-, Wald-, Sumpf- u. Blut-S.						
Tauben-Skabiose, Acker-Witwenblume (25)			X			
Thymian-Arten (26) Arznei- u. Sand-T.						
Wiesen-Knöterich (27)						
Wiesenknopf-Arten (28) Kleiner u. Großer W.	X					
Glockenblumen (29) Knäuel-, Rapunzel-, Wiesen- u. Rundblättrige G.	X					
Kreuzblumen (30) Sumpf-, Gewöhnl. u. Schopfige K.						
Sumpf-Vergissmeinnicht (31)						
Teufelskrallen (32) Schwarze, Ährige u. Kugel-T.						
Wiesen-Salbei (33)		X				
Summe der Kennarten	**6**	**8**	**7**			

* Umfasst eine Artengruppe (nach Buttler et al. 1998: Florenliste von Baden-Württemberg. Reihe Naturschutz-Praxis – Artenschutz, Band 1. Hrsg. Landesanstalt für Umweltschutz Baden Württemberg, Karlsruhe. 486 S.)

 # Eine Excel-Vorlage der Tabelle zur Dokumentation ist im Infodienst und unter www.lazbw.de verfügbar.

LAZBW

Sources:

Result based payment network’s overview of the project

Agricultural Centre Bader-Württemberg guidance

IEEP’s review of the scheme

Irish ACRES Scorecard System

Scheme: Agri-Climate Rural Environment Scheme, Ireland CAP Strategic Plan, 2023-2027. The ACRES results-based agri-environment scheme relies on a scoring system undertaken by advisors visiting farms and scoring together with the farmer. Farmers receive annual payments on a 5-year contract based their parcels' score for that year, according to positive and negative indicators for ten ecosystem types (including grassland, peatland, scrub/woodland, rough grazing, coastal grassland). The advisor holds a pre-scoring discussion with the individual farmers. After the visit, farmers receive feedback on the scoring, as well as management and potential non-productive investments recommendations.

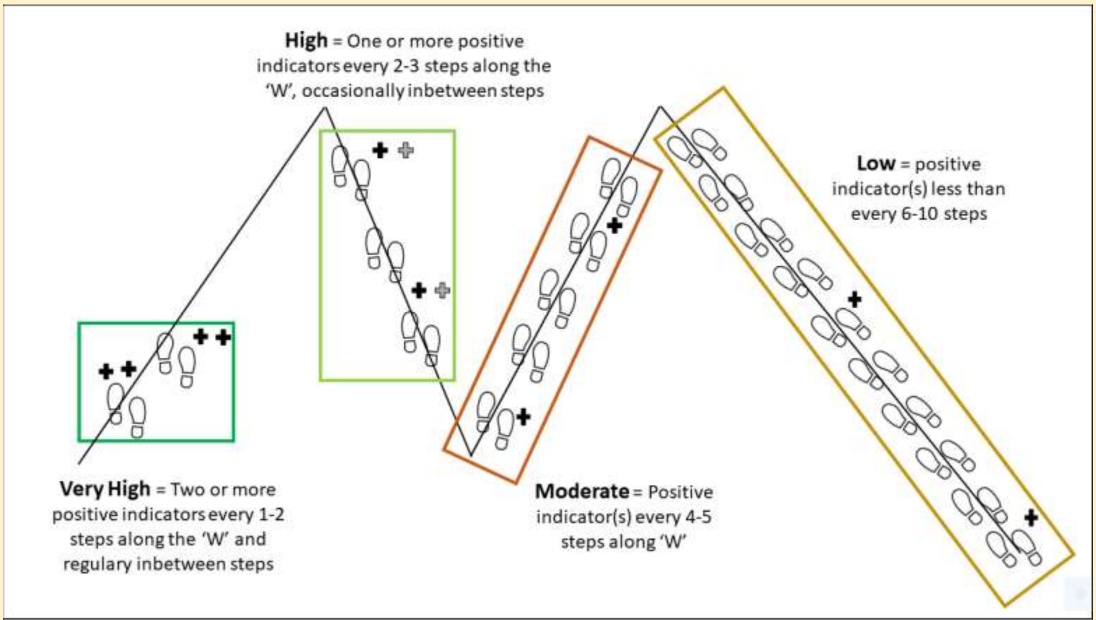
Monitoring method: Scorecards and field visit. Before the visit to the farm, the advisor plans the walking route for the field's scoring and checks that appropriate equipment for the scoring is available. Field scoring is undertaken in spring/summer months and is submitted via an online form. The AgriSnap precision photo app for smartphones allows farmers or their advisor to send land parcel geotagged pictures and information to the department to validate scheme payments. A geotagged photograph is one that contains the Global Positioning System (GPS) location co-ordinates of the position of where the photo was captured.

The scoring is based on an ecological integrity assessment and an assessment of threats and future prospects. The scoring includes positive indicators, such as the presence of indicator plant species, and negative indicators, such as signs of soil erosion or invasive species. The aggregation determines the field's scoring, in association with other parameters (like vegetation structure). Positive indicators are aggregated following a simple method, based on the number of positive indicators per walking steps.

Accessibility and cost: The method and the AgriSnap application is free for farmers. A user-friendly booklet details indicators for each ecosystem type (Talmhaiochta, 2024). Mobile apps and training courses are available for farmers to get familiar with the system. The development of the AgriSnap application cost the government €300 000.

Example of a scorecard for rough grazing land:

The method for walking the parcel being scored:



Sources: ACRES handbook (Talmhaiochta, 2024)

Agriland.ie (25 March 2024) DAFM spends €300,000 developing AgriSnap app.

4. INFORMING POLICY FROM BIODIVERSITY MONITORING

Developments in biodiversity monitoring technologies and methods are rapidly advancing and generating much larger biodiversity data sets, with higher frequency, scope, and detail than was possible just a few years ago.

There are, however, still significant differences of opinion and a lack of trust in some techniques, which require dialogue and agreements on standards and governance. There is also a need for further development of methods to process and manage the data, despite the rapid developments in the use of artificial intelligence (AI). Technologies should not and cannot completely replace taxonomic expertise and on the ground surveying – there is an ongoing need to establish and maintain its accuracy by testing and ground-truthing with experts with the taxonomic expertise gained from work in situ.

4.1 Advantages of new technologies

Using automated technologies avoids surveyor bias, reducing labour costs and providing a partial solution to the decline in taxonomic expertise availability. These technologies are opening up opportunities to develop large-scale biodiversity monitoring schemes that can process large amounts of data over greatly extended temporal and spatial monitoring scales – day and night, throughout the growing season, and in remote or inaccessible places such as tree canopies.

- **Remote sensing imaging techniques** allow continuous and repeatable monitoring that already provides efficient and cost-effective means to determine plant and ecosystem diversity or ecological structures over large areas (Wang and Gamon, 2019).

- **DNA-based monitoring – eDNA and metabarcoding** – is already widely used for measuring water quality, looking for the presence of invasive alien species, and more. With rapid advances in reference databases and knowledge, its use for the previously 'black box' area of soil biodiversity, the bacteria, fungi, and other micro-organisms in soil, is being mainstreamed in the EU LUCAS survey.

- Automation through **robotics** offers quick species identification from **images or sound** recordings with the help of machine learning algorithms. Their use can reduce the need for extra time and resources as unskilled labour or volunteers can do the fieldwork. Image recognition solves the issue of the limited spatial and temporal cover of traditional surveying methods. It offers the opportunity to up-scale citizen monitoring projects, which generate large quantities of data.

- **Citizen science** approaches with farmers, using simple scorecards, indicators, and field transect or scanning methods, increase the understanding and engagement of farmers with managing their land for biodiversity (Ruck et al, 2024).

Access to improved biodiversity monitoring techniques can improve the monitoring quality in payment schemes and other incentive programmes. This can incentivise more farmers to enrol in results-based schemes where payments are dependent on the results of the monitoring, if they have greater trust in the results, or the techniques allow more differentiated results and payments (Zavalloni et al 2025). Monitoring developments can therefore contribute to the wider adoption of such schemes.

Automated biodiversity monitoring techniques are also a key component of biodiversity credit and certificate methods and markets, allowing the standardised and independent measurement of outcomes.

4.2 Limitations and challenges of new technologies

A recent expert review of advances in biodiversity monitoring technologies (Dornelas et al, 2023) identified the advantages and disadvantages of progress so far. Some technologies are not ready to be deployed yet and more developments are needed before committing to the new methodology (i.e. some methods lack enough validation of their ability to reliably target taxa groups and habitats). The experts point to the need for more validation studies and the need for long term funding for biodiversity monitoring. Key points highlighted were:

- **Species identification** remains a large hurdle for automation even if data are available to 'train' the system. This is a limitation to using such methods for rare species monitoring, given that there is much less data available for reference and training.

- Automation could **unintentionally "lock in" previous biases and errors in taxonomy**, and any automation system should have an auditing mechanism with expert supervision to avoid this.

- **Need for in situ observations and taxonomic experts**: There is a consensus among experts that these technologies should supplement rather than replace in situ observations for both scientific and social reasons.

- **Hidden costs**: Deploying a network of automated monitoring devices still requires infrastructure for maintenance and experts to verify the results, so the real costs are sometimes underestimated.
- **Equality of access issues**: governments, conservation agencies, and individuals vary greatly in their ability to access and pay for these technologies. For the public sector, there is the challenge of paying the costs on a long-term basis.

4.3 Key messages

- Technologies and the methods and tools to process data are developing rapidly, and **human trust in the reliability of the results** sometimes takes more time to develop. A current example is the conflicts in the discussions on the proposed EU forest monitoring law that question the reliability of remote sensing of forest characteristics and statistics.
- New technologies **cannot replace specialist taxonomic knowledge** and traditional methods, as the technologies need to be calibrated, tested or taught, and verified by human expertise. Human taxonomic expertise is still needed for describing new species, for building and improving reference libraries, and for validating results from automated monitoring. However, technologies can save a great deal of labour and save time on species identification, upscale and expand monitoring capabilities, and some can enable nonlethal monitoring.
- Before new technologies can be deployed for large-scale biodiversity monitoring, international standards need to be developed via collaboration across borders, projects, and technologies. There is a need for large-scale collaboration to develop international databases and metadata standards. To encourage biodiversity **data sharing and interoperability**, biodiversity monitoring schemes are being connected in the Biodiversa+ project BioDash, whilst the EuropaBON project developed a standardisation framework for reporting (Breeze et al, 2023; Naeslund et al, 2023).
- Hardware and software development should follow the **principles of fair and open access** to data and developments. This allows greater sharing of scientific expertise and development, and accessibility to all to use the technologies.
- The European Commission is about to launch a pilot for a **European Biodiversity Observation Coordination Centre**. The objective is to improve the availability, quality, coherence, timeliness, and access to biodiversity data

in the EU, while taking due account of the objective of the Commission to reduce administrative burden (EC 2025). The centre should support the Member State bodies responsible for the implementation of the Nature Restoration Regulation, the Birds and Habitats Directives, the Water Framework Directive and the Marine Strategy Framework Directive. This pilot will build on the proposal of the EuropaBON project for a biodiversity observation network (BON) for Europe based on 84 Essential Biodiversity Variables (EBVs) (Lumbierres et al 2025).

- Where publicly funded payments or sanctions are linked to measurements made with remote sensing or other automatic technologies, the contractors or recipients of such payment schemes or inspections should have **access to a channel to question and ask for a review of decisions, a means of submitting alternative evidence, and access to justice**. For example, farmers should be able to challenge CAP payment eligibility decisions on their parcels by submitting geo-tagged photos of the parcel to show that it does meet the eligibility criteria.

5. REFERENCES

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Nature Restoration Regulation: Regulation (EU) 2024/1991 on nature restoration and amending Regulation (EU) 2022/869

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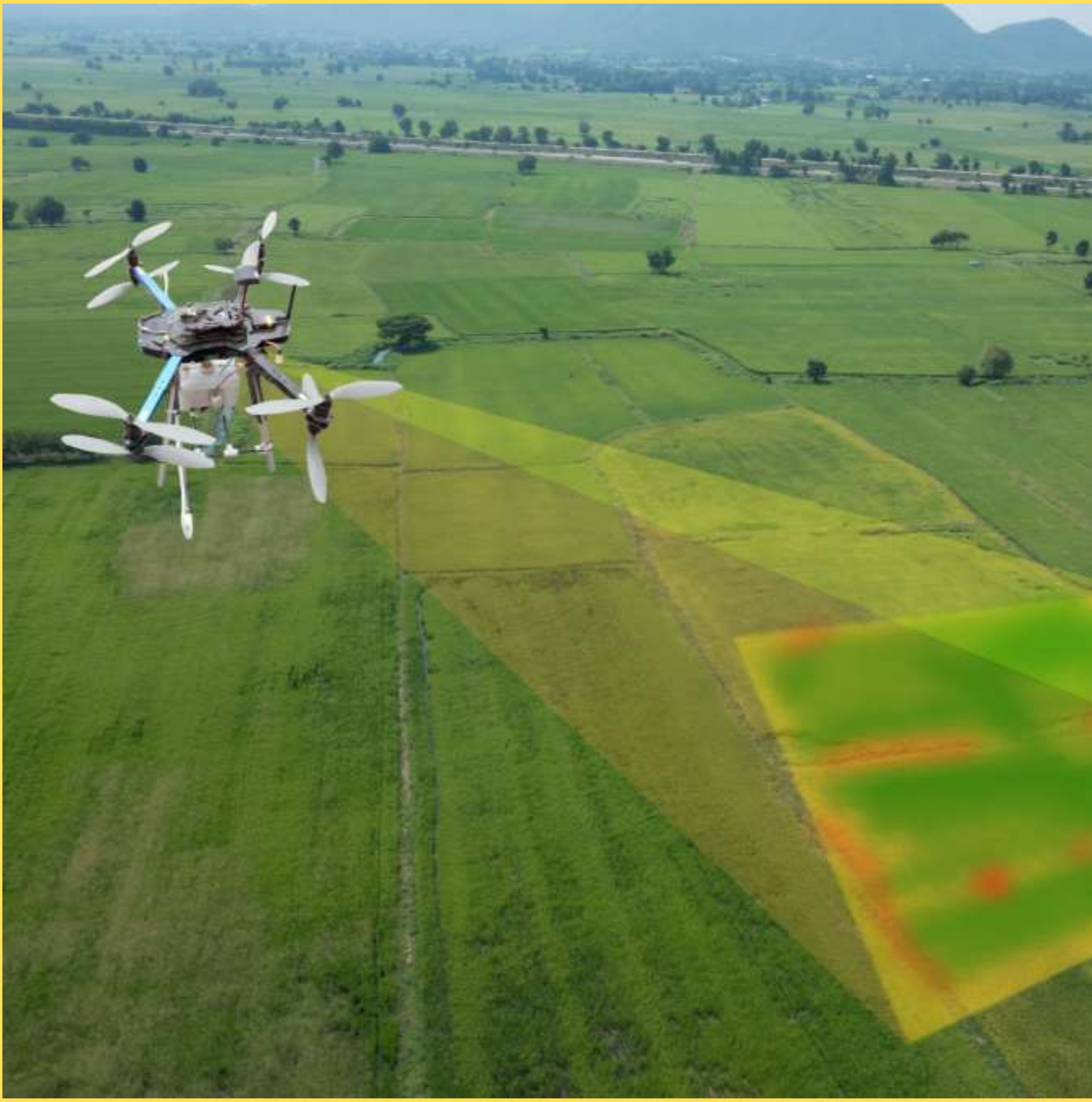

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