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Nature FIRST: Forensic Intelligence and Remote Sensing Technologies for nature conservation

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Abstract
The EU biodiversity strategy contains concrete objectives to protect and restore biodiversity and to address the main pressures and threats to biodiversity. However, knowledge gaps exist for many habitats and species. More and better information is needed to support the implementation and monitoring of the Birds and Habitats Directives. In response, the consortium 'Forensic Intelligence and Remote Sensing Technologies for nature conservation' (Nature FIRST) proposes a number of innovations for monitoring nature by combining ecology sciences and environmental forensics with environmental observations (satellite-based and on-site). This paper examines how this novel approach results in propositions and related services for: 1. Biodiversity monitoring in Natura 2000 areas, for both habitats and species; 2. Early warning systems for the prevention of Human-Wildlife Conflicts (HWC); 3. Management and compliance reporting. Services include tools as well as methods, including software, checklists, instruction videos and more. The research objective is to move from a reactive approach and remediation of biodiversity loss to a preventive approach and a move from Human-Wildlife Conflict to Human-Wildlife Coexistence (HWCo). This paper describes how existing technologies combined with new technologies and data science, allows proactive nature conservation management. Semantic web technology is used to create knowledge-graphs that interlink and harmonise diverse data sources to provide new insights. Forensic data science and techniques are used to equip conservation managers with observation skills. These new observations are being combined with remote sensing data from wildlife cameras (camera-traps), drones and satellites, into automated risk and likelihood maps. Finally, predictive digital twins are being developed: two species related (bear and sturgeon) and one aimed at more integral biodiversity monitoring). To ensure the tools and methods are fit-for-purpose, they are co-developed with four field site partners, representing different habitat-species combinations in Europe. The first is Ancares-Courel in Spain (key species: bear, wolf), the second Stara Planina Mountain (key species: bear, wolf) in Bulgaria, the third the Danube Delta (key species: sturgeon) in Romania, and the fourth the Maramures Transboundary Area (key species: bear, wolf, lynx, golden jackal) between Ukraine and Romania. Testing of the new solutions will take place in four field site workshops. These also feature a Policy Lab, to familiarise policy makers with the tools they can use for management as well as compliance assurance purposes.
Keywords: biodiversity, conservation, ecosystems, forensics, monitoring, remote sensing

Acronyms/Abbreviations
Convention on Biological Diversity (CBD), European Commission (EC), European Union (EU), Essential Biodiversity Variables (EBVs), Global Environment Monitoring System (GEMS), Global Resource Information Database - Geneva (GRID-Geneva), Human-Wildlife Conflict (HWC), Human-Wildlife Coexistence (HWCo), Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), monitoring & evaluation (M&E), Open Geospatial Consortium (OGC), United Nations Environment Programme (UNEP), World Conservation Monitoring Centre (WCMC), World Wildlife Fund (WWF)

1. Introduction

This paper starts by introducing the background and context of biodiversity policy and the regulatory framework that governs the protection of our natural environment. The paper introduces the project Nature FIRST, developed to respond to the research and innovation challenges confronting adequate nature conservation activities. In section 2 the paper describes activities foreseen at the start of the project. The results after the first year (1 September 2023) of the project are presented in section 3, including a discussion of their significance. The paper finishes by drawing some preliminary conclusions and outlining further work by the project in section 4.

1.1 Background and context

Biodiversity (or biological diversity) refers to the variety and variability of and within constellations of animals, plants, fungi and microorganisms and all other forms of life that make up our natural world. All species work together in ecosystems, like an intricate web, that maintains balance and supports life [1]. In 1992, 150 government leaders signed the Convention on Biological Diversity (CBD) at the Rio Earth Summit, recognising that biodiversity is essential for our food security, medicines, fresh air and water, shelter and a clean and healthy environment to live [2]. Also in 1992, the World Conservation Monitoring Centre (WCMC) published an extensive review of global biodiversity, structured in three parts: Part 1 Biological Diversity, Part 2 Uses and Values of Biodiversity, Part 3 Conservation and Management of Biodiversity. Its data contributes to the Global Environment Monitoring System (GEMS), a collective programme to acquire, through global monitoring and assessment, the data that are needed for the rational management of the environment [3]. The most recent manifestation of those early initiatives is the Global Resource Information Database - Geneva (GRID-Geneva) [4]. The importance of conserving biodiversity and managing the Earth's natural resources, and consequently the need to monitor the status of species, habitats and ecosystems, was thus recognised in the early 1990s. Nevertheless, in 2019 the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), in a comprehensive assessment, concluded that "biodiversity is still being lost, ecosystems are still being degraded and many of nature's contributions to people are being compromised". One of the identified actions is improving the monitoring and enforcement of existing laws and policies through better documentation and information-sharing [5].

In the European Union (EU), the most important pieces of legislation to preserve and restore biodiversity are the Birds (1979) and Habitats (1992) Directives, offering (on paper) protection to species and habitats. The network of protected areas created under these Directives is the Natura 2000 network of Special Areas of Conservation [6]. In 2015, the European Commission (EC) carried out a Fitness Check to assess the performance of the two Directives. It concluded that, although the status of species and habitats would likely be worse without, substantial improvements were needed in the implementation to fully achieve their objectives. The report's "actions required to implement objectives of the Directives" include *i.a.* Defining favourable conservation status, identifying research gaps, Monitoring the status of habitats and species and Reporting on the implementation of the Directives [7]. Nature FIRST is set up to contribute to these objectives, as will be illustrated in this paper.

As part of the Green Deal, the EC published the EU Biodiversity Strategy 2030 on 20 May 2020. It contains actions and targets to put Europe's biodiversity on the path of recovery by 2030. One of the ambitions is not only to improve the status of protected (Natura 2000) areas but to enlarge the network of protected areas and to improve nature conservation more broadly (such as in urban areas) [8].

1.2 The need for research and innovation

A much better understanding of status and trends is needed, to effectively and efficiently manage and conserve natural resources and get Europe's (and global) biodiversity on a recovery path. The EU's research and innovation programme Horizon Europe addresses knowledge gaps through thematic clusters, including "Food, Bioeconomy, Natural Resources, Agriculture and Environment". Under this cluster, projects in the domain of "Biodiversity and ecosystem services" fill the specific knowledge gaps in the understanding of the status and trends of biodiversity conservation [9].

The project "Forensic Intelligence and Remote Sensing Technologies for nature conservation" (Nature FIRST), the subject of this paper, responded to the call "Data and technologies for the inventory, fast identification and monitoring of endangered wildlife and other species groups” [10]. The research objective is to move from a reactive approach and remediation of biodiversity loss to a proactive and thus preventive approach and a move from Human-Wildlife Conflict (HWC) to Human-Wildlife Coexistence (HWCo).

The Nature FIRST consortium is led by not-for-profit organisation Sensing Clues (the Netherlands) with 10 partners from Ukraine, Romania, Bulgaria, Spain, the Netherlands, United Kingdom and South Africa. It brings together expertise in ecology sciences, environmental forensics with environmental observations (satellite-based and on-site). Novelties in the project include the use of semantic web technologies for the creation of knowledge graphs and the development of digital twins. Nature FIRST started 1-9-2022 with a duration of three years. At the time of writing this paper, the first year has been completed.

2. Material and methods

2.1 Nature FIRST concept

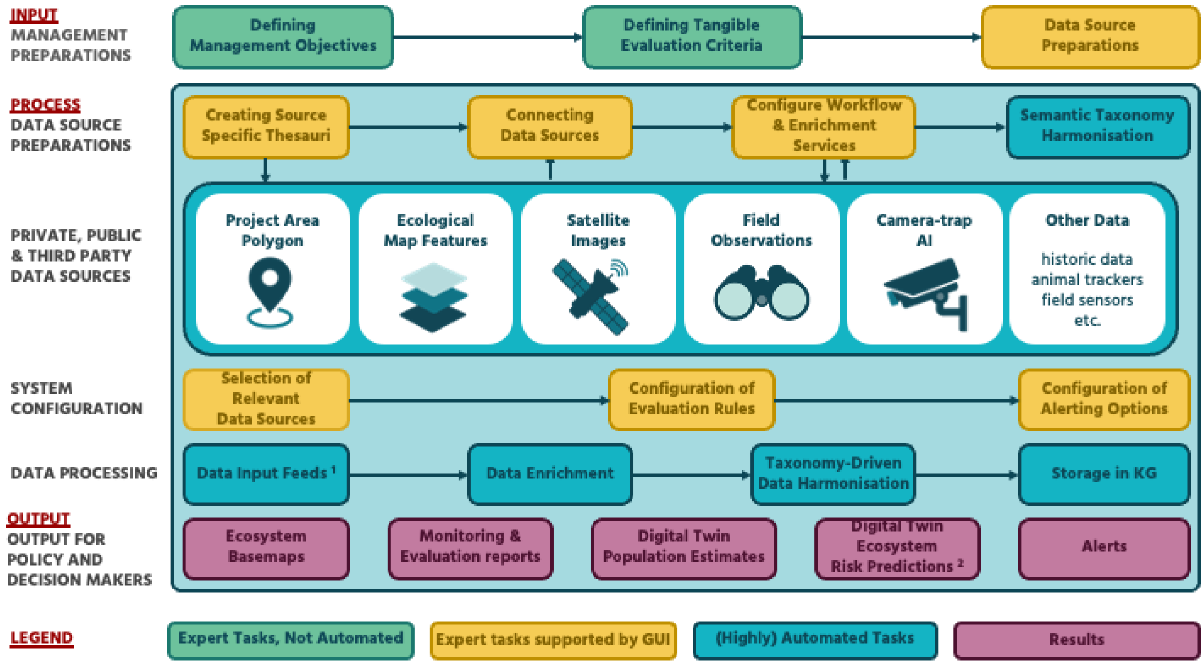

Figure 1: Nature FIRST concept

The concept is problem-driven (defined by conservation management objectives) and delivers the following results: ecosystem basemaps, monitoring and evaluation reports, risk predictions and alerts.

Technology is only part of the solution, therefore Nature FIRST builds the alignment of:

- policies: shared urgency, necessity and will to share data and insights.
- organisations: bridging methods, best practices, using knowledge from other conservation organisations that operate in the same protected area or field of activity.
- technologies: among other things, developing, testing and implementing new (long-term) approaches that make use of recent technological advances and existing data from multiple origins (e.g., observation data, remote sensing, DNA technologies and isotope analysis (e.g. for sturgeon), big data analysis, AI, deep learning, historical records, use of citizen science and volunteer data).

2.2 Study area

The project selected four areas, representing different habitat-species combinations in Europe (Figure 2 in Appendix A, hereafter referred to as field sites). The first is **Ancares-Courel** in **Spain** (key species: bear, wolf), the second **Stara Planina Mountain** (key species: bear, wolf) in **Bulgaria**, the third the **Danube Delta** (key species: sturgeon) in **Romania**, and the fourth the **Maramures Transboundary Area** (key species: bear, wolf, lynx, golden jackal) between **Ukraine** and **Romania**. Selecting these four areas meant the research and development could focus on very specific and concrete conflict situations, develop fit-for-purpose tools and methods and test these for their applicability to the Natura 2000 sites and areas of high value outside the EU.

2.3 State of Play

The first activity of the project was to carry out a gap analysis and establish the baseline on which to base the development of tools offering insight into (emerging) HWC situations and solutions to move to HWCo. Establishing the state of play is done in four iterative steps:

1. Inventory and assessment of conservation objectives, illegal activities, HWC and best conservation practices.
2. Inventory and assessment of conservation status evaluation criteria and compliance. Law enforcement efforts.
3. Inventory and assessment of monitoring and evaluation methods and data sources in-use.
4. Identification of gaps to assess conservation status and to address the threats.

To ensure we are capturing evolving gaps and needs, this process is repeated several times during the project.

2.4 Development of proactive methods and technologies

Based on the input from the gap analysis and state of play assessment, the development of methods, standards and tools was started, allowing for 1) cross-organisational data harmonisation in support of 2) real-time monitoring of ecosystems and wildlife, 3) the creation of early warning signals to reduce HWC, and 4) the creation of prediction and simulation models that help better understanding the increase or decline of biodiversity, wildlife population trends and habitat status due to anthropogenic pressures and threats (current and future).

To ensure validity, reliability and credibility of the output of the systems developed, quantitative data is combined with qualitative scientific knowledge. In the ecological field, environmental observations (including satellite images and on-site observations) are combined with knowledge about species-specific factors and behaviours and tangible criteria that can be evaluated. In the law enforcement field, encoded rules and regulations are combined with forensic evidence and recorded offences. Moreover, static data is combined with periodically updated data and real-time observations, to gain optimal insight in seasonal and longer-term trends and developments.

The core innovation of the project is realised through the following interrelated activities:

Data access preparations of environmental observations. These range from direct observations (people, camera-traps) to raw or classified satellite images.

Design of thesauri and aggregated monitoring ontologies. This innovation is at the core of enabling data integration and aggregation at cross-partner, regional and even interregional level.

Development of auto-generated ecosystem basemaps, containing a minimum number of features to describe the ecosystem(s). It covers *i.a.* altitudes, gradients, soil types, ground water levels, vegetation and moisture indexes, roads, villages, and more.

Development of a (near) real-time monitoring & evaluation (M&E) system, in which tangible rules and evaluation criteria and scales can be encoded and executed as knowledge rules. These knowledge rules are linked-up with the ecosystem basemap and the incoming data stream of environmental observations, thus enabling (near) real-time monitoring.

Digital Twins, which still constitute unchartered territory in the modelling of complex natural systems in which people, animals, and the wider natural environment interact. The digital twin models will be fueled by the basemap models and the four types of data described above to ensure its results are valid, reliable, credible and useful. The first products of the digital twins will include estimates and predictions related to species distribution and population sizes, and risk distributions of man-made and natural threats to biodiversity.

2.5 Operationalising the methods and technologies

The aim of the project is to develop predictive and proactive methods and tools to monitor nature and to prevent HWCs. An important ambition of the project is to demonstrate and test the methods, maps, routines and models in real-life situations at the four field sites. A further objective is to engage policy makers in the process to get an understanding of their needs in developing, implementing and monitoring policies as well as to raise awareness of the impact they have on ecosystem services and biodiversity.

A Policy Lab is set up to help to close the gaps (section 2.3) by co-designing policies and management practices and guiding the operationalisation of the data-driven nature conservation cycle at the four field sites. Moreover, the results of the project and their effectiveness in terms of fit-for-purpose (better intelligence through strengthening the evidence-base) and increasing efficiency (more useful information at lower costs) will be tested. At the time of writing this paper, the first field site workshop and Policy Lab were being prepared.

2.6 Creating impact

Impact can only be created if the methods and technologies developed provide added value and fit in with the operational processes of the people and organisations responsible for the development, implementation, management, and monitoring of natural resources and ecosystems. This paper therefore described in the previous sections how the project emphases interactive and iterative co-design and development, coupled with field site testing and feedback.

In addition, attention is paid to the affordability of the propositions and related services to maximise interest and the chance of uptake by the intended market. The primary target audience are organisations responsible for the implementation and management of Natura 2000 sites. Ultimately, services are developed to be scalable and replicable with minimum extra effort, allowing for an EU-wide rollout to all Natura 2000 areas.

The introduction of new tools requires capacity building and training. This applies not only to the users of the tools (field site partners), but also to the Nature FIRST consortium as a whole and to the wider public (represented through stakeholders). Special targeted stakeholder groups for training are:

- Nature conservation organisations: preparation in the integration of new software/toolkits to maximise use of the generated intelligence packages for the identification of biodiversity challenges.
- First responders including rangers in conservation areas: how to use the project tools for documenting biodiversity challenges and changes in the field including the further gathering of evidence at scenes that have indicated disruptive human behaviour.
- Law enforcement agents: utilisation of the project tools for building case strategies and decision making, in particular the use of the intelligence information generated.
- Legal personnel, e.g., barristers and judges: implications of the Nature FIRST tools for the purposes of building cases pertaining to conservation crimes.

Impact creation is being supported through targeted communication and dissemination activities, as well as knowledge sharing through webinars and workshops.

3. Results and Discussion

Exactly one year after the start of the project, this paper can already present some early and very promising results.

3.1 Establishing the baseline

In the first year of the project, the following results were delivered to establish the baseline in the four field sites.

Matrix of tangible criteria, methods and data sources, including descriptions and references

Data collection from personal interviews were obtained from 20 relevant stakeholders, including policy makers (3), law enforcement officers (3), scientific institutions (2), nature conservation organisations (1), national parks (2), hunting associations (2), companies (2), farmers and land managers (1) and the field partners of Nature FIRST (4). The diversity of responses was considerable, which was to be expected given the different types of organisations consulted.

The key conservation components of the sites are mostly linked to species of these sites, mainly large carnivores: (brown bear, wolf, lynx) and in the case of the Danube Delta sturgeons mainly, but also species of commercial importance allowed to be fished (Carp, Catfish, Perch, Pike).

Other species identified as relevant to the conservation of the sites are herbivores such as chamois, red deer, domestic livestock, as well as invasive species that affect habitats in natural areas. When interviewees have referred to ecosystems in the field sites, the most recurrent have been those of the forest type and those linked to human activity, such as grasslands.

The collected data was synthesised in the Matrix of tangible methods and data sources in use as a spreadsheet, organised according to the type of data obtained: (conservation) problems, objectives, needs, monitoring measures, best practices, indicators, methodologies for monitoring, data sources in use:

Problems: Most of the conservation problems of the field sites are linked to the management of these areas (161), being an aspect common to all field sites. Second are incidences between local communities and wildlife in these sites (71). Problems linked to policies (12) are the least frequently recorded.

Objectives: the conservation and management objectives at the field sites follow a similar pattern to that of the conservation problems, highlighting especially those objectives linked to the management of the sites (88), second would be those associated with the communities of these spaces (31) and finally those related to the policies (11).

Needs: the group with the highest number of needs is that of species (38), related to monitoring key species, as well as reducing HWCs, with measures to protect livestock or apiaries. The need for modern fit-for purpose technologies is also widely shared.

Monitoring measures: These included measures on a variety of topics, from raising awareness among the local population, to conservation actions, HWCo, legal issues, monitoring, poaching or resource-related actions. The assessment and monitoring of habitats is recurrent, as well as measures to evaluate the production of fruit from the habitats. On the other hand, at species level (including the genetic level), monitoring measures are related to the different species considered key in the sites, including the use of DNA.

Best practices: A total of 65 best practices were obtained, mainly related to conservation actions, habitat monitoring, HWC reduction or awareness raising.
Indicators: The most recurrent indicators are those linked to the presence of an element, a damage or pressure, a species, etc. Most of them are of the binary type (67), followed in number by those referring to a count of elements (32) e.g. poaching cases.
Methods: Most of the responses (39) in relation to monitoring methodologies in the protected area are associated with large carnivore species. In the case of methodologies for habitats, those associated with remote sensing are included.
Data sources: At the thematic level, data sources associated mainly with species (occurrence, distribution, HWC incidents) were collected. The formats in which information is available include maps, reports, registers or papers.

List of challenges to be addressed by the project
Applying a logical scheme through a Matrix of tangible methods and data sources in use, a selection of conservation challenges that could be addressed in Nature FIRST was made.

Figure 3: Scheme for the synthesis of information from the Matrix of tangible methods and data sources in use by thematic areas

The challenges were grouped in 4 thematic areas: HWCs, Poaching, Habitat management and Species management:
HWCs. The conservation challenges identified are related to monitoring, aimed at helping managers of protected areas to reduce the incidence of HWCs. This monitoring would focus on how to collect species data, estimate their population, their expansion, as well as organising this data in an efficient way from a management point of view. Linked to monitoring are aspects such as enabling the exchange of information between institutions in the protected area, facilitating the process of compensation for damage caused by HWC, or finally achieving tools that can predict the risk of HWCs occurrence or emulate animal behaviour in order to avoid damages (digital twin).
Poaching: aspects linked to monitoring are repeated as with HWCs, although in this case the matter of illegal human activities takes on more relevance, as they are a major player, with hunting or logging being particularly important. However, identifying species subject to poaching and monitoring them is key to aiding the management of these species. The overlap of these results with those of HWCs is clear, also with other species and habitat management issues. In this sense, the organisation of surveillance data or the exchange of information between institutions are common aspects to highlight with HWCs, as well as the identification of species or individuals through photo-trapping cameras. The development of digital twins that can predict poaching of sturgeon or bear is also a challenge to be considered by the project.

Species management: The main challenge is providing better data for the management of protected areas in relation to species. The aim is to provide data on species and site activities that lead to improved species conservation, such as identifying or improving ecological corridors, new areas for conservation, increasing species protection, and data that enable natural resource managers to minimise risks to species, facilitate the exchange of information with stakeholders, and improve visualisation and understanding.

Habitat management: the conservation challenges identified begin with the mapping of habitats to obtain ecosystem basemaps, to know how they are distributed in the protected area and, based on this information, to generate tools for better management of the site, for example, identifying areas with a better representation of habitats, illegal activities or changes that occur in habitats, measuring variables that translate into an assessment of the conservation status of habitats, and even generating a digital twin to track essential biodiversity variables in near real-time.

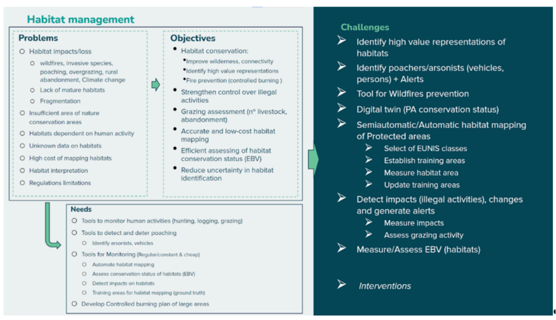

Figure 4: Selection of challenges in the thematic area Habitat management

Based on the selection of challenges, the aim was to select those that could be taken up in the context of Nature FIRST. On the other hand, specific issues of the more general challenges were explored in greater depth, which is necessary to make them tangible and respond to the specific needs of the protected areas. Finally, an attempt was made to complement the information on these challenges in the sections on available data sources, methods for their implementation, to which conservation indicators they respond, or existing gaps.

Table 1: List of tangible challenges.

CHALLENGES	DATA SOURCES	METHODS	CRITERIA/INDICATORS	GAPS
Semi-automatic habitat mapping of Protected Areas	+Area of interest +Satellite data (Sentinel) +Elevation/Slope (EU DEM) +Rivers (EU-Hydro) +Canopy Height model (HRL Forestry-Copernicus) +Environmental units (EUNIS) +Buildings, Roads, Power Lines (OSM)	+Data integration of external sources +Machine learning (RF). OBIA +Training areas +Set of rules +Reuse data from KG	+Terrestrial Ecosystem distribution of terrestrial EUNIS habitats (EBV)* +Distribution area of habitats of community interest (art. 17 Habitats Directive)* **Those mappable by Remote Sensing*	-Data or layers availability -EUNIS classes per site -Training areas and their maintenance -Remote Sensing limitations for mapping ecosystems -Heterogeneity of ecosystems -Scale of application of results for different users
Automatic detection of changes, impacts on the land (incl. alerts)	+Global Forest Watch +European Forest Fire Information System +Nature FIRST habitat mapping	+Data integration of external sources +RS change detection based on NF habitat mapping +Set alert rules	+Fire disturbance per habitat type (EBV) +Terrestrial Ecosystem disturbance as measured by HANPP (EBV) +Connectivity of terrestrial ecosystem habitat types (EBV) +Structure, functions and impacts on habitats of community interest (art. 17 Habitats Directive)	-Remote Sensing limitations for identifying changes -Scale of application of results for different users
Assessment of conservation status of habitats (EBV-art. 17 Habitats Directive)	+Article 17 periodic assessment +NF ecosystem basemaps +NF change detection	+EU manuals +EuropaBON references +EU National governments initiatives +Scientific papers	+EBVs (Structure, function, composition) including the above +Structure and functions of habitats of community interest	-Remote Sensing limitations -Data availability (spatial resolution, type of data -spectral bands / LiDAR- for specific indicators) -Scale of application of results for different users

Based on this work, the first List of tangible challenges and criteria was made, visualised in the image in Table 1 and included in Appendix B.

The results described in this section have led the development activities, the results of which are described in the sections below.

3.2 Biodiversity monitoring & assessment of conservation status: maturity levels

As shown in Figure 3, the project provides interactive support in the four progressively interrelated activities mentioned under section 2.4:

1. Data collection tools and 3rd party access and processing of environmental observations to support (continuous) Mapping of the area.
2. Design of trend-reports and change-detection algorithms for enhanced biodiversity monitoring.
3. Development of likelihood and risk maps to make Periodic predictions.
4. Development of (near) real-time monitoring & evaluation (M&E) systems, including digital twins, to create Real-time predictions.

Through combinations, these activities deliver input for scenario-based projections.

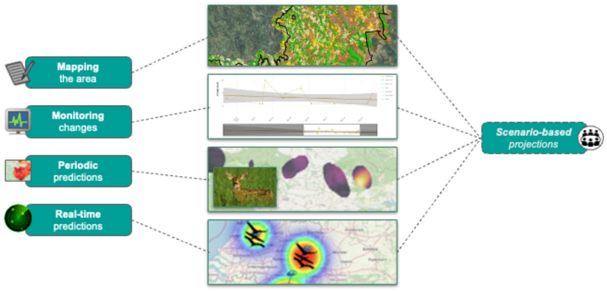

Figure 5: Maturity levels (a full-sized image is provided in Appendix C)

3.3 Mapping the area

Mapping starts by collecting observations from the field, by professionals, researchers, citizen scientist-apps and sensors such as camera traps. Historic data can be added, such as images from camera-traps collected over a period of years and data collected from damages inflicted by wildlife on farmers and beekeepers. The next step is to add remotely sensed data, from drones to satellites, to create ecosystem basemaps and identify and classify habitats.

Figure 4 shows a sample of ecosystem basemap layers that form one source of inputs for the creation of risk maps. These layers can be stylised and made shareable with others and with 3rd party applications through the GeoServer.

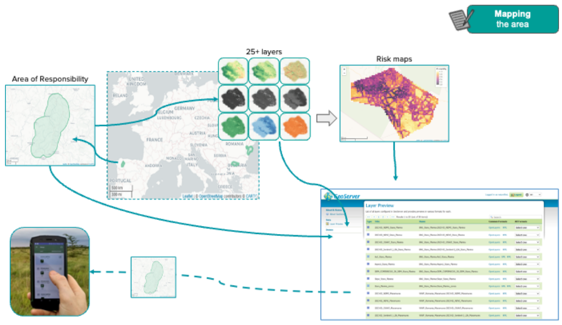

Figure 6: Ecosystem basemap and the GeoServer (a full-sized image is provided in Appendix D)

The ecosystem basemap is a collection of environmental data which captures the environmental characteristics of natural areas, such as the Natura 2000 sites. The environmental data is represented by a large set of map layers (currently 25), which together form the basemap. These map layers are created for each of the 4 Nature FIRST's Natura 2000 field partner areas: Ancares Courel, Danube Delta, Maramures and Stara Planina.

The first full version of the ecosystem basemap is readily accessible to the field partners through the GeoServer platform. GeoServer is a well-known platform for styling and sharing geospatial data, and it is open source. Moreover, the GeoServer adheres to the open standards of the Open Geospatial Consortium (OGC).

On GeoServer, the ecosystem basemap is organised in workspaces. One workspace contains the collection of layers for one of the field sites. The layers can be from a vector data source or raster data source. All common geospatial formats are accepted for storing data and the data can in turn be retrieved in any preferred format. The workspaces are only accessible with credentials so sensitive information can safely be stored on the GeoServer.

All ecosystem basemap layers can be easily accessed through GeoServer by the field partners in their geospatial software of choice, such as ArcGIS or QGIS. There is also the possibility to connect GeoServer to MapBox, which is the foundation of the FOCUS tool in which all ecosystem map layers can be displayed as well. Another option is to use the GeoServer REST API to manage the geospatial data in an automated way.

Figure 7: Habitat classification (a full-sized image is provided in Appendix E)

For **habitat classification**, a semi-automated classifier has been generated based on satellite images (adaptable to aerial, aircrafts or drones) and training areas collected in the office through photo-interpretation and validated in the field through the online application Cluey by Sensing Clues. Thematic layers such as roads, infrastructure, hydrography, etc. as well as the ecosystem basemaps are also included in the classifier, which serves to establish specific rules to support and improve habitat classification in the field site. The classifier uses artificial intelligence algorithms for the segmentation and classification of the satellite images. As a result, a specific habitat mapping model has been generated for the field site Ancares-Courel (Spain), a Natura 2000 site, which has been applied on Sentinel 2 satellite images corresponding to six different phenological periods within the same calendar year, generating a vector map of habitats according to the EUNIS classification, as well as its correlation with habitats of community interest. In the future, a specific model will be generated for each field site.

3.4 Monitoring changes

Data collection for Mapping (previous paragraph) is not a one-time exercise. In fact, many types of environmental observations are collected very frequently, if not continuously. This provides opportunities for automated trend and change detection, which in turn helps area managers to detect and act upon disturbances more rapidly. The frequency with which environmental variables are assessed, depends on various factors, including that of data availability, relevance, the speed of change, and the progressive impact of the change when it is not timely stopped.

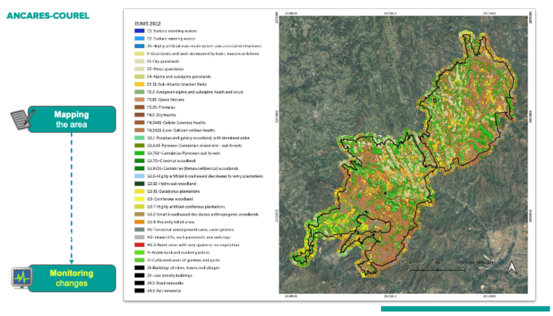

Figure 8: Monitoring changes (a full-sized image is provided in Appendix F)

3.5 Periodic predictions

By analysing wildlife sightings and disturbances within the context of relevant landscape characteristics and the efforts made to find and record them, periodic predictions can be made. In case of disturbances, we frame them as risks. In case of wildlife sightings, we frame them as likelihood. These maps can be created automatically for any given theme. In the example below a likelihood map is made to show where bears are most likely to be spotted. For that same area a human-bear-conflict-riskmap is created. By comparing the two, important lessons can be deduced about good and bad practices, thus giving area managers hands-on actionable insights to tackle the identified problems.

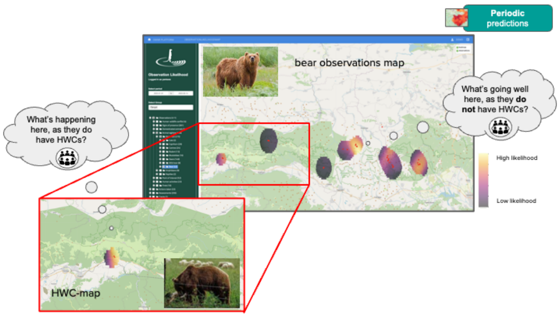

Figure 9: Periodic predictions (a full-sized image is provided in Appendix G)

3.6 Real-time predictions

Field observations from field officers and citizen scientists, data from collars, tags and cameras that send real-time alerts can be combined to generate real-time predictions. In the Romanian Maramures area a bear was collared at the start of September 2023. The live-location data of this collar can be used to construct various types of knowledge rules. For example, a rule has been created to send automatic alerts to the people in the field when the bear is seen heading towards a village. This allows them to intervene in time and prevent bear attacks, and retaliatory action by the villagers. Other examples of interesting rules include non-movement (wounded? killed?), prolonged running (being chased? shot at?), and patterns related to search for mates, etc. This is work in progress for the next few months to make the system fully operational. Figure x shows an already fully operational digital twin of crane migration, the crane radar [11].

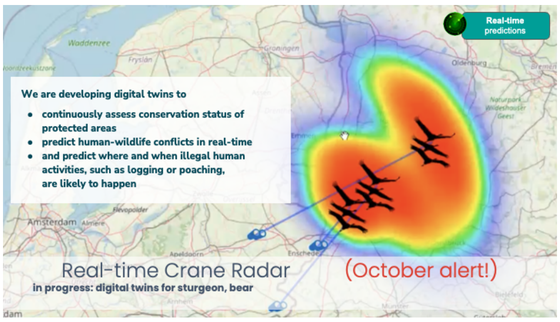

Figure 10: Real-time predictions (a full-sized image is provided in Appendix H)

The information generated not only assists professionals in the field but can also be used to inform management and compliance reporting. Reports can be created according to needs established by current regulations like those regarding articles 17 and 12 of the Habitats and Birds Directives respectively, as well as for reporting on the site-specific conservation objectives of the Natura 2000 sites, or regarding the Essential Biodiversity Variables (EBVs) and their dynamics. The application of knowledge-graphs enables the use of different and diverse taxonomies for more efficient reporting. Being explored is the creation of a recommendation system that can be queried to find out if certain site-specific conservation objectives are set elsewhere and which measures could be replicated to get the similar results. Such references and recommendations make information findable and easily consumable, and can help for example Natura 2000 managers to define site-specific conservation objectives, attributes and reference values, and action plans.

4. Conclusions

This paper describes novel approaches to combine and introduce known and new technologies to the domain of biodiversity conservation. The early results demonstrate that Nature FIRST can develop and deliver quality tools for professionals to conserve and monitor biodiversity more effectively and efficiently than current practices.

The work done to establish the baseline reveals that there is a great need for more and better monitoring to address the challenges of HWC, poaching, species and habitat management.

The remaining two years of the project will be dedicated to further developing and field-testing these services. Further (market) research is needed to identify how to get the tools in the hands of the professionals that need them.

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Appendix A Nature FIRST field sites

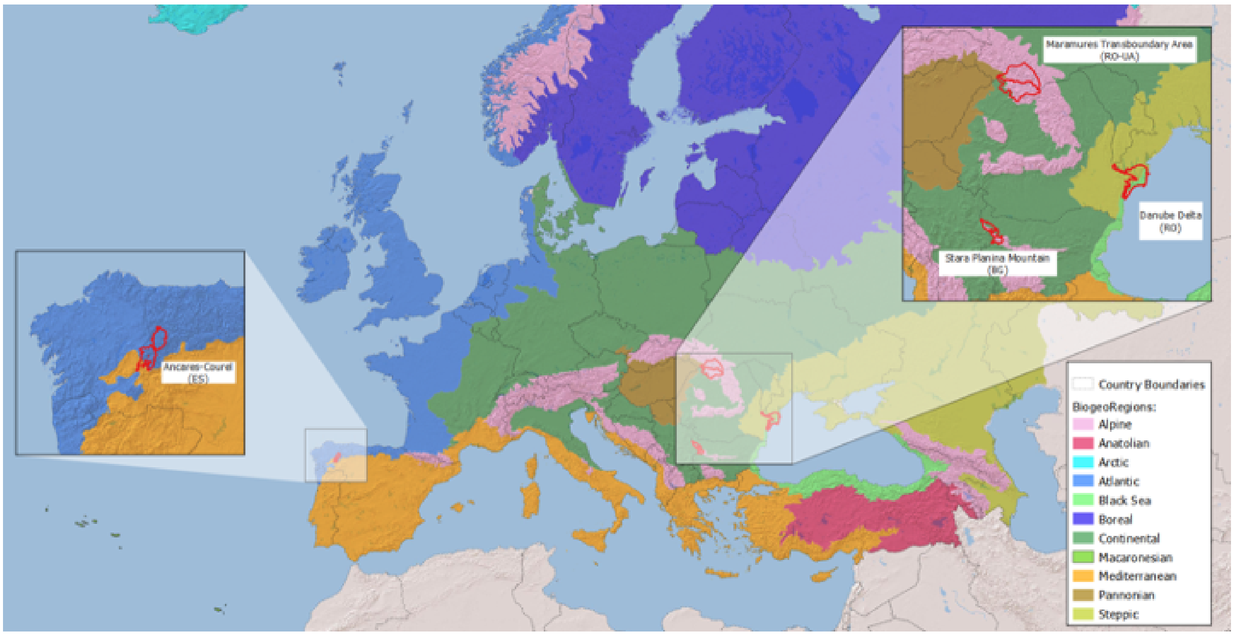

Figure 2: Nature FIRST field sites

Appendix B List of tangible challenges

CHALLENGES	DATA SOURCES	METHODS	CRITERIA / INDICATORS	GAPS
Semi-automatic habitat mapping of Protected Areas	+Area of interest +Satellite data (Sentinel) +Elevation/Slope (EU DEM) +Rivers (EU-Hydro) +Canopy Height model (HRL Forestry-Copernicus) +Environmental units (EUNIS) +Buildings, Roads, Power Lines (OSM)	+Data integration of external sources +Machine learning (RF). OBIA +Training areas +Set of rules +Reuse data from KG	+Terrestrial Ecosystem distribution of terrestrial EUNIS habitats (EBV)* +Distribution area of habitats of community interest (art. 17 Habitats Directive)* **Those mappable by Remote Sensing*	-Data or layers availability -EUNIS classes per site -Training areas and their maintenance -Remote Sensing limitations for mapping ecosystems -Heterogeneity of ecosystems -Scale of application of results for different users
Automatic detection of changes, impacts on the land (incl. alerts)	+Global Forest Watch +European Forest Fire Information System +Nature FIRST habitat mapping	+Data integration of external sources +RS change detection based on NF habitat mapping +Set alert rules	+Fire disturbance per habitat type (EBV) +Terrestrial Ecosystem disturbance as measured by HANPP (EBV) +Connectivity of terrestrial ecosystem habitat types (EBV) +Structure, functions and impacts on habitats of community interest (art. 17 Habitats Directive)	-Remote Sensing limitations for identifying changes -Scale of application of results for different users

CHALLENGES	DATA SOURCES	METHODS	CRITERIA / INDICATORS	GAPS
Assessment of conservation status of habitats (EBV-art. 17 Habitats Directive)	+Article 17 periodic assessment +NF ecosystem basemaps +NF change detection	+EU manuals +EuropaBON references +EU National governments initiatives +Scientific papers	+EBVs (Structure, function, composition) including the above +Structure and functions of habitats of community interest	-Remote Sensing limitations -Data availability (spatial resolution, type of data -spectral bands / LiDAR- for specific indicators) -Scale of application of results for different users
Identify species/individuals through images/video (incl. alerts) - mammals	+Images Camera traps	+Data integration of external sources +Integration of TrapTagger image classificator and cAIman (AI algorithms)	+Species distributions of all terrestrial mammals (EBV)	-Transforming data in actionable information for developing management plans -Infrastructure for acquisition of images and its maintenance across a PA -Individuals identification within the same species
Digital twin (sturgeon, brown bear, biodiversity /crane migration)	+Environmental data +Data on poacher activity +Data on HWC +Ecological behaviour, knowledge +Species distribution and movement +NF Ecosystem basemaps	+Digital twin	+Species distributions of freshwater fishes (EBV) +Species distributions of all terrestrial mammals (EBV) +Phenology of migration of terrestrial birds or wetland birds (EBV) +Distribution area, population, future prospects and impacts on species of community interest (art. 17 Habitats Directive) +Structure, functions, future prospects and impacts on habitats of community interest (art. 17 Habitats Directive)	-Data availability [in (near) real time]
Identify/improve/create ecological corridors Identify new conservation areas	+NF ecosystem basemaps +Species distribution and movement +Ecological knowledge +Digital twin	+Spatial distribution models +Movement models +Dynamic range models +Scientific papers	+Connectivity of terrestrial ecosystem habitat types (EBV)	-Specific knowledge and data needs for species and habitats from the PAs
Generate forensic tools to help prosecute/ prevent illegal activities	+Forensic and CSI Knowledge +Adapted wildlife crime cases to PAs +NF data (Cluey)	+Train the trainer package +Wildlife kits CSI Based +Personal training	+Increase deterrence +Reduction of wildlife crime +Increase skills and knowledge +Increase of conviction rate +Capacity building	-Translate scientific knowledge from regular CSI to wildlife CSI -Engagement with local authorities to enable layman to provide evidence -To collect evidence through a layman with sufficient quality to hold up court. -Concrete cases aligned with the problem

CHALLENGES	DATA SOURCES	METHODS	CRITERIA / INDICATORS	GAPS
				identified within the PAs
Enable information exchange between institutions. Organising data and efficient data collection Provide better and more comprehensive data in management PAs, or to develop management plans	+Data collected in PAs (Cluey) +Taxonomies on species, habitats, biodiversity parameters or indicators	+Creation of KG and application of Semantic technologies. +Taxonomies harmonisation for species, habitats, biodiversity parameters or indicators +Establishing ontologies +Data organisation and processing through a data platform (Wildlife tool suite) with data science possibilities	+Data integration and usability	-Engagement with governmental institutions -Engagement of local population in the management of the PAs -Data gathering and availability -Diverse taxonomies to integrate

Appendix C Maturity levels of biodiversity monitoring & assessment of conservation status

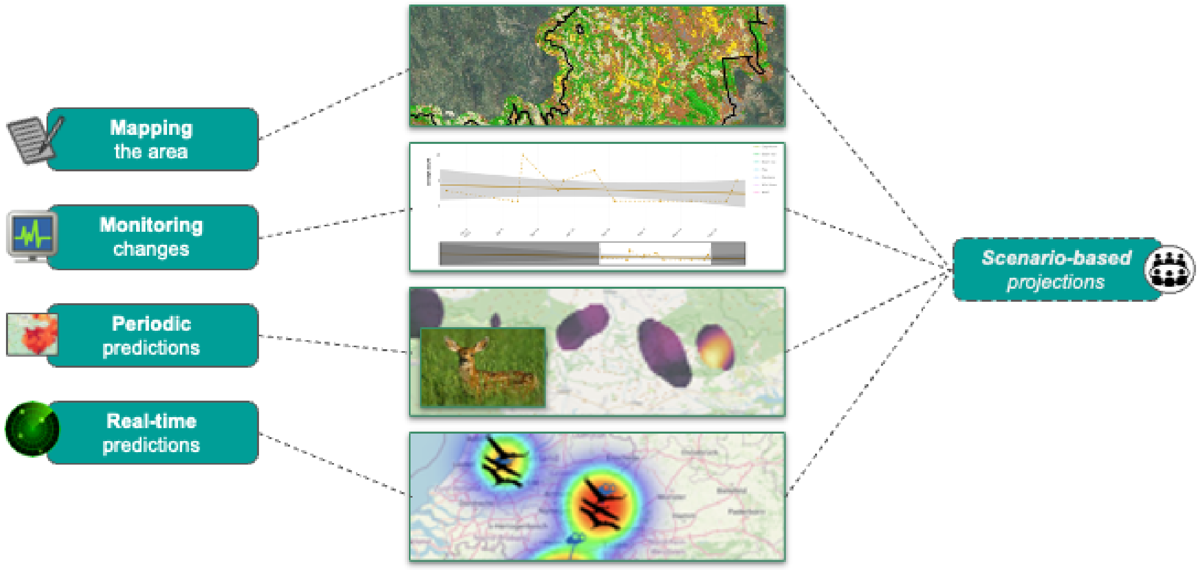

Figure 5: Maturity levels of biodiversity monitoring & assessment of conservation status

Appendix D Ecosystem basemap and the GeoServer

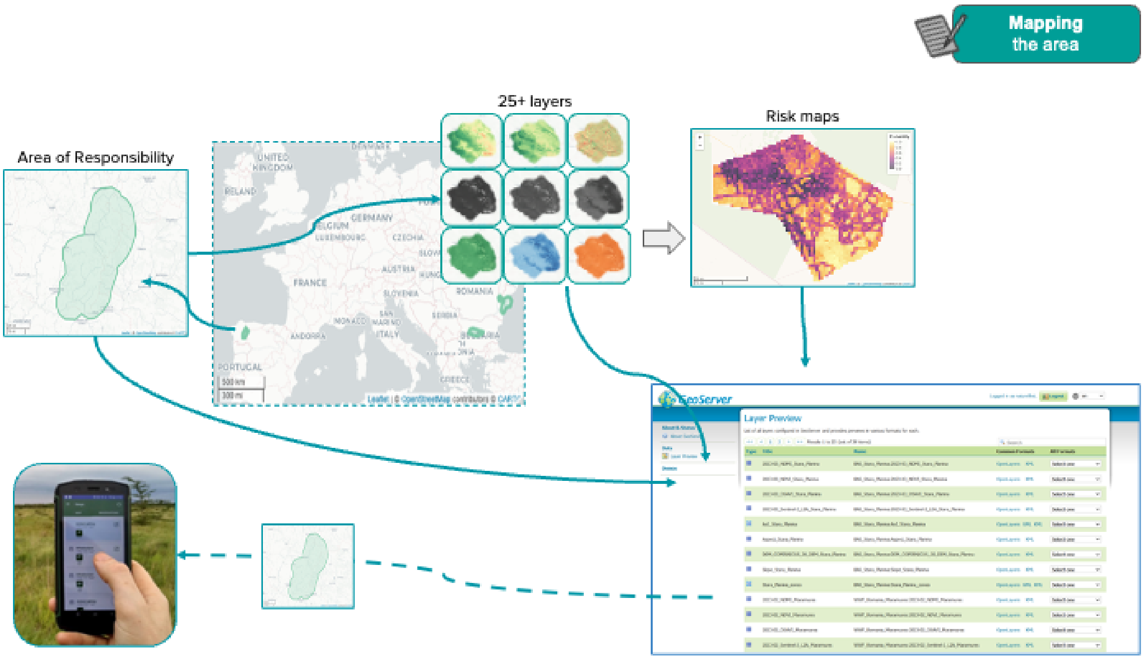

Figure 6: Mapping the area - Ecosystem Basemap and the GeoServer

Appendix E Habitat Classification Process

Figure 7: Mapping the area - Habitat Classification Process

Appendix F Monitoring changes

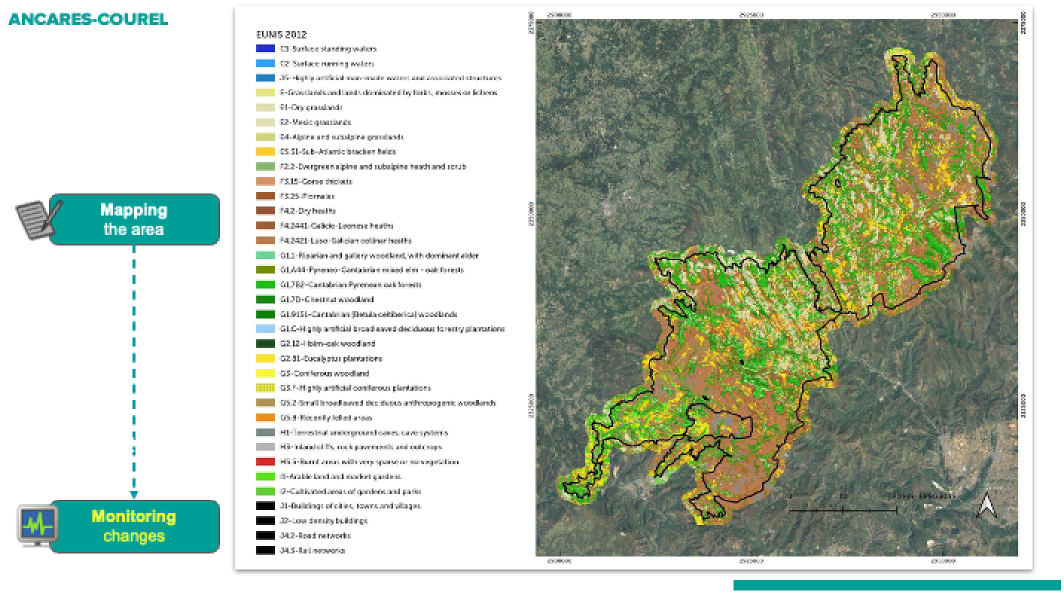

Figure 8: Monitoring changes

Appendix G Periodic predictions

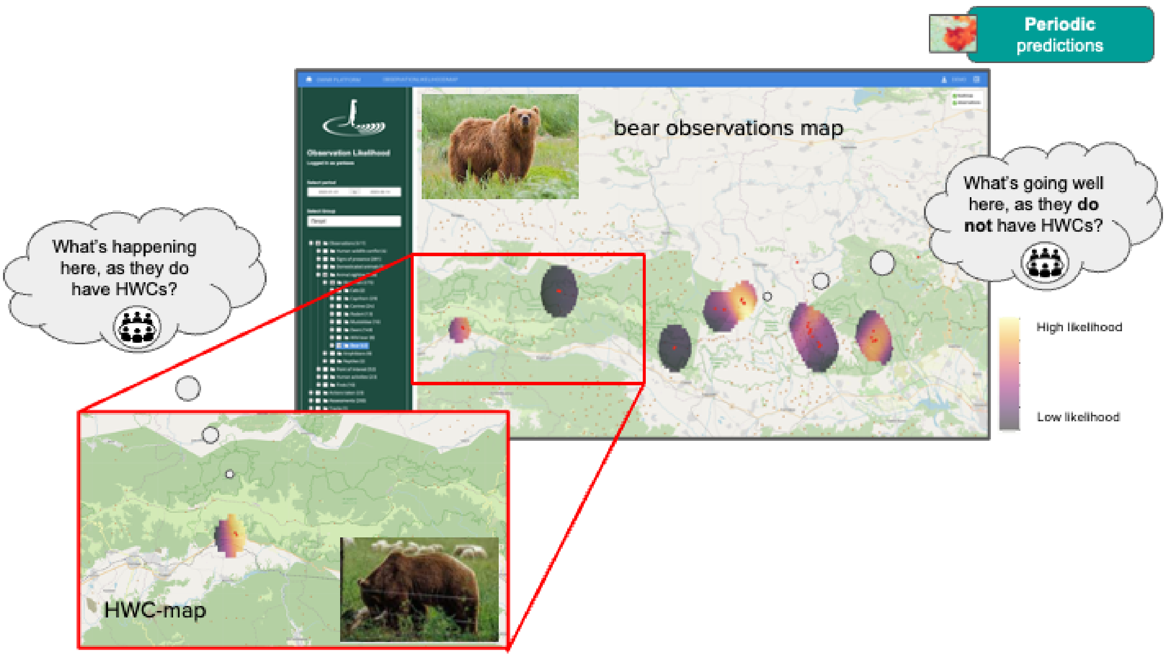

Figure 9: Periodic predictions

Appendix H Real-time predictions

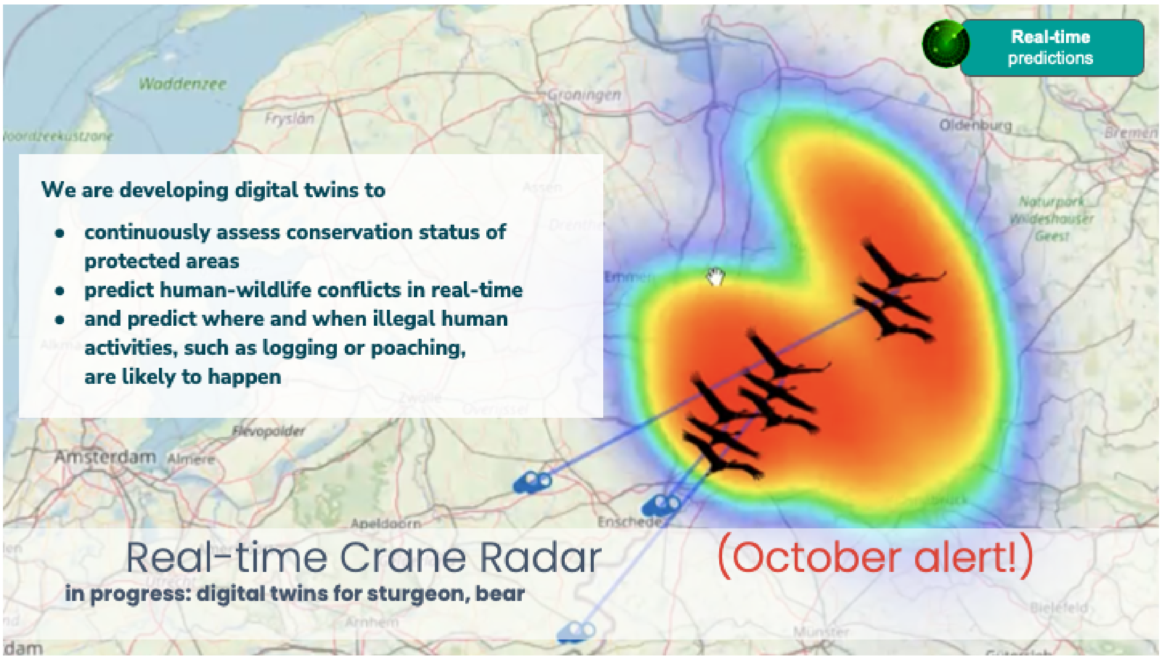

Figure 10: Real-time predictions