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Grant Proposal

Modern Approaches to the Monitoring of Biodiversity (MAMBO)

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Abstract

EU policies, such as the EU biodiversity strategy 2030 and the Birds and Habitats Directives, demand unbiased, integrated and regularly updated biodiversity and ecosystem service data. However, efforts to monitor wildlife and other species groups are spatially and temporally fragmented, taxonomically biased, and lack integration in Europe. To bridge this gap, the MAMBO project will develop, test and implement enabling tools for monitoring conservation status and ecological requirements of species and habitats for which knowledge gaps still exist. MAMBO brings together the technical expertise of computer

science, remote sensing, social science expertise on human-technology interactions, environmental economy, and citizen science, with the biological expertise on species, ecology, and conservation biology. MAMBO is built around stakeholder engagement and knowledge exchange (WP1) and the integration of new technology with existing research infrastructures (WP2). MAMBO will develop, test, and demonstrate new tools for monitoring species (WP3) and habitats (WP4) in a co-design process to create novel standards for species and habitat monitoring across the EU and beyond. MAMBO will work with stakeholders to identify user and policy needs for biodiversity monitoring and investigate the requirements for setting up a virtual lab to automate workflow deployment and efficient computing of the vast data streams (from on the ground sensors, and remote sensing) required to improve monitoring activities across Europe (WP4). Together with stakeholders, MAMBO will assess these new tools at demonstration sites distributed across Europe (WP5) to identify bottlenecks, analyze the cost-effectiveness of different tools, integrate data streams and upscale results (WP6). This will feed into the co-design of future, improved and more cost-effective monitoring schemes for species and habitats using novel technologies (WP7), and thus lead to a better management of protected sites and species.

Keywords

species, habitats, monitoring, EU, cutting-edge technologies, deep learning, remote sensing, citizen science

1. Excellence

1.1. Objectives and ambition

The MAMBO project aims to realise the huge potential of cutting-edge technology for species and habitat monitoring in the EU by advancing and integrating sensor development, deep learning, computer vision, acoustics, ecology, remote sensing, biodiversity monitoring, citizen science, data pipelines and ecological modelling. Fine-grained classification algorithms have matured to the point where it is possible to accurately identify organisms automatically from digital data such as images or sound. Similarly, high spatial resolution remote sensing data from the Copernicus satellite Earth observation programme and other sources such as drones and airborne LiDAR are bringing new opportunities for habitat extent and condition assessments. These technical breakthroughs set the future of ecological monitoring as automated systems will expand the extent and resolution of biodiversity monitoring and increasingly complement traditional approaches used by professional ecologists and community scientists. These systems are highly scalable, especially in remote locations that are often data sparse yet highly sensitive to environmental change. They also have the potential to revolutionize the number of observations being gathered on diverse but often overlooked taxa that play a major role in overall biodiversity, ecosystem health, and ecological services such as pollination. Furthermore, these tools will engage a much wider diversity of stakeholders to

become involved. In particular, these tools open up the potential for active involvement of non-experts in the process of environmental monitoring and biodiversity assessments and will finally help to bridge taxonomic and monitoring gaps and lead to a better understanding of biodiversity declines and their main drivers.

The EU Biodiversity Strategy 2030 in support of the Green Deal is very clear about biodiversity and our future: We need nature in our lives and protecting and restoring biodiversity and well-functioning ecosystems is key to our own future. One of the reasons for this call is that the status of biodiversity in Europe is generally below standard and many targets are not being met (e.g., a favourable situation for all species and habitats listed in the Birds and Habitats Directives). Specifically, biodiversity status and trends have not improved since 2010 despite biodiversity targets and actions that were planned. Major pressures on biodiversity have remained high, and are increasing in many instances. For example, more than 80% of EU territory is under agricultural or forestry management and is only slowly becoming more sustainable and biodiversity-friendly. Similarly, the supply of ecosystem services have not increased since 2010, while the demand has (Maes and al. 2020). The combination of ecosystem degradation and biodiversity loss with the mismatch in supply and demand of nature's services is not what we want or need, and costs of our inaction are high and increasing (OECD May 2019). The Green Deal, including the EU biodiversity strategy 2030 and international strategies such as the UN Decade on Ecosystem Restoration, the CBD post-2020 framework, the IPBES Global Assessment on Biodiversity and the post-2020 Global Biodiversity Framework all point in the same direction: We need an integrated approach to securing biodiversity, economy and human well-being. This requires substantial transformative change across policy domains (nature conservation, agriculture, economy, energy). MAMBO will help to achieve this by making substantial progress beyond current practice and state-of-the-art in biodiversity monitoring and respective data integration. It will do so in a way that is not only completely compatible with the EU strategies mentioned above, but that guides the way towards healthy, living landscapes. Here, we summarize our main objectives and how we will address the technical and practical challenges of realising new ways of monitoring biodiversity in the EU:

The main objectives of MAMBO are to:

1. Develop, evaluate and integrate image and sound recognition-based AI solutions for EU biodiversity monitoring from species to habitats.
2. Develop, test and deliver high spatial resolution regional EU habitat extent maps (satellite remote sensing) and site-specific (e.g. Nature 2000), but EU consistent, habitat condition metrics (airborne LiDAR and drone data).
3. Promote the standardized calculation and automated retrieval of habitat metrics using in-situ observations, deep learning and remote sensing.
4. Co-design MAMBO's novel ecological monitoring tools with researchers, policy makers, citizens and other stakeholders, evaluate their costs and benefits and make them widely available.

5. Build a new global community of practice for the development and application of these cutting-edge technologies through proof-of-concept implementation across the EU.
6. Test and implement existing and MAMBO's novel tools for upscaling, and contribute to an integrated European biodiversity monitoring system with potential for dynamic adaptations.

How MAMBO relates to the work programme?

The main aim of the work programme is to provide the knowledge, tools and infrastructure for monitoring wildlife and their habitats. Related to aim:

1. MAMBO tools and data will be FAIR and thus contribute to the digital literacy of Europe. MAMBO will make use of a wealth of data sources (from remote sensing to citizen science and from global and European to national and local data) and integrate them into tools and applications that can become the basis of public and private technologies to enable spatial planning (e.g. biodiversity mapping and recording), well being and health (e.g. identification of disease vectors and development of green space), and green growth (e.g. tools for precision agriculture and monitoring the impact of economic activities).
2. MAMBO tools will facilitate ecological restoration as its tools make monitoring of all biodiversity (species and habitats, with focus of EU directives) easier and more accurate, provide decision-support for nature conservation and guidance of nature restoration and development.
3. MAMBO image and sound recognition tools will facilitate digital decision support tools in other sectors such as agriculture, transport and energy. For example, chemical-free crop protection depends on accurate early-warning of looming pests and diseases. Image-recognition tools, such as automated insect cameras, will be used to do that. Also, MAMBO tools can be used to evaluate and monitor impact of economic activities. Not only their harmful effects (e.g. habitat degradation), but also their positive contribution (e.g. afforestation and restoration).
4. MAMBO tools will enable citizens to sense their environment directly. This will increase citizen participation level (and influence) in environmental, protection, health, and wellbeing areas.

Specifically, MAMBO will address the following challenges identified in the work programme:

1. How can we implement a cost-efficient system for species and habitat monitoring across the EU that maximises the automation, extent and resolution of biodiversity monitoring?
2. Which tools, technologies, and AI-identification methodologies can bridge taxonomic and monitoring gaps for European wildlife supporting adaptive monitoring?

3. How can we integrate, access and promote (standardised, open and FAIR) data, knowledge and models for improving conservation status and ecological requirements of species and habitats in the EU?
4. How can we inform EU policy (e.g. the Birds and Habitats Directives, EU biodiversity strategy 2030) and other sectors (e.g. agriculture, energy or bioeconomy) in (near) real time about biodiversity status and trends, emerging threats and underlying drivers of decline?

Innovation potential

In order to make biodiversity something that society can quantify and monitor, MAMBO is bringing together world leaders in research on novel monitoring technologies (proximal sensors, remote sensing, crowd sources), and decision support tools. MAMBO will invent, build, evaluate, and promote tools that are streamlined with existing data collection efforts and engage with stakeholders and end-users (Fig. 1). Using these easy-to-use and reliable tools, MAMBO will equip a wider range of people to participate in species and habitat monitoring. Stakeholder engagement will occur from project inception through to completion to ensure that user needs, and co-development form a core part of this project. We will ensure open and clear lines of communication between the technological innovations team and relevant groups of stakeholders from policy makers through to practitioners, at local, national, and regional levels, to enable useability and ease of uptake for the tools being developed. This interdisciplinary approach will maximise the potential for both technological, social and institutional innovations. Co-design (WP1) and demonstration (WP5) of MAMBO's unique collection of hardware solutions, open-source software and crowd sourced data (WP3, WP4), which monitors and assesses the impact of various actions on different ecosystems and which is fully aligned with existing and ongoing research infrastructures and data sources (WP2). Furthermore, community engagement and crowdsourcing platforms are immensely important (from WP1, 5, and 7). Due to the integration, improvement, and application of existing technologies on a variety of real-world biodiversity challenges, this will offer great opportunities for innovations in application and uptake. Social innovations need a strong focus on co-design and cost-benefit analyses to increase acceptance and ensure the ultimate implementation of novel monitoring technologies and approaches. MAMBO will ensure this by co-designing novel monitoring tools with constant involvement of, and feedback to relevant stakeholders, identifying ways to incentivize their uptake, while overcoming potential barriers (WP1). Also, cost-benefit analyses will identify the optimal combination of monitoring approaches under given local or regional contexts (WP6). Close interactions with local stakeholders at demonstration sites (WP5) empower local communities, train local actors, raise the societal appreciation of biodiversity and engage local governments and regulators to change priorities. This unique, multi-disciplinary and innovative approach will guarantee a significant, long-term and sustainable impact maintained due to local involvement.

Research and innovation maturity of MAMBO tools

A range of innovative tools conceived by members of the consortium will be enhanced and made more widely available as part of MAMBO (Table 1). In addition, MAMBO will exploit

its gravitational force for new monitoring technology to form a hub for tool developers to increase technology readiness levels (TRLs) of their products and services.

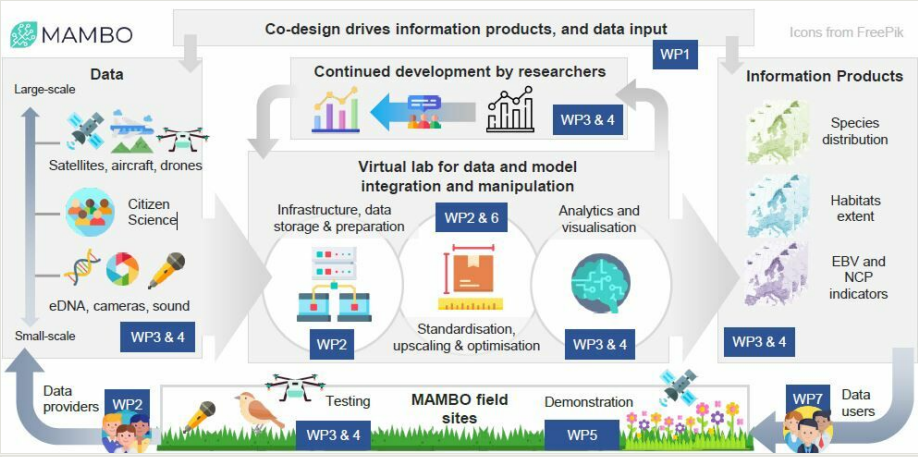

Figure 1. doi

Schematic illustration of how MAMBO innovation will contribute towards a cloud based virtual lab solution for biodiversity assessment and monitoring.

Table 1.

List of MAMBO tools (and relevant WP) and the technology readiness levels (TRLs) at the start and end of MAMBO.

MAMBO tool	TRL start	TRL end
Image-recognition software for species on the annexes of the Habitats Directive (WP3)	2	7
Sound-recognition software for birds, bats, marine mammals, crickets and grasshoppers (WP3)	2	5
Insect camera for monitoring nocturnal insects (WP3)	3	6
Insect camera for monitoring pollinators (WP3)	3	6
Habitat extent mapping tools (WP4)	2	6
Habitat condition metric derivation from airborne LiDAR and/or drone data (WP4)	3	6

1.2. Methodology

1.2.1 Overall methodology

From concept to structure: The core concept of MAMBO is that new technology will bring the highest value to society through a co-design process with users and other

stakeholders. Too often tools are built without thinking enough about the linkages to existing research infrastructures and products or the long-term sustainability of their use by the often highly variable end-users. The project is therefore structured across three pillars. First, we will identify existing tools, approaches and research infrastructures and the respective user needs (co-design and infrastructures). On this basis, we will build and refine novel tools based on cutting edge technology (tools and technologies). Finally, we will test and demonstrate the implementation of MAMBO's novel monitoring tools across the EU, integrate and disseminate the outcomes, and assess their pros and cons and relevance to EU policy (Implementation and dissemination).

Taxonomic focus of MAMBO: Our taxonomic focus is intentionally broad, driven by the needs of the EU as expressed through the EU Habitats and Birds Directives, EU Red Lists and the EU list of invasive alien species. Using images and sounds as input, we specifically target rare and threatened species and knowledge gaps in European birds, bats, mammals, plants and insects, including many important pollinators (bees, butterflies, moths and hoverflies). At present there are many pilot projects and field tests for automated (AI-based) monitoring of these taxa, but major knowledge gaps exist as hardly any reliable, well standardised, and cost-efficient data pipeline is currently available for deriving quantitative (data-driven) biodiversity indicators at the European scale.

Species identification using deep learning (objective 1): In the last ten years, automated identification tools have progressed considerably thanks to deep learning techniques and the increasing availability of training data. There are now mobile applications such as Pl@ntNet, ObsIdentify, Seek, Merlin or BirdNet that allow millions of users to identify the species they encounter simply by taking pictures of them or recording the sounds they make. The data collected by this type of application, however, are subject to significant observation bias, in particular because not all species present on the observation site are listed. Data from repeated, standardised surveys, therefore, remain indispensable, if only to correct the biases of models built from opportunistic citizen data. However, the high costs of implementation of these inventories strongly limits the frequency of their realization and their replication incontrasting environments. Passive acoustic monitoring, in particular, is a valuable sampling tool for habitat assessments and the observation of environmental niches which often are endangered. However, manual processing of large collections of soundscape data remains a challenge. Similarly, the recurrent monitoring of plants carried out in the form of protocolized inventories of uniformly sized quadrats (typically 1x1m) is one of the most common approaches used by natural area managers for monitoring over time and along environmental gradients. The automation of this type of approach would transform the capacities of managers, by granting them greater autonomy as well as an unprecedented study capacity. In order to significantly reduce monitoring costs, MAMBO will develop a new generation of automated identification tools aimed at identifying species assemblages directly. In particular, we will develop new deep learning models for the detection and identification of birds in soundscapes with the objective to bridge the acoustic gap between high-quality training recordings and soundscapes with high ambient noise levels which is one of the most challenging tasks in the domain of audio event recognition. In addition, we will also work on

the realization of floristic monitoring from cover pictures (quadrat photos in particular). This will require working on new deep learning approaches based on tile classification or instance segmentation utilizing the data collected and models trained within the Pl@ntNet platform.

Structured species monitoring using field sensors (objective 1): Sensors are widely used for many areas of environmental monitoring, solutions for sensor-based ecological monitoring are in their infancy. In theory, cameras have many advantages over traditional approaches. They remove observer bias and data collection and can collect standardised, high-resolution data across long time scales. Cameras can be baited in similar ways to traditional light and pheromone traps or placed over ephemeral natural resources such as flowers, fruits, dung, fungi, or carrion. Cameras can be installed in remote locations using solar, wind or battery power. “Internet of Things”- enabled hardware offers the potential of ‘edge computing’ to implement classification algorithms in the field to provide fully autonomous systems that report detection and classification data back to the user in real time. When harnessed together, camera traps and computer vision can deliver novel high-throughput systems for detection, classification, and enumeration of species and alongside functional metrics such as biomass. Machine listening/audio analysis has a similar potential for biodiversity monitoring. Originating in speech recognition technology, systems now exist for diverse general music, urban and domestic sound. Automated audio sensors are increasingly common in ecological surveys, while smartphone birdsong recordings are widely collated in projects such as Xeno Canto and iNaturalist, and can be automatically recognised (Stowell and Plumbley 2014, Stowell et al. 2018). In practice, there are still many challenges associated with the transition to sensor based monitoring. In MAMBO, we will build on newly developed sensors (by partner AU) for automated monitoring (Bjerge et al. 2021, Høye et al. 2021).

Habitat type classification and mapping (objective 2): Modern deep learning techniques have great potential for modeling species distributions (SDM) and recognizing habitats (Botella et al. 2018). In particular, experiments with convolutional neural networks (CNN) have shown that they have the ability to capture complex information about the spatial structure of the environment and landscape (Deneu et al. 2021). One limitation of CNNs, however, is that their architecture induces an intrinsic inductive bias in the sense that they process the signal only locally (e.g. in the neighbourhood of each pixel), and thus, they cannot accurately model long-distance relationships. They are, therefore, not really suitable for modelling the relationship between habitats at micro and macro-level. In contrast, transformers (Dosovitskiy and al. 2020), which are a different kind of deep learning models, go beyond local processing and exploit long-term dependencies for increased performance. However, their use in geographic information systems is still a largely unexplored but promising research field. Such models should allow segmenting habitats in a much more efficient manner than current methods without requiring expensive field surveys. In particular, MAMBO will build on Inria’s recent work on transformer models (Caron et al. 2021, Liutkus et al. 2021) to segment and classify habitats in high-resolution satellite data (typically sentinel 2 image series) coupled with environmental rasters. The models will be pre-trained in a self-supervised manner on very large volumes of data and

then fine-tuned on supervised data to produce habitat type maps (EUNIS typology in particular). For this second step, we will help ourselves with recent results coupling EUNIS types with plant species composition (plant occurrence data being much more numerous than habitat type records).

Assessing habitat condition (objective 3): Being able to accurately assess a habitat's condition is vital to cost-efficient nature management. Condition indicators vary with habitat but generally are based on metrics that range from describing the presence/abundance of plant and animal species to characterising 3-dimensional vegetation structures and temporal vegetation dynamics. Establishing habitat condition and conservation status remains a challenge. It generally involves in-situ surveying and can be semi-qualitative, and currently, there is no consistency in how condition is measured and reported across Europe. While some of these metrics (e.g. plant height, % bare ground, % woody cover, vertical woody density, individual plant abundance, disturbance feature density) are well suited for a remote sensing (RS) approach, wide-scale condition assessment has been limited so far because available relevant data is either of insufficient spatial detail (i.e. free satellite data) or of limited temporal frequency, limited coverage, costly or not easily accessible and varied across countries and regions (i.e. drone, airborne or commercial satellite data). In addition, national RS-based habitat level condition assessments would require the storage, access and processing of large data volumes. Cloud-based solutions exist, however, so far the focus is on satellite data (e.g. Google Earth Engine, Sentinel Hub Platform) or limited to drone data pre-processing using licensed software (e.g. Agisoft) and the shared open source scripts are mostly research project specific and so difficult to reuse. The lack of easily accessible computational infrastructure (with standardised analysis tools and enhanced processing workflows) for LiDAR and drone data is stifling operational use.

MAMBO will focus on developing condition metrics from airborne LiDAR and drone data. Both offer the high spatial detail required for condition assessment at scales useful to land managers and decision makers and have the potential of delivering metrics that are relevant to a wide range of habitats. These metrics will be identified through a review of field manuals and stakeholder feedback. Critically, MAMBO will evaluate in detail current barriers to airborne LiDAR and drone data use in habitat condition assessments and share its findings with stakeholder groups interested in LiDAR and drone data exploitation. Envisaging a future where LiDAR and drone data are two of many data types (e.g. satellite, in situ, citizen science) processed to deliver metrics through a user-friendly cloudbased virtual lab for biodiversity monitoring, MAMBO will convert the scripts developed by MAMBO's RS experts into interactive computing workflows and automate workflow deployment. The idea is to produce processing pipelines that will work with locally relevant LiDAR and/or drone data but deliver metrics that are consistent across the EU, enabling both local and EU- wide reporting to the Habitat Directive.

To derive the selected condition metrics from LiDAR and drone data, MAMBO will apply current state-of-the-art methods, but will also develop new methods that can better exploit the large volume and spatially detailed information coming from these types of technology. Specifically, we will apply deep learning directly to raw LiDAR point clouds and

preprocessed drone data (RGB, multi-spectral, point clouds) to avoid losing important details when using only statistical approaches. This is particularly relevant for metrics reliant on feature identification (e.g. drainage, erosion features, individual indicator plants, flower heads). We will test and validate our approaches across habitats and countries by working with available (open-access) LiDAR and newly collected drone data on 3 single large and data-rich sites (UK: Salisbury Plain; The Netherlands: Oostvaardersplassen; Denmark: Mols Bjerge), and demonstrate our computing workflows on data available for a German LTER site (Friedeburg).

Using apps to support society (objective 4): Smartphone applications that embed computer vision and machine listening democratise assessments of species and habitats. This empowers new sections of society to create their own understanding of their environment and take action in response. Smartphone applications that make use of these new technologies can also host data and information that help the user to ensure the quality of the data they collect, provide context to the observations they are making, and suggest actions in response to what is learned. In agriculture, this approach is being used by the ESurveyor app (https://assist.ceh.ac.uk/e-surveyor) to provide farmers with a tool for monitoring the wildflower habitats that they create on their land. Apps of this kind could also help to build on existing efforts (e.g. https://www.plantlife.org.uk/everyflowercounts) to encourage gardeners to improve the quality of their green spaces for biodiversity. This has the effect of raising awareness of the issues of biodiversity decline amongst the public, empowering them to make a change using data they collect about their garden, and through many small actions help to reverse declines. MAMBO will provide image classifiers through APIs that can be integrated within a range of user interfaces. This will be facilitated through community engagement, provision of exemplar demonstrations and documentation on how to access (e.g. through APIs) and deploy MAMBO tools.

Demonstration of enabling tools (objective 5): All tools developed as part of MAMBO can be applied throughout Europe. In order to test these tools, we will make use of a series of demonstration sites described below and presented in Fig. 2. Some tools, such as the image and sound recognition models, will be developed on a European scale and will be tested on larger regions by making them available to national biodiversity portals (BE, DE, DK, FR, MT, NL, UK).

- France: French Mediterranean natural reserves, which are based in the Mediterranean Basin world biodiversity hotspot. We will focus on the middle elevation habitats, and temporary swamps to highlight key habitats of the EU Habitat directive. This will be done in close collaboration with the French Mediterranean National Botanical Conservatory, which has rich data on the species and habitats of the territory for which it is responsible and which has already expressed its interest in the type of tools we are considering for plants monitoring in WP3 and WP4.
- Denmark: We will work at a 1.5 km2 nature reserve known as a biodiversity hotspot in Denmark and located within Mols Bjerge National Park. Recently, the site was divided into separate zones with trophic and passive rewilding. A monitoring program for vegetation and arthropods using traditional plot surveys, time-lapse

cameras and drone surveys is combined with detailed records of the space use of introduced horses and cattle.

- UK: Salisbury Plain (Natura 2000 site code UK9011102, Special Area of Conservation, Special Protected Area) is the single largest area of chalk grassland in Western Europe and represents 45% of the remaining habitat in the UK. This military training area occupies some 38,000 ha, and of this 20,000 ha are notified as a Site of Special Scientific Interest, which includes 14,000 ha of chalk grassland. UKCEH has led major ecological surveys commencing in 1996, establishing a long-term monitoring network for vegetation within different areas of disturbance and shrub encroachment and undertaking larval web surveys for the Marsh Fritillary butterfly. A 1m 2014 airborne LiDAR survey and a time-series of 0.25m aerial photographic surveys are available.
- The Netherlands: Oostvaardersplassen Nature Reserve (part of National Park Nieuw Land in province of Flevoland, NL), an extensive, 5400 ha large restoration and rewilding site with reed marshland, dry scrubland, swamp forests, grasslands and open water. The area is of great importance to birdlife (breeding birds, migratory birds and wintering birds) and has a focus on rewilding and the effects of large grazing herbivores (horses, cattle, deer). It is a wetland of international importance according to the Ramsar Convention, part of the Natura2000 network (site code NL9802054), and a Special Protected Area (SPA) according to the EC Bird Directive. The protected area is managed by Staatsbosbeheer, the National Forest Service of the Netherlands.
- Germany: Friedeburg is a 16 km² LTER site located in the typical agricultural area of Central Germany with comparably high habitat diversity. It is also part of the Terrestrial Environmental Observatoria (TERENO) of the Helmholtz Association and provides a wealth of long-term monitoring and environmental background data (e.g. vascular plants, wild bees, butterflies, birds).
- Malta: The island of Comino and the surrounding islets are found in the Malta-Gozo Channel and are part of the Natura 2000 network (MT0000017) as a Special Area of Conservation and Special Protection Area. The site is dominated by scrub, phrygana and maquis habitats but supports other habitats of national and community importance (with a total of 10 Annex I habitats being recorded within the island and surrounding islets) and various rare and endangered endemic species. Large-scale habitat restoration of maquis, woodland and inland wetland habitats has also been carried out over the past 4 years.
- Bulgaria: LTER Petrohan is situated in the West Balkan range with a total area of 7192 ha. The region is mountainous, and steep, with deeply cut river valleys and secondary watersheds with the lowest point at an altitude of 350 m, and the highest at 1900 m. While parts of this area are forested, higher-altitude grasslands and meadows are also present. Ecosystem investigations have been carried out since the establishment of the site in 1986. Petrohan falls into the North-Bulgarian climatic zone with a moderate continental climate.

Figure 2. doi

MAMBO sites are widely distributed across climatic and biogeographical regions.

Linking data and models to promote integrated European biodiversity monitoring schemes (objective 6): The development of an integrated European biodiversity monitoring system faces several challenges related to integrating different data streams, taxonomic gaps, geographic gaps and a lack of up-scaling ability due to context dependencies. In particular, rare and other threatened species are less well covered by 'standard' large-scale monitoring schemes, which often impede the assessment of their status and trends in relation to changing environmental conditions based on the quantification of their ecological niches, especially at large spatial scales. MAMBO will test the usability of daily and seasonal performance patterns obtained from novel continuous monitoring tools to quantify the ecological niche of selected species and the transferability and upscaling ability of respective mechanistic ecological niche models in space and time.

A comprehensive biodiversity monitoring system also needs to integrate the wealth of citizen science data. They often underpin models that seek to understand or explain changes in species distributions across space and time at national and international levels. MAMBO will result in advances in computer vision and machine listening leading also to increases in the quality and volume of citizen science species occurrence data. As we develop and adopt these new sensing technologies, MAMBO will also develop the necessary connections between the models and the data in parallel so that new data can be effectively used to improve our understanding of the natural world, and so that model outputs can direct data collection efforts to fill geographic data gaps. However, the imminent uptake of computer vision and machine listening tools will introduce their own biases. These may originate in the sensor used, the algorithm selected, or the threshold used to accept or reject the AI classification. MAMBO will capture these metadata, and develop modelling approaches that account for these to ensure the best quality inference from the multiple types of data collected. Further to this, integrated modelling approaches

will be designed to allow these new data to be used in combination with historical and future 'traditional' datasets to assess long-term changes.

Successfully transferring ecological models in space and time critically depends on the upscaling ability of the models, especially when local relationships between species performance and environmental conditions are dependent on a larger-scale biogeographic context. By combining high-precision local-scale data from multiple European regions, obtained by demonstrating the MAMBO tools, and respective large-scale environmental variation, MAMBO will identify the impact of environmental drivers, their interrelations and in particular their contextdependencies and test the ability and limitations of upscaling and transferring ecological models in space and time. Citizen science data often underpins models that seek to understand or explain changes in species distributions across space and time at national and international levels. We see advances in computer vision and machine listening leading to increases in the quality and volume of citizen science species occurrence data. As we develop and adopt these new sensing technologies we must develop the connections between the models and the data in parallel so that new data can be effectively used to improve our understanding of the natural world, and so that model outputs can direct data collection efforts to fill data gaps.

Efforts over the last decade have seen rapid improvements in models for detecting changes in species across time and space, accounting for the ad-hoc nature of citizen science data (Isaac et al. 2014). These models seek to account for common biases in citizen science data, such as non-random distribution in space and time, changes in detectability over time, and variation in sampling effort between site visits. The imminent uptake of computer vision and machine listening tools will introduce their own biases that models will need to account for. These may originate in the sensor used, the algorithm selected, or the threshold used to accept or reject the AI classification. Capturing these metadata, and developing modelling approaches that account for these is key to ensure the best quality inference from the data collected. Further to this, integrated modelling approaches must be designed to allow these new data to be used in combination with historical and future 'traditional' datasets to assess changes over long time periods. The output of models should drive data collection to ensure that new data is collected where it is needed most. Variations of this approach have long existed in citizen science projects; identifying areas on a map where data has not been collected, and targeting these for data collection in the upcoming field season. Recently the DECIDE project has taken this a step further and uses models to explicitly map uncertainty in species distributions, identifying accessible locations where new observations by citizen scientists will have the greatest chance of improving our understanding of species distributions in space. Similar efforts are being made to best inform changes in species over time (Anonymous 2021). This novel concept of 'adaptive citizen science' brings modelling and data collection into close alignment, each supporting the other in near real-time. These new methods will be important for directing the deployment of sensors for autonomous monitoring and demonstrating to citizen scientists the value of the observations they make.

Data available to MAMBO: RS - Sentinel-2 multispectral satellite imagery: A wide range of RS data can be acquired and are available for use to map and monitor land cover, use,

dynamics and status, landscape features and objects. For habitat type classification and mapping, Mambo will use data from the Copernicus Sentinel-2 mission that since 2015 has been delivering unique 5day 10-20m global multi-spectral imagery, and jointly with the Landsat missions provides the core data source for future national, continental and global scale land cover mapping (e.g. Sentinel-2 Global Land Cover (S2GLC) http://s2glc.cbk.waw.pl) and monitoring (e.g. the Copernicus for Natura2000 http://www.cop4n2k.eu).

RS - Airborne LiDAR: Across Europe, an increasing number of countries (Denmark, UK, The Netherlands, Finland, Italy) are performing and sharing nation-wide or regional airborne surveys with light detection and ranging (LiDAR) technology, providing meter resolution terrain and habitat/vegetation structure information. Some countries (e.g. Denmark and the Netherlands) have already conducted repeated surveys, thus providing multi-temporal LiDAR data for monitoring biodiversity and habitat change. MAMBO will tap into the LiDAR repositories of the UK, The Netherlands and Denmark.

RS - Drones: Drones and drone sensor technology are evolving fast and their very high spatial resolution (mm to cm) data has the potential to transform local site monitoring. Various drone-sensor setups exist. MAMBO will focus on the most prolifically used and affordable rotary drones with red, green, blue and near infrared cameras. When these are flown to generate high overlap between image frames, structure from motion delivers 3-dimensional point clouds that are very similar to LiDAR point clouds. MAMBO will use both the mm/cm 2 and 3-dimensional drone data.

Relevant international, European and national projects and initiatives are presented in Table 2.

Table 2.

Links with other international, European and national projects and initiatives.

Project and partners involved	Contribution to MAMBO
ARISE Lead: Naturalis Involved: UvA	The €18M project will build an infrastructure to identify and monitor all eukaryote species in the Netherlands using DNA, image, sound and radar recognition. MAMBO will benefit from the experience of ARISE in building the RI (including AI pipelines and publicly accessible algorithm library) through Biesmeijer, Kalkman, Stowell and Kissling.
BIOSCAN-Europe Lead: Naturalis	Builds an interconnected facility of DNA-based monitoring of biodiversity (organisations, researchers, technology) in Europe, will be the sister project of MAMBO if awarded. MAMBO will benefit fully from BIOSCAN tools and infrastructure.

Project and partners involved	Contribution to MAMBO
DECIDE Lead: UKCEH	DECIDE aims to collect new species occurrence data to improve biodiversity models for decision-making by putting recorders' motivations at the heart of the process. Focusing initially on butterflies, moths and grasshoppers, this pioneering project aims to map 1,000 species at fine-resolution and to improve these models through the records submitted by Recorders. Recorders will be guided where and when to make records in their region, so that their records can optimally improve the species maps - a process called 'adaptive sampling'.
DISSCO-EU Lead: Naturalis	The Distributed System of Scientific Collections (DISSCo) is the Research Infrastructure (RI) for Natural Science Collections. With its >130 partners (including the major natural historymuseums, botanic gardens and collection-holding universities in the world) DiSSCo RI aims todigitally unify all European natural science assets under common access, curation, policies andpractices that ensure that all the data is FAIR. It will create a unique access point for integrated data analysis and interpretation through a wide array of digital services provided by itscommunity. MAMBO will benefit from DISSCo through use of its FAIR procedures, datastandardization protocols and vast network of partners.
Easy RIDER Lead: UKCEH	Real-time IDentification for Ecological Research and Monitoring (Easy RIDER): a UKResearch and Innovation Global Partnership Seedcorn fund project to support the developmentof long-term partnerships with international researchers (UKCEH, UA, Naturalis). Easy RIDER will standardise automated insect camera traps with a global community (e.g. through WildLabs), and field testing traps in multiple locations.
ECOSTACK Participant: AU	This €10M H2020 project's overall objective is to develop and support ecologically, economically and socially sustainable crop production via stacking and protection of functional biodiversity. This includes prototyping novel monitoring technology by AU (Høye), which will be available to MAMBO. Through ECOSTACK, MAMBO will also have access to a strong network of stakeholders in the agriculture sector across the EU.
EU PI Contributors: All MAMBO partners	EU Pollinators Initiative sets strategic objectives and a set of actions to be taken by the EU and its Member States to address the decline of pollinators in the EU and contribute to global conservation efforts. It sets the framework for an integrated approach to the problem and a more effective use of existing tools and policies. The initiative sets long-term objectives (towards 2030), and short-term actions under three priorities: Improving knowledge of pollinator decline, its causes and consequences; Tackling the causes of pollinator decline; and Raising awareness, engaging society-at-large and promoting collaboration.
EuropaBON WP lead: UvA	Designing an EU-wide framework for monitoring biodiversity and ecosystem services, and aiming to engage users at the regional, national and European level to identify the data and policy needs (UvA, UREAD, UFZ). MAMBO will benefit from EuropaBON through the identified policy and stakeholder needs, and the developed framework for the future monitoring of biodiversity (through Kissling as EuropaBON lead of monitoring co-design).

Project and partners involved	Contribution to MAMBO
LifeWatch Scientific coordinator: UvA	LifeWatch-ERIC is a European Research Infrastructure Consortium with focus on biodiversity and ecosystem research. Kissling (UvA) is scientific coordinator of the LifeWatch Virtual Laboratory Innovation Center (LW-VLIC) and responsible for the implementation of virtual labs and the development of workflows, data products, and eScience tools related to LiDAR,remote sensing and Essential Biodiversity Variables (EBVs).
ORBIT	Developing resources for European bee inventory and taxonomy (UREAD) aims to create a centralised taxonomic facility that lays the groundwork for the identification of European wild bees that will support other European projects such the EU Pollinator Monitoring Scheme (EUPoMS).
Safeguard Cocoordinator: UREAD	Safeguarding European wild pollinators (H2020 2021-2025, UREAD, UFZ, PEN). Safeguard brings together world-leading researchers, NGOs, industry and policy experts to substantially contribute to Europe's capacity to reverse the losses of wild pollinators. Safeguard will significantly expand current assessments of the status and trends of European wild pollinators including bees, butterflies, flies and other pollinating insects.
SPRING Coordinator: UFZ	Strengthening Pollinator Recovery through Indicators and monitoring (UFZ, UKCEH, UREAD, Naturalis) aims to strengthen taxonomic capacity in EU Member States with regard to pollinating insects, and support preparation for the implementation of the EU PoMs.
STING Chair: UREAD	Science and Technology for pollinating insects (STING): A pool of experts assisting the European Commission with Action 1 of the EU Pollinators Initiative (design of the EUPollinator Monitoring Scheme). Chaired by UREAD with Naturalis, UFZ, UKCEH. Major enduser for MAMBO technologies and tools.

Interdisciplinarity and the integration of social science: MAMBO brings together natural scientists who are involved in habitat and species conservation alongside technology and software specialists to produce tools to help with monitoring, management and delivery of the habitats directives and species action plans. Social science methods and principles will be applied throughout MAMBO, most notably in the early stages of the project in WP1 (User needs and co-development) and towards the end of the project in WP6 (Synergies, gap-filling and optimisation in a European context). By directly engaging with national and international stakeholders (Task 1.4, and Task 1.6.) and exploring how actors interact with one another (Task 1.3.), the project will integrate qualitative research directly into the testing of novel technologies, identifying challenges and opportunities that would be missed by technical assessments alone. In addition, we will assess the economic benefits of the proposed technology in Task 6.4., identifying the opportunities these technologies present for:

- reducing the costs of monitoring in the short and long term,
- delivering better value for money in achieving conservation objectives and
- safeguarding economically valuable biodiversity.

The outputs of this task will include proposals to link monitoring natural capital accounting projects, including the recent Eurostat INCA system of accounts. Collectively, this will contribute to effective policy and practice at the local, national, and European levels and help maximise the uptake of the technologies through the project's lifespan and beyond.

Gender dimension: In MAMBO the gender dimension will be considered in the co-design, stakeholder mapping, and cost-benefit analyses. Co-design: We will ensure that user needs and tool design considers all kinds of gender to make them equally attractive and intuitive. Stakeholder mapping: Questionnaires and workshop invitations will be screened for unconscious bias in the language, which can affect the outcome due to gender aspects. Cost-benefit analyses: In the context of the cost-benefit analysis, we will specifically examine gender differences in the estimates of costs and benefits associated with novel monitoring tools.

Open Science: MAMBO will address open science practices by making each stage of the developmental process open and accessible. The open access publishing platform Open Research Europe (ORE), enabling the beneficiaries of HORIZON Europe to publish their results after a thorough examination and maximally open process, will be explored for publishing the completed development stage models and documentation. The project will also make use of the highly innovative Open Access journal Research Ideas and Outcomes (RIO), where a special Open Science Collection for MAMBO is envisaged (D7.3). In addition to conventional research papers, the journal welcomes contributions documenting the entire research cycle, including data, models, methods, workflows, results, software, perspectives, and policy recommendations. Moreover, a project collection in RIO is designed to feature all project research outputs that have been published in various journals and/or platforms. The journal only displays the metadata of the article and the link to the original repository, hence fully adhering to copyright regulations. These features allow to centrally collect all project outputs and make these available beyond the project's lifetime.

In order to enforce exploitation, MAMBO will make use of EC's Horizon Result Platform (HRP) - a tool that enables important exploitable results to be announced and disseminated to investors, stakeholders, politicians, potential business partners, etc. the project will use this platform to publish the project's Key Exploitable Results (KERs). Beyond the HRP, MAMBO will get support from the Horizon Results Booster (HRB) to better exploit the project activities. HRB includes various services, including clustering of projects for common dissemination, enhanced exploitation plans, business plans for R&I results and commercialisation services for the more mature results. Communication to society at large using social media and easy to digest practice abstracts will be used to make the science accessible for non-scientists.

Data management: To coordinate data management within the project, MAMBO will develop a guiding Data Management Plan (DMP) (D8.3), detailing what data the project will generate, whether and how it will be exploited or made accessible for verification and re-use, and how it will be curated and preserved. The DMP will support the data management life cycle for all data that will be collected, processed or generated by the

project. The DMP will be prepared in accordance with the guidelines on FAIR Data Management in Horizon Europe.

The DMP will specifically cover:

- Data types generated and their standards: MAMBO will generate a large amount of data of various types including images, data, code, software, and algorithms. These will be held by MAMBO partners but will adhere to the MAMBO policies, including archiving and preservation policy (see below). MAMBO tools and data will adhere to set data standards (e.g. DANS) and based on activities and funding to WP2 will strive to be Accessible and Interoperable.
- Datasets description: The DMP will provide the dataset metadata specification that will be used in the data registry, following an appropriate standard (e.g. http://www.dcc.ac.uk/resources/metadata-standards). In the cases where the datasets cannot be publicly shared, the reasons will be mentioned in its metadata description (e.g. ethical, rules of personal data, intellectual property, commercial, privacy-related, security-related). This will guarantee that MAMBO data will be Findable.
- Data sharing policies: These include policies for both newly generated data and data and knowledge existing among the MAMBO partners or external parties to be used in MAMBO. The DMP will outline how data can be exploited, shared, or made accessible for verification and re-use. Explanation of policies will be an integral part of MAMBO annual meetings to facilitate data sharing among MAMBO partners.
- Data archiving and preservation: Partners will be responsible for the preservation of raw data, final products will be stored in repositories maintained by the partners or open repositories (depending on data type).
- Open source policies: MAMBO will in principle favour open-source approaches. Some results, however, may be based on proprietary knowledge and components, which would not allow for open-source. In such cases, selfcontained parts of the project modules (including manuals and interfaces) will be made available through open repositories like GitHub or GitLab if possible to allow for further development by third parties.

2. Impact

2.1 Project's pathways towards impact

2.1.1 MAMBO's contributions to the expected outcomes in the topic

The HORIZON-CL6-2021-BIODIV-01-02 "Data and technologies for the inventory, fast identification and monitoring of endangered wildlife and other species groups" call states four expected outcomes, and we demonstrate how MAMBO meets these in contributing to:

1) Systemic, integrated and (open-)standardised data, knowledge and models on the conservation status and ecological requirements of species and habitats, with a focus on those covered by the Birds and Habitats Directives and IUCN Red List

Impact: MAMBO will develop integrated species distribution models and habitat extent maps at high resolution, with a focus on the species covered by the Birds and Habitats Directives and IUCN Red List (WPs 4,6). These models and the resulting maps will allow computing automatically some of the IUCN criteria used to evaluate if a taxon belongs in an IUCN Red List threatened category (CRITICALLY ENDANGERED, ENDANGERED or VULNERABLE). Criterion B, in particular, focusing on the geographic range of species and habitats (B1-Area of occupation or B2-Extent of Occupancy) will be directly computable. This automated approach to conservation status determination will not replace the assessment by experts but will greatly facilitate and accelerate their work. This will allow to have a quick and recurrent estimate of the status and to identify the species for which there seems to be an urgent need of more precise assessment and/or revision by the experts. The high transferability of the models used will also allow an estimation of the status of the rarest species for which there are not enough observation data available for the standard procedure.

MAMBO will also develop a deep-learning and remote sensing based habitat type mapping approach, applicable at local, national and European scale (T4.1) which will support Europe wide data integration and standardised scaling. MAMBO will also support the development of standardised data and knowledge on habitat conservation status by developing, and demonstrating common RS derived habitat condition metrics (T4.2; T5.3) and encouraging future standardised processing of airborne LiDAR and drone data, key remote sensing data sources for condition monitoring. Reviewing the challenges of upscaling LiDAR and Drone data processing and tackling it directly by converting scripts into interactive computing workflows, and automating workflow deployment (T4.3; T5.3) will encourage future targeted interventions (investments and focussed efforts) and so speed up LiDAR and drone data use.

Impact indicators: Impact will be measured in terms of feedback from IUCN. The impact of the RS based tools is measured in the feedback from stakeholders, interest in the reviews and demonstrations (number of webinar and workshop participants T5.3), and script and computing workflows usage (access and development on GitHub).

2) Bridging of taxonomic and monitoring gaps thanks to new enabling tools, technologies, fast identification methodologies and integrated monitoring systems across Europe on wildlife species

Impact: MAMBO will result in three key developments addressing taxonomic and monitoring gaps:

- developing AI-powered identification based on sound and images,
- development of insect camera’s capable of monitoring both diversity and biomass and

- creating AI-tools allowing monitoring of vegetation quadrants.

AI based sound and image identification will be made freely available for specialist and citizen scientists throughout Europe and will include species of EU Habitats and Bird directive, EU pollinator initiative, EU Red lists and EU Invasive Alien Species. The tools developed for insect cameras make it possible to deploy these on a larger scale helping to address questions regarding insect decline, biomass decline (impact on food web) and the early detection of invasive and/or pest species. The tools for vegetation quadrants will make monitoring of vegetation more cost-efficient, less dependent on specialists and better standardized allowing for vegetation quadrant monitoring being applied on a larger scale. The tools developed in MAMBO are of importance to governmental organisations, NGO's and citizen scientists, will be used on a large scale for both plants and animals and will help to increase the monitoring effort while at the same time reducing the cost.

Impact indicators: The impact of the three key tools developed is measured in their use. By the end of the project, we will have image and sound recognition available for all above mentioned groups with at least 30,000 European species included. The algorithms will be open access, the identification service will be available throughout Europe and will be incorporated in at least six different national biodiversity portals, and will be used annually by over 20,000 persons contributing to millions of records on biodiversity. At the end of the project at least 10 national biodiversity portals are willing to participate in a consortium aimed at further developing the identification tools. The software tools developed for the insect cameras (diversity and biomass detection of insects) will at the end of the project be used in at least 200 cameras in over 5 European countries with the aim to develop a European wide insect biomass monitoring. The tools for AI-driven analyses of vegetation quadrants will at the end of the project be freely available and will be used for spin-off projects in >5 European countries.

3) Models upscaling the results of biodiversity assessments to wider areas, based on existing datasets of environmental descriptors

Impact: MAMBO will develop novel modelling approaches that integrate multiple data streams from various monitoring tools (T6.1) and combine them with existing high-resolution environmental data and newly developed metrics of habitat condition (T6.2). These models will be upscaled to provide information on the distribution, status and trends of focal species and entire communities (T6.3), enabling the assessment of less-well monitored species or the identification of geographic monitoring gaps. Results and underlying workflows will be provided to respective citizen science-driven monitoring schemes, such as the European Butterfly Monitoring Scheme or the EU Pollinator Monitoring Scheme to allow for adaptive monitoring approaches. Results will also support local authorities inmonitoring Annex species of the EU Habitats Directives. The development of the novel integrated modeling approaches, together with the upscaling procedures will also have a considerable impact on the scientific community, by enhancing our ability to transfer ecological niche models in space and time.

Impact indicators: Improving predictive capacity via better models means publication in international peer-reviewed scientific press, where methodological advancements and respective results are independently evaluated and verified. Given the envisaged significant improvements in modelling capacity and our consolidated expertise, we expect ground-breaking scientific publications in high impact journals. In addition to these publications, we will further spread our results and engage in dialogue via targeted conference presentations. To boost this process, we will make our publications broadly available as open-source and open-data. Scientific impact will be measured by citation metrics (Web of Science) and Altmetrics (e.g. coverage in blogs, social media) and presentation at majorscientific conferences. Uptake by national and international monitoring schemes will be assessed by the number of novel monitoring sites.

4) Integrative taxonomy of inventory pollinator species (bees, butterflies, moths and hoverflies), soil fauna (mites, springtails, woodlices, millipedes and earthworms) and/or other threatened species groups

Impact: MAMBO forms the linking pin between the large number of partners and initiatives focussed on the conservation of pollinators. It will ensure that information and tools generated as part of the European Pollinator Initiative, the EU Pollinator Monitoring Scheme, SPRING (Strengthening Pollinator Recovery through INdicators and monitorinG), ORBIT and TAXOFLY will be freely accessible at a central location. This will include data on ecology, distribution, taxonomy (checklists), and identification. The latter will be partly generated as part of WP3 of MAMBO. In addition, the training data mobilised for the AI-powered image and sound recognition will be linked to the system giving taxonomist access to 100thousands of images identified by other experts and thus facilitating exchange of taxonomic know-how. A similar infrastructure will be in place for soil fauna and other groups of EU conservation concern. During the project, MAMBO will engaged in cooperation with HORIZON-CL6-2021-BIODIV-01-01 (European participation in global biodiversity genomics endeavours) ensuring that molecular data of European species of conservation concern will be readily accessible. This cooperation is especially important for soil organism as lack of DNA-barcode data is currently hampering the structured monitoring of these groups.

Impact indicators: Impact will be measured by the completeness of enclosed data, the amount of data made available and the use of the data. For pollinators the data linked will consist of at least basic data on ecology, distribution, taxonomy (checklists), the availability of DNA-data and data of relevance to the identification of butterflies, moths, hoverflies and bees of all species found in Europe (< 5,700). This will include images of use to taxonomy and identification of 80 percent of the species based both on field data and collections. For pollinators, a complete overview of available DNA barcodes will be available with a plan to fill gaps in addition. We expect at least 1000 people from all European countries accessing the information available in the portal annually, with user numbers potentially increasing over time.

2.1.2 MAMBO's wider impact beyond the lifetime of the project

The main aim of Horizon Europe is to provide the knowledge, tools and infrastructure to contribute to well-being and prosperity in Europe (and beyond). The Horizon Europe Work Programme 2021-2022 "Food, Bioeconomy, Natural Resources, Agriculture and Environment" states eight overall expected impacts, which can be summarized under four impact areas: The work programme wants to:

1. lead the development of the digital and green transformation of Europe,
2. restore Europe's ecosystems and biodiversity and manage natural resources sustainably,
3. make Europe the first digitally-enabled circular, climate-neutral and sustainable economy, and
4. all that in a more resilient, inclusive and democratic Europe.

MAMBO will contribute to all four impact areas, but mostly to 1, 2 and 3. Related to aim (1): MAMBO tools and data will be FAIR and thus contribute to the digital literacy of Europe. MAMBO will make use of a wealth of data sources (from remote sensing to citizen science and from global and European to national and local data) and integrate them into tools and applications that can become the basis of public and private technologies to enable spatial planning (e.g. biodiversity mapping and recording), wellbeing and health (e.g. identification of disease vectors and development of green space), and green growth (e.g. tools for precision agriculture and monitoring the impact of economic activities). Related to (2): All MAMBO tools will facilitate ecological restoration as its tools make monitoring of all biodiversity (species and habitats, with a focus on EU directive targets) easier and more accurate, provide decision-support for nature conservation and guidance of nature restoration and development. Related to (3): MAMBO image and sound recognition tools will facilitate digitally-supported agriculture and economy. For example, chemical-free crop protection depends on accurate early warning of looming pests and diseases. Image-recognition tools, such as automated insect cameras, will be used to do that. Also, MAMBO tools can be used to evaluate and monitor the impact of economic activities. Not only their harmful effects (e.g. habitat degradation) but also their positive contribution (e.g. afforestation and restoration). Related to (4): Some MAMBO tools will target citizens as its end-users and will enable citizens to sense their environment directly. This will increase citizen participation level (and influence) in environmental, protection, health, and well-being areas.

Impact beyond the work programme: Biodiversity and ecosystem services in a European and global context are in crisis. One-fifth of the world's countries are at risk of their ecosystems collapsing due to the destruction of the environment and ecosystems. Biodiversity and the ecosystem services that depend upon it face ever greater pressures due to human activity around the globe. Resolving this involves a standardised and easy-to-implement, cost-efficient adaptive monitoring. MAMBO addresses these challenges with a multi-dimensional approach, recognising the need for co-design at all levels. The project builds on an integration of sciences to deliver a set of monitoring tools to identify the root challenges in the loss of biodiversity.

MAMBO will establish a community of practice for novel monitoring technology. By networking with like-minded researchers, we will expand the scope of this field, beyond the main project partners, working towards a global ambition to develop automated biodiversity monitoring methods to generate high temporal and spatial resolution image data for monitoring species and habitats. Knowledge exchange will be invaluable in breaking down the barriers between our domains: AI, ecology, citizen science, and engineering. Effective knowledge exchange activities between the MAMBO partners and relevant stakeholder communities will take place at regular intervals to ensure user needs are considered at every stage and the uptake of tools and technologies developed during the project can be maximised. The coordinated field trials across the EU will help refine best practice guidelines and will stimulate the community of practice in challenging environments. Trials of the automated systems will be run alongside traditional sampling methods and will quantify the relative biases in the datasets from the two methods and assess how data from the two might be combined in spatiotemporal statistical analyses of species populations. We will quantify the labour and material costs of each approach and assess the efficiency of various monitoring schemes. A key MAMBO output will be a series of best-practice guides for species and habitat monitoring using automated methods.

MAMBO is expected to:

- Model the complex interdependencies between biology, and societal structures including governance and community aspiration, national and local policy and actions, financial requirements and social constraints.
- Provide opportunities for new technological innovation to be applied to the biodiversity sector that make such landscapes financially sustainable as well as ecologically stable.
- Provide targeted multi-dimensional support in the project to adopt or to co-develop innovative solutions to biodiversity challenges, and make these portfolios of monitoring solutions available for future upscaling.
- Develop and integrate innovative technologies to underpin, support and enable the upscaling of these actions by providing tools to monitor, measure and enable decision support, ensuring data is used effectively for the transformative restoration of biodiversity.
- Validate both the tools and the assessment frameworks developed in the project within the context of the demonstration sites and regions and communicate across multiple platforms the best practices we have identified.

Contribution to Sustainable Development Goals:

1. Biosphere Dimension: the project will contribute to SDG 15 (Life on Land) by addressing all targets of this SDG, with an impact on the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, the promotion of sustainable land use planning, and the restoration of degraded soils. Importantly, MAMBO will significantly lower the costs for monitoring biodiversity.

2. Societal Dimension: MAMBO will contribute to SDG 11 (Sustainable cities). We will impact a) the capacity to ensure sustainable food production by informing the benefits of implement resilient agricultural practices for biodiversity, b) the maintenance of ecosystems, strengthening capacity for adaptation to climate change, c) the improvement of land and soil quality and the status of agrobiodiversity, genetic diversity of seeds and the crop wild relatives (SDG 2).

3. Economic Dimension: Healthy and resilient ecosystems, characterised by a complete structural and functional diversity of species, are an essential requirement for economic resilience. MAMBO contributes to SDG 8 (economic growth) through technological innovation (AI-based monitoring equipment and tools), economic productivity through entrepreneurship and job creation (e.g. promoting new start-ups using LiDAR, drone and Copernicus EO data), and through promoting sustainable tourism (in biodiverse landscapes).

Contribution to the EU Biodiversity Strategy, European Green Deal and the Habitats Directive:

1. As part of the European Green Deal, MAMBO results will support the implementation of the EU Biodiversity Strategy, for all objectives where the inventory of species is a core aspect. These are related to the following components of the BDS strategy: 2.1 A coherent network of protected areas. This includes a truly coherent Trans-European Nature Network; setting up ecological corridors to prevent genetic isolation, allow for species migration, and maintain and enhance healthy ecosystems; and investments in green and blue infrastructure. MAMBO will contribute to the aim of Member States to demonstrate significant progress in legally designating new protected areas and integrating ecological corridors. On this basis, the Commission will assess by 2024 whether the EU is on track to meet its 2030 targets or whether stronger actions, including EU legislation, are needed, for which results of MAMBO could be made available. Also for section 2.2 “An EU Nature Restoration Plan: restoring ecosystems across land and sea”, it is of importance, in particular for sub-section 2.2.2. “Bringing nature back to agricultural land”, where it is explicitly stated that farmland birds and insects, particularly pollinators, are key indicators of the health of agroecosystems and are vital for agricultural production and food security; and where an aim is to bring back at least 10% of agricultural area under high-diversity landscape features. These include, inter alia, buffer strips, rotational or non-rotational fallow land, hedges, non-productive trees, terrace walls, and ponds, where modern methods for the inventory of species as developed in MAMBO can be integrated, also for section 2.2.10. “Addressing invasive alien species” such methods should be integrated. MAMBO results can also be used for an improved EU-wide framework for the mapping and monitoring of biodiversity and ecosystem services that will be put in place with support from the EuropaBON project and the Biodiversity Partnership under Horizon Europe. It will be fully aligned with the future EU Nature Restoration Law, to be proposed in 2021.

2. For the Habitats Directive MAMBO will enlarge the toolbox for the assessment of species which are typical for the habitats listed in the Annexes of the Directive or even listed themselves (like e.g. some butterfly & moth species).

Requirements and potential barriers to expected outcomes

Stakeholder fatigue, lack of interest or conflicts of interest in participating in MAMBO activities may present a risk to the project's impact. MAMBO will minimise this risk by following EU guidance for stakeholder engagement and co-design (e.g. http://spiral-project.eu/content/documents.html; http://www.biodiversa.org/702). We will provide training for local teams, introduce various ways for stakeholder engagement and commitment, utilise longstanding partnerships across the stakeholder spectrum and develop approaches accounting for diverse interests, values, benefits and socio-political contexts. **Economic concerns driven by the COVID-19** crisis may still override the interest of local, regional and national actors in engaging with the project. However, sustainable development is central to the EU Green Deal and requires reconciling biodiversity and economic welfare. MAMBO will actively support this strategy by demonstrating the direct and indirect values and innovative implementation of its results. **Possible changes in the EU and national policies** can modify the framework within which MAMBO is aiming to achieve impact. We will continually horizon-scan the MS/EU policy landscape for initiatives that may affect the project (e.g. new or revised incentives or implementation targets between member states). MAMBO views this as a challenge and an opportunity to improve policy impact and decision-making by providing knowledge and methods for the EC, MS and civil society to improve designs of species and ecosystem assessments.

2.2 Measures to maximise impact - Dissemination, exploitation and communication

Purposefully designed dissemination, exploitation, and communication activities are key components for maximising the impact of MAMBO. The project will ensure the effectiveness of these activities by developing a Dissemination and Communication Strategy (DCS, MS7.2), outlining the key target groups and relevant messages and channels corresponding to the needs of each group. A Plan for Exploitation and Dissemination of Results (PEDR, D7.2) will be created to incorporate lessons learned and to strictly define the dissemination and communication measures planned to ensure the uptake of project innovation. The plans will serve as a management tool for defining how the project's progress and results are shared with stakeholders and target audiences. Their updates will include any necessary modification and adapt appropriately to project progress and new circumstances, including feedback from stakeholders and target audiences. The DCS and PEDR will identify target audiences ('who'), project research activities, outcomes and the MAMBO monitoring and modelling framework ('what'), tools and channels employed ('how'), and the envisioned timeline for implementation of these activities ('when'). All activities have the objective to maximise the short-, medium- and long-term impact of MAMBO results.

2.2.1 Dissemination

To maximize impacts, MAMBO will actively target its dissemination, exploitation, and communication activities to audiences and stakeholders. MAMBO will tailor various uni-

and bi-directional dissemination channels to the needs of the target stakeholders and audiences, eliciting expertise, knowledge, and perceptions from stakeholders as part of the project's co-design and engagement activities. A preliminary mapping of dissemination tools and channels, their target audiences, and relevant Key Performance Indicators (KPIs) is shown in Table 3 and will be refined in the PEDR. To effectively disseminate project results, specific dissemination tools and channels will be established by the project and existing channels used by MAMBO consortium participants will be fully exploited. MAMBO will engage participants to multiply the effects of the project's social media channels by using their institutional social media channels. Furthermore, consortium participants will use their existing networks and develop new links, presenting the project and its results at relevant events at local, national, and international scales.

Table 3.

Dissemination tools and targets, measures to maximise impact and Key Performance Indicators (KPIs).

Tool: Target	Measures to maximise impact	KPIs
General Project website and Microsoft Teams: Project partners, Policy, Practice, General Public	Inform and discuss specific topics of common interest; engage interested parties through information on the project's main outcomes. The project website will act as a hub for all online communication efforts and as a repository for all public information on the project. MS Teams will support smooth internal communication.	Number of visits >12,000/ project duration; average session duration >120s, returning visitors>30%; country distribution: Europe & beyond
Presentations at meetings, webinars, events and workshops: Practice, Policy	Direct raising of awareness among stakeholders; interaction with key persons and direct conversations with relevant public-sector bodies (within the EU and outside), industry bodies, consumers, waste managers, decision-makers from cities, and other organisations.	Number of international or national conferences, where the project results are presented >2 / project year
Marketing Materials: Practice, Policy, General Public	Marketing materials, including, but not limited to leaflets, posters, infographics and other visuals will promote and raise awareness about the project. These materials will enhance the communication of project outputs to facilitate knowledge transfer.	≥500 brochures distributed
Training video series: Practice, General public	Project results and developments are translated in an easy-to-digest format for practitioners and private persons. The website will host various training materials, which will provide clear guidance on the processes involved in using central MAMBO outputs.	≥4 training videos produced; ≥100 views/ video

Tool: Target	Measures to maximise impact	KPIs
Social media(Twitter, Facebook,YouTube, etc.): Policy, Practice, General public	Create communities and inform members about project developments, results, and recommendations.	Posts >1/week; reposts>1/ week; followers & “likes”> 100/ year; impressions>100000/ project duration
MAMBO e-Newsletter: Policy and decision-makers, Industry, SMEs, Practice, General public	Disseminate ongoing activities, results, and other project-relevant news and events.	Number of subscribers +50/ year, no. of opens >35%
Factsheets, guidelines: Practice, Policy	Transferring key results directly to project end-users to ensure maximum uptake and use. Factsheets will provide a clear overview of MAMBO outputs for practitioners and policy-makers.	≥200 copies distributed/ downloaded
Press releases: Journalists, media	Announcement of significant project results to leading scientific media outlets (e.g. EurekAlert!, AlphaGalileo.).	≥1 press release(s) published/ year
Scientific publications: a collection of results in the Research Ideas and Outcomes (RIO) journal: Project partners, Researchers, Practice	Project results will be presented in open access journals and popular media (including Open Research Europe). A collection of results in the Research Ideas and Outcomes (RIO) journal will host an open science compendium of data, factsheets, policy briefs, project reports and infographics published with a permanent DOI to ensure MAMBO collective knowledge is available, citable and reusable beyond the project lifetime.	Journal’s impact factors, download and citation statistics
Partner’s existing communication structures: Policy, Practice, General public	We will leverage the existing communication structures - such as partner websites, newsletters, social media, events and online communities — to disseminate project developments that are relevant to the field of activity of each partner. This will greatly extend our reach with minimal additional effort.	Number of visits, downloads, engagement rate; 4 partners’ channels (websites, social media etc.) utilised

Dissemination tools and targets, measures to maximise impact and Key Performance Indicators (KPIs) are presented in Table 3.

2.2.2 Exploitation

In order to ensure effective exploitation of project results, we will explore the use of Open Research Europe (ORE), the HORIZON Europe open access publishing platform, for publishing our project outputs and documentation. The project will also make use of the

highly innovative Open Access journal Research Ideas and Outcomes (RIO), where a special Open Science Collection for MAMBO is envisaged (D7.3). In addition to conventional research papers, the journal welcomes contributions documenting the entire research cycle, including data, models, methods, workflows, results, software, perspectives, and policy recommendations. Moreover, a project collection in RIO is designed to feature all project research outputs that have been published in various journals and/or platforms. The journal only displays the metadata of the article and the link to the original repository, hence avoiding any copyright issues. These features allow to central collection of all project outputs and make these available beyond the project's lifetime. Furthermore, MAMBO will make use of EC's Horizon Result Platform (HRP) - a tool that enables important exploitable results to be announced and disseminated to investors, stakeholders, politicians, potential business partners, etc. The project will use this platform to publish the project's Key Exploitable Results (KERs, Table 4). Beyond the HRP, MAMBO will get support from the Horizon Results Booster (HRB) to better exploit the project activities. HRB includes various services, including clustering of projects for common dissemination, enhanced exploitation plans, business plans for R&I results and commercialisation services for the more mature results.

Table 4.

A preliminary list of project Key Exploitable Results (KERs), their novelty, stakeholders, scale and potential outcomes and impact.

KER	Main novelty	Stakeholders	Scale	Potential outcomes & impact
Published review of habitat condition metrics used across the EU, suitable for remote sensing based monitoring	There are currently noconsistent approaches to monitoring habitat(conservation) status across the EU	EEA, national environment departments, Nature reserve and landmanagers	European	An adopted set of common metrics (complementing other habitat specific metrics) will greatly improve consistent reporting across the EU
Published report/ paper assessing the interoperability and maturity for upscaling LiDAR and drone derived habitat condition metrics	Exploitation of LiDAR and drone data consistently at country and Europe wide level cannot progress without a detailed analysis of the main bottlenecks associated with data acquisition, storage, access, pre-processing and analysis.	Domain scientists, eScience engineers, VRE developers, API developers EEA, national environmental agencies	European	Targeted interventions (investments and focussed efforts) will facilitate and speed up the use of RS data as part of a future virtual lab for habitat and biodiversity monitoring community

KER	Main novelty	Stakeholders	Scale	Potential outcomes & impact
Prototype open source and documented frameworks, software and pipeline for RS based habitat extent mapping and habitat condition metric derivation	Novel publicly available RS based methods for habitat monitoring, delivered in a format that is easily adaptable and exploitable by technical experts	Domain scientists, eScience engineers, VRE developers	European	As part of our virtual lab vision, a first bundle of scripts introduced at a technical workshop, will hopefully instigate a European wide useof RS data for habitat monitoring
Image and sound recognition algorithms available for species of EU policy concern	Large scale and EU wide introduction of AI- powered identification of biodiversity, available for both specialists and citizens	National biodiversity portals	European	Steep increase in quality and quantity of available distribution data on species of EU policy concern

A preliminary list of project Key Exploitable Results (KERs), their novelty, stakeholders, scale and potential outcomes and impact are present in Table 4.

2.2.3 Communication

In order to achieve maximum exposure and impact, we will prioritise our communication channels based on the ones that are actively used by our target audiences. With our professional audiences, our focus will be on establishing two-way communication, whereas for the general public, we will adopt the “getting our message out there” mantra (mainly through collaboration with associations and networks, as well as public administration at regional and local levels).

Internal communication: Communication and document exchange tool MS Teams will be used as part of a web-enabled communications and learning platform, to create a chat-like environment that simultaneously eases communication and streamlines information and access to documents into relevant channels to alleviate workload and stimulate fruitful and focused discussions. It will provide a place where the MAMBO project team and collaborators can communicate, share documents and work together. The platform allows for an easy exchange of messages and calls, hence avoiding the need for unnecessary email exchanges.

External communication: MAMBO's external communication strategies will be bi-directional, i.e. not only disseminating project outputs to targeted actor groups and the public at large but also eliciting expertise, knowledge and perceptions as part of the project’s engagement activities. The different Communication & dissemination tools and targets, measures to maximise impact and KPIs are outlined in Table 3.

2.2.4 Management of intellectual property and foreseen protection measures

Knowledge generated will be managed in compliance with the Consortium Agreement (CA), which will be signed at the beginning of the project. The CA will address background and foreground knowledge, ownership, protected third-party components, and protection, use, and dissemination of results and access rights. The principles are:

- Background information and knowledge contributed to the project by each participant will be listed in the CA. When included in the work plan, access to background information will be provided royalty-free to other participants for the implementation of the project's tasks.
- Results shall be owned by the participant who generated them. Each participant will be responsible for ensuring the fulfilment of their obligations under the GA regarding results by planning with any third parties that could claim rights to them.
- Whenever results have been produced jointly by two or more participants, the ownership of the results will be shared among the participants who carried out the work. The terms of joint ownership, protection, share of ownership, and costs for possible protection will be agreed upon in writing via a joint ownership agreement.
- Each participant will be responsible for examining possibilities to protect results that may be commercially or industrially exploited. When deciding on protection, the participant must consider their own legitimate interests and the interests of the other participants. Participants will ensure that adequate steps towards protection are taken prior to DEC activities, preventing unapproved public disclosure of results, models, tools, and data.
- Access rights to results will be granted on a royalty-free basis for further research, and on fair and reasonable conditions if needed for commercial exploitation.

2.3 Summary

A summary of the key elements of the impact section is present in Table 5.

Table 5.

Key elements of the impact section.

SPECIFIC NEEDS	D & E & C MEASURES	EXPECTED RESULTS
Evidence is mounting of widespread biodiversity declines across the globe. This gives a stark warning for the perilous state of our planet, yet the evidence base remains biased to a few regions and a few species groups which are feasible to monitor. General conclusions on the status of biodiversity are complex given their diverse ecologies and high variability between and within taxon groups, over time and geographic regions.	**Dissemination**: By leveraging existing communication structures, MAMBO will disseminate key project developments. Consortium partners will represent the project at international, national or regional events, and directly engage with interested actors. Through demonstration, we will raise awareness of the potential for using AI species identification tools, camera systems, and acoustic sensors for species monitoring.	Automated tools (AI software for animalidentification from images and sound, insectcameras, and image-based surveys of plant species in local permanent plots or quadrats) for speciesmonitoring will have reached a level of maturity,where they are reproducible, reliable and havebeen tested and demonstrated in realistic settings across the EU.

Repeatable sampling methods that can automate and expand the extent and resolution of biodiversity monitoring are urgently needed to provide robust estimates of long-term trends. Closing the knowledge gap has never been more important. MAMBO is addressing this challenge through innovative approaches to develop, test and deploy modern enabling tools for monitoring wildlife species and their habitats. MAMBO will help to realise the potential of very high spatial resolution remotely sensed data (in particular airborne LiDAR, drone and Sentinel2 data) to support habitat and biodiversity monitoring. MAMBO will provide cost-effective, long-term, and user-friendly solutions to land managers, member states agencies and the EEA for monitoring biodiversity and habitats, and help to evaluate the conservation status of nature reserves.	A technical workshop will further train and encourage interested stakeholders to adapt and use our resulting open source remote sensing data processing frameworks, scripts and pipelines. MAMBO will reach interested professionals through webinars, scientific publications and mobiliseresearch journalists. **Exploitation**: Open Research Europe (ORE) and the Open Access journal Research Ideas and Outcomes (RIO) will be used to ensure effective exploitation of project results and availability beyond MAMBO's lifetime The project's Key Exploitable Results (KERs) will be published on EC's Horizon Result Platform (HRP). Beyond the HRP, MAMBO will get support from the Horizon Results Booster (HRB) to better exploit the project activities. We will provision open access data by making MAMBO data and tools FAIR. **Communication**: Online activities will use the website as a hub and a repository for all public information on the project, supported by the use of social media channels (Twitter, LinkedIn and YouTube).	MAMBO will identify metrics and indicators thatcan be commonly used across Europe for habitatcondition monitoring, measurable with remotesensing. MAMBO will further advance knowledge on how to take up LiDAR and drone data for operational habitat monitoring, specifically in habitats prioritised for conservation action (e.g. grasslands, wetlands). MAMBO will also develop, test and share remotely sensed based methods for mapping habitat extent, using in-situ observations, deep learning and EO data from Copernicus. MAMBO will contribute to developing a framework for integrating data from new and existing biodiversity data streams into the future European system of biodiversity monitoring (EuropaBON), thus providing the next generation of biodiversity indicators needed to measure progress in tackling the biodiversity crisis.
TARGET GROUPS	**OUTCOMES**	**IMPACTS**
European Commission, particularly DG Environment for the implementation of the Biodiversity Strategy (see WP 7.5), and the ECKnowledge Centre for Biodiversity (KCBD) regarding data and knowledge. EU-level assessments made by the European Environmental Agency(EEA) through its European Topic Centre on Biological Diversity (ETC-BD). National, regional and local level policy and decision makers, incl. environmental agencies and ministries of member states with responsibility for reporting to the Birds and Habitats Directives. Land managers and land owners (e.g. inside and outside Natura 2000 sites). Non-governmental organisations - e.g. IUCN.Existing monitoring schemes (e.g. eBMS, EUPoMS, SPRING, EuMon). Ecologists and biodiversity scientists working on bioacoustics and AI based image recognition. Domain scientists developing scripts and analysis tools for mapping and monitoring habitat extent and condition. eScience engineers and developers of virtual research infrastructures with focus on biodiversity, ecosystems and the environment (e.g. LifeWatch, ENVRI). Citizen science communities.	We expect that the technical developments and research networks developed and strengthened through MAMBO will help maximise the potential for a revolution in the scope and capacity for monitoring species and habitats,especially those for which knowledge gaps still exist, and crucial elements of ecosystems that humans depend on. We expect to see a widespread uptake of remote sensing technology for habitat monitoring, in particular LiDAR, drone and Sentinel-2 data. We expect an increase in LiDAR and drone data sharing and use triggered by the adoption of standard practices and harmonized protocols for data acquisition, pre-processing and storage. We expect that our best practice guide for insect monitoring using automated sensors, deeplearning and computer vision will accelerate and standardise the adoption of this exciting new technology. We believe that MAMBO will play an important role in the rise of deeplearning and computer vision in transforming ecological research to address the global challenge of insect declines.	It thus supports the implementation of the Green Deal, the EU biodiversity strategy 2030 and the Birds and Habitats Directives, and will contribute to the Commission's new governance framework for biodiversity under the future EU Nature Restoration Law. MAMBO will deliver new ways of monitoring species and habitats via automated (sound and image) recognition and remote sensing (drones, LiDAR, satellite). Reliable data on the natural environment is fundamental to support science on species conservation in human-modified landscapes. We will make a substantive contribution to understanding climate change and land-use impacts on biodiversity and advise beneficiaries at global (e.g. IUCN, IPBES, IPCC), regional (e.g. EU, EEA) and national levels (reporting of member states).

3. Quality and efficiency of the implementation

3.1 Work plan and resources

MAMBO is organised into eight work packages (WPs) grouped along three main pillars (Fig. 3). WP1 and WP2 aim to engage users into the co-design process and link the tools and data streams to existing infrastructures, respectively. WP3 and WP4 will develop new and enhance existing tools for monitoring species and habitats, respectively. WP5, WP6, and WP7, will ensure that these tools are demonstrated to relevant user groups, which the data streams are integrated with existing monitoring and that results are disseminated and taken up by policy makers. WP8 will ensure efficient coordination across and beyond this truly interdisciplinary project.

The project period duration of MAMBO is 48 months and the timeline of the work in individual WPs and tasks is indicated in the GANTT chart in Fig. 4.

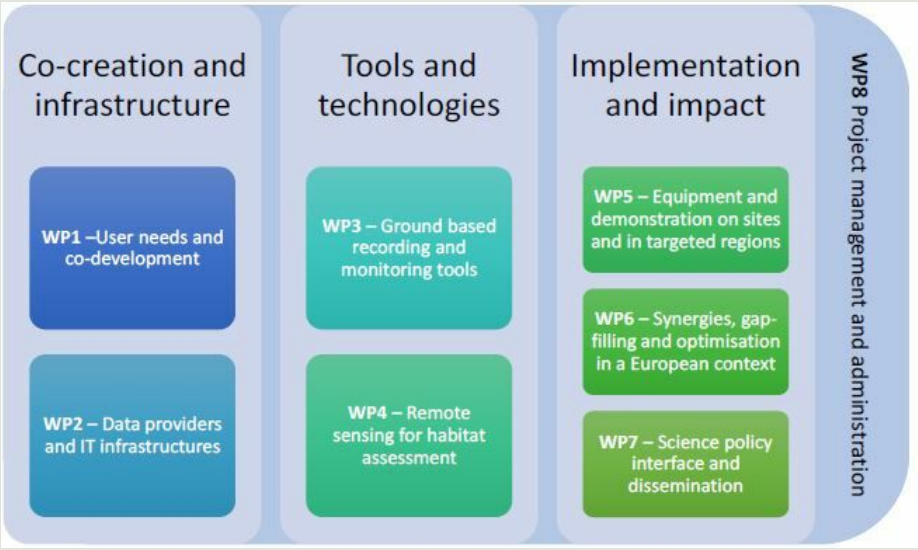

Figure 3. doi

The three main pillars of activity in MAMBO and the underlying work packages.

3.2 Capacity of participants and consortium as a whole

The MAMBO consortium brings together key global research leaders related to the monitoring of species and habitats as is evident from Table 2 individually, these partners represent major strengths which are elaborated below. Many partners have an excellent track record of numerous past collaborations in large-scale projects and are known to complement each other in areas such as stakeholder involvement, biological monitoring, citizen science, and science policy integration. MAMBO connects these key elements of expertise with leaders in cutting-edge biodiversity monitoring technology from the plot to

the continent. Together, the consortium has the necessary experience and capacity to make step changes in efficient ecological monitoring for the conservation of species and habitats.

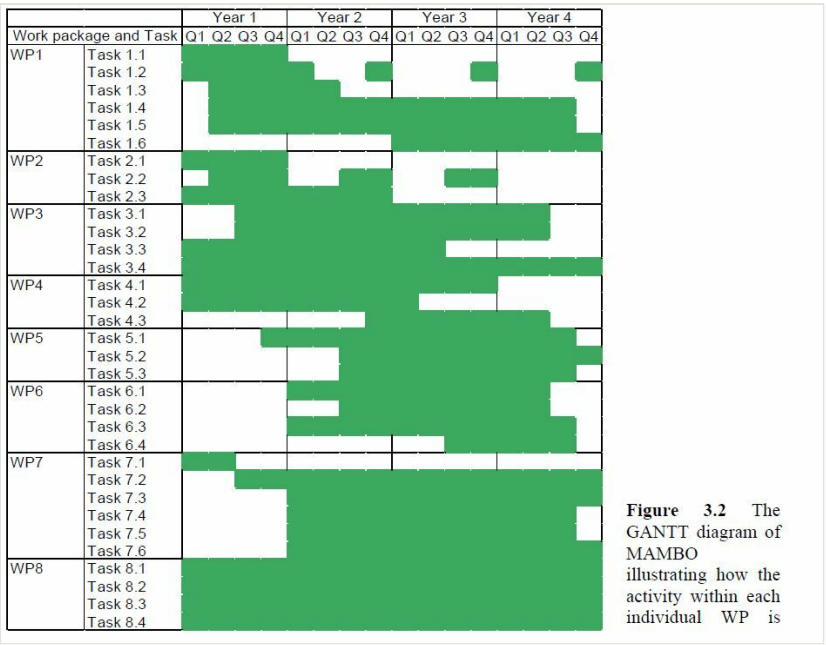

Figure 3.2 The GANTT diagram of MAMBO illustrating how the activity within each individual WP is

Figure 4. doi

The GANTT diagram of MAMBO.

Aarhus University (AU) is a strong public university that is internationally recognised for the high quality of its research, research-based degree programmes, and public sector government consultancy, in addition to value-creating collaboration with private businesses, public sector institutions and civil society. In 2021, it is no. 106 on the Times Higher Education World University Ranking. AU was founded in 1928 and subscribes to the fundamental values described in the Magna Carta of European Universities. Today its academic portfolio is broad-ranging, from the classic university disciplines of the humanities, natural sciences, social sciences, health sciences and theology to business and engineering, educational theory and practice, and the environmental and agricultural sciences. AU has around 38,000 students, 10,700 employees, 1,800 PhD students and close to 1,000 postdoctoral scholars. Internationalisation is at the heart of AU's mission and activities. AU has an increasing number of international research and innovation partnerships and is participating in 410 H2020 projects, 41 of these as coordinators. It also hosts 37 ERC projects, and it has a strong track record of attracting individual fellowships and hosting visiting researchers at all career stages for both training and knowledge transfer purposes.

Naturalis is the Dutch national research institute and infrastructure on biodiversity and systematics. Employing over 100 researchers, the institute provides an innovative and

integrated research program and BA/MA courses towards its core expertise of species identification and monitoring. Our research projects comprise a whole array of disciplines, ranging from taxonomy, systematics, evolution, biodiversity, ethnobiology, biogeography, bioinformatics, and mineralogy. The Naturalis mission is “to describe, understand and explore biodiversity for human wellbeing and the future of our planet”. Naturalis offers a state-of-the-art research infrastructure and has a world-leading position in the development of (inter)national research infrastructures on biodiversity data (ARISE, GBIF, DiSSCo, COL, iBOL). The NWO-funded ARISE project as part of the Dutch National Roadmap for Large-Scale Research Facilities enables Naturalis to build an infrastructure to accelerate the discovery and description of biodiversity in the Netherlands and beyond using AI-facilitated image and sound recognition. Naturalis has a proven track record in project management currently coordinating projects like the H2020-MSC-ITN 4D REEF, the ESFRI Research Infrastructure DiSSCo, the FA COST Action MOBILISE and the DiSSCo Prepare project (INFRAIA).

The Helmholtz Centre for Environmental Research - UFZ, is the only centre in the Helmholtz Association to be exclusively devoted to environmental research in a great variety of fields. The UFZ has become a worldwide acknowledged centre of expertise in integrated and interdisciplinary environmental research and in the development of sustainable land management strategies. UFZ has a strong focus on methodological advancements in the modelling and simulation of environmental systems, both in fundamental and applied research. UFZ is and was participating in more than 90 Projects funded within FP7 and Horizon 2020, 34 of them coordinated by UFZ (collaborative and individual projects). UFZ is or was the host for 3 ERC grants and is leading the European Topic Centre on Inland, Coastal and Marine waters (ETC/ICM) funded by the European Environment Agency (EEA) since 2014. For MAMBO, UFZ will provide its expertise in merging animal and plant ecology, and population, community and macroecology to develop scientific principles to explain functional relationships across organisational levels and spatio-temporal scales, in particular for the integration envisaged in the lead of WP6. In order to make our research policy relevant, the UFZ team is heavily involved in international, especially intergovernmental, assessments (IPBES, IPCC) as well as scientific communication and outreach, which makes it a natural candidate to lead WP7.

Institut National de Recherche en Informatique et Automatique (Inria) is the main French public research body fully dedicated to computer sciences. More than 3,500 researchers and engineers work in 200 project teams, most of which are shared with major research universities, to explore new avenues, often in an interdisciplinary manner and in collaboration with industrial partners. With 62 ERC fellowship winners, awarded since their creation in 2007 by the European Research Council, Inria is the leading European player in exploratory research in the field of digital sciences and computing. In MAMBO, Inria will act as the representative partner of the Pl@ntNet consortium and will leverage more than 10 years of technical experience in designing, developing, deploying and sustaining the Pl@ntNet platform. Pl@ntNet is one of the largest citizen observatories in the world involving more than ten million active users of Pl@ntNet mobile app (AI-based plant identification). Since 2020, Pl@ntNet has become one of the largest data publishers in

GBIF (the world's largest biodiversity data platform). Pl@ntNet is also a service provider within the European Open Science Cloud (EOSC), in particular a plant identification service used by several thousand application developers in fields such as agroecology, biodiversity management or garden maintenance.

The University of Amsterdam (UvA) is the largest university in the Netherlands, with >30,000 students, almost 5,000 staff, and a budget of almost 500 million euros. UvA ranks amongst the largest universities in Europe and is a core member of the League of European Research Universities (LERU). The Faculty of Science at the UvA is located at Amsterdam Science Park, one of the largest research hubs in Europe, and is surrounded by numerous knowledge institutes and spin-off companies with their roots in science and research. The UvA was involved in >200 H2020 projects (122 of which were coordinated), including 61 ERC projects, 56 Marie Curie Individual Fellowships, and 20 Marie Curie ITN projects. The work will be carried out at the UvA Institute for Biodiversity and Ecosystem Dynamics (IBED). At the core of IBED lies an integrated approach to studying biodiversity, ecosystems and the environment, with core expertise in ecology, evolutionary biology, physical geography, and environmental chemistry. IBED's research is supported by excellent research facilities, including technical equipment for geospatial data collection (differential GPS, mobile GIS, drones, hand-held laser scanner) and infrastructure for big data storage and analysis (e.g. high-performance computing facilities, dedicated servers, UvA Geoportal, GIS studio, and virtual labs).

The French Agricultural Research Centre for International Development (CIRAD) is a public industrial and commercial enterprise joint authority of the Ministry of Higher Education and Research and the Ministry of Foreign Affairs, which bases its operations on development needs, from field to laboratory and from a local to a global scale. CIRAD plays a major role in the aim to generate and pass on new knowledge and support agricultural development and biodiversity conservation, with activities involving the life, social and engineering sciences applied to agriculture, biodiversity and rural territories. During the MAMBO project, CIRAD will leverage its strong expertise in the development of innovative tools for plant identification, in a multitude of contexts, including protected or endangered plant species. CIRAD team involved in MAMBO is affiliated with the Univ. of Montpellier, which has been in the Top 3 of the Shanghai World University Ranking for Ecology for 5 years (2017-2021). Due to its experience in global agro-biodiversity analysis, management and conservation, its involvement in the coordination of large-scale ICT projects, such as the Pl@ntNet citizen science platform, and its good understanding of the EU biodiversity policies (with its involvement in more than 100 European projects), CIRAD will coordinate the WP5 of MAMBO, ensuring the equipment and demonstration on sites and in targeted regions. CIRAD will also develop new approaches for the identification of species communities (Task T3.4), and make use of its capacities and network for wide dissemination and valorization of the developed results.

Pensoft Publishers' project department is comprised of a motivated team of active scientists, project managers and science communicators offering long-standing expertise in delivering the full set of science communication services. It has been involved in the science communication of over 30 projects, which guarantees the company's experience

and competence. Besides being a science communication expert, PENSOFT is also a science publisher. Since the company's founding in 1992, it has published more than 1000 books and e-books. In 2014, the company launched a novel Open Access book (re-)publishing platform, Advanced Books. PENSOFT is well-known among academics worldwide with its technologically advanced peer-reviewed Open Access journals. The company is actively developing new tools, workflows, and methods for text- and data publishing, dissemination of scientific information and technologies for semantic enrichment of an article's content.

Ecostack Innovations Limited (EcoINN) is an SME that was established with the objective of providing innovation and consultancy services to tackle the trade-offs between development and biodiversity. The company provides consulting services in the fields of agri-environment, ecological and environmental monitoring and analysis, and stakeholder involvement. Currently, EcoINN provides environmental expertise to governmental and private organisations whilst the company is establishing a one-stop solution that may be accessed by different businesses to assess sustainability at the corporate level.

The University of Reading (UREAD, Associated partner) aims to solve some of the biggest problems facing people today, based on themes of Environment; Agriculture, Food and Health; and Prosperity and Resilience. The School of Agriculture, Policy and Development, is currently ranked 12th globally for agriculture and forestry (QS rankings 2021) and consistently ranked as the UK's top university for impact in Agricultural Sciences research (ISI Web of Knowledge, Essential Science Indicators). Our research is supported by significant external funding and from national research councils, government, the European Commission, industry and charities and has a well-established track record for impact, with long-term partnerships with a wide range of local, national and international stakeholders from industry, policy and NGOs. Individuals within the UREAD MAMBO team manage and chair the expert pool that will deliver a monitoring design for the European Pollinator Initiative (Prof. Simon Potts). For MAMBO, UREAD will provide its considerable expertise in identifying stakeholder needs and planning engagement activities with users (Dr Deepa Senapathi: WP1), assessing the costs and benefits of monitoring technology (Dr Tom Breeze: WP6) and contribute significantly to developing the science-policy interface at national, European and international level (WP7). UREAD will be part of the consortium as an associated Partner, with national funding from UKRI.

The UK Centre for Ecology & Hydrology (UKCEH, Associated partner) is an independent, not-for-profit research institute carrying out excellent environmental science with impact. Our 500 scientists work to understand the environment, how it sustains life, and the human impact on it. We provide the data and insights that governments, businesses and researchers need to create a productive, resilient and healthy environment. Scientific curiosity, integrity and transparency are at the heart of how we work. UKCEH staff within the MAMBO team lead UK programmes for citizen science biodiversity monitoring, have more than 25 years of expertise in vegetation remote sensing, have expertise in environmental monitoring and assessment, computational ecology, computer vision, and deep learning and have experience with high performance and cloud computing, are qualified drone pilots with expertise in drone technology and

drone data processing and analysis. UKCEH has the following drones available for use in MAMBO WP4 and WP5: DJI Mavic 2 pro with high-quality RGB sensor; DJI Matrice 600 with Rikola hyper spectral sensor 500-900nm; DJI M300 with L1 Lidar, P1 photogrammetry grade RGB, and Micasense RGBNIR sensor. UKCEH will be part of the consortium as an associated Partner, with national funding from UKRI.

4. Ethics self-assessment

The MAMBO project will employ quantitative as well as qualitative methods to collect and process data. Specifically, MAMBO includes a range of qualitative methods (stakeholders, audiences, interviews, workshops, meetings, focus groups, digital tools) and data collection through quantitative methodologies (surveys, interviews and document reviews). MAMBO will involve policymakers, decision-makers, and stakeholders in the development of the tools and impact plans. MAMBO will develop best practices, tools, governance options and guidelines to support national and international biodiversity in the EU. The storage and handling of data will happen in ways that as far as possible eliminate the risk of confidentiality breaches, comply with legislation on data in the respective countries, and conform to the EU General Data Protection Regulation (GPDR). Moreover, to live up to the principles of reliability, honesty, respect and accountability in the European Code of Conduct for Research Integrity (ALLEA 2017), we will throughout the project ensure these operational steps:

- Make all data publicly available after the anonymisation of all direct and indirect identifiers.
- Make succinct study protocols for each empirical WP.
- Send the protocols for ethical review to the Steering board, whenever personal data is involved.
- Before data collection, pre-register our study at i.e. OSF (www.osf.io).

The research outlined in the MAMBO project does not intend to involve the collection of sensitive information. It could be anticipated, however, that informants' responses to any open questions in the study or deliberations through groups by the digital tools, or similar settings might, unintended, reveal sensitive information. Such potential situations will be anticipated in the study protocols and will be submitted for ethical assessment.

Compliance with ethical principles and relevant legislation

Before the commencement of the research activities involving human participants, the relevant WP leader in collaboration with the Steering Board will ensure that the research practices are in line with the European Code of Conduct for Research Integrity, national and organisational Research Ethics and Integrity Policies, and the operational steps presented in bullet points above. The study protocol will account for all ethical issues related to research involving human participants. It will form the basis for the selection and recruitment of participants. This includes the number of participants, inclusion/exclusion criteria and direct/indirect incentives for participation. A cover letter will be communicated to

all participants and thereby ensure that all informants and respondents are duly informed about the scope and purposes of their involvement and the research activities of the project. Moreover, all human participants will be ensured anonymity and confidentiality when appropriate. Procedures for informed consent will be strictly maintained, and copies of Informed Consent Forms and Information Sheets will be prepared, duly signed, and preserved. These will be concise and in language and terms understandable to the participants. Participants will have the right:

- To know that participation is voluntary.
- To ask questions and receive understandable answers before making a decision,
- To know the degree of risk and burden involved in participation.
- To know who will benefit from participation.
- To know the procedures that will be implemented in the case of incidental findings.
- To withdraw themselves, their samples and data from the project at any time.
- To know of any potential commercial exploitation of the research.

'Personal data' is understood as data about an individual who can be identified from that data or from related information. The project partners will respect and strictly adhere to national and international regulations and laws while conducting research involving human participants and when collecting and processing their personal data. In particular, the partners will respect and strictly abide by the ethical principles expressed in:

- Charter of Fundamental Rights of the European Union.
- Directive 95/46/EC on the protection of individuals with regard to the processing of personal data and on the free movement of such data.
- Directive 2002/58 on Privacy and Electronic Communications.

The project will be designed according to the Data Protection Act which was approved by the EU Commission and Council in April 2016 and came into effect in 2018. Based on this new regulation the data protection of the project will furthermore include the following issues:

- Access to own data and right to be removed.
- Informing about hacking.
- The use of data for public interest and profiling.
- Privacy by design.

Responsibilities of the controller and the processor

In the context of the MAMBO project, which will collect personal data and also provide open access to data generated as part of the research project, it is crucial to ensure concise procedures for deleting personal identifiers before offering open access. Responsibilities between the controller of the data and the processor of the data will be clearly defined in the Data Management Plan developed in the early phases of the project. While the project does not expect to collect sensitive data, it is nonetheless important to implement strict procedures for safeguarding anonymity whenever relevant. All data from either individual or social interactions will be dealt with on the basis of two main principles:

informed consent and privacy. Photographs, audio and video recordings are personal data and will be handled as such. Participants will be informed at the beginning of interviews or group discussions that video or tape recordings will be used, and they will have the option to agree or to decline. The Consortium will be supported by an external independent ethics advisor in order to be advised in i) the activities involving the collection and/or processing of personal data for supporting the Consortium in dealing with them in compliance with the GDPR, the national legislation and the HE ethical standards; ii) the identification and thorough analysis of the ethics issues raised in the demonstration sites; iii) the measures that will be taken to mitigate such risks and to ensure compliance with the ethics standards of Horizon Europe. The external independent Ethics Advisor must be appointed by month 6, and the frequency of reports: once at the end of each reporting period.

Conflicts of interest

The authors have declared that no competing interests exist.

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