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THEMATIC GUIDANCE MONITORING LARGE CARNIVORES

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THEMATIC GUIDANCE MONITORING LARGE CARNIVORES

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Executive summary

The recovery and expansion of large carnivores across Europe and the Carpathians has increased the need for reliable, harmonised and comparable monitoring systems. Effective conservation and management of wolves, lynx and bears require robust data on species occurrence, distribution, population size, reproduction, demographic structure and long-term trends. In transboundary mountain regions such as the Carpathians, where populations move across national borders and monitoring capacities differ among countries, standardised approaches are essential for producing credible evidence for conservation planning, reporting and management.

Developed within the LECA project, this Thematic Guidance on Monitoring Large Carnivores provides practical, evidence-based recommendations to harmonise monitoring across the Carpathian region and support the implementation of the Carpathian Convention. It builds on tested and transferable solutions that can be adapted to local, national, transboundary and Carpathian-wide contexts. The guidance promotes a scalable monitoring framework based on the integrated use of complementary methods, including camera trapping, genetic sampling, snow tracking, simulated howling, GPS telemetry, mobile applications, online databases and standardised validation procedures.

Core elements of the guidance

The framework is structured around four mutually reinforcing pillars:

- **Assessment of occurrence and distribution of large carnivores:** using harmonised 10×10 km grid-based mapping, SCALP-compatible validation and LCIE-compatible distribution assessments;
- **Mobile applications and central online databases:** supporting efficient field data collection, storage, validation, photo-video management, data export and reporting;
- **Integrated wolf monitoring:** combining camera trapping, snow tracking, documentation of field signs, genetic sampling, howling surveys and GPS telemetry to assess wolf presence, pack distribution, reproduction, minimum population size and demographic parameters;
- **Intensive deterministic monitoring of Eurasian lynx:** using systematic camera trapping, individual identification based on coat patterns and capture-recapture approaches to estimate occurrence, minimum abundance, population density and trends.

These components are supported by **case studies from LECA cross-border pilot areas**, demonstrating how harmonised monitoring approaches can be implemented in practice and how their outputs can support conservation planning, transboundary cooperation and reporting.

Key policy and management recommendations

To strengthen large carnivore monitoring in the Carpathians, decision-makers and responsible institutions should prioritise:

- **Harmonised monitoring protocols:** based on compatible spatial grids, standardised evidence categories, comparable reporting periods and shared methodological principles;
- **Centralised and secure data systems:** including database with species records, photo-video databases, mobile field applications and clear data-access rules;
- **Standardised validation procedures:** preferably compatible with SCALP criteria, ensuring that confirmed and unverifiable records are clearly distinguished;
- **Integration of complementary monitoring methods:** because in most cases no single method provides sufficient information on occurrence, reproduction, individual identity, population structure or trends;

- **Minimum monitoring standards:** enabling reliable baseline assessment even in regions where full-scale intensive monitoring, genetic capture-recapture or GPS telemetry cannot be implemented;
- **Long-term funding and institutional continuity:** to avoid dependence on short-term projects and to ensure repeated monitoring, database maintenance, expert validation and analytical capacity;
- **Transboundary cooperation and data sharing:** to allow population-level assessments of large carnivores that move across administrative and national borders

Key message

Reliable monitoring is the foundation of effective large carnivore conservation and management. In the Carpathians, monitoring must be harmonised, long-term, transboundary and based on standardised data collection, validation and analysis. The LECA guidance provides a practical framework for improving data quality, strengthening cooperation and producing robust outputs that can support evidence-based decision-making at local, national and international levels.

1. Introduction

Large carnivores are among the most ecologically important and socially visible species in European landscapes. Their recovery and expansion in many parts of Europe represent a major conservation achievement (Chapron et al. 2014), but also create new demands for monitoring, management and reporting. Reliable information on the occurrence, distribution, population size, reproduction and demographic trends of wolves (Canis lupus), Eurasian lynx (Lynx lynx) and brown bears (Ursus arctos) is essential for evaluating conservation status, guiding management decisions and supporting coexistence in human-dominated landscapes.

The Carpathian Mountains represent one of the most important strongholds for large carnivores in Europe. However, the region is characterised by pronounced ecological, geographical, socio-economic and institutional heterogeneity that give rise to various challenges. Large carnivore populations frequently extend across national borders, while monitoring systems, methodological standards, institutional responsibilities and data availability differ among countries. As a result, population assessments may be inconsistent, difficult to compare or based partly on expert opinion rather than systematically collected empirical data. This is particularly problematic for transboundary conservation planning, where management decisions should be based on shared and up-to-date knowledge of population status at both national and population levels.

At the European level, large carnivore monitoring is directly relevant to several reporting and assessment frameworks. Under the EU Habitats Directive, Member States are required to monitor the distribution and conservation status of species of Community interest and report these parameters to the European Commission every six years. In parallel, the IUCN Large Carnivore Initiative for Europe (LCIE) coordinates periodic assessments of the distribution and population status of large carnivores across Europe (Kaczensky et al. 2024). For the Eurasian lynx, the SCALP and SCALP+ approaches provide an additional framework for evaluating species occurrence and distribution based on standardised evidence categories (Molinari-Jobin et al. 2026). To be useful for these reporting processes, monitoring data must be spatially explicit, validated, harmonised and comparable across regions and countries.

This Thematic Guidance on Monitoring Large Carnivores was prepared within the LECA project, “Supporting the coexistence and conservation of Carpathian LargE CArnivores”, implemented under the Interreg Central Europe Programme. The project aimed to strengthen structured cross-border cooperation in large carnivore monitoring and conservation across pilot areas in Czechia, Slovakia, Poland, Hungary and Ukraine, with reference areas in Slovenia and Romania. The guidance contributes to the implementation of the Carpathian Action Plan, particularly the objective of standardising monitoring procedures for large carnivores in the Carpathians.

The document presents selected best practices and practical solutions validated through LECA activities in cross-border pilot areas. It focuses on four key components of large carnivore monitoring: harmonised assessment of occurrence and distribution, centralised data collection, integrated wolf monitoring, and intensive deterministic camera-trap monitoring of Eurasian lynx. These approaches are illustrated through case studies showing their practical application in assessing large carnivore occurrence, wolf population structure and lynx density.

Overall, the guidance provides a practical policy and technical tool for strengthening harmonised and evidence-based monitoring in the Carpathians. Rather than prescribing a single uniform model, it promotes a scalable framework adaptable to different ecological, institutional and financial contexts. Minimum standards ensure reliable baseline data on species presence, reproduction and minimum population size, while best-practice approaches support more advanced assessments where sufficient capacity is available. Such a harmonised and adaptive system is essential for credible reporting, conservation planning and long-term transboundary management.

The document is structured as a comprehensive thematic guidance on the systematic cross-border monitoring of large carnivores in the Carpathian region. It begins with an introductory chapter on the three large carnivore species living in the region and the current state of monitoring practices. The core chapters then present selected best practices and validated approaches from Carpathian pilot areas. First, we present the comprehensive practice of large carnivore presence and distribution assessment, providing background as well as detailed assessment process. Next, we address the issue of monitoring data management and provide detailed insight into practical solutions in the form of mobile applications, including their development, use and maintenance. We further present detailed integrative monitoring practices focusing on wolf and lynx. Each section contains background information to the topic, detailed descriptions of processes and recommendations, and is concluded with tables summarising minimum recommended standards and recommended best practice. Finally, the guidance concludes with a lessons learned section summarising the key risks, systemic weaknesses, and recommendations for improving legal frameworks, institutional coordination, enforcement capacity, and long-term conservation of large carnivores in the Carpathians. The document is complemented with a set of detailed case studies related to validation of monitoring practices we have collected during the project application.

2. Selected Best Practices from Carpathian cross-border Pilot Areas under the thematic pillar "Monitoring Harmonisation"

In line with the strategic objective #1 of the Carpathian Action Plan (to standardise monitoring procedures for large carnivores in the Carpathians), one of the key challenges across the region is harmonising monitoring efforts to ensure the collection of reliable, up-to-date data on the distribution, occurrence, and population size of large carnivores. In this context, we present the selected recommendations and practices that were validated through project activities in cross-border pilot and reference areas. Detailed results on the monitoring thematic pillar from these areas can be found in the Output section: https://www.interreg-central.eu/projects/leca/?tab=outputs.

A. Assessment of occurrence and distribution of large carnivores

Monitoring of large carnivores in Europe and the Carpathians currently has multiple dimensions and varies considerably in methodological scope and quality. Present-day monitoring usually combines several methodological approaches, ranging from the documentation of field signs and camera-trap monitoring to GPS telemetry. The collected data are evaluated at different levels by various institutions and organisations, either in the form of scientific publications or monitoring reports. This takes place both at the national level and within broader international frameworks.

One of the key reporting obligations is linked to the EU Habitats Directive, under which large carnivores are listed among species of Community interest. As mentioned before, member States are required to monitor their distribution and conservation status and to report these parameters to the European Commission every six years. In addition, coordinated assessments of the distribution and population status of large carnivores are carried out by the IUCN Large Carnivore Initiative for Europe (LCIE), which prepares Europe-wide reports at approximately five-year intervals (Kaczensky et al. 2024). Another specific assessment focused on the distribution of large carnivores, particularly the Eurasian lynx, is the SCALP+ distribution assessment (Molinari-Jobin et al. 2026), prepared in cooperation with several countries within the Linking Lynx Initiative.

Validated complex approach to large carnivore occurrence and distribution assessment

The most effective monitoring system for the transboundary Carpathian region, with subsequent extrapolation to the national and Carpathian-wide levels, is based on a harmonised approach and effective cooperation across border areas. Such a system should be consistent with the above-mentioned European reporting frameworks and should provide robust, comparable and spatially coherent data for large carnivore monitoring.

This approach enables cross-border data harmonisation through the production of various types of comparable analytical outputs, maps and graphical outputs that can support monitoring, reporting at regional, national and international levels (e.g. EU Habitats Directive, LCIE, SCALP+), conservation planning and management decision-making. The individual steps of this process are summarised in the graphical workflow (Figure 1) and described below:

1) *Definition of mapping area and grid*

   The first step consists of defining the spatial extent of the monitoring area and applying a standardised mapping grid. In the presented workflow, the area is divided into 10 × 10 km grid cells using ETRS89-

LAEA Europe reference grid (EEA Reference grid 2026, available here http://www.eea.europa.eu/data-and-maps/data/eea-reference-grids-2).

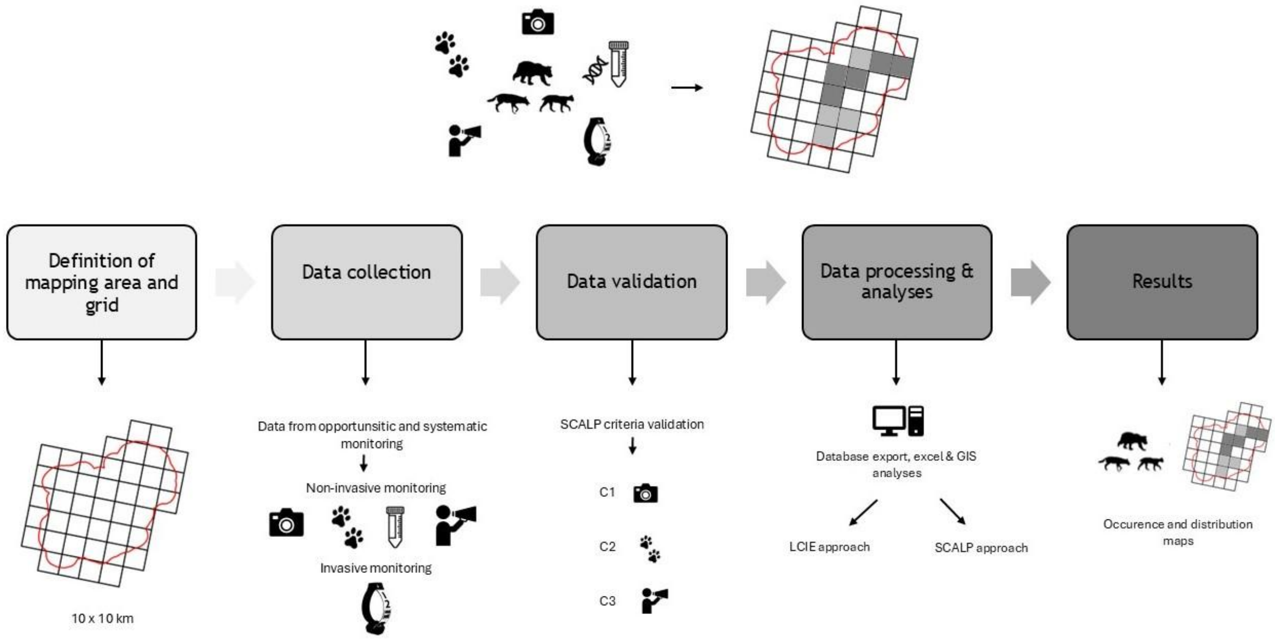

Figure 1: Graphical workflow of recommended assessment of presence and distribution of large carnivores in cross-border areas

2) *Data collection*

Data are collected from both systematic and opportunistic monitoring. Systematic monitoring includes targeted field surveys, camera trapping, snow tracking, genetic sampling, simulated howling and GPS telemetry where available. Monitoring data include non-invasive evidence such as tracks, scats, hair samples, photographs and videos, as well as invasive or telemetry-based information where relevant. Opportunistic data may include verified and unverified observations, records from stakeholders and additional evidence provided by hunters, foresters, livestock breeders or the public.

3) *Data validation*

All collected records are validated using standardised criteria, preferably following the SCALP approach (Molinari-Jobin et al. 2012, Kaczensky et al. 2024, Marucco et al. 2025). According to this method, records are classified according to their reliability into evidence categories such as C1, C2 and C3. C1 records represent hard facts, such as clear photographs, genetic confirmation or verified carcasses; C2 records include confirmed signs validated by experts (e.g. scats or tracks); and C3 records represent unconfirmed observations or indirect evidence. This step ensures that only reliable and comparable data are used for further analyses.

4) *Data processing and analyses*

Validated records are exported from the database and processed using GIS and statistical tools. Spatial analyses are performed to assess species presence, distribution and temporal patterns within the grid system. Depending on the reporting objective, data can be analysed using the LCIE approach (Kaczensky et al. 2024), which distinguishes confirmed and unconfirmed occurrence, or the SCALP approach, which maps evidence categories (Molinari-Jobin et al. 2012, 2026). A comprehensive overview of the relevant monitoring approaches is provided in the latest LCIE standard, Monitoring Standards for Large Carnivores in Europe (Marucco et al., 2025). Database exports, spreadsheet summaries and GIS layers form the basis for further interpretation and reporting.

5) *Results*

The final outputs include occurrence and distribution maps of large carnivore species within the monitored area. Results can be presented as grid-based maps showing confirmed species presence, SCALP evidence categories, broader distribution patterns and overall reliability and quality levels according to SCALP methodology and LCIE standards (Molinari-Jobin et al. 2012, Kaczensky et al. 2024, Marucco et al. 2025, Molinari-Jobin et al. 2026). These outputs provide a harmonised basis for monitoring reports, conservation planning, cross-border cooperation and reporting under European and international frameworks.

Box 1. Recommended measures (best practice) to assessment of presence and distribution of large carnivores

Establish a **transboundary, harmonised monitoring system** for the Carpathian region, supported by formal cooperation and agreed procedures among participating countries and institutions.

Define a common monitoring extent and use the **10 × 10 km ETRS89-LAEA Europe grid** as the standard spatial unit for data collection, assessment, mapping and reporting.

Combine **systematic monitoring** with verified opportunistic records to maximise coverage while retaining analytical rigour.

Apply a **multi-method monitoring design**, using appropriate combinations of field-sign surveys, camera trapping, snow tracking, non-invasive genetic sampling, simulated howling and GPS telemetry.

Maintain a shared or interoperable database structure that enables routine exchange of standardised records, metadata, validation decisions and spatial outputs across borders.

Validate all records using harmonised expert criteria, preferably the **SCALP C1-C3 evidence classification**, before they are used in analyses or reporting.

Ensure that C1 and C2 records form the principal basis for confirmed occurrence assessments, while C3 records are retained separately as supplementary information.

Use GIS-based analyses to generate spatially coherent, grid-based assessments of presence, distribution and temporal change at local, national and Carpathian-wide scales.

Produce outputs compatible with the principal reporting frameworks, including the EU Habitats Directive, LCIE assessments and SCALP+ distribution assessments.

Implement regular quality assurance, joint cross-border review and periodic methodological updates so that monitoring remains comparable, transparent and fit for management decision-making.

B. Large carnivore monitoring data management

Mobile applications have become an essential tool for the documentation and monitoring of wildlife, including large carnivores, in the field. These apps, designed for both researchers and the general public, enable users to report sightings, track movements, and document evidence of large carnivores, such as tracks, scat, and visual observations. Widely used platforms, such as iNaturalist (iNaturalist 2026) allow users to record geotagged data, including photos and videos, which can be uploaded directly to centralised databases. These apps not only facilitate data collection but also contribute to citizen science initiatives by involving a broad public audience in wildlife monitoring.

These apps often allow users to log their observations along with relevant metadata, such as location, date, and time, and then export the collected data for further analysis. This data can be used for tracking the distribution and presence of species, assessing population dynamics, and understanding habitat use. Additionally, these mobile platforms provide a way to communicate findings with researchers and conservation organisations, leading to improved collaboration and more efficient monitoring efforts.

In addition to mobile applications, online databases play a crucial role in storing and organising the vast amounts of data on the presence of large carnivores, generated by mobile apps or directly by users. Furthermore, online databases are essential for storing photos and videos from camera traps, with numerous platforms established worldwide for this purpose, such as Agouti platform (Casaer et al. 2019). These solutions use AI tools to classify species automatically, identifying them from camera trap images or user-uploaded photos. This AI functionality significantly reduces the time and effort needed for manual data sorting, ensuring accurate species identification and speeding up the data processing workflow.

The integration of mobile applications with online databases has significantly enhanced the ability to monitor large carnivores, providing a valuable tool for both professional researchers and wildlife enthusiasts. It enables widespread data collection that can contribute to long-term ecological studies and conservation efforts.

Developing and establishing a functional database and mobile application

The most effective system for collecting, storing and validating data in large carnivore monitoring consists of two interconnected components: a **central database**, which stores and organises monitoring data, and a **user application**, which allows field teams and administrators to record, access, and manage these data. The central database serves as the core infrastructure of the system. It stores different types of information, including field observations, records of tracks and signs, photographs and videos from camera traps, geographic coordinates, monitoring events, and user data. The database must be designed to handle structured ecological data as well as large volumes of multimedia files. The mobile application provides an interface through which users interact with the database. It may include a web interface for data management and a mobile application for recording observations directly in the field. Field mappers can use the application to document signs of large carnivores, upload photographs, record geographic locations, and synchronise data with the central database.

Workflow demonstrated below illustrates the recommended steps of a digital monitoring system for large carnivores, from field data collection to data analysis and reporting (Fig.2). Field observations, tracks, signs of presence, GPS locations, photographs, videos and monitoring events are collected through a mobile application or field forms and synchronised with a central database. The database stores and organises ecological records, spatial data, multimedia files and user information. Administrators and expert validators then check, edit, verify and approve the records through a web interface. Validated data can subsequently be exported and used for mapping, monitoring reports, trend analyses and conservation planning.

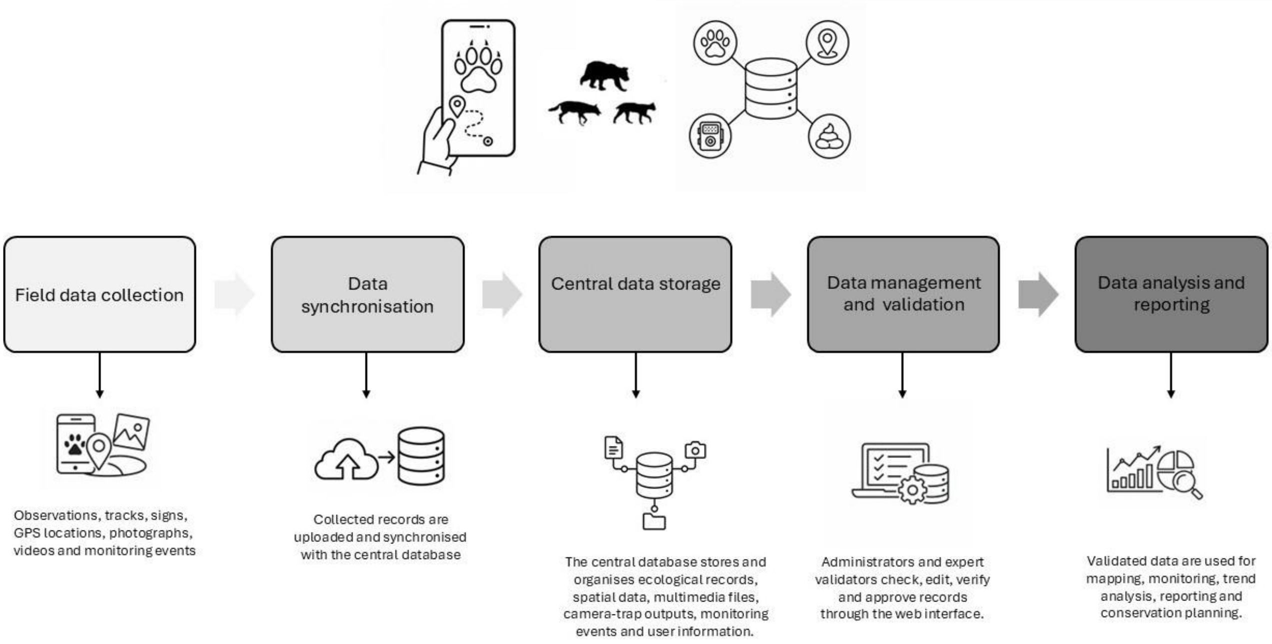

Figure 2. Graphical workflow of large carnivore monitoring data collection, storage, validation, management, analysis and reporting using a mobile application, a central database of records

and a camera-trap photo-video database.

The development of a monitoring database and application system for large carnivores is a stepwise process that usually begins with a clear project idea and gradually develops into a fully operational digital infrastructure. The system is not only a technical tool, but also a practical response to the needs of field monitoring, data management, expert validation and long-term conservation planning. The development time depends on the complexity of the system and available resources. A basic database may be developed within several months, while a complex system with a central database, web interface, mobile application, multimedia management, user roles, validation tools and analytical functions usually requires 6–18 months. Financial costs also vary considerably and depend on tools used and on complexity of the application functions.

There are also two main development approaches. One option is to use an existing commercial or open-source platform. This can reduce development time and initial costs, especially if the platform already supports spatial data, mobile data collection and multimedia records. However, such platforms may be less flexible, may involve licensing costs and may not fully match specific monitoring protocols. The second option is to develop a custom-built system. This approach is more expensive and requires long-term technical support, but it allows full adaptation to the organisation’s monitoring methods, data structure, validation rules and security requirements.

Overall, the development of a monitoring database and application system should be understood as a gradual process. It starts with a clear definition of monitoring needs, continues through database and application development, testing and operational deployment, and then requires long-term maintenance and further improvement. In the context of large carnivore monitoring, such a system can substantially improve the efficiency of field data collection, reduce manual work, standardise records, strengthen data validation and provide a reliable basis for conservation management and decision-making.

Figure 3: Training of volunteers and field data documentation and validation using the mobile application, together with camera-trap checking and data download (Photo credit: Friends of The Earth, Carnivore Conservation Programme).

Below, we provide the key recommendations and steps for developing and establishing a functional database and mobile application.

a) The first stage is the **project idea**, where the main purpose of the system is defined. In this case, the objective is to create a centralised platform for collecting, storing, managing and analysing data on large carnivore occurrence, including field observations, signs of presence, GPS locations, camera-trap outputs, photographs, videos and monitoring events. At this stage, it is important to clarify whether the system should serve only as a database, or whether it should also include a mobile application, web interface, data validation tools, reporting functions, analytical and AI modules.

b) The next step is a **needs assessment**. This involves analysing existing monitoring workflows, identifying the main user groups and defining the types of data that need to be collected. Typical users include researchers, rangers, protected area staff, volunteers, administrators and expert validators. The needs assessment should describe how data are collected in the field, how they are currently transferred to the database, who validates them, what types of outputs are required and what problems should be solved by the new system.

c) After the needs assessment, the process continues with **system design**. This stage defines the database architecture, data structure, user roles, application interface, data security requirements and communication between system components. The database must be able to store both structured ecological data and large volumes of multimedia files. It should include records of observations, tracks and signs, camera-trap data, spatial coordinates, monitoring events, users and validation status. At the same time, the application interface must be designed in a way that is practical for field users, including simple data entry, GPS recording, photo upload and offline functionality.

d) The next stage is **software development**. This includes implementation of the database, server infrastructure, web administration interface and, if required, a mobile application. The central database forms the core of the system, while the mobile application acts as a field tool for direct data collection. Without the application, field workers would otherwise have to record information in the field and later manually enter everything into the database after returning from fieldwork. The mobile application allows them to collect data directly in the field and synchronise them with the central database once the fieldwork is completed.

e) Once the first functional version is available, the system enters the **testing and pilot-use phase**. During this stage, the system should be tested under real monitoring conditions. Field users should record observations, upload photos, save GPS locations and test the synchronisation process.

Administrators should test data validation, searching, filtering, editing and export. This phase is essential because it reveals technical problems, missing functions, unclear forms or difficulties in user workflows. Feedback from field workers is particularly important, because they are the main users of the mobile application and often identify practical problems that are not visible during office-based development.

f) After testing and correction of errors, the system can be deployed for **operational use**. At this stage, the database and application become part of regular monitoring practice. Field users collect data through the mobile application, while administrators and experts manage, validate and analyse the collected records through the web interface. The system can then support national or regional monitoring, reporting, conservation planning, camera-trap data management and communication between different institutions.

g) The next stage is **long-term operation**. A monitoring system cannot be considered finished after launch. It requires regular maintenance, technical support, server management, data backups, security updates and user support. New users may need training, data structures may need adjustments, and monitoring protocols may change over time. Long-term sustainability is therefore a key issue. Without maintenance and support, even a well-designed system may become outdated or difficult to use.

h) The final stage is **future development**. As monitoring programmes evolve, the system can be expanded with new functionalities. Possible future developments may include automated species recognition from camera-trap images, individual identification of lynx, integration of genetic data, GPS telemetry, damage records, ecological corridor monitoring, advanced GIS tools, automated reporting or connection to national and international conservation databases. The system should therefore be designed as modular and expandable from the beginning.

Box 2. Minimum standard measures to large carnivore monitoring data management

Maintain a centralised or interoperable database for storing large-carnivore monitoring records.

Use standardised digital forms for field observations, including species, date, location, evidence type, observer and validation status.

Allow attachment of supporting photographs, videos or other evidence where available.

Capture geographic coordinates for all spatially relevant records.

Provide a basic mobile or web-based method for entering field data and transferring them to the database.

Assign user roles and restrict editing or approval rights according to responsibility.

Include a documented process for expert review and validation of submitted records.

Ensure that validated data can be exported in standard tabular and GIS-compatible formats.

Maintain regular data backups and basic data-security procedures.

Provide user guidance and initial training for field staff, administrators and validators.

Box 3. Recommended measures (best practice) to large carnivore monitoring data management

Establish an integrated digital monitoring system comprising a central database, web-based administration interface and mobile field application.

Design the system around agreed monitoring workflows, data standards, validation rules and reporting requirements before development begins.

Support structured records on ecology, spatial data, camera-trap outputs, photographs, videos, GPS locations and monitoring-event data within one interoperable system.

Enable field users to record observations directly in the mobile application, including GPS location, date, evidence type, photographs and supporting metadata.

Provide offline data entry and secure synchronisation to support use in remote areas with limited connectivity.

Define role-based access for field users, administrators and expert validators, with clear responsibilities for data entry, review, approval and export.

Include standardised validation workflows so that records can be checked, corrected, classified and approved before use in analysis or reporting.

Test the system through a field pilot before operational deployment, using feedback from field staff to improve usability and functionality.

Ensure routine maintenance, backups, security updates, technical support and user training are funded as part of long-term operation.

Develop the system as modular and expandable, allowing future integration of AI image classification, genetic data, telemetry, automated reporting and external conservation databases.

C. Integrated wolf monitoring

Monitoring wolves, whose spatial activity can extend over several hundred square kilometres, is highly challenging. However, modern technologies such as camera trapping, genetic analyses, and telemetry now enable the collection of detailed data on population size, density, spatial distribution of territories, and population dynamics. At the European level, several studies have addressed wolf monitoring and the estimation of demographic parameters across study areas, countries, and entire populations, and several countries have developed their own monitoring methodologies. However, in the Carpathians, characterised by extensive mountainous and forested landscapes that pose specific challenges for monitoring this apex predator, only a limited number of studies have been conducted to date. Across Carpathian countries, systematic monitoring of wolves at the transboundary or national level remains highly limited and insufficient. As a result, currently reported population estimates are still largely based on expert opinion rather than robust empirical data.

Comprehensive assessment of wolf population

A comprehensive assessment of wolf population status and dynamics, including pack size, territorial distribution, and demographic structure, requires the integration of multiple complementary methods. **Priority should be given to intensive genetic sampling within a defined period, supplemented by extensive year-round sampling, snow tracking, camera trapping, and simulated howling surveys.** The combination of these approaches allows for the identification of territories (i.e., breeding pairs), estimation of pack size, assessment of reproduction, spatial distribution of territories, and estimation of robust demographic parameters.

A key prerequisite for implementing such monitoring is securing sufficient funding. Costs associated with camera trap deployment, genetic analyses, and professional field teams can reach tens of thousands of euros, depending on the size area, sampling intensity, laboratory costs and personnel requirements. Additional methods that can further refine these core techniques include telemetry, which provides more precise estimates of territory size and offers valuable supplementary data. For example, intensive monitoring of cluster sites and specific location fixes during key periods of the year can be used to estimate predation rates, determine diet composition, and assess habitat selection.

Below, we present a step-by-step approach for establishing and implementing an integrated wolf monitoring system. The main workflow is summarised in Figure 4 and described in detail in the following sections.

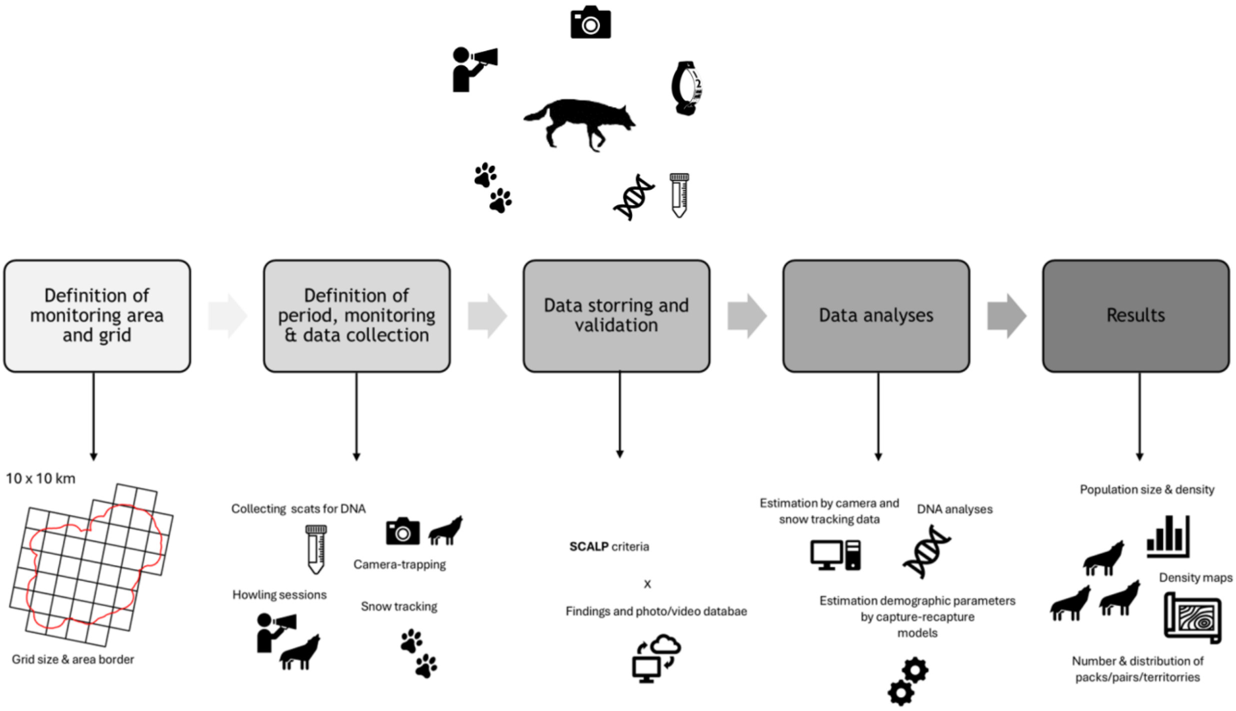

Figure 4: Graphical workflow of establishment and implementation of integrated wolf monitoring

1) *Definition of the monitoring are and grid*

The first step is to clearly define the spatial extent of the monitoring area and the grid system used for data evaluation. For wolf monitoring, a 10 × 10 km grid, preferably compatible with the EEA reference grid, is recommended. This grid size allows harmonised assessment of wolf presence and distribution and is consistent with broader European reporting standards for species distribution mapping (e.g. LCIE Kaczensky et al. 2024). The definition of the monitoring area should also consider expected wolf territories, administrative borders, transboundary continuity and the availability of field teams and funding.

2) *Selection and integration of monitoring methods and data collection*

The next step is to define the monitoring period and select an appropriate combination of field methods. Integrated wolf monitoring should combine opportunistic and systematic data collection. Recommended methods include camera trapping, snow tracking, documentation of field signs, collection of genetic samples, simulated howling and, where available, GPS telemetry. An integrated monitoring framework combining multiple monitoring approaches and complementary analytical outputs has already been applied in several studies at different spatial scales, from pilot areas and regional assessments to country-wide evaluations (e.g. Mysłajek et al. 2018, Vorel et al. 2025, Duľa et al. 2025, Kutal et al. 2025). We recommend combining both conventional and more advanced monitoring techniques, briefly described below.

a) Camera trapping

Camera trapping is currently a widely used method in wolf monitoring and research. Camera traps are applied either systematically or opportunistically for various purposes, most commonly to document wolf presence, determine the number of individuals in a pack, confirm reproduction, density (e.g. Mattioli et al. 2018, Jimenéz et al. 2023, Kutal et al. 2025, Vorel et al. 2025) or assess other aspects such as spatio-temporal activity, interactions with humans or prey, and related ecological patterns (e.g. Rossa et al. 2021, Smith et al. 2024). Compared to Eurasian lynx monitoring, where white-flash camera traps are typically used for deterministic monitoring and reliable individual identification (e.g. Kubala et al. 2018, Duľa et al. 2021), wolf monitoring can rely on a wider range of infrared camera traps. At the initial stage of monitoring, particularly in previously unstudied areas, we recommend deploying more than 5 camera traps per grid cell (10 × 10 km) at strategically selected locations (e.g., road crossings, marking sites identified through tracking such as scats, scratches, or urine marks). Camera traps should preferably be set to video mode, with a recording duration of 10–20 seconds and no delay between consecutive triggers. This setting helps capture the passage of multiple individuals and allows a more accurate assessment of pack size. This approach, applied within the LECA pilot actions in the Beskydy-Kysuce area, increases the probability of obtaining sufficient data (Duľa et al. 2025). Over time, as key locations are identified and regularly yield detections, the number of camera traps can be reduced to 2-3 per grid cell, improving both logistical and time efficiency.

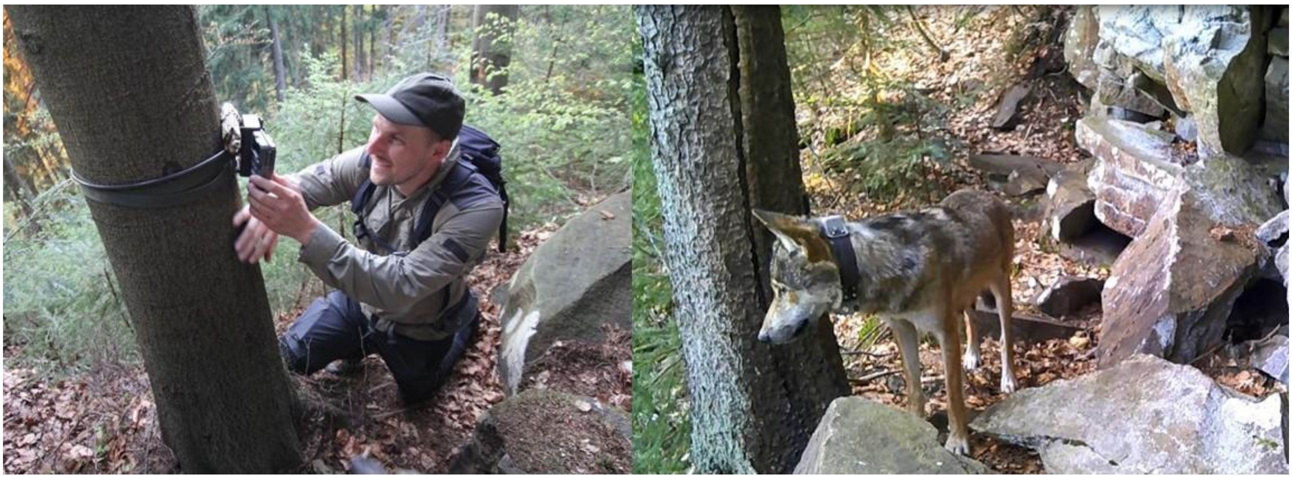

Figure 5: The combination of GPS telemetry and camera trapping is a highly effective approach for wolf monitoring and research

b) Snow tracking and documentation of field signs

During winter, snow tracking should be used to complement genetic and camera-trapping data. This method provides valuable information on pack size, space use, and helps identify optimal locations for camera trap placement, particularly at marking sites. Intensive tracking also increases the probability of locating samples for genetic analyses and other complementary studies. Where possible, the ideal approach is to organise a coordinated snow-tracking campaign across the entire mapping area over 2-3 days with continuous snow cover. Such campaigns should involve trained volunteers, rangers, zoologists and other key stakeholders.

This approach provides valuable data for refining territory distribution, estimating the number of individuals, and enabling efficient collection of samples for genetic analysis Throughout the year, field signs such as tracks, scats, marking sites and other signs of presence are routinely documented within the mapping grid cells. These records provide valuable information, particularly when camera-trapping or genetic data confirming species presence are insufficient, of poor quality, or entirely unavailable (Duľa et al. 2025).

c) Genetic sampling (extensive and intensive)

Genetic analyses are now a standard tool in wolf monitoring and research across Europe (e.g. Hulva et al. 2018, Bischof et al. 2020, Marucco et al. 2023). They have also been applied in several pilot studies in the Carpathians, where the main objectives included the identification of wolf territories, reconstruction of pack structure, estimation of the number of individuals, documentation of reproduction events or estimation of population density (Rigg et al. 2014, Kutal et al. 2017, Bolfíková et al. 2024, Iosif et al. 2025, Duľa et al. 2025).

We recommend combining intensive sampling during clearly defined monitoring periods with extensive year-round sampling. This combined approach is essential for reliable individual identification, assessment of pack structure, estimation of abundance and density, and evaluation of other key demographic parameters.

For intensive sampling aimed at estimating population size and density under Carpathian conditions, we recommend focusing on the winter period, preferably when continuous snow cover is available. This approach has been successfully applied in Romanian and Slovak Carpathians (Rigg et al., 2014, Iosif et al. 2025, Duľa et al. 2025). The sampling period should be as short as possible to meet the assumption of population closure, ideally around four to five months, but long enough to ensure sufficient population coverage and an adequate number of samples for robust estimates. The sampling design should include predefined transects and systematic recording of sampling effort within individual mapping grid cells. This allows sampling intensity to be quantified and later incorporated into spatial or non-spatial capture-recapture analyses. A similar design, based on defined sampling units, transect-based searches and explicit recording of sampling effort, was applied by Marucco et al. (2023) and provides a suitable methodological framework for intensive wolf genetic monitoring in the Carpathians (Duľa et al. 2025).

Figure 6: One of the GPS-collared female wolves monitored in the Beskydy–Kysuce pilot area, at the western edge of the Carpathians.

d) Howling surveys

Simulated howling can be used to detect the presence of wolf packs and, in particular, to confirm reproduction through pup responses (Nowak et al. 2007). We recommend applying simulated howling primarily in known or suspected wolf territories during August and September, when pup vocal responses are most likely to be detected. Confirming reproduction at this stage can help identify rendezvous sites or areas regularly used by pups, allowing more effective placement of camera traps and increasing the probability of documenting pups and estimating their number.

e) GPS telemetry

Telemetry represents an advanced complementary method that allows for precise estimation of territory size and space use. It also provides additional ecological insights, such as movement patterns, habitat selection or diet composition and kill rate, particularly when intensive cluster investigation periods are included. Telemetry has been used as a complementary method in wolf monitoring in several European areas (e.g. Vorel et al. 2025, Kutal et al. 2025) and represents an irreplaceable tool for studying home-range size, spatial behaviour and habitat preferences (e.g. Mysłajek et al. 2018, Vorel et al. 2024).

We recommend combining non-invasive monitoring with GPS telemetry in the target area, using wolf captures with Belisle foot snares during trapping campaigns conducted in early spring and autumn. To obtain high-quality spatial data, GPS-GSM collars are recommended, with regular location fixes every two hours. During intensive cluster checks aimed at estimating diet composition and kill rates, the fix interval should be increased to 30 minutes during the night-time period (Duľa et al. 2025).

3) Data storing and validation

All collected records should be stored in a centralised database with species records and, where relevant, in a linked photo-video database (see chapter B. "Mobile app & central online database"). Effective data storage is essential for rapid access, quality control, export and subsequent GIS or statistical analyses. Each record should include at minimum the date, location, type of evidence, observer, monitoring method, validation status and, where applicable, links to photographs, videos or genetic samples. Records should be validated using standardised criteria, preferably compatible with SCALP methodology and categories (Molinari-Jobin et al. 2012, Kaczensky et al. 2024). This ensures that only reliable and comparable data are used for further analyses of wolf distribution and demographic parameters.

4) Data analyses

Validated data should be analysed using a combination of spatial, genetic, camera-trap and field-based approaches. GIS analyses can be used to evaluate wolf presence, distribution and territory arrangement within the 10 × 10 km grid. Genetic analyses allow identification of individuals, sex determination, reconstruction of relatedness, pack structure and, where sampling intensity is sufficient, estimation of population size. Camera-trap and snow-tracking data support the assessment of pack size, reproduction and spatial activity. Capture–recapture or other demographic models may be applied where data quality and sampling design allow robust estimation. GPS telemetry data can be used to estimate territory size, movement patterns, habitat selection and additional ecological parameters.

5) Results

The final outputs should include maps of wolf occurrence and distribution, estimates of population size and density where possible, identification of packs, pairs and territorial individuals, and maps of wolf territories. Additional outputs may include information on reproduction, pack composition, demographic structure, movement patterns and trends over time. These results provide a basis for conservation planning, transboundary cooperation, reporting under European and international frameworks, and evidence-based management of wolf populations.

Baseline wolf monitoring standard

While best-practice wolf integrative monitoring combines systematic camera trapping, intensive and While best-practice integrated wolf monitoring combines systematic camera trapping, intensive and extensive genetic sampling, snow tracking, howling surveys and GPS telemetry, the minimum standard should ensure that monitoring provides reliable information on wolf presence, pack distribution, reproduction, minimum number of individuals and basic demographic structure. This approach should be applicable also in regions where full-scale intensive monitoring or GPS telemetry cannot be implemented, either because these methods are not available or because financial, personnel or logistical capacities are insufficient to cover the full recommended integrative monitoring framework.

At a minimum, integrated wolf monitoring should include the following components:

- Monitoring should be carried out within a clearly defined area and evaluated using a standardised spatial grid, preferably compatible with European reporting frameworks, such as the EEA 10 × 10 km grid. The monitoring area should reflect expected wolf territories, habitat continuity, administrative borders and, where relevant, transboundary population units.

- The monitoring period should be clearly defined and repeated consistently, ideally on an annual basis or within a fixed multi-year monitoring cycle. This is essential for comparing results among years and assessing changes in wolf occurrence, reproduction and pack distribution over time.

- The minimum field approach should combine camera trapping, documentation of field signs, snow tracking where possible, and opportunistic genetic sampling. These methods should be used together to improve detection probability and to provide mutually verifiable evidence of wolf presence.

- Camera traps should be placed at locations with a high probability of wolf detection, such as forest roads, trails, road crossings, marking sites, repeatedly used passages and rendezvous sites. These sites should be selected based on previous monitoring records, local knowledge and field evidence, particularly repeated findings of scats, tracks, urine marks, scratching or other signs of wolf presence. In areas where wolf presence is poorly known, several camera traps should initially be deployed per 10 × 10 km grid cell to identify key detection sites. Once regularly used locations are identified and repeatedly confirmed, monitoring can be optimised and reduced to fewer strategically placed cameras.

- Camera traps should be placed at locations with a high probability of wolf detection, such as forest roads, trails, road crossings, marking sites, repeatedly used passages and rendez-vous sites. In areas where wolf presence is poorly known, several camera traps should initially be deployed per 10 × 10 km grid cell to identify key detection sites. Once regularly used locations are identified, monitoring can be optimised and reduced to fewer strategically placed cameras.

- Field signs should include tracks, scats, urine marks, scratching, prey remains and other signs of wolf presence. Each record should be documented with photographs, GPS coordinates, date, and observer name. Snow tracking should be used whenever possible, as it provides important information on pack size, movement direction, spatial use and potential marking sites. It also increases the probability of locating suitable genetic samples and selecting effective camera-trap locations. Simulated howling should be applied where feasible, especially during the summer (August–September), to support confirmation of pack presence and reproduction.

- Genetic sampling should be considered a minimum requirement for reliable individual-level wolf monitoring. Scats, hair, urine on snow and tissue samples, where legally and ethically available, should be collected whenever possible. Each genetic sample should be linked to the corresponding field record, including date, coordinates, sample type and collector. Genetic analyses should be used to confirm species identity, identify individuals, determine sex, detect hybridisation where relevant, reconstruct pack structure and support estimates of minimum population size.

- Reproduction should be systematically assessed. Minimum evidence of reproduction should include camera-trap records of pups, confirmed pup vocalisations during howling surveys, genetic evidence of related individuals, repeated observations of pups or other well-documented and validated records.

- All monitoring records (findings/camera traps records) should be stored in a basic database. Data should be easily searchable and exportable for GIS analyses, statistical analyses and reporting. Each record should include at least the date, time, geographic coordinates, grid cell, type of evidence, monitoring method, observer or data provider, species identification and validation status

- All records should be validated using standardised criteria, preferably compatible with SCALP categories (See data management and validation in previous sections) .

The minimum outputs should include:

- Confirmed wolf presence and distribution map evaluated within the standardised 10 × 10 km grid.
- Basic map of wolf territories and reproductive territories
- Database of individuals and minimum number of pairs and packs based on genetic analyses and other monitoring methods
- Minimum population size estimate
- Basic demographic summary

The outputs should provide a robust baseline for assessing wolf occurrence, reproduction, pack distribution and minimum population size. They should also create a foundation for future expansion toward more advanced approaches, including systematic camera trapping, intensive genetic sampling, capture-recapture modelling and GPS telemetry.

Box 4. Minimum standard measures for integrated wolf monitoring

Define the monitoring area, reporting period and standardised 10 × 10 km grid before fieldwork begins.

Repeat monitoring annually or within a fixed multi-year cycle to allow comparison of wolf occurrence, reproduction and pack distribution over time.

Combine camera trapping, field-sign documentation, snow tracking where possible and opportunistic genetic sampling.

Place camera traps at locations with a high probability of wolf detection, including trails, forest roads, crossings, marking sites and regularly used passages.

Document all field signs with photographs where possible, GPS coordinates, date, observer and evidence type.

Collect genetic samples whenever feasible and **link each sample** to the associated field record and metadata.

Use genetic analysis to confirm species identity and support identification of individuals, sex, pack structure and minimum population size.

Assess reproduction using validated evidence, such as camera-trap records of pups, pup responses during howling surveys or genetic evidence of related individuals.

Store and validate all records in a searchable database using standardised, preferably SCALP-compatible, reliability categories.

Produce, at minimum, confirmed-presence maps, basic territory and reproductive-territory maps, a catalogue of identified individuals, a minimum population estimate and a basic demographic summary.

Box 5. Recommended measures (best practice) for integrated wolf monitoring

Implement an integrated, transboundary wolf-monitoring programme using a defined monitoring area and a standardised 10 × 10 km grid compatible with European reporting frameworks.

Combine intensive winter genetic sampling with year-round extensive genetic sampling to support individual identification, pack reconstruction, abundance and density estimation.

Integrate camera trapping, snow tracking, field-sign surveys, simulated howling and genetic sampling as core complementary methods.

Deploy camera traps strategically at marking sites, trails, crossings and other high-use locations; **use video mode where possible** to improve pack-size assessment.

Conduct coordinated snow-tracking campaigns during suitable snow conditions to refine territory boundaries, assess pack size and locate genetic samples.

Use simulated howling in known or suspected territories during August-September to confirm reproduction and identify rendez-vous areas.

Apply GPS telemetry as an advanced complementary method to estimate territory size, movement, habitat selection, kill rates and diet composition.

Record sampling effort systematically, particularly for genetic surveys, to enable robust capture-recapture or other demographic analyses.

Store all records in a centralised database, link genetic samples and multimedia evidence to field records, and **validate observations using SCALP-compatible criteria**.

Produce integrated outputs including occurrence and territory maps, pack and reproductive-territory assessments, individual catalogues, abundance or density estimates, and demographic trends.

D. Opportunistic and deterministic camera-trap monitoring of Eurasian lynx

Effective conservation and management of the Eurasian lynx require reliable information on species occurrence, distribution, population size, density, demographic trends and, where feasible, demographic parameters such as survival and recruitment (Gaillard et al. 2003, Molinari-Jobin et al. 2012). The Carpathian Mountains are characterised by pronounced geographic, ecological and socio-economic heterogeneity (Kubala et al. 2021). Consequently, monitoring and conservation strategies should be adapted to local ecological conditions, management objectives and available resources while maintaining sufficient methodological consistency to allow comparison among regions (Boitani et al. 2015).

Because lynx populations occupy extensive areas that frequently cross-national borders (Kubala et al. 2024), conservation planning must operate at broad spatial scales, as exemplified by the LECA pilot areas (Fig. 16). Effective implementation requires coordinated transboundary action based on a shared and up-to-date assessment of conservation status at both national and population levels (Breitenmoser et al. 2015, von Arx 2021).

Complex assessment of lynx population

Such assessments depend on standardized, systematic monitoring. For territorial and individually recognizable carnivores such as the Eurasian lynx, camera trapping represents one of the most robust non-invasive monitoring approaches, providing information on occurrence, reproduction, minimum population size, abundance and population density (Breitenmoser et al. 2006; Rovero & Zimmermann 2016).

Prior to camera-trap deployment, a preparatory survey is strongly recommended to improve detection probability and optimise sampling design. This includes recording presence signs (tracks, marking sites, visual observations), snow tracking when possible, collecting genetic samples (scats, hair), and verifying occurrence through preliminary camera trapping (Kubala et al. 2019, Duľa et al. 2021). These data help identify core activity areas and movement corridors, thereby improving site selection for both opportunistic and deterministic camera-trap monitoring and increasing the likelihood of obtaining sufficient detections and recaptures for capture–recapture analyses. Because not all lynx present within a study area will necessarily be detected, monitoring designs should aim to maximise detection probability through appropriate site selection, sufficient sampling effort and repeated sampling.

Figure 7: Identification and confirmation of the same lynx at two different camera trap locations, based on its unique coat pattern (Kubala et al. 2025).

Lynx can be individually identified based on its unique coat pattern (Breitenmoser & Breitenmoser-Würsten 2008; Figure 7). Because individuals maintain relatively stable home ranges (Kubala et al. 2024), camera trapping allows estimation of occurrence, minimum population size, abundance, population density and population trends through capture–recapture (CR) models (Karanth & Nichols 1998). Two complementary camera-trap monitoring approaches are recommended: opportunistic (extensive) monitoring and deterministic (capture–recapture-based intensive) monitoring.

Opportunistic (extensive) camera-trap monitoring

Opportunistic monitoring aims to maximise the probability of detecting lynx across large spatial extents and over extended time periods while maintaining moderate logistical requirements. Camera traps are placed at sites frequently used by lynx (travel routes, marking sites, passes) and at fresh prey remains where repeated visits are expected (Breitenmoser et al. 2006). This approach benefits from cooperation with hunters, foresters and volunteers, which increases spatial coverage and improves real-time information flow while reducing costs (Kubala et al. 2018).

All images and videos are archived in a centralised database and compared with existing records to identify individuals (Picek et al. 2026; see also chapter “B Mobile app & central online database” and “Case study 2“). Data are primarily used to document distribution, minimum number of individuals, reproduction events and dispersal patterns. Long-term implementation may enable reconstruction of individual life histories and provide valuable information on survival, reproduction and population trends (Duľa et al. 2021). Although opportunistic monitoring does not meet statistical requirements for unbiased density estimation, it provides essential baseline information and supports individual identification during deterministic surveys (Kubala et al. 2019). Opportunistic monitoring should therefore be regarded as a complementary monitoring approach rather than a standalone method for estimating population density. Photographic confirmation of depredation events also strengthens communication with stakeholders and supports compensation procedures, thereby enhancing trust and cooperation.

Implementation requires trained personnel, standardised data management, appropriate equipment (camera traps, security housings, batteries, data storage systems) and effective coordination. Limitations include variable detection probability depending on field effort and local knowledge, as well as risks of equipment damage or theft.

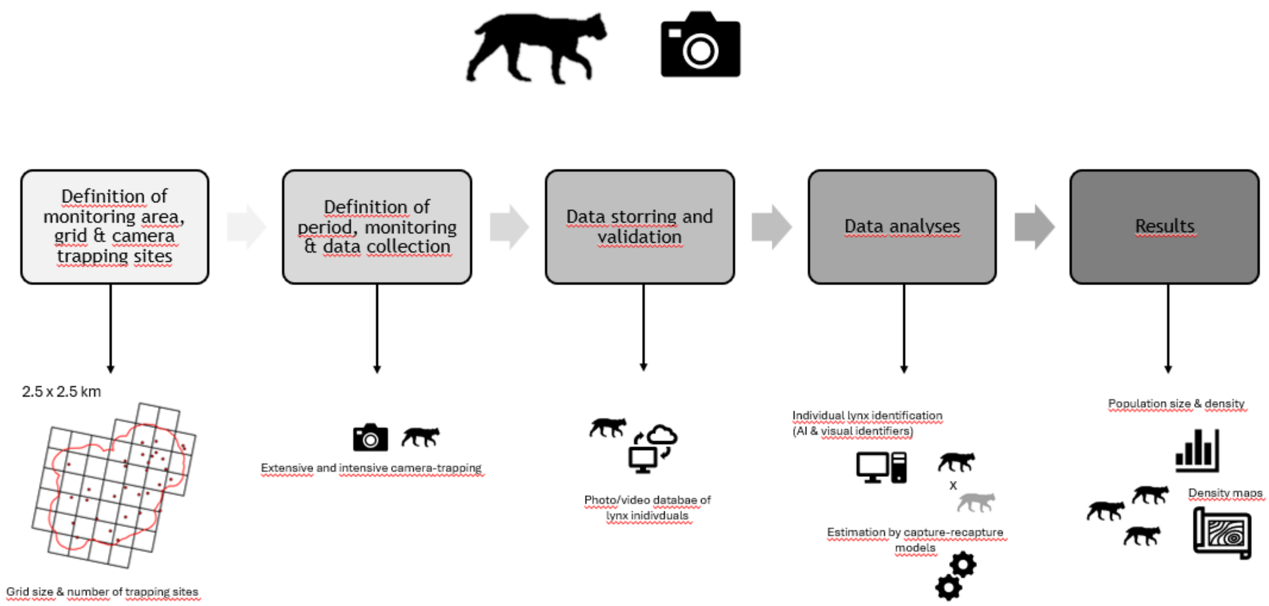

Figure 8: Graphical workflow of establishment and implementation of intensive deterministic monitoring of lynx

Deterministic (intensive) camera-trap monitoring

Deterministic (capture-recapture-based) monitoring aims to estimate lynx abundance and population density through systematic camera-trap sampling and standardized capture-recapture analytical approaches (Karanth & Nichols 1998; Rovero & Zimmermann 2016). Camera traps are deployed within a predefined spatial grid covering a representative portion of the population (Palmero et al. 2023). For Eurasian lynx, a grid with approximately 2.5 × 2.5 km cells is recommended, ensuring that multiple camera stations are located within a typical female home range and allowing repeated detection of resident individuals (Breitenmoser et al. 2006). Within selected cells, paired camera stations (two opposing cameras) are installed to photograph both flanks (Fig. 7). Cells dominated by unsuitable habitat are excluded (Kubala et al. 2019).

At least two stations should fall within a single home range to ensure recaptures; typically, 3-6 camera traps are placed within a resident female’s home range (≈1 camera per 15 km^2; Duľa et al. 2021). The optimal survey period is late autumn to winter (October–February), when lynx activity is higher and human disturbance lower (Kubala et al. 2018). Cameras are checked every 2–4 weeks, and surveys last at least 60 days to obtain sufficient capture histories.

The first detection is treated as a capture and subsequent detections as recaptures. To minimise identification bias, records are verified by multiple observers. All data are stored in a secure centralised database with multiple backups (Picek et al. 2026). Population size and density are estimated using capture–recapture (CR) or spatial capture-recapture (SCR) models implemented in software such as R, MARK or other specialised analytical platforms (Rovero & Zimmermann 2016). Repeated surveys allow assessment of population trends (Duľa et al. 2021). In addition to density estimates, camera-trap data provide information on reproduction, marking-site use and presence of non-target species. Deterministic estimates can also calibrate other monitoring methods (Breitenmoser et al. 2006).

This approach is logistically demanding and requires coordinated field teams for 60–80 days annually, year-round database management and continuous equipment maintenance (Kubala et al. 2018). Key challenges include maintaining demographic and geographic closure assumptions during sampling, difficult terrain, harsh weather conditions and risk of camera loss. Together, opportunistic and deterministic camera-trap monitoring provide a robust, complementary framework for assessing lynx population status and supporting evidence-based conservation planning at national and transboundary scales (Kubala et al. 2021).

Figure 9: Placement of two opposing camera traps forming a camera station (indicated by red arrows) during deterministic camera-trap monitoring (Kubala et al. 2018).

Minimum standards

Minimum monitoring standards are intended to provide a realistic baseline for regions where intensive capture-recapture monitoring cannot be implemented. Although such approaches do not generally allow unbiased estimation of abundance or population density, they can provide reliable information on occurrence, reproduction, minimum population size and broad population trends when applied consistently over time.

As a practical minimum, extensive lynx camera-trap monitoring should include:

- Deployment of camera traps in all 10 × 10 km grid cells with confirmed or expected lynx presence where suitable camera-trap locations are available. At least one camera station per occupied or potentially occupied 10 × 10 km cell is recommended for baseline occurrence monitoring. For individual identification, each station should ideally consist of two opposing cameras to photograph both flanks.
- Centralised data storage, where all photographic & video records are archived in a secure database.
- Minimum metadata for each record, including date and time, camera-trap location, type of evidence, species identification, record quality, individual identity where possible, and confidence level of identification.
- Expert validation of records, with individual identification verified by experienced observers. Uncertain records should be treated conservatively and clearly flagged in the database.
- Comparable protocols across years, allowing repeated monitoring to provide information on persistence of individuals, turnover, reproduction frequency, minimum population size and broad population trends.

The minimum outputs should include:

- Maps of confirmed lynx occurrence
- A database of individually identified lynx
- Minimum number of identified individuals
- Basic information on spatial distribution and movements
- Repeated detections of known individuals
- Documented reproduction, number of family groups and kittens
- Multi-year comparison where comparable data are available

Box 6. Minimum standard measures to lynx camera-trap monitoring

Deploy camera traps at sites with a high probability of lynx detection, particularly marking sites, forest roads, trails, passes, corridors and fresh prey remains.

Position cameras to obtain clear lateral images of lynx flanks for individual identification.

Maintain monitoring for sufficient duration to obtain repeated detections and document seasonal presence and reproduction.

Check cameras regularly to maintain operation, replace batteries and memory cards, and prevent data loss.

Archive all photographs and videos in a secure, centralised database with routine backups.

Record minimum metadata, including date, time, location, camera station, species, record quality and identification confidence.

Verify species and individual identification through expert review; flag uncertain records clearly and treat them conservatively.

Apply comparable camera-placement, data-management and identification protocols across years.

Produce maps of confirmed lynx occurrence and basic information on spatial distribution and movements.

Maintain records of identified individuals, repeated detections, confirmed reproduction events and the minimum number of detected lynx.

Box 7. Recommended measures (best practice) to lynx camera-trap monitoring

Implement complementary opportunistic and deterministic camera-trap monitoring to assess lynx distribution, abundance, density, reproduction and population trends.

Conduct preparatory non-invasive surveys, including field-sign recording, snow tracking, genetic sampling and preliminary camera trapping, to identify core areas and optimise camera placement.

Use opportunistic camera trapping year-round at high-probability sites such as marking sites, travel routes, mountain passes, movement corridors and prey remains.

Engage trained hunters, foresters, rangers and volunteers to increase spatial coverage and improve the reporting of lynx detections.

Archive all photographs and videos in a centralised database and apply standardised individual-identification procedures based on coat patterns.

Apply deterministic capture-recapture monitoring within a predefined, representative survey area using a 2.5 × 2.5 km grid.

Install paired camera stations in selected grid cells to obtain images of both flanks and maximise reliable individual identification.

Ensure sufficient camera density to obtain recaptures, with at least two stations within a typical home range and approximately one camera station per 15 km^2 of suitable habitat.

Conduct deterministic surveys for at least 60 days, preferably between October and February, with camera checks every 2–4 weeks.

Estimate abundance and density using appropriate capture-recapture models, report confidence intervals, and repeat comparable surveys to assess population trends.

3. Case studies from LECA cross-border pilot areas

Case study 1: Occurrence & distribution of large carnivores in LECA cross-border areas

Introduction

In the transboundary areas where wolf and lynx monitoring was carried out, namely Beskydy–Kysuce, the Eastern Carpathians, and Slovak Karst-North Hungarian Mountains, the presence and distribution of large carnivores were assessed through intensive cross-border cooperation and data exchange. The assessment integrated data from both non-invasive and invasive monitoring, as well as additional information provided by relevant stakeholders, including foresters, hunters and livestock breeders. Records of damage to livestock, agricultural crops and beehives were also included as supplementary information to support the evaluation of large carnivore occurrence and distribution in these areas.

Methods used and results achieved

The collected data were evaluated at the level of wolf and lynx monitoring years, (2023/24, 2024/25) and validated according to the SCALP methodology (Molinari-Jobin et al. 2012). Based on this validation, SCALP maps were produced to show species presence within a 10 × 10 km grid, classified into three evidence categories: C1, C2 and C3 for wolf and bear.

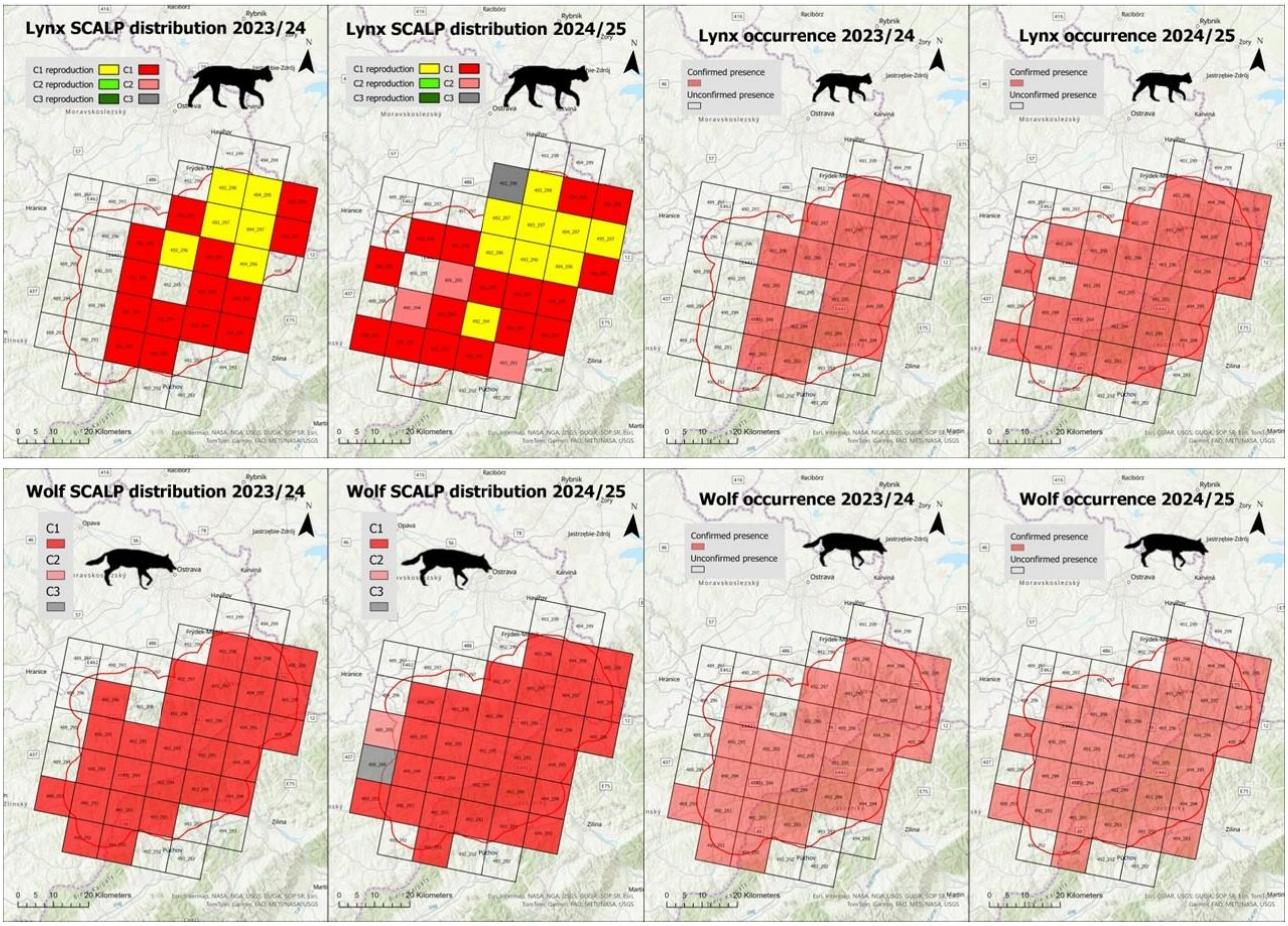

Figure 10: Wolf and lynx SCALP distribution based on C1-C3 data as well as confirmed wolf and lynx presence based on C1 & C2 SCALP data visualised by EEA 10×10 km grid level in the two consecutive wolf/lynx years (2023/24, 2024/25).

For lynx also C1-C3 reproduction category was categorised. Subsequently, distribution maps following the LCIE methodology (Kaczensky et al. 2024) were prepared for all large carnivore species, distinguishing between confirmed and unconfirmed presence.

For example, in the Beskydy-Kysuce pilot area, confirmed wolf presence increased from 28 grid cells in 2023/24 (67% of all mapping grids) to 31 grid cells in 2024/25 (74%). Lynx presence showed a similar increase, from 20 grid cells in 2023/24 (48%) to 28 grid cells in the 2024/25 lynx year (67%). For all three large carnivore species, C1 records represented the majority of grid cells with confirmed presence, based on SCALP validation and the resulting spatial assessment (Figure 10; Duľa et al. 2025).

Key takeways

This approach provides high-quality and reliable outputs on the presence and distribution of large carnivores, which can be directly used for further reporting purposes. These outputs are particularly suitable for periodic LCIE assessments covering the evaluated reporting period, usually five years (Kaczensky et al. 2024), as well as for comprehensive conservation status reporting to the European Commission under Article 17 of the EU Habitats Directive.

Another important advantage of this approach is that it also allows species presence to be assessed using basic data sources, such as public observations or opportunistic monitoring records. This makes it possible to generate and refine initial information on large carnivore presence in transboundary areas where systematic large carnivore monitoring has not yet been fully established. More detailed results from the LECA cross-border pilot areas are available in the project outputs section: https://www.interreg-central.eu/projects/leca/?tab=outputs.

Case study 2: Using of Mobile application and Online databases in Beskydy-Kysuce pilot area

Introduction

Within the LECA project, a large carnivore records database and a photo-video database were used to store field survey tracks, record and validate observations, and manage large volumes of photographic and video material obtained from camera traps. These data were collected as part of integrated wolf monitoring and long-term large carnivore monitoring in the Czech-Slovak transboundary region.

In addition, the CarniTrack application was developed and tested. The application enables users to record field survey routes and enter large carnivore observations directly in the field, with the collected data being automatically stored in the online records database.

Methods used and results achieved

The system used in LECA cross-border area under responsibility of Friends of the Erat Carnivore Conservation Programme represents a **central database and application platform for the collection, management, validation, analysis and sharing of data on large carnivore occurrence** (Fig. 11). Its main purpose was to integrate field monitoring, occurrence records and camera-trap outputs from wolf integrated monitoring into one functional environment, allowing efficient data handling from field collection to expert evaluation and practical use during LECA project and conservation and managgement of wolf in cross-border region.

The system is built around **field users**, including researchers, protected area staff, rangers, volunteers and other trained persons involved in large carnivore monitoring. These users collect field data on the occurrence and signs of large carnivores, such as direct observations, tracks, scats, hair samples, prey remains, other signs of presence, damage reports or other relevant records. Each record may include photographs, videos, GPS coordinates, date and time, species, record type, observer identity, notes on the circumstances of the finding and additional information required for later validation.

Field data collection is carried out through a **mobile monitoring application CarniTrack** (https://www.carnivores.cz/carnitrack-mobile-app/, Fig. 12C). The application enables users to record observations directly in the field, attach photographs and videos, automatically store GPS locations and complete standardized forms for different types of records. An important function is offline use, which is essential in remote mountain areas where mobile signal is often limited. Once an internet connection is available, the data are synchronized with the central server and database.

Communication between the mobile application and the central system is ensured through a secure **internet/API interface**. The API acts as the communication layer between the mobile application, central server, database and web administration interface. It enables secure data synchronization, user authentication, access control and potential connection to external tools or databases.

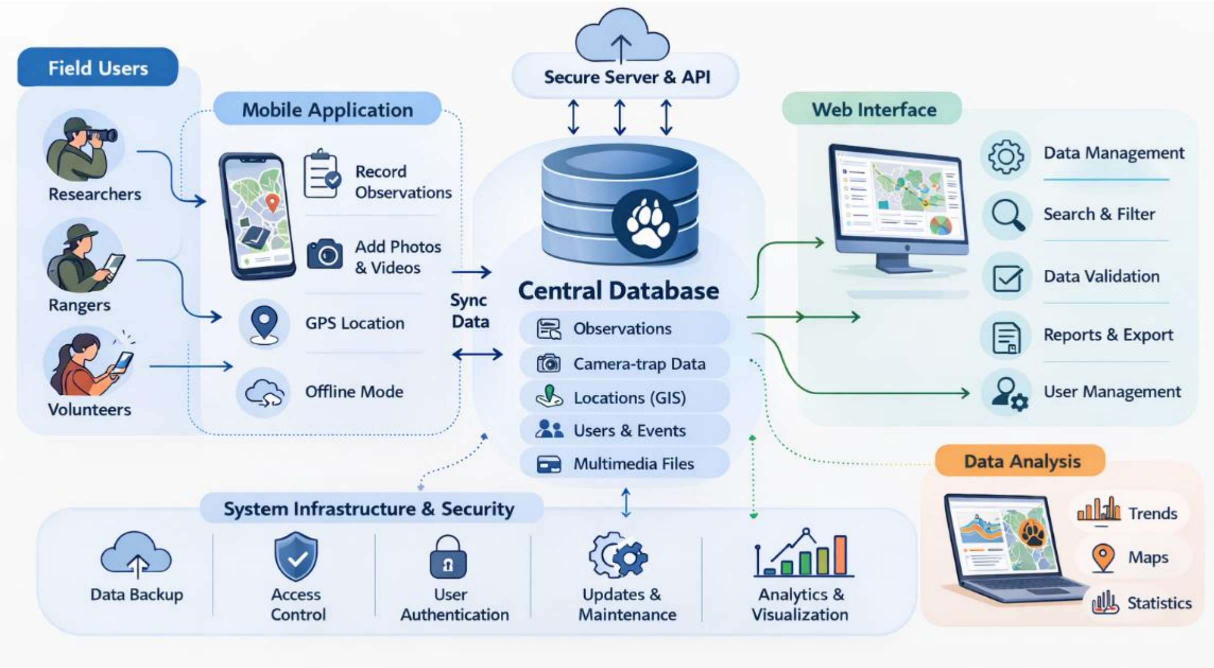

Figure 11: Schematic overview of a large carnivore monitoring data system, showing field data collection through a mobile application, synchronisation with a central database, secure server infrastructure, web-based data management and validation, and subsequent data analysis, reporting and visualisation.

The technical core of the system is the central server, which provides the system infrastructure, application operation, user management, security mechanisms, backups, updates and maintenance. The server ensures user authentication, access permissions, encrypted communication, protection of sensitive location data and regular backups. This is particularly important for large carnivore data, as precise locations of occurrence, breeding sites or camera traps may be sensitive from a conservation perspective.

All data are stored in a central database (https://www.carnivores.cz/carnitrack-online-database/; https://vlcihlidky.selmy.cz/admin/, Fig 12B,D), which serves as the main repository of the system. The database contains records of large carnivore observations and signs of presence, camera-trap data, spatial information, user accounts, monitoring events, multimedia files and validation information. For occurrence records, the system stores information such as species, record category, location, date and time, observer, type of evidence, photographic documentation and validation status. For camera-trap data, the database can store information on the device, location, deployment period, individual images and videos, recorded species, identified individuals, record quality, animal activity and the results of expert evaluation.

A specific component of the system is the camera-trap output database (https://l2y0n1x2.selmy.cz/en/admin/; Fig 12A), which enables the structured storage, classification and evaluation of large numbers of photographs and videos. Each camera-trap record can be linked to a specific location, device, monitoring period, monitoring type and identified species. For large carnivores, the system may also store information on individual identification features, such as coat pattern in lynx, body marks, sex, age category, reproductive status or repeated records of the same individual. The database can therefore support not only media storage, but also long-term population monitoring, assessment of reproduction, spatial activity and changes in occurrence over time.

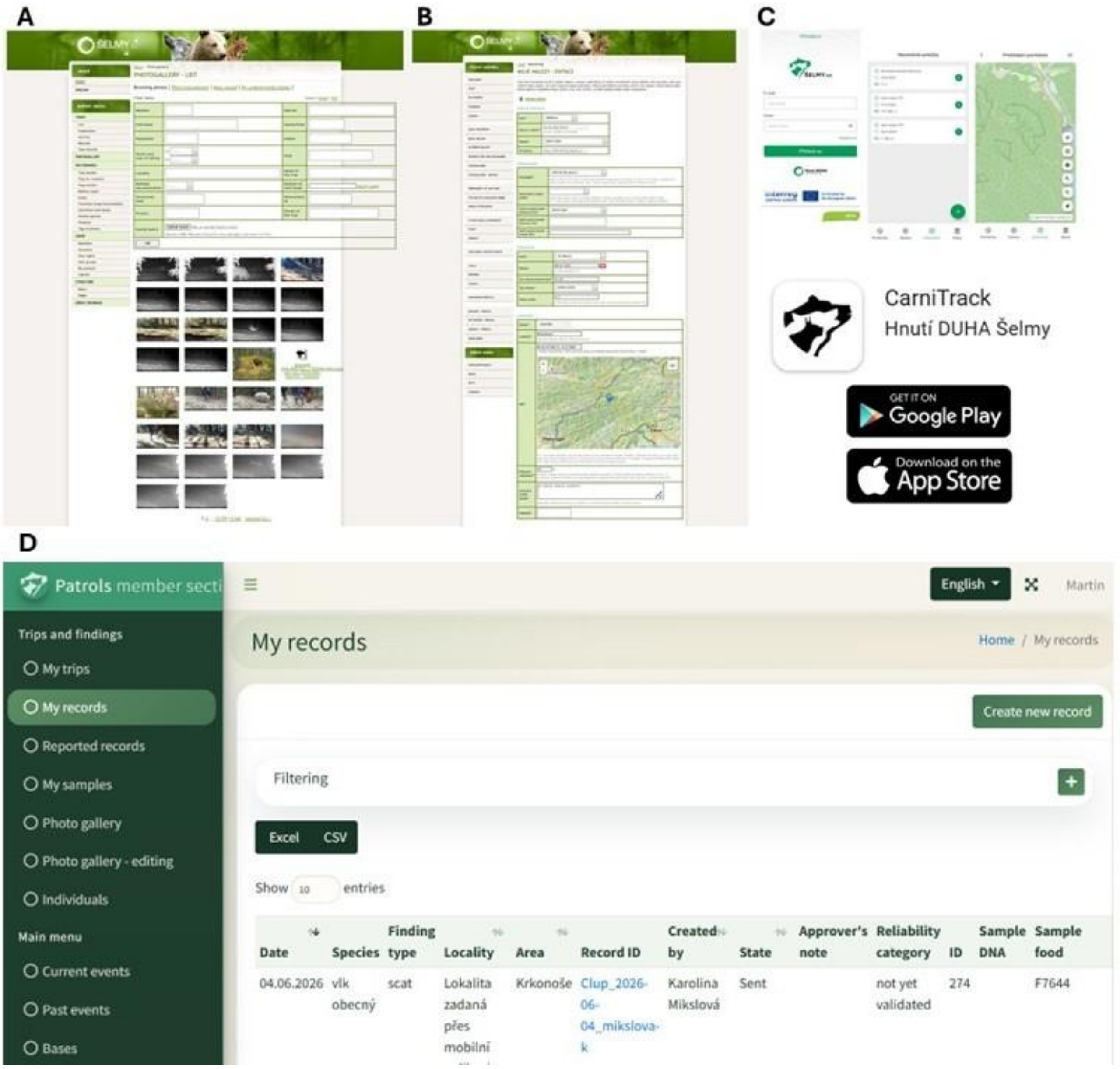

Figure 12: Graphical interface of the photo-video database (A), database with species records in its older and newer versions (B, D), and the CarniTrack mobile application (C).

Data management and expert processing are carried out through a web administration interface. This interface enables data validation, search and filtering, editing, quality control, user management and data export for further analyses. Validators can assess the reliability of individual records, complete missing information, change the validation status and assign the appropriate category of evidence. For large carnivores, such validation can be linked, for example, to SCALP categories, distinguishing confirmed, probable and unverified records. The web interface also supports map-based work, spatial filtering of records, duplicate checks and export of validated data for reporting.

The system also includes an analytical and visualization component. The data can be used to produce occurrence maps, trend analyses, monitoring reports, statistics, spatial activity assessments and comparisons between different periods or regions. These outputs can support expert reports, protected area management, national reporting, action plans, public communication and decision-making by public authorities. In the case of camera-trap data, the system can be used for analyses of site occupancy, seasonal activity, detection frequency, individual identification or reproduction monitoring.

A key element of the system is data standardization. Unified forms, predefined categories, controlled vocabularies and validation procedures ensure that data collected by different users and in different regions are comparable. This is especially important for cross-border monitoring of large carnivores, where monitoring methods, record classification and evaluation procedures need to be harmonized.

The system is designed as modular and expandable. It can include a basic occurrence database, a camera-trap module, a mobile application, an analytical module, a map interface, user management and export tools. In the future, it could be extended by automated species recognition from photographs, individual lynx identification, integration of genetic data, GPS telemetry, damage records, monitoring of ecological corridors or links to national and international databases.

Overall, the system represents a comprehensive tool for modern large carnivore monitoring. It connects field data collection, a secure central database, camera-trap data management, expert validation, spatial analysis and reporting. As a result, it supports more efficient monitoring coordination, better availability of verified data, improved decision-making and long-term sustainable management of information on large carnivore populations in the landscape.

Key takeways

Within the LECA project, this integrated system, consisting of a photo-video camera-trap database, a monitoring records database and a mobile application, was used to support the effective collection, storage, validation and export of monitoring data. The system enabled the assessment of the presence and distribution of all large carnivore species within the defined project area.

Case study 3: Integrated monitoring of wolf in Beskydy-Kysuce pilot area

Introduction

Within the LECA project, integrated wolf monitoring was implemented in the Beskydy-Kysuce pilot area, combining both non-invasive and invasive monitoring approaches. This provided comprehensive data on wolf distribution, abundance, the spatial arrangement of wolf territories and other demographic parameters of the population along the Czech–Slovak border region.

Methods used and results achieved

Monitoring was carried out within a predefined study area using a 10 × 10 km grid system. It combined several complementary methods, including camera trapping, snow tracking, documentation of field signs, extensive and intensive collection of genetic samples, simulated howling and GPS telemetry.

a) Camera-trapping & documentation of signs of occurrence

Friends of the Earth Czech Republic – Carnivore Conservation Programme in cooperation with MENDELU and the State Nature Conservancy of the Slovak Republic, implemented intensive non-invasive wolf monitoring across 42 EEA 10 × 10 km grid cells. Monitoring combined field-sign documentation, snow tracking, genetic sampling and camera trapping, complemented by two coordinated winter monitoring campaigns in 2024 and 2025.During the project period, more than 800 field trips were conducted and over 200 camera traps were deployed. All records were stored in a joint database, shared among project partners and validated according to the SCALP methodology, distinguishing C1 hard evidence, C2 verified signs and C3 unconfirmed records. Validated data were used to produce SCALP-based occurrence and distribution maps for wolves and other large carnivores, following the EEA grid and LCIE-compatible mapping framework.

Wolf presence was confirmed in 28 of 42 grid cells in wolf year 2023/24, corresponding to 67% of the pilot area, and in 30 of 42 grid cells in 2024/25, corresponding to 71%. In total, 5,194 wolf presence records were documented. The dataset was dominated by C1 evidence, mainly camera-trap photographs and videos, with 3,865 records representing 74% of all wolf presence data (Fig. 13).

b) *Extensive and intensive non-invasive genetic sampling*

Extensive and intensive non-invasive genetic sampling was carried out in the Beskydy–Kysuce pilot area between April 2023 and March 2025 to characterise the local wolf population, obtain individual genotypes and provide a basis for population size and density estimation. Sampling was coordinated by MENDELU in cooperation with FoE CZ, SNC SR, partner institutions, stakeholders and volunteers.

Extensive sampling was conducted from April 2023 to November 2024 to provide an initial genetic screening of the local population and obtain genotypes from known wolf territories. This was followed by systematic intensive sampling from December 2024 to March 2025 (Fig. 13), designed to support non-spatial and spatial capture–recapture analyses, demographic assessment and kinship reconstruction. Samples, mainly scats, were collected along forest and tourist trails, road crossings and wolf tracks in snow. The sampling methodology followed the approach published by Marucco et al. (2023).

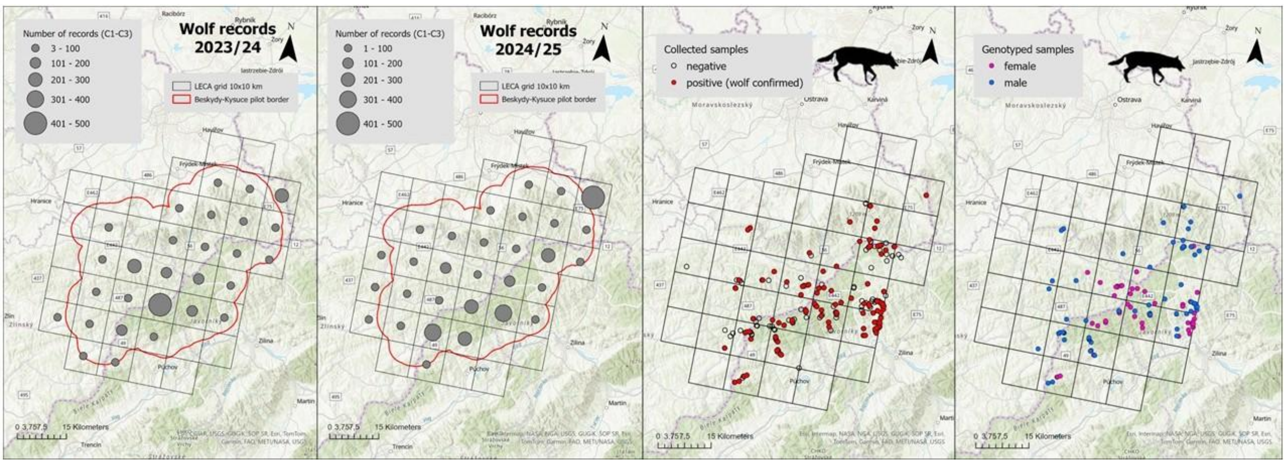

Figure 13: Number and distribution of obtained wolf presence records (C1-C3) in the two consecutive wolf years (2023/24 and 2024/25) across the Leca grid cells (left) and collected genetic samples during intensive genetic sampling (December 2024 to March 2025; right).

The intensive sampling design was based on a 10 × 10 km grid, with 29 grid cells mapped intensively, 9 extensively and 4 excluded due to unsuitable habitat or lack of previous wolf presence. During the intensive period, 278 grid-cell visits were conducted along 38 transects. Samples were preserved and processed according to laboratory requirements, and DNA analyses followed approaches previously applied in Central European wolf genetic studies (e.g. Hulva et al., 2018, 2024).

In total, 274 genetic samples were collected, including 48 from extensive and 226 from intensive sampling. Wolf DNA was confirmed in 152 samples, and genotype and sex were successfully determined in 125 samples. No evidence of hybridisation was detected. Extensive sampling identified 16 unique wolves, while intensive sampling confirmed 42 unique individuals, including 22 males and 20 females. These results provide a robust genetic dataset for assessing individual occurrence, sex structure, pack composition and subsequent estimates of wolf population size and density in the study area.

c) GPS Telemetry

GPS telemetry was used as an advanced complementary method within the integrated wolf monitoring framework in the Beskydy–Kysuce pilot area. Its main purpose was to obtain detailed information on wolf spatial behaviour, territory size, dispersal, reproduction, pack structure, prey selection and interactions with human activities. During the project, several wolf capture sessions were conducted by MENDELU and SNC SK in the Czech and Slovak parts of the pilot area, particularly in the Javorníky Mountains, Vsetín Beskids and Moravian-Silesian Beskids. Wolves were captured using foot snares under the required permits issued by the relevant Czech and Slovak authorities. In total, six female wolves were fitted with GPS collars, including individuals monitored within the LECA project and complementary projects (OPŽP, LIFE WILD WOLF).

The collars were programmed to record locations at regular intervals, with increased fix frequency during intensive prey-search periods. GPS data were downloaded automatically from the server, through the Inventa application, via terminal, or directly from the collar after the end of monitoring. Spatial analyses were carried out in GIS and R, including home-range estimation, movement analyses and evaluation of GPS clusters.

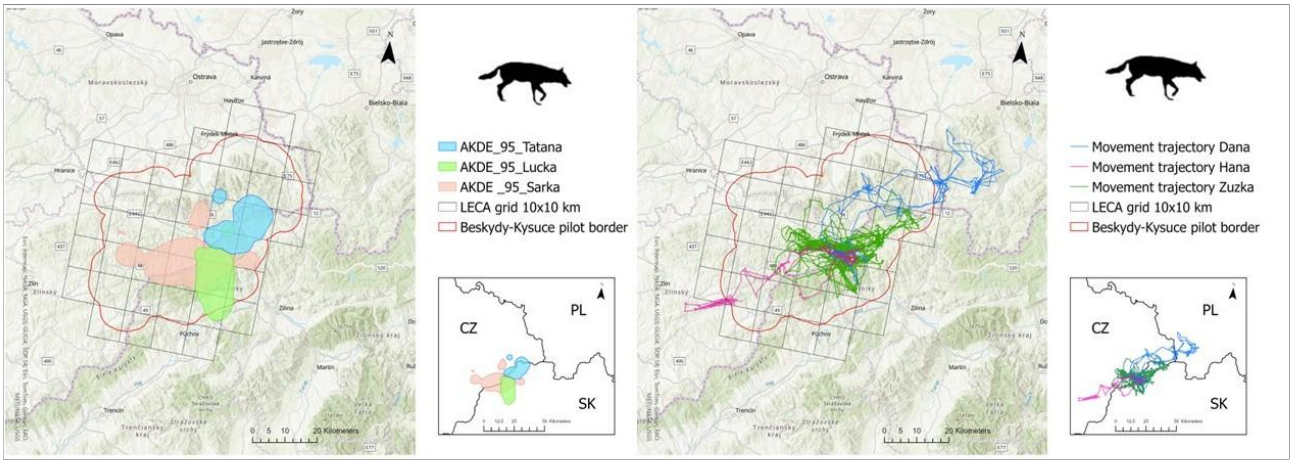

Figure 14: Spatial activity and estimation of home range of three resident wolf females by 95% autocorrelated kernel density estimation (AKDE95%; left) and movement trajectories of three GPS-monitored wolf females with exploratory/dispersing status (right).

Telemetry provided high-resolution data that substantially improved the interpretation of other monitoring results. It allowed identification of territories, confirmation of reproduction, detection of dispersal behaviour and assessment of territory overlap between neighbouring packs. In several cases, telemetry revealed information that would probably have remained undetected through camera trapping, snow tracking or genetic sampling alone, such as the establishment of new territories, denning areas, reproduction events or mortality of monitored individuals.

The monitored wolves showed diverse spatial strategies, including residency, exploratory movements and long-distance dispersal (Fig. 14). Telemetry also enabled targeted field inspections of GPS clusters, which provided valuable information on prey composition, kill rates and scavenging behaviour. The data confirmed the importance of roe deer and red deer as key prey species, while also documenting occasional livestock depredation and use of carcasses or remains from other sources. Overall, GPS telemetry proved to be a highly valuable method for understanding wolf ecology in the transboundary Beskydy-Kysuce region. Although it is financially and logistically demanding and cannot replace broader non-invasive monitoring, it provides detailed information on spatial behaviour, reproduction, territory structure, dispersal and feeding ecology. When combined with camera trapping, genetic sampling, snow tracking and field-sign documentation, telemetry significantly strengthens the reliability and interpretation of integrated wolf monitoring outputs.

d) Synthesis of the main results: SCALP & Occurrence maps/Distribution maps of wolf territories

Wolf presence was confirmed across most of the Beskydy–Kysuce pilot area in both monitoring years. In the 2023/24 wolf year, confirmed occurrence was recorded in 28 mapping grid cells, representing 67% of all grids, with C1 evidence documented in each of these cells. In 2024/25, confirmed occurrence increased to 31 grid cells, corresponding to 74% of all grids. Of these, 30 cells were supported by C1 evidence and one by C2 evidence. An additional grid cell contained C3 evidence and was therefore treated as unconfirmed occurrence. Overall, the results demonstrate a broad and well-documented wolf distribution in the pilot area, supported mainly by high-quality evidence such as camera-trap records, telemetry data and confirmed genetic samples (Fig. 15).

By integrating data from telemetry, camera trapping, snow tracking, genetic sampling, and howling sessions, within the pilot area, we preliminarily identified 9 distinct wolf territories (6 territories occupied by wolf packs with confirmed reproduction and 3 territories occupied by wolf pairs) in the wolf year 2023/24 and 10 distinct wolf territories in the wolf year 2024/25 (4 territories occupied by wolf packs with confirmed reproduction and 6 territories occupied by wolf pairs; Fig. 15).

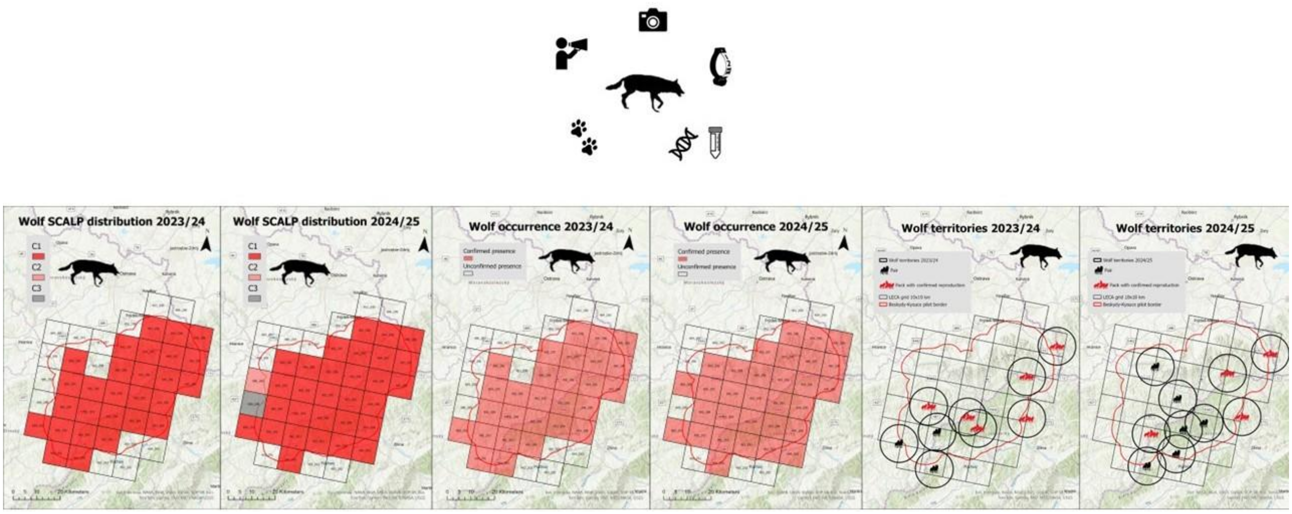

Figure 15: Wolf distribution based on data (C1–C3) validated according to the SCALP methodology and confirmed wolf presence based on SCALP data (C1 & C2) at the EEA 10×10 km grid level in the wolf years 2023/24 and 2024/25 (four distribution maps from the left) and distribution of wolves' territories and reproduction units (on the right). Circles represent one territory (pair, pack, pack with confirmed reproduction) and their size (approx. 214 km2) refers to the average size of wolf territory in Central Europe known from GPS telemetry reported by Vorel et al. (2024).

e) Synthesis of the main results: Estimation of population size and density

By integrating data from telemetry, camera trapping, and snow tracking, 47 wolves were documented in winter WY 2023/24 (26 pups in summer) in an area approx. 1920 km2 (area permanently occupied by pack and pair with average size of the territory 214.3 km^2 according to Vorel et al., 2024) and 36 wolves documented in winter WY 2024/25 (19 pups in summer) in an area approx. 2133 km2. Based on non-invasive genetic sampling, 42 unique individuals were identified in the wolf year 2024/25 (sampling area 3800 km^2).

The average pack size during the winter period across both wolf years was 7 (±1.2) individuals, with an average of 4.5 pups per pack (±0.9). Population density was estimated in areas occupied by a pack based on the average size of home ranges in Central Europe (Vorel et al. 2024) and data from our study (9 observations from 7 packs). To obtain a robust estimate, 10,000 Monte Carlo simulations were performed using the mean pack size per wolf pack (n=7) combined with known territory sizes (n=16) in study Vorel et al. (2024) to calculate average wolf density with 95% confidence intervals. All analyses were conducted in R using the dplyr package. Estimated population density for both wolf years was 5.01 (±1.21) individuals per 100 km^2 (95% CI: 2.92–7.69).

Key takewas

Integrated monitoring in the Beskydy-Kysuce pilot area provided the most comprehensive wolf dataset collected in the region to date. By combining camera trapping, field-sign documentation, snow tracking, genetic sampling, simulated howling and GPS telemetry, the project confirmed wolf presence in more than two thirds of the pilot area and produced robust information on territories, reproduction, pack structure and population size.

The approach identified 9 wolf territories in 2023/24 and 10 territories in 2024/25, including reproductive packs and territorial pairs. Genetic sampling confirmed 42 unique individuals during the intensive sampling period, while integrated field data documented 47 wolves in winter 2023/24 and 36 wolves in winter 2024/25. The estimated density of wolves in occupied areas was 5.01 ± 1.21 individuals per 100 km^2.

The case study demonstrates that only an integrated monitoring framework can reliably capture the spatial and demographic complexity of wolf populations in transboundary mountain regions. The combination of non-invasive methods with GPS telemetry substantially improved interpretation of territory boundaries, reproduction, dispersal and feeding ecology, providing a strong evidence base for conservation planning, cross-border cooperation and management decisions.

More detailed results from the Beskydy-Kysuce cross-border pilot area are available in the project outputs section: https://www.interreg-central.eu/projects/leca/?tab=outputs.

Case study 4: Deterministic monitoring of lynx in the East Carpathians and Slovak Karst and North Hungarian Mountains

Introduction

Deterministic camera-trap monitoring was implemented in two LECA cross-border pilot areas to assess the status of the Eurasian lynx using a standardised capture-recapture framework. The approach was applied in the Eastern Carpathians, covering Bieszczady National Park, Poloniny National Park and Uzhanskyi National Nature Park, and in the Slovak Karst-North Hungarian Mountains pilot area, including Slovak Karst and Aggtelek National Parks.

The main objective was to obtain robust, comparable and spatially explicit information on lynx occurrence, individual identity, population size and density. The monitoring was conducted during the winter and pre-mating period, when lynx activity is generally higher, detection probability increases and field logistics are more favourable. This cross-border design provided a practical test of harmonised deterministic lynx monitoring in areas with contrasting population and conservation status.

Methods used and results achieved

Deterministic camera trapping in the Eastern Carpathians was conducted over a 60-day period, from 26th November 2024 to 24th January 2025. The survey was scheduled for winter and early spring, corresponding to the pre-mating and mating periods of lynx, which are considered the optimal periods for systematic camera trapping due to biological factors (i.e. high lynx activity), logistical advantages (i.e. reduced human disturbance), and favourable environmental conditions.

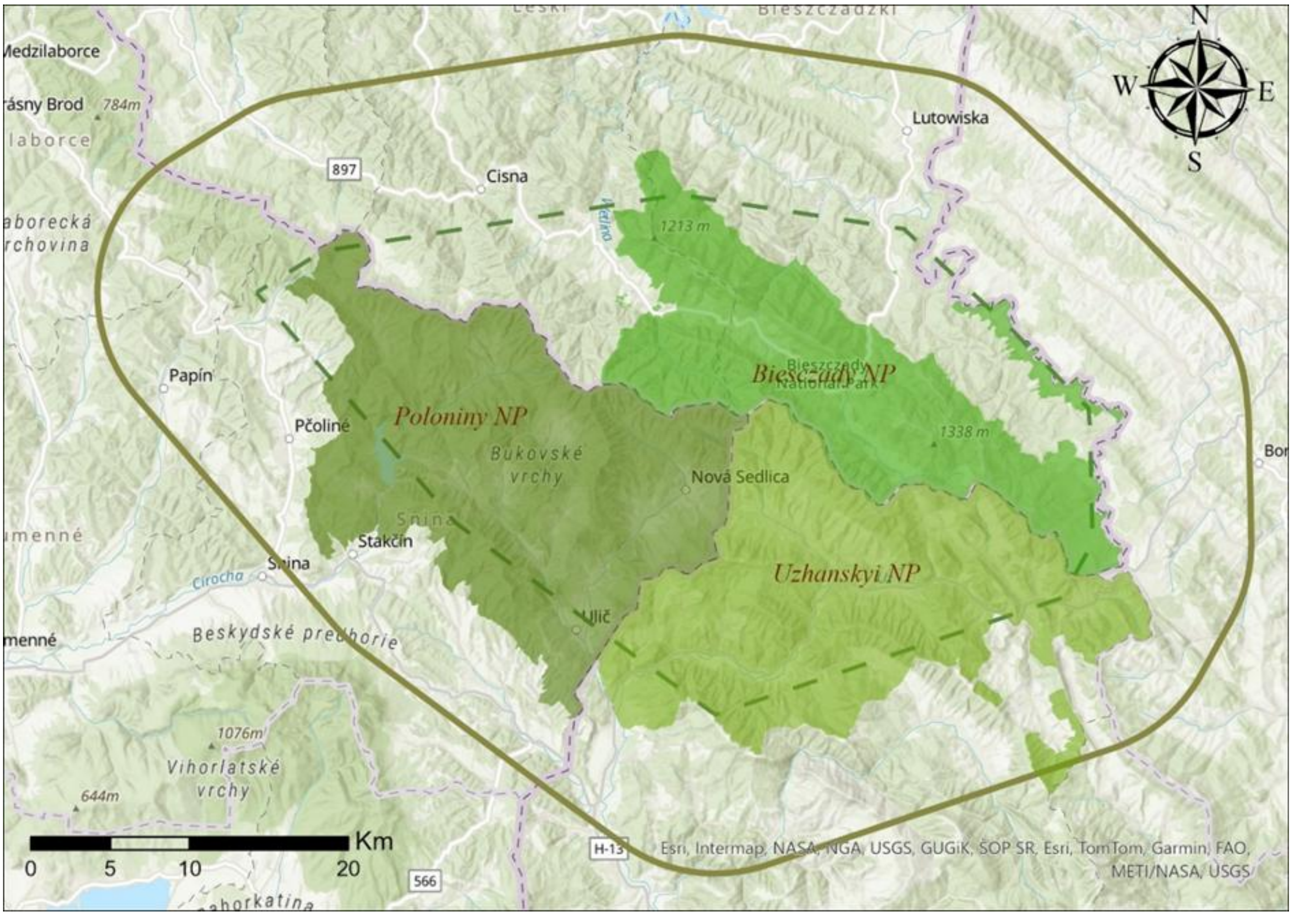

Figure 16. Schematic representation of cross-border deterministic camera-trap monitoring of the Eurasian lynx in the Eastern Carpathians pilot area, including Bieszczady National Park (Poland), Poloniny National Park (Slovakia) and Uzhanskyi National Nature Park (Ukraine; Kubala et al. 2025). The figure shows the monitored sampling area (dashed green line) and the state space (dark green line), comprising 2,762.3 km² of suitable habitat used for lynx density estimation (sampling area plus a 10-km buffer). The buffer corresponds to the average lynx home-range radius in the region (Kubala et al. 2024).

In the Slovak Karts/North Hu Mts. the cumulative survey effort of the deterministic monitoring amounted to 3,680 effective trap nights (number of monitoring days × number of active stations). During the survey, two camera stations were stolen. Throughout the deterministic monitoring the lynx was detected only at 6 of the 46 monitored stations (13.04%). Two independent lynx individuals and a kitten were identified (Figure 17). All detections originated from the Slovak side of the pilot area, indicating extremely low occurrence and limited spatial distribution of lynx within the monitored transboundary landscape.

During deterministic camera trapping in the Eastern Carpathians (26 November 2024–24 January 2025), 102 camera stations were active resulting in a total survey effort of 6,090 effective trap nights/days (number of monitoring days × number of active stations) across a monitored area of 1,116.5 km² (Fig. 16). One camera station was stolen during the survey period, but we normally used the collected photographs until the event. In total, 17 individual lynx were detected and identified at 31 of the 102 camera stations surveyed (30.39%). The population in the Eastern Carpathians pilot area was statistically estimated at 33.2 ± 6.32 within 2,762.3 km² of suitable habitat, yielding a density of 1.12 ± 0.21 lynx per 100 km².

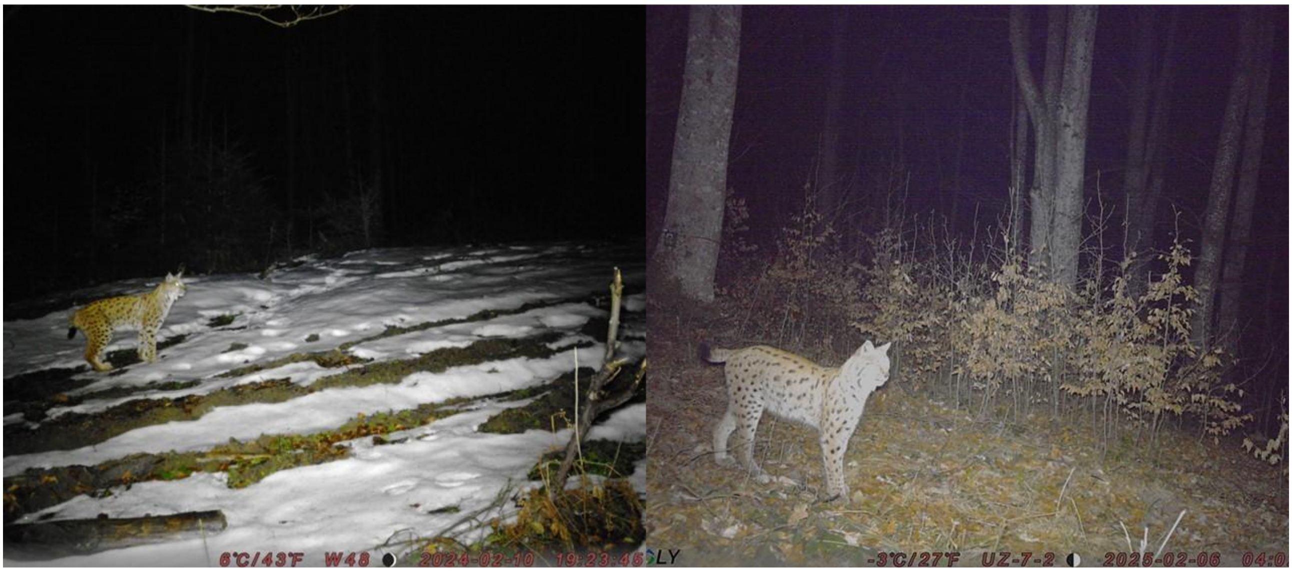

Figure 17: Two different lynx individuals captured by camera traps in the Bieszczady Mountains and Uzhanskyi National Nature Park (Source: WWF PL, WWF UA)

The statistically estimated Eurasian lynx population within the Slovak Karst (SK) and Aggtelek (HU) National Parks was 3.03 ± 1.05 adult individuals, corresponding to a density of 0.1 ± 0.03 lynx per 100 km².The estimated density was substantially lower than values reported from most other monitored areas of the Carpathians. These findings suggest that the lynx population in the Slovak Karst-North Hungarian Mountains pilot area is small and potentially vulnerable, highlighting the need for further monitoring and targeted conservation measures

Key takeaways

Deterministic camera trapping provided robust and comparable lynx population estimates in both pilot areas but revealed strongly contrasting conservation status. The Eastern Carpathians supported a viable transboundary lynx population, with 17 identified individuals and an estimated density of 1.12 ± 0.21 lynx per 100 km² of suitable habitat. By contrast, the Slovak Karst-North Hungarian Mountains pilot area showed critically low lynx occurrence, with only two adults and one kitten detected and an estimated density of 0.1 ± 0.03 lynx per 100 km². The contrasting results likely reflect substantial differences in population status, connectivity and recent population history between the two pilot areas, demonstrating the value of standardized cross-border monitoring for identifying population strongholds, detecting areas of conservation concern and guiding targeted conservation action.

Detailed results from the East Carpathians and Slovak Karst-North Hungarian Mountains cross-border pilot areas can be found in the LECA project outputs section: https://www.interreg-central.eu/projects/leca/?tab=outputs.

4. Lessons learned – risks & recommendations

Large carnivore monitoring in the Carpathians requires long-term continuity, methodological harmonisation and strong cooperation among institutions, researchers, protected area administrations, NGOs, hunters, foresters and other stakeholders. The LECA project demonstrated that reliable assessment of large carnivore occurrence, distribution and population parameters is achievable when multiple monitoring methods are combined and when data are stored, validated and analysed in a standardised way.

At the same time, the project also highlighted several operational, technical, financial and institutional challenges that may limit the quality and long-term sustainability of monitoring systems. These risks are particularly relevant in transboundary areas, where large carnivore populations move across administrative and national borders, while monitoring responsibilities, data systems, funding schemes and institutional capacities often differ between countries.

One of the main lessons learned is that monitoring cannot rely on a single method or a single institution. Opportunistic observations, camera trapping, snow tracking, genetic sampling, howling surveys and GPS telemetry each provide different types of information, but their value increases substantially when they are integrated into one harmonised framework. Such integration allows better assessment of species presence, individual identification, pack or territorial structure, reproduction, population size and spatial distribution.

A second key lesson is that data management is as important as field data collection. Even high-quality monitoring data may lose much of their value if they are not stored in a centralised and searchable database, if metadata are incomplete, or if validation procedures are inconsistent. The development and use of mobile applications, online records databases and photo-video databases can significantly improve the efficiency of field data collection, reduce manual work and facilitate rapid data export for GIS, statistical analyses and reporting. However, such systems require long-term technical maintenance, stable funding, user training and regular updates.

A third lesson is that monitoring standards should be realistic and scalable. Best-practice approaches, such as intensive genetic sampling, systematic camera-trap monitoring, capture-recapture modelling or GPS telemetry, provide the most robust outputs, but they are not always feasible in all regions. Therefore, minimum standards are needed to ensure that even less-resourced areas can produce reliable baseline information on large carnivore presence, reproduction, individual occurrence and minimum population size. These minimum standards should be compatible with future expansion toward more advanced monitoring schemes.

Finally, the project confirmed that monitoring outputs must be directly usable and routinely used for conservation planning, management and reporting. Grid-based distribution maps, SCALP-validated occurrence records, LCIE-compatible distribution assessments, catalogues of identified individuals, maps of wolf territories or lynx occurrence, and estimates of population size and density all provide essential evidence for national and transboundary decision-making. Without such evidence, management remains vulnerable to political pressure, expert opinion, inconsistent reporting and public mistrust.

Summary of key potential risks and recommendations for their mitigation

Risk/ Obstacle	Category	Description	Impact severity	Mitigation measures	Responsible Actor(s)	Key actors
Insufficient harmonisation of monitoring protocols	Methodological/ Institutional	Different countries or institutions may use different monitoring methods, validation criteria, grid systems, reporting periods or evidence categories. This reduces comparability of data across borders and weakens transboundary population assessments.	Very high	Develop and adopt common monitoring protocols; use standardised grid systems, preferably compatible with European reporting frameworks; apply harmonised evidence categories such as SCALP; organise regular cross-border methodological meetings.	National environmental agencies, protected area administrations, research institutions	NGOs, hunters, foresters, LCIE/SCALP experts, Carpathian Convention bodies
Incomplete or inconsistent data collection	Operational / Technical	Monitoring effort may vary between regions, years or field teams. Opportunistic records may be spatially biased, while systematic monitoring may not cover all relevant areas. This can lead to underestimation of species presence, reproduction or population size.	High	Define minimum monitoring standards; ensure repeated monitoring within fixed periods; document monitoring effort; combine opportunistic and systematic data; prioritise data gaps and under-monitored areas.		Field mappers, hunters, foresters, volunteers, local authorities

Risk/ Obstacle	Category	Description	Impact severity	Mitigation measures	Responsible Actor(s)	Key actors
Lack of centralised database and data-management system	Technical / Institutional	Data stored in separate files, personal archives or incompatible databases are difficult to validate, compare, export and use for reporting. Loss of data or duplication of records may occur.	Very high	Establish a centralised database with species records linked to a photo-video database; use standardised forms and metadata fields; ensure secure storage, backups and export functions; provide long-term technical maintenance.	National monitoring institutions, research organisations, database administrators	NGOs, protected areas, IT providers, field users
Insufficient metadata quality	Technical / Data quality	Records without exact coordinates, date, time, observer, evidence type, validation status or links to photos, videos and genetic samples have limited analytical value.	High	Define mandatory metadata fields; use mobile applications with GPS recording and standardised forms; train field users; implement database checks for missing or inconsistent information.	Database administrators, monitoring coordinators	Field mappers, volunteers, validators
Inconsistent validation of records	Methodological / Data quality	Records may be classified differently by different experts or institutions. Unverified observations may be used in analyses, leading to overestimation or unreliable maps.	High	Apply standardised validation criteria, preferably compatible with SCALP; ensure expert review of records; classify uncertain records conservatively; document validation decisions in the database.	Expert validators, monitoring coordinators	SCALP experts, researchers, protected area staff
Limited capacity for genetic sampling and analysis	Financial / Technical	Genetic sampling is essential for individual identification, sex determination, hybridisation detection and wolf pack structure assessment, but it can be costly and logistically demanding.	Very high	Prioritise genetic sampling in key areas; combine intensive sampling periods with year-round opportunistic sampling; secure laboratory capacity and long-term funding; link all genetic samples to field records.	Research institutions, laboratories, national agencies	Field mappers, NGOs, protected areas, hunters

Risk/ Obstacle	Category	Description	Impact severity	Mitigation measures	Responsible Actor(s)	Key actors
Low detection probability in poorly known areas	Operational / Ecological	In newly colonised or poorly monitored regions, camera traps and field surveys may fail to detect large carnivores if placed without prior knowledge of movement routes or marking sites.	Medium to high	Conduct preparatory surveys; use snow tracking, local knowledge and previous records to select camera-trap sites; initially deploy higher camera density in unknown areas; adapt sampling design based on first detections.	Monitoring coordinators, field teams	Hunters, foresters, local stakeholders
Insufficient documentation of reproduction	Methodological / Conservation	Reproduction is a key indicator of population status, but may remain undetected without targeted monitoring such as camera trapping, howling surveys or genetic analyses.	High	Include reproduction assessment as a core monitoring objective; use camera traps near rendezvous or marking sites where appropriate; apply simulated howling during suitable periods; record pups and family groups systematically.	Monitoring coordinators, research institutions	Field mappers, protected areas, local experts
Camera-trap theft, damage or technical failure	Operational / Technical	Camera traps may be stolen, damaged by weather, animals or people, or fail due to battery and memory-card problems. This reduces survey effort and may compromise deterministic monitoring.	Medium to high	Use security housings and locks; place cameras discreetly; check cameras regularly; maintain backup equipment; record effective trap nights and camera failures in the database.	Field coordinators, protected area administrations	Hunters, foresters, landowners
Insufficient funding for long-term monitoring	Financial / Institutional	Monitoring often depends on short-term projects. Once project funding ends, fieldwork, database maintenance, genetic analyses and expert validation may decline or stop.	Very high	Secure multi-annual funding; embed monitoring into national conservation programmes; combine national, regional and EU funding; allocate dedicated budgets for fieldwork, genetic analyses, data management and technical support.	Ministries, national agencies, regional authorities	EU programmes, NGOs, research institutions

Risk/ Obstacle	Category	Description	Impact severity	Mitigation measures	Responsible Actor(s)	Key actors
Dependence on short-term projects and personnel changes	Institutional / Governance	Project-based monitoring may lead to discontinuity when staff, coordinators or funding streams change. Loss of experienced personnel can reduce data quality and institutional memory.	High	Institutionalise monitoring responsibilities; create formal cooperation agreements; maintain training materials and protocols; ensure handover procedures; support long-term expert networks.	National agencies, protected areas, research institutions	NGOs, universities, local authorities
Limited transboundary data sharing	Institutional / Political	Data may not be shared across borders due to legal, administrative, technical or trust-related barriers. This prevents population-level assessment of large carnivores.	Very hugh	Establish data-sharing agreements; define rules for sensitive data; create joint transboundary databases or export formats; organise regular cross-border evaluation meetings.	National authorities, Carpathian Convention bodies, protected areas	Research institutions, NGOs, LCIE, SCALP experts
Sensitivity of location data	Conservation / Security	Precise locations of breeding sites, camera traps, telemetry fixes or rare individuals may be misused, increasing the risk of disturbance or illegal killing.	High	Apply access control in databases; restrict sensitive data to authorised users; publish only generalised locations where needed; develop clear data-protection protocols.	Database administrators, conservation authorities	Researchers, NGOs, protected areas
Overreliance on expert opinion instead of empirical data	Scientific / Governance	In areas without systematic monitoring, population estimates may be based mainly on expert judgement, leading to uncertainty and potential conflict over numbers.	High	Expand empirical monitoring; clearly distinguish confirmed data from expert estimates; use minimum standards where full monitoring is not feasible; report uncertainty transparently.	National monitoring bodies, research institutions	Policy-makers, NGOs, hunters, LCIE experts

Risk/ Obstacle	Category	Description	Impact severity	Mitigation measures	Responsible Actor(s)	Key actors
Limited analytical capacity	Technical / Scientific	Even when data are collected, institutions may lack capacity for GIS analyses, genetic interpretation, capture-recapture modelling or density estimation.	Medium to high	Provide training in GIS, database management and statistical analysis; develop standard analytical workflows; involve universities and research institutions; use open-source tools where possible.	Research institutions, universities, monitoring coordinators	National agencies, NGOs, data analysts
Telemetry-related risks and limitations	Technical / Ethical / Conservation	GPS telemetry provides high-value data but is expensive, invasive and vulnerable to collar failure or loss of collared individuals	Medium to high	Use telemetry as a complementary method; follow ethical and legal standards; protect collared individuals where possible; combine telemetry with non-invasive monitoring; ensure rapid data backup.	Research institutions, wildlife authorities	Veterinarians, trapping teams, protected areas
Weak integration of monitoring outputs into management	Governance / Practical implementation	Monitoring results may not be translated into conservation planning, conflict prevention, reporting or management decisions.	High	Define expected outputs from the beginning; produce maps and summaries in formats usable by decision-makers; communicate results regularly; link monitoring outputs to action plans, reporting and management measures.	National agencies, ministries, protected areas	Policy-makers, municipalities, NGOs, hunters, foresters
Low stakeholder involvement and trust	Social / Governance	If hunters, foresters, livestock breeders or local communities are excluded from monitoring, they may distrust results or oppose management decisions based on them.	High	Involve stakeholders in field monitoring where appropriate; provide feedback on results; organise joint training and communication activities; build ownership of monitoring outputs.	Monitoring coordinators, protected areas, NGOs	Hunters, foresters, municipalities, livestock breeders

Risk/ Obstacle	Category	Description	Impact severity	Mitigation measures	Responsible Actor(s)	Key actors
Lack of long-term database maintenance	Technical / Financial	Even well-designed databases and mobile applications may become outdated if they are not regularly updated, backed up and technically supported.	High	Allocate long-term maintenance budgets; ensure technical support contracts; conduct regular backups and security updates; collect user feedback and update forms and functions as monitoring needs evolve.	Database owners, IT providers, national agencies	Field users, validators, data managers

5. References

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