Alliance for IoT and Edge Computing Innovation

Role of IoT and Edge Computing in addressing biodiversity and environmental monitoring

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Executive Summary

The European Commission presented in 2019 the European Green Deal as the European response to the serious challenges posed by climate change and environmental degradation. Biodiversity and environment are key areas under the umbrella of the Green Deal. In particular, biodiversity/environment observation and understanding has been identified as a key supporting element to fight climate change and achieve a sustainable economy, prosperous for all European citizens. Spurred by the EU Green Deal policy, a number of relevant monitoring initiatives are currently being launched at different scales, with ambitious objectives, towards the preservation of landscapes and biodiversity. After reviewing in Section 2 the most relevant initiatives for biodiversity and environment monitoring, the current paper focuses on the use of Internet of Things technologies for fulfilling the monitoring needs. Section 3 analyses the concept of IoT-based monitoring and presents four illustrative use cases in different fields, as well as a short list of commercial solutions. Based on the preliminary findings, Section 4 finally summarises the main gaps identified and provides recommendations on the way to go. It is important to note that the current paper is on-going work and will be refined in subsequent iterations in order to deepen the preliminary analysis and stock-taking.

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1. Context of biodiversity and environmental monitoring

The European Commission (EC) presented in 2019 the European Green Deal [EC19], one of the six core political guidelines for the European Union in the period 2021-2027. The Green Deal is the European response to the serious challenges posed by climate change and environmental degradation.

The Green Deal comprises numerous areas of intervention encompassing climate and energy, agriculture and industry, transport and environment, among others, and sets out ambitious objectives towards the decarbonisation of EU economy while ensuring economic growth and prosperity for all EU citizens. The ambition of the Green Deal is commensurate to the resources committed to support its action plan, representing roughly one third of the 2021-27 budget for the EU.

Biodiversity and environment are key areas under the umbrella of the Green Deal. In 2020, the EC adopted the Biodiversity Strategy 2030 [ECDGE21], with the overall objective of putting EU's biodiversity on the path to recovery by 2030, as it is an essential element to achieve higher resilience to climate change, forest fires, food insecurity and disease outbreaks.

The Biodiversity Strategy sets out a series of actions and objectives/commitments (quantitative and qualitative) for 2030, in line with the ambition of protecting and restoring nature in the European Union (the following is a non-exhaustive list):

1. **Legally protect at least 30% of the EU's land area and 30% of the EU's sea area**
2. **Strictly protect at least a third of the EU's protected areas**
3. **Effectively manage all protected areas, including proper monitoring measures**
4. **Reverse the decline in pollinators**
5. **Reduce the use of chemical pesticides by 50%**
6. **Bring at least 10% of the agricultural area under high-diversity landscape features**
7. **At least 25% of the agricultural land is under organic farming, and significantly increase the uptake of agro-ecological practices.**
8. **Reduce the use of fertilisers by at least 20% and reduce the losses of nutrients from fertilisers' use by 50%**
9. **Eliminate the use of chemical pesticides in sensitive areas such as EU urban green areas**

The impact of agricultural activity in biodiversity is well recognized [Dudley17, IPBES18]. At the same time, the health of agriculture as a key economic sector in Europe depends on the health of nature, and their interdependence has become ever clearer in recent years. Hence, it is not surprising that a number of objectives in the Biodiversity Strategy are directly related to agriculture, and in turn shared with the Farm to Fork Strategy [EC20a] released in 2020 by the EC.

The strong relationship between agriculture and biodiversity is one of the reasons for the relevance that the latter has gained in the new Common Agricultural Policy (CAP) [EC21], in line with the Green Deal general objectives. In fact, both policies share the common objective [EC20b] of reinforcing the protection of biodiversity and ecosystem services within agrarian and forest systems. Indeed, the new CAP explicitly introduces support measures for agroecology and other practices ("eco-schemes") that improve the environmental performance of farmers. In this way, the CAP aims to become an effective instrument to contribute to the Biodiversity objectives, such as Objective #6 above (10% increase of high-diversity landscape features) through the CAP Strategic Plans that must be implemented at regional level.

In summary, a major shift of the new agriculture and environmental EU policies can be clearly seen towards preserving landscapes and biodiversity. A consequence of this objective is the need for measurement and monitoring capabilities that are scalable, reliable and practical. This will require significant investments in IoT monitoring tools and mechanisms, as explained in the previous AIOTI paper on agroecology and the Green Deal [AIOTI22], in particular in recommendation #3: *Digital tools for reliable and certified measurement of environment indicators ("digital evidences") affected by agricultural activity, on a farm level*.

Biodiversity measures the number, variety, and variability of living organisms (animal and plant species, fungi, micro-organisms). It includes diversity within species, between species, and among ecosystems. The term also covers how diversity changes from one location to another and over time [UN92, Gaston04]. A significant challenge remains that inventories of species remain incomplete – mainly due to limited field sampling to provide an accurate picture of the extent and distribution of all components of biodiversity. Ongoing research has shown a global collapse in biodiversity [WWF22] measured in a variety of ways (variety of species, species range, population sizes). Nonetheless measuring the biodiversity present on a specific farm or narrowly defined geographical region presents a number of challenges which need to be borne in mind when using or developing further tools for ecological monitoring including measuring change in biodiversity [Gabel18].

A recent policy brief from the EUROPABON project addresses a number of challenges that greater monitoring of biodiversity faces in Europe. According to this analysis "the current biodiversity monitoring system in Europe is fragmented, lacking in standardisation, and insufficiently resourced". Lack of data from the agricultural sector is also mentioned . The brief further identifies the role that new technologies may play in enhancing future capabilities for biodiversity monitoring such as 24/7 automated monitoring, biologgers, remote sensing and eDNA. In short, there is a great deal of work to be done and IOT technologies have a significant role to play.

2. Overview of related, relevant initiatives

In this section a short description of ongoing and most prominent biodiversity-related initiatives on EU level is presented.

2.1. Strategic Initiatives and Services

EU Mission: A Soil Deal for Europe

The main goal of the Mission 'A Soil Deal for Europe' is to establish 100 living labs and lighthouses to lead the transition towards healthy soils by 2030.

Life on Earth depends on healthy soils. Soil is the foundation of our food systems. It provides clean water and habitats for biodiversity while contributing to climate resilience. It supports our cultural heritage and landscapes and is the basis of our economy and prosperity.

However, it is estimated that between 60% and 70% of EU soils are unhealthy. Soil is a fragile resource that needs to be carefully managed and safeguarded for future generations. One cm of soil can take hundreds of years to form, but can be lost in just a single rainstorm or industrial incident.

The Mission leads the transition towards healthy soils by:

- funding an ambitious research and innovation programme with a strong social science component
- putting in place an effective network of 100 living labs and lighthouses to co-create knowledge, test solutions and demonstrate their value in real-life conditions
- developing a harmonised framework for soil monitoring in Europe
- raising people's awareness on the vital importance of soils

EU Mission: Restore our Ocean and Waters

This initiative aims to achieve the marine and freshwater targets of the European Green Deal, such as protecting 30% of the EU's sea area and restoring marine eco-systems and 25,000 km of free-flowing rivers. As one of its objectives, the Mission will prevent and eliminate pollution by, for example, reducing plastic litter at sea, nutrient losses and use of chemical pesticides by 50% and it will also contribute to make the blue economy climate-neutral and circular with net-zero maritime emissions. Cross-cutting enabling actions will support these objectives, in particular broad public mobilisation and engagement and a digital ocean and water knowledge system, known as Digital Twin Ocean.

Destination Earth (DestinE)

Destination Earth (DestinE) aims to develop – on a global scale - a highly accurate digital model of the Earth to monitor and predict the interaction between natural phenomena and human activities. As part of the European Commission's Green Deal and Digital Strategy, DestinE will contribute to achieving the objectives of the twin transition, green and digital.

Users of DestinE, will be able to access and interact with vast amounts of Earth system and socio-economic data in order to:

- Perform highly accurate, interactive and dynamic simulations of the Earth system, informed by rich observational datasets: for example allowing to focus on thematic domains of societal relevance such as the regional impacts of climate change, natural hazards, marine ecosystems or urban spaces.
- Improve prediction capabilities to maximize impact: for example to protect biodiversity, manage water, renewable energy and food resources, and mitigate disaster risks in a changing world.
- Support EU policy-making and implementation: for example, to assess the impact of existing environmental policies and legislative measures and support future evidence-based policy-making.
- Exploit the potential of distributed and high performance computing (HPC) and data handling at extreme scale: for example through an interactive platform that will host complex digital twins and comprehensive toolkits to develop and operate analytics-based models, with full access to vast amounts of diverse data.

Europe's industrial and technological capabilities will be reinforced through, for example, the simulation and observation of the entire Earth system and the use of artificial intelligence (AI) for data analytics and predictive modelling.

Knowledge Centre for Biodiversity

The Commission established in 2020 the Knowledge Centre for Biodiversity (KCBD) (https://knowledge4policy.ec.europa.eu/biodiversity_en) in close cooperation with the European Environment Agency. The strategy foresees that the KCBD will:

- Track and assess progress by the EU and its partners, including in relation to implementation of biodiversity-related international instruments;
- Foster cooperation and partnership, including between climate and biodiversity scientists; and
- Underpin policy development.

The KCBD is co-chaired by DG Environment and the Joint Research Centre and it is steered by a committee with members from four other Commission services and the European Environment Agency. The KCBD is establishing a close cooperation with other Commission services and with a broad range of research networks and collaborators.

Digital Observatory for Protected Areas

The Digital Observatory for Protected Areas (DOPA) (https://dopa.jrc.ec.europa.eu/dopa/) is a set of web services and applications that can be used primarily to assess, monitor, report and possibly forecast the state of and the pressure on protected areas at multiple scales. The data, indicators, maps and tools provided by the DOPA are relevant to a number of end-users including policy makers, funding agencies, protected area agencies and managers, researchers and the Convention on Biological Diversity (CBD). The information can be used, for example, to support spatial planning, resource allocation, protected area development and management, and national and international reporting. Using global reference datasets, the DOPA supports global assessments but also provides a broad range of consistent and comparable indicators at country, ecoregion and protected area level.

BIODIVERSA – European Biodiversity Partnership

BIODIVERSA (https://www.biodiversa.eu/) is the European co-fund partnership focusing on research on biodiversity with an impact on society and policy, and forms an important part of the European Biodiversity Strategy (mentioned in Section 1). The partnership involves research programmers and funders from 36 EC and associated countries, with fiver key objectives: 1) Support research and innovation on biodiversity through annual calls for projects and capacity building; 2) set up a networked of harmonised biodiversity monitoring schemes; 3) contribute to Nature-Based Solutions in the private sector; 4) ensure science based support for policy makers; 5) strengthen the impact of European research in a global context. The partnership has published reports on the need for harmonisation of biodiversity monitoring across the EU.

European data spaces

Under the EU Data Strategy, the European Commission has envisioned the creation of interoperable European data spaces in several strategic sectors and domains of public interest, supported by the Digital Europe programme. Data spaces are intended to enable a true European data market through data sharing by removing trust and data governance barriers, as well as providing technical tools and infrastructures. In the recent overview [EC22] about the state of play of the different data spaces projected by the EC, we can find information about two of them which are strongly interconnected to biodiversity monitoring.

- The **Green Deal data space**, which aims *"to facilitate evidence-based decisions and expand the capacity to understand and tackle environmental challenges"*. Among other objectives, it will support data services for the monitoring of environmental objectives set out in the biodiversity strategy [ECDGE21], providing access to environmental geospatial data.

- The **Agriculture data space**, which will *"facilitate trustworthy pooling and sharing of agricultural data between private as well as with public authorities"* in a way that *"contributes to increased competitiveness and the sustainability performance of the sector, e.g. through increasing the effectiveness of precision farming applications, and thus to the ambitions laid out in the Common Agricultural Policy and the Farm-to-Fork-Strategy"*.

These initiatives are being funded as part of the overall funding for Digital Europe.

2.2. European projects

EU BON - European Earth Observation programme (Copernicus) and biodiversity monitoring

The main objective of EU BON (European Biodiversity Observation Network) is to build a substantial part of the Group on Earth Observation's Biodiversity Observation Network (GEO BON). A key feature of EU BON is the delivery of near-real-time relevant data – both from on-ground observation and remote sensing – to the various stakeholders and end users ranging from local to global levels.

EU BON supports national and international authorities, as well as private stakeholders and the general public with integrated and scientifically sound biodiversity data analyses. The project intends to develop a full-scale model for a durable mechanism for higher level integration of biodiversity information providers and users through a network of networks approach scalable from local to global biodiversity observation systems.

EUROPABON - Europa Biodiversity Observation Network: integrating data streams to support policy

This project (https://europabon.org) has as its main objective to identify user and policy needs for biodiversity monitoring and investigate the feasibility of setting up a center to coordinate monitoring activities across Europe. Together with stakeholders, EUROPABON will assess current monitoring efforts to identify gaps, data and workflow bottlenecks, and analyse cost-effectiveness of different schemes. Among its many objectives the project will adapt the generic Essential Biodiversity Variables (EBVs) and Essential Ecosystem Services Variables (EESVs) and their characteristics (spatial, temporal and biological entity, scope and resolution) to address the specific user needs. The project will also identify gaps in the current monitoring of European biodiversity, including thematic, taxonomic, geographic and temporal gaps, and how novel technologies and modelling approaches can assist in filling those gaps.

BioDT: a Digital Twin prototype to help protect and restore biodiversity

The Biodiversity Digital Twin prototype provides advanced models for simulation and prediction capabilities, through practical use cases addressing critical issues related to global biodiversity dynamics. BioDT exploits the LUMI Supercomputer and employs FAIR data combined with digital infrastructure, predictive modelling and AI solutions, facilitating evidence-based solutions for biodiversity protection and restoration. The project responds to key EU and international policy initiatives, including the EU Biodiversity Strategy 2030, EU Green Deal, UN Sustainable Development Goals, Destination Earth. A group of use cases will test the digital infrastructure developed in the project which include covering species responses to environmental change, modelling threats for species of policy concern, genetically detecting biodiversity, and species interaction with humans. The project involves major biodiversity research infrastructures that curate large data sets on biodiversity from Europe and around the world. A significant challenge faced by the project is that while the conventional uses of Digital Twins (e.g. in manufacturing or factory control) assume continuous feeds of data from IoT sensors, such data streams are still largely unavailable in the biodiversity community. Most data sets are time series snap shots (usually annual samples) for specific species or geographic locations.

2.3. Standardisation initiatives

A key aspect for successful biodiversity and environmental monitoring is the standardisation of data. As is usual in all standardisation efforts, there are a number of different communities undertaking activities relevant to data standardisation in parallel without sufficient coordination or alignment. These include the following:

- **Essential Biodiversity Variables** (EBVs) and Essential Ecosystem Services Variables (EESVs) – a great deal of work has been undertaken by the biodiversity community to develop standards for biodiversity monitoring data. EBVs provide a way to aggregate the many biodiversity observations collected through different methods such as in situ monitoring or remote sensing. Efforts are underway to ensure that data collected following these standards adheres to the FAIR data principles[1] (e.g.) although a recent policy report [Moers22] from the EUROPABON project argued that there was still a great deal of work to develop FAIR compliant standards.

- Significant work is being done by standardisation organisations such as **ISO**, with the technical committee ISO/TC 331 devoted to biodiversity with the aim to "*develop principles, framework, requirements, guidance and supporting tools in a holistic and global approach for all organizations, to enhance their contribution to Sustainable Development*". Other ISO technical committees relevant to this area are the ISO/TC 190 Soil quality, the ISO/TC 147 Water quality, or the ISO/TC 146 Air quality. In the field of soil quality monitoring, for instance, ISO/TC 190 addresses aspects such as terms (related to soil, soil material, land and sites), descriptions of soil (characteristics, water, properties of soils and substances, contamination, pollution, etc.), and in particular digital exchange of soil-related data between individuals and organisations[2], as well as format for recording soil and site information including those recorded on-site[3].

- A variety of semantic data standards are relevant to the biodiversity domain and should be adhered to as IoT technologies develop. These include such ontologies as the Environment Ontology (ENVO[4]), BioDivOnto[5], the Biological Collections Ontology[6], an oontology for Indian biodiversity (InBioDiv-O[7]), and from the XML domain the Ecological Metadata Language (EML[8]). The latter appears to be fully aware of the need for semantically explicit metadata.

[1] https://www.go-fair.org/2022/01/12/biodifairse-establishes-new-concept-to-better-scale-workflows/
[2] ISO 28258:2013 Soil quality — Digital exchange of soil-related data
[3] ISO 15903:2002 Soil quality — Format for recording soil and site information
[4] https://sites.google.com/site/environmentontology/
[5] https://link.springer.com/chapter/10.1007/978-3-030-80418-3_1
[6] https://github.com/BiodiversityOntologies/bco
[7] https://www.igi-global.com/article/inbiodiv-o/315021
[8] https://eml.ecoinformatics.org/

2.4. Initiatives at national/regional level

This subsection contains a few examples of biodiversity monitoring initiatives that are being tackled at national or regional level. Further examples will be included in future releases of this paper.

"Exploration, analysis and prospective of biodiversity".[9] This is a coordinated action to be implemented among six regions in Spain (Galicia, Andalucia, Asturias, Canary Islands, Extremadura, Balearic Islands), under the framework of the Spanish Recovery and Resilience Plan, within a timeframe of 5 years and a budget of 66 M€. The program is focused on the development of solutions for studying the impact of human activity in nature, stop biodiversity decline, and allow mitigation and adaptation of natural systems to climate change.

This ambitious project is implemented in part through the instrument of Public Procurement for Innovation (PPI), as in the cases of Galicia[10] and Canary Islands[11]. In particular, these sub-projects envisage: 1) the development of a technological infrastructure for the collection of biodiversity data, based on the use of unmanned vehicles (aerial - UAVs, sea - USVs) and HAPS (High-Altitude Platform Station); 2) the development of the on-board observation sensors (hyperspectral, radar, Lidar, biosensors, etc.) and communications systems (based on LTE, 5G, satellite); 3) a "mission and biodiversity data processing center" and applications for managing the biodiversity data as well as providing data-based services to public operators.

- **ARISE project Netherlands**. The ARISE project, funded by the Dutch government, is a multi-year multimillion euro project to develop a comprehensive infrastructure for biodiversity monitoring for the Netherlands. The infrastructure will combine information from eDNA, AI-based recognition of both images, audio, and radar data to yield a comprehensive picture of the country's biodiversity. Researchers will have access to advanced near-real-time identification service for species detection and monitoring biodiversity. ARISE is using for example autonomous cameras to track insect biodiversity and are using a bird radar system to track the quantity and movement of birds.

[9] https://www.ciencia.gob.es/en/Estrategias-y-Planes/Plan-de-Recuperacion-Transformacion-y-Resiliencia-PRTR/Planes-complementarios-con-CCAA/Biodiversidad.html
[10] https://www.civiluavsinitiative.com/estrategia-2021-2025-es/programa-de-id/
[11] Creación de soluciones innovadoras en áreas de biodiversidad, seguridad, emergencias y otras de servicio público mediante plataformas y tecnologías aeronáuticas y aeroespaciales, en desarrollo de los retos de Canarias Geo Innovation Program 2030. Expediente 187/2022.

3. IoT as an enabler of biodiversity and environmental monitoring

3.1. IoT technologies for biodiversity monitoring

Rapid advances in technology and the Internet of Things (IoT) now offer people a number of tools that may be able to improve biodiversity monitoring. For example, advances in battery technology, global positioning systems, and cellular networks have revolutionized wildlife telemetry and added a wealth of information about animal movements at continental scales [Bridge11, Tomkiew10].

With regard to in-situ monitoring, there is a plethora of IoT based approaches aiming to monitor biodiversity capturing for example camera trap insect images and sound fingerprints in a non-intrusive manner, automatically analyse and label them with deep learning and edge computing mechanisms and transmit this information to scientists in a timely manner [Zapico21]. Other approaches [Bruggem21] include regional monitoring of selected bird species as a method to analyse the causality and detect changes given that their presence is a good indicator of ecosystem health and integrity. Cost-efficient, long-term monitoring mechanisms are being developed through Wireless Acoustic Sensor Systems for automated remote bird identification, census, and localisation. Such systems are expected to be able to record and transmit the audio samples combined with a classification framework for automated evaluation.

Multispectral sensors: Visual Multispectral sensor networks and images collected by satellites, airplanes, wave gliders, and (autonomous) un-manned both ground and aerial vehicles have made it easier to track of changes at the landscape scale [Thaxter09, Bagree10, Fretwell12, Vermeulen13, Schiffman14, Ogden13, Krukowski21]. These innovations provide cost-effective ways to collect biological data at large spatial scales over long survey windows, thereby increasing the statistical power of these survey efforts. Surveillance in multispectral ranges may help in both determining not only the biodiversity over the given area, but also the health of the crops and fauna, thus offering invaluable tools for more geo-focussed actions aimed at preservation and protection of the natural habitat [AgriBIT2021].

Audio sensors: Remotely controlled audio sensors can provide a unique monitoring capability for vocal animals such as birds and frogs, and they can capture insights into animal occurrence and behaviour [Gallacher21]. And by coupling bio-acoustic data with data on soil, vegetation, meteorology, water quality and long-term observations of gas and water exchanges, they can even act as an early warning system. Recent works [Maeder22, Robinson23] suggest direct acoustic monitoring of soil can also provide data on biodiversity of soil, and such work could naturally lead to long-term IoT-mediated monitoring of soil.

Soil sensors: Conventional digital soil sensors monitoring chemical and physical properties of the soil (pH, moisture, temperature, nitrogen, phosphorus and potassium) could be used to extract information about the existence of soil organisms and the overall health of the soil. Such an approach to using soil sensors, however, is still far from current reality [Wadoux21].

Multi sensors: A multi-sensor apparatus can work as a biodiversity assessment centre [Wagele22]. Such a system can combine cutting-edge technologies with biodiversity informatics and expert systems that conserve expert knowledge. Each station can combine autonomous samplers for insects, pollen and spores, audio recorders for vocalizing animals, sensors for volatile organic compounds emitted by plants (pVOCs) and camera traps for mammals and small invertebrates. They can be largely self-containing and have the ability to pre-process data (e.g., for noise filtering) prior to transmission to receiver stations for storage, integration and analyses.

3.2. IoT for biodiversity monitoring – some current use cases

The current section describes four use cases of biodiversity monitoring with state-of-the-art, non-commercial technology, as illustrative examples.

Case #1 – Pollination monitoring and optimisation	
Relationship to biodiversity	Wild-insect pollinators are essential for a healthy nature. Bees are one of the most economically valuable pollinators of crop monocultures worldwide and yields of some fruit, seed and nut crops would decrease by more than 90% without these pollinators [Klein07]. Bees are critically important for the environment and economy as they ensure pollination for over 80 percent of crops and wild plants growing in Europe [Williams94]. Different bee species play a key role in improving the production profitability of crops like rapeseed, oilseed sunflower and cherry. Productivity in apiculture sector can be affected by different factors, such as: diseases, exposure to chemicals, losses in plant diversity, adverse climatic conditions or the deterioration of bees' natural habitats owing to natural or human factors [Potts10]. Unfortunately, many recent surveys indicate that pollinators world-wide are declining that is a challenge to biodiversity but also to global food and farm industry. The European Biodiversity Strategy [ECBDSW20] and the EU Pollinators Initiative[12] set the objective of reversing the decline in wild pollinators by 2030.
Other possible benefits	Deploying the services proposed below can help in creation of the pollination maps and identify the regions that needs intervention.
Maturity level of the use case (if applicable)	There are different TRL's depending on the components of the service. The most advanced is the ControlBee IoT platform (e.g. deployed in WODR apiaries) that is on the TRL 8 level, where the whole pollination optimisation service is on the TRL 6.
Case study description To support monitoring of the well-being of hives, beekepers can use several dedicated IoT platforms available on the market. Those usually consist of sensor units installed in each hive which monitors among others temperature, weight, position and sound. Information is then transferred via chosen communication protocol to the cloud IoT platform, which collects and analyses the incoming data to present it to the user via web portal or mobile application. However, that is not enough for preserving well-being of the colonies as bees can be exposed to the dangerous plant protection products, ans as such close collaboration with farmers are needed. According to a Kleffmann Group study commissioned by the Polish Plant Protection Association in 2016, about 74% of beekeepers declare cooperation with farmers, using plant protection products which are as safe as possible for bees (84%) and informing beekeepers about the dates of plant protection interventions (81%). However, the communication between beekeepers and farmers is informal and not monitored and it leads to the accidental poisoning of bees. Within the EU DEMETER project specialized digital service for beekeepers and farmers have been developed. The main goal of the service was to create and establish the common platform for cooperation and to share important information between apiary owners and farmers and enable information exchange between virtual farm service (part of the national eDWIN platform) and the ControlBee IoT Platform (developed by Ideatronik) that monitors the apiaries (e.g. humidity, acoustic monitor and temperature, colony development, queen mating). The service estimation of the number of bee families which are needed to pollinate a given field providing information to provide how many bee families (hives) are needed to provide optimum pollination, provides the mechanism of the exchange of data between farm management system and the apiary management system and is providing spraying treatment alerts. This use case is a collaborative effort of the PSNC, Ideatronik and WODR.	
Acknowledgments: The work presented in the use case is based on work carried out under the H2020 DEMETER project (Grant Agreement No 857202) that is funded by the European Commission under H2020-EU.2.1.1 and eDWIN, that is a Polish national project under patronage of Polish Ministry of Science in the Digital Poland initiative and was supported under grant from the European Regional Development Fund, Polish Innovative Economy Programme, award No. POIG.02.03.00-00-096/10 titled "Dziedzinowo zorientowane usługi i zasoby infrastruktury PL-Grid dla wspomagania Polskiej Nauki w Europejskiej Przestrzeni Badawczej – PLGrid Plus".	

[12] https://environment.ec.europa.eu/topics/nature-and-biodiversity/pollinators_en

Case #2 – soil nutrients monitoring	
Relationship to biodiversity	Soil is becoming contaminated by the overuse of fertilizers and plant health is being adversely impacted and a subsequent decrease in biodiversity as a consequence. The United Nation (UN) set 17 interlinked Sustainable Development Goals (SDGs) to achieve a better and more sustainable future. Coincidentally, the EU GreenDeal targets to reduce fertilizer usage by 20% as well as nutrient losses by 50% by 2030 in order to transform the agri-economy into a significantly more sustainable one. Fertilizers help crop growth, however long-term excessive use of chemical fertilizers can bring a series of problems, including decreased soil fertility, increased greenhouse gas emissions, changes to soil pH, decreased biodiversity of the microbiome, water body pollution, climate change, and excessive consumption of natural resources.. However, no efficient methods are available currently to farmers to optimize the fertilizer usage as there is no tool for real-time in-field measurements for farmers to understand the soil nutrients level and accurate quantification of soil pH and oxygen content in their field. Existing monitoring techniques have limitations, such as non-portability, turnaround time and requirement for chemical reagents to be added. New digital technologies are therefore required, to provide informed decision-making capacity to farmers at all stages of production, to enhance food security, reduce losses, increase sustainable production (through precision agriculture), increase economic return while also protecting biodiversity.
Other possible benefits	In addition to agricultural applications, these sensors can be used for river/ surface/ underground water quality monitoring. With the association of data collection, cloud analytics and computing technologies, the IoT sensor system has the potential to improve the existing soil data analysis and thereby to update the global soil database to improve the overall sustainability of food systems (social/health, climate/environmental and economic).
Maturity level of the use case (if applicable)	The solution described is currently in TRL 5 and has been deployed in in commercial farms in Romania and France over 3 months (still on-going). This work clearly demonstrated that the application of silicon chip digital technologies to soil analysis has tremendous potential by enabling rapid analysis to provide high-end analytical data on different analytes.
Case study description **Electrochemical sensors** are valuable for in-field monitoring due to low cost, high integrability, and fast (a few seconds) accurate detection (±0.1%). However, the target analytes in the soil water are usually below 100 ppm, and the extracted water quantity is often small (< 1 mL). Thus, use of nanoscale electrodes offers many potential advantages. Nanoscale electrodes exhibits enhanced mass transport, arising predominantly from radial diffusion to nanowire electrodes[1], which offers improvements for analytical and sensor applications including: improved the detection limits, shorter response times, increased sensitivity and greatly reduced sample volumes. Advanced nano electronic fabrication approaches e.g., electron beam lithography and lift-off will be employed to define the nanosensor electrodes. Optical lithography and lift-off techniques are typically employed to define on-chip counter and quasi reference electrodes, interconnection track and electrical pinouts followed by a silicon nitride passivation layer to prevent any unwanted electrochemical reactions occurring during the measurements. The on-chip multi-sensor system with interdigitated electrodes permit direct analysis in soil obviating the need of chemical reagent addition for the first time and has been buried in soil to continuously monitor soil nutrients over 3 months. This in-field assay for soil nutrients that can enable constant monitoring and rapid analysis to help farmers understand the soil health status in real-time.	

Case #3 – Phenology observation	
Relationship to biodiversity	Main focus on the phenology are observations of the life cycle events of plants (e.g. the first flower dates) and animals (e.g. birds migrations). Phenological observations are useful in particular for the study on the climate change, as the observed phenomenas are frequently very sensitive to climate variations. Actually they are one of the simplest methods of observation of the climate change, that records if for selected plants phenophases are occurring. Phenological observations have a long tradition and already in XIX century there were already first networks of observers with the uniform instructions. Nowadays, the observers could be substitute with the IoT/EDGE solutions that automates whole process.
Other possible benefits	In addition to phenological observations this use case has a value for agriculture. Combined with the AI models for pests and diseases recognition it can be used for the pest and diseases observations, and providing source of the information for the decision support systems in example in integrated plant protection.
Maturity level of the use case (if applicable)	The solution described has been used for over 8 years in production. Recently a new system with the new hardware and software has been developed that is currently in TRL 6 and has been deployed in 20 selected locations in Poland. It is also part of the eDWIN platform that is the advisory platform and has the functionality of integrated plant protection.

Case study description

PSNC has been for many years involved in the fully automated fitophenological observations pipeline which were archiving continuous time-lapse pictures of plant species identified at the deployment site in Wielkopolska National Park. Images along with meteorological data measured on-site allowed to accurately create full phenological spectra for those plants and observe long-term evolution changes over years. Initial approach was based on the dSLR cameras equipped with a telephoto lens, and the set composed of the camera turntable, waterproof camera housing, heater and the edge and communication device. This setup has been installed together with the Meteo station in the Wielkopolska National Park and also next to it in the animal crossing over one of the main roads (thanks to the observations, first wolf in this region since over 20 years has been spotted). The developed software allowed for automated workflows of observations of several objects in the cyclic manner, sending the raw material for the data processing. The setup was used both for teaching and for scientific observations. Within the framework of the national eDWIN project that aimed at creating a national IT system for plant protection we have deployed 20 automatic observation phenological stations, based on cameras, and the agro-meteostations. In the context of the AI4EOSC project it is planned to develop the models for the selected diseases recognition in the wheat and sugar beets.

Acknowledgments: The work presented in the use case is based on work carried out under eDWIN, that is a Polish national project under patronage of Polish Ministry of Science in the Digital Poland initiative and was supported under grant from the European Regional Development Fund and under the Horizon Europe AI4EOSC project (Grant Agreement No 101058593) that is funded by the European Commission in the call of HORIZON-INFRA-2021-EOSC-01.

Case #4 – forest fire monitoring	
Relationship to biodiversity	In recent years, due to the fact that forest fires occur more frequently and at large scales, great damage occurs in natural life and habitats. According to the European space agency fire affects an estimated 4 km^2 each year. The damage of such a huge area due to forest fires causes irreversible damage to nature and people, directly or indirectly. Since fires in forests threaten natural habitats, biodiversity and the chance of survival of animals are adversely affected. The animal diversity in these areas may show a trend toward fire-adapted fauna. Similarly, plants exhibit adaptations such as rooting deep into the soil and shedding the roots of the lower branches of the trees to be protected from fire. For early detection of forest fires, a wireless sensor network can be created using sensors with IoT technology. Early fire detection can be made using the data received from IoT smoke detectors. To prevent false fire alarms possibly caused by human activities cameras can be used together with smoke detectors. In this way, a more robust forest fire monitoring system can be established.
Other possible benefits	In addition to preventing forest fires and helping to preserve biodiversity, this sensor network can protect and monitor natural life. At the same time, it can have a significant impact on climate change, which poses a great risk to the world, by protecting forests and reducing carbon emissions. It is also aimed to prevent smoke pollution, which arises as a direct effect of forest fires and poses a vital danger to human life in the long run. With this fire detection system, forests that are home to many endangered animals such as the Amazon forests can be prevented from being damaged by fires.
Maturity level of the use case (if applicable)	The solution described is currently in TRL 6 and has been deployed in some small forest areas. When the proposed artificial intelligence-based system is implemented, it will be able to reduce the destructive effects of forest fires to a minimum with early detection.
Case study description Based on data from the European Forest Fire Information System (EFFIS), fires in Europe, the Middle East, and North Africa in 2021 are the second-worst year since 2000. The main reasons for the increase in forest fires are climate change and human activities in the forest. As forest fires increase, the number of trees decreases, and carbon emissions increase. The increase in carbon emissions causes climate change. The effects of climate change cause forest fires to be more frequent and damaging. These fires pose a significant threat to the ecological balance and biological diversity. In order to break the cycle of fires and prevent damage to nature, fires should be detected as soon as possible. Early detection of fires is crucial to break the cycle of fires and preventing more damage to nature. With the planned positioning of IoT smoke detectors in forest areas, it is possible to detect fires before they start. However, the use of smoke detectors and cameras together creates a more reliable system to prevent false fire alarms caused by human activities in these areas. With an Artificial Intelligence-based system, early detection of forest fires is possible by processing data collected from smoke detectors and camera images. When the data coming from the smoke detectors indicate a possible fire, the system will examine the area where the detector is located through the camera in proximity. The image obtained from this area will be examined using image processing techniques. If the system decides that there is a fire, it will be reported to the firefighting teams without delay. This system design can provide automated protection of large forest areas and utilize the workforce efficiently.	

3.3. Example commercial products of biodiversity monitoring IoT devices

Here we provide an initial list a few commercial products which enable monitoring of biodiversity on the farm or in the wider environment. The list will be enlarged in future releases of this paper.

3.3.1. Swiss Birdradar

According to its website, Swiss BirdRadar[13] is a company that provides a range of solutions for quantitative monitoring of aerial fauna density and migration using compact and mobile radar devices.

The technology analyses the spatiotemporal distribution of the captured signal and allows for classification of the bird species and quantification ("mean traffic rate").

3.3.2. Progenies

According to its website, Progenies[14] is a provider of solutions to monitor and digitize honeybee's hives, bumblebee's colonies, and solitary bees nesting places/bee hotels. Based on sensor's data, AI-based data analytics provides information for early detection and notification that can be used for improving pollinators' survival. The company currently offers two solutions:

- **Pollinator guard**, an IoT monitoring system for tracking beehives' status as well as nesting places for solitary bees.
- **iBumble**, an IoT monitoring system for improving the management of pollination effectiveness using commercial bumblebee colonies.

3.3.3. Bird Detection by Gradiant

According to its website, Bird Detection by Gradiant[15] is an automatic system for bird detection and classification in open spaces and natural environments designed for different scenarios, in particular wind farms or airports, that can impact the aerial biodiversity in the regions where they are deployed. The system is intended to work both during environmental impact assessment and the operation phase of the infrastructures.

The system is based on video sensors and AI technology providing real-time bird identification and classification.

[13] https://swiss-birdradar.com/

[14] https://progenies.eu/

[15] https://www.gradiant.org/en/portfolio/bird-detection/

4. Identified gaps and recommendations

Biodiversity/environment observation and understanding has been identified as a key supporting element to fight climate change and achieve a sustainable economy, prosperous for all. Spurred by the EU Green Deal policy, a number of relevant monitoring initiatives are currently being launched at different scales, with ambitious objectives, towards the preservation of landscapes and biodiversity.

The achievement of these objectives demands monitoring capabilities which involve a number of technologies (both for in-situ observation as well as remote sensing) suitable for a variety of environments comprising water, soil and air. The scientific literature describes image/video and audio sensors, chemical sensors, and even radar technologies that can be used for monitoring parameters directly or indirectly related to biodiversity features. The use cases provided as examples in Section 3 show non-commercial IoT developments, at different TRLs above 5, which serve as proofs of concept.

A number of projects and a body of research have generated reports on the needs of the biodiversity sector, especially with regard to biodiversity monitoring. The Essential Biodiversity Variables (EBVs) and Essential Ecosystem Service Variables (EESVs) provide a core set of variables that need to be captured while monitoring any biodiversity domain [Moers23]. The EUROPABON has produced a detailed report on the current maturity of monitoring technologies [Dornelas23]. That report observes that a) there was great variability in the technology readiness level of different technologies, particularly with regard to a lack of validation of the methodology with regard to taxa and locations; b) technical questions arose regarding standardisation, data integration and data storage. New technologies needed to be designed to *complement* rather than replace human observations. Further issues arose as to what extent the data derived from new technologies was commensurable with previous human observation time series, if not it was considered of limited or no use. Another issue was that technologies were usually suitable for the "extremes scales" of EBV classes i.e. specialised high resolution data such as tracking individual birds or large-scale coarse level data such as species present in a region [ibid.].

Another key technical aspect is the management of data, in particular the terminology, representation and semantics. This is essential to achieve interoperability among different distributed data repositories and data spaces which will be fed from multiple sources, if we want to make sense from aggregated data, build reliable biodiversity models and do meaningful benchmarking.

A major incentive beyond the needs of the traditional biodiversity community has now arisen due to the requirements for the CAP (Common Agricultural Policy) to monitor the environmental impacts of policy instruments and the determination of the EC to undertake large scale data collection for this purpose. This issue is a major topic in the context of the new Partnership Agriculture of Data[16]. A significant part of environmental monitoring includes biodiversity trends, and this results in the end for reliable, efficient and cost-effective tools to undertake the necessary data collection.

Based on the preliminary findings described above, we propose the following recommendations which we intend to address in subsequent updates of this document.

Recommendations:

[16] https://commission.europa.eu/system/files/2022-04/ec_rtd_he-partnership-agriculture-data.pdf

1. **Elaborate lists of requirements for the monitoring of biodiversity (what and why should be measured) which bridges the gap between the needs of the biodiversity community and capabilities of the technology developers.**
2. **Elaborate a mapping between biodiversity features and physical variables/parameters to be measured, with a special focus on understanding indirect monitoring techniques.**
3. **Analyse rigorously the business case for biodiversity monitoring in order to facilitate the feasibility analysis of different monitoring approaches.**
4. **Connect the biodiversity monitoring initiatives and projects with the EU Green Deal and Agriculture data spaces, taking into account from the beginning the data standardisation aspects.**
5. **Identify synergies with the new CAP where biodiversity monitoring can form an integral part of the technologies under development to facilitate environmental monitoring and linked policy impact assessment.**

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About AIOTI

AIOTI is the multi-stakeholder platform for stimulating IoT and Edge Computing Innovation in Europe, bringing together small and large companies, academia, policy makers and end-users and representatives of society in an end-to-end approach. We work with partners in a global context. We strive to leverage, share and promote best practices in the IoT and Edge Computing ecosystems, be a one-stop point of information on all relevant aspects of IoT Innovation to its members while proactively addressing key issues and roadblocks for economic growth, acceptance and adoption of IoT and Edge Computing Innovation in society. AIOTI's contribution goes beyond technology and addresses horizontal elements across application domains, such as matchmaking and stimulating cooperation in IoT and Edge Computing ecosystems, creating joint research roadmaps, driving convergence of standards and interoperability and defining policies.