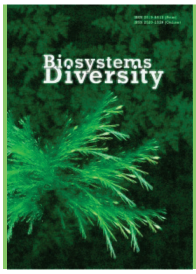

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Geospatial applications as an integral component of wildlife monitoring in the Chornobyl Radiation and Ecological Biosphere Reserve

T. Melnychuk*, K. Korepanova*, T. Fedoniuk**, A. Zymaroieva**

**Chornobyl Radiation and Ecological Biosphere Reserve, Ukraine*
***Polissia National University, Zhytomyr, Ukraine*

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Chornobyl Radiation and Ecological Biosphere Reserve, Tolochyna st., 28, Ivankiv, 07201, Kyiv region, Ukraine.
Tel.: +38-097-444-91-41.
E-mail: info@zapovidnyk.org.ua

Polissia National University, Stary Boulevard 7, Zhytomyr, 10008, Ukraine.
Tel.: +38-097-770-65-02.
E-mail: mail@polissiauniver.edu.ua

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The large area of the Chornobyl Radiation and Ecological Biosphere Reserve and the inaccessibility of some areas to the reserve's staff due to radioactive contamination make geospatial data collection methods a good alternative to traditional field sampling. The aim of the study is to assess the effectiveness and limits of applying contemporary tools of data collection and biodiversity monitoring in the Chornobyl Reserve. We used hierarchical cluster analysis to compare how well different ways of collecting data worked by finding the distances between groups of species in the following samples: the Fauna questionnaire, the iNaturalist platform, monitoring of large mammals as part of the Polissia without Borders project, and low-resource mammal surveys using camera traps. Incorporating GIS data collection techniques into field studies or inventories in a reserve is undeniably a powerful additional source of biodiversity information. The iNaturalist platform provides reliable data on species richness as well as seasonal and topographic distribution, despite its limitations in terms of the relative abundance and structure of species communities. The data obtained with the help of the Fauna questionnaire adequately describes the situation with the relative abundance and spatial distribution of large and medium-sized mammals, approaching such an accurate method as photographic monitoring using photo traps. Increasing the quantity and quality of results is possible by expanding the competence of staff in using the questionnaire and training aimed at identifying species by indirect signs such as traces, burrows, gnawing marks, etc. Geostatistical tools are valuable for the efficient use of technology and resources for inventory identification and generation, uniformity in biodiversity data collection, and effective data dissemination.

Keywords: biodiversity data collection; protected area; Geographic Information System; platform iNaturalist; camera traps.

Introduction

Protected areas (PAs) have emerged as a crucial tool for conserving biodiversity (Oldekop et al., 2016; Pulido-Chadid et al., 2023). Biosphere reserves have traditionally been regarded as sites for studying the environment, biodiversity, conservation, and sustainable development (Yoccoz et al., 2001). Therefore, biodiversity monitoring is a mandatory component of protected area activities (Mandeville et al., 2023). Biodiversity monitoring is a continuous and organized study of the many components of biodiversity, aimed at determining their current condition, potential risks, and patterns of change (Hochkirch et al., 2021). So, biodiversity monitoring is an important aspect of protected area management, as it helps to assess the effectiveness of biodiversity conservation (Rodrigues & Cazalis, 2020).

Based on the existing method of identifying and monitoring biodiversity, it seems inevitable that the rate at which species become extinct will surpass the rate at which biodiversity is being documented and described (Roy et al., 2012). The current biodiversity monitoring in most protected areas in Ukraine relies on field sampling, which entails making approximate assessments of the location and using a field notebook to document the findings. The documentation of biological diversity parameters primarily relies on project-specific approaches and lacks a standardized methodology for field sampling (Galushchenko et al., 2020). The measured variables generally exhibit restricted accuracy. Furthermore, there is an absence of uniformity in the recording of field parameters, such as phytosociological characteristics, field description, GPS location, and associated field photos (Proença et al., 2017). So, we need to fundamentally change our approach to quantifying and documenting biodiversity by combining landscape-level (top-down) and species-level (bottom-up) methods. Developments in remote sensing technology and geographic information systems now enable mapping of the spatial assemblages of species, and stratification of vegetation types based on environmental gradients and environmental variables (Corbane et al., 2015). However, the effectiveness of this methodological solution for biodiversity monitoring in the system of protected areas in Ukraine and the potential for its application are not clearly assessed.

The Chornobyl Radiation and Ecological Biosphere Reserve is the largest nature reserve in Ukraine, with an area of 226,964.7 hectares (Zymaroieva et al., 2021). However, the main feature of the reserve is the high but heterogeneous density of surface contamination with radionuclides formed because of the Chornobyl disaster (Talerko, 2005; Beresford et al., 2020). Thus, the large area of the reserve and the inaccessibility of some areas to the reserve's staff due to radioactive contamination make geospatial data collection methods a good alternative to traditional field data collections (Fedoniuk et al., 2021). The aim of the study is to assess the effectiveness and limits of applying contemporary tools of data collection and biodiversity monitoring in the Chornobyl Radiation and Ecological Biosphere Reserve.

Materials and methods

The study area includes the Chornobyl Radiation and Ecological Biosphere Reserve and some areas of the industrial use zone. All of them are located within the Chornobyl Exclusion Zone (CEZ).

The Chornobyl Radiation and Ecological Biosphere Reserve was established in accordance with the Decree of the President of Ukraine No. 174/2016 dated April 26, 2016, to preserve the most typical natural complexes of Polissa in their natural state, to maintain and improve the barrier function of the exclusion zone and the zone of unconditional (mandatory) resettlement, to stabilize the hydrological regime and rehabilitate the territories contaminated with radionuclides, to facilitate the organization and conduct of international scientific research.

The Reserve is located within the Exclusion Zone and the Zone of Unconditional (Mandatory) Resettlement of the Territory Affected by Radioactive Contamination as a Result of the Chornobyl Nuclear Power Plant Disaster (Fig. 1).

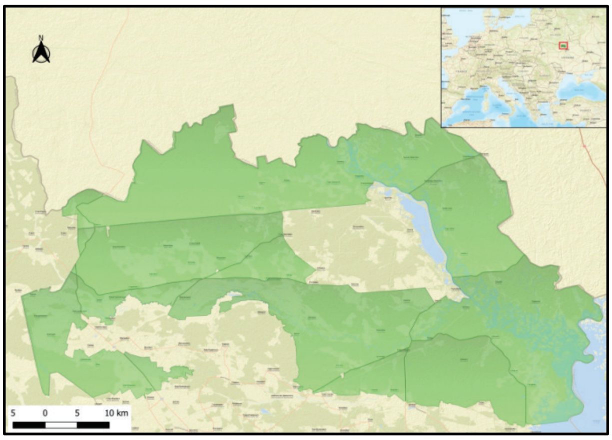


Fig. 1. Boundaries of the Chornobyl Radiation and Ecological Biosphere Reserve

The boundaries of the Reserve in the north and northeast coincide with the state border of Ukraine and the Republic of Belarus (Fig. 1). According to the scheme of geomorphological zoning, the territory of the Reserve is located within the Prypiat lowland of Kyiv Polissia. In general terms, the territory of the Reserve is characterized by a weakly undulating relief type with small amplitudes of relative elevation fluctuations, where extensive poorly drained (often swampy) depressions alternate with small elevations with flat tops and gentle slopes, the steepness of which does not exceed 1–2°. Geomorphologically, the surface is flat, with minor elevation differences caused by water and glacial activity. After the glacier melted, the surface runoff changed its direction to the northeast and river valleys began to form, which are significant geomorphological features of the Reserve's modern relief. The modern morphosculpture of the Reserve includes water-erosion, water-accumulative, glacial and water-glacial, denudation and aeolian landforms (Galushchenko et al., 2020).

The modern hydrographic network of the Reserve is dense and consists of wide river valleys. The main rivers of the Reserve (Pripyat and Uzh) are confined to tectonic depressions. The Pripyat River flows in the northeastern part of the Reserve in the most low-lying part of the lowland, in the direction from northwest to southeast. The Uzh River flows through the central part of the Reserve from west to east and northeast. Its tributaries and streams densify the hydrographic network. The largest among them are the rivers Veresnya, Ilya, Radynka, Beaver, Hrezlya, Radcha, Slovechna, Zhelon, Sakhan and others. The floodplains of most of the rivers are swampy (Fedoniuk et al., 2023).

The density of the river system within the study area is 0.39 km/km^2. But the density of the river network within the Reserve differs: in the western part, the density is higher due to higher rainfall, while in the southeastern part it is low, which is explained by a slightly higher continental climate and, accordingly, lower rainfall (Sansone et al., 1996; Fedonyuk et al., 2020).

Forests make up 55% of the Reserve's vegetation cover, including pine forests (up to 40%), oak-pine forests (35%), oak and hornbeam-oak forests, alder forests and secondary small-leaved forests (up to 25%). Meadows occupy 10% of the vegetation cover, and marshes – 5%. An atypical biotope for Polissia is fallow land, which was formed on the site of former agricultural lands (30%), which is a kind of analog of steppe ecosystems (Gemitzi, 2020; Zymaroieva et al., 2023).

Currently, the flora of the Reserve includes 164 species, which are included in the protection lists of various ranks. There are 355 species of fauna on the Reserve's territory, which are included in various nature protection lists.

To collect geospatial data on biodiversity, the Reserve's staff uses the ArcGIS Survey123 mobile application, in which they created the Fauna questionnaire (Table 1). The questionnaire includes only species of terrestrial vertebrates. The amount of data collected by the Fauna questionnaire in 2020–2023 is 1978 records. The questionnaire is closed – you can choose only answer options. Notes are entered in the "Description" category.

Table 1
Structure of the "Fauna" questionnaire

Category	No.	Contents
Unit	1	Management
	2	Department of security guards of the reserve
	3	Scientific department
	4	Department of wildlife conservation and reproduction
	5	Department of special regime
Class of animals	6	Fish
	7	Amphibians
	8	Reptiles
	9	Birds
	10	Mammals
Object	11	Animal
	12	Corpse, remains
	13	Trace
	14	Gnawing and scratching marks
	15	Burrow
	16	Nest
	17	Dam
	18	Hut
	19	Prey
	20	Other
Description	21	Free-form notes

The iNaturalist application is used voluntarily to record data on plants and invertebrates. Using the iNaturalist mobile platform for collecting biodiversity data, 3117 records were collected on the territory of the CEZ between 2004 and 2023. Unlike the Fauna questionnaire, it focuses on all systematic categories of biodiversity. Also, importantly, the identification process requires minimal intervention by the platform user – the species identification process is almost automatic, but in the presence of photo or audio material. In some PAs, the iNaturalist platform is used as a tool for recording data during field research.

Camera trap locations were selected by using the central point of randomly chosen 3.1 x 3.1 km grid cells, within an overall project area. Camera traps were deployed no more than ~25 m from this central point, on a tree with an unobstructed North facing view of at least 5 m to avoid reflections from direct sunlight. Camera traps were Cuddeback C and G series with infrared black flashes and Acorn with infrared flashes. If no suitable location for the camera trap was available in a pre-selected cell, the camera trap was relocated to a random central point in a backup grid. In total, 92 cameras were deployed: 76 successfully operated during the summer season in 2020 and 13 camera traps during summer 2021.

To evaluate the similarity of species sets, we used the Hierarchical Tree method, based on which we built a distance matrix (Euc-lidean distance) (Chen et al., 2009). The effectiveness of different methods of data collection was compared using cluster analysis by calculating the distances between sets of species in the following samples: the Fauna questionnaire, the iNaturalist platform, monitoring of large mammals within the Polissia without Borders project (Halushchenko et al., 2022), and low-resource mammal surveys using camera traps (Vishnevskyi, 2021). To normalize the indicators, the number of animals was converted into percentages.

The analysis of the spatial distribution of data and the construction of a heatmap were performed in QGIS3. Hierarchical cluster analysis and correspondence analysis were executed in Statsoft Statistica 10.0 (Data Analysis Software System, version 10, 2011).

Results

Data structure of the "Fauna" questionnaire. The spatial distribution of the data collected by the Fauna questionnaire is not uniform (Fig. 2). The points of highest concentration of observations are the city of Chornobyl, the villages of Cherevach and Otashiv. In addition, the number of observations increases from west to east.

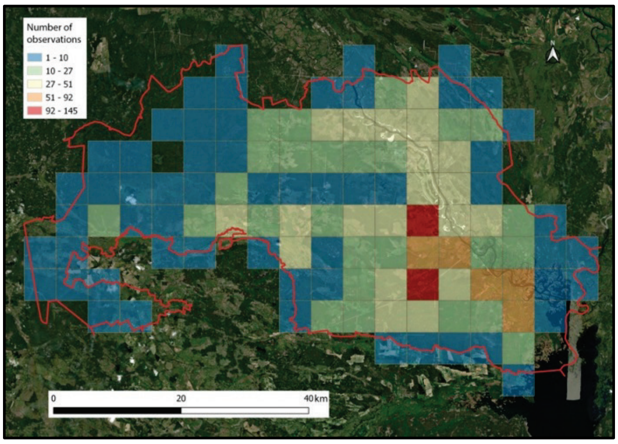


Fig. 2. Spatial distribution of records of the "Fauna" questionnaire

At the landscape level, the highest concentration of observations is near roads, with 74% of observations recorded in the 100-meter belt along roads (Fig. 3). Moving further away from roads, the increase in observations is quite small: only a few percent for every 100 meters.

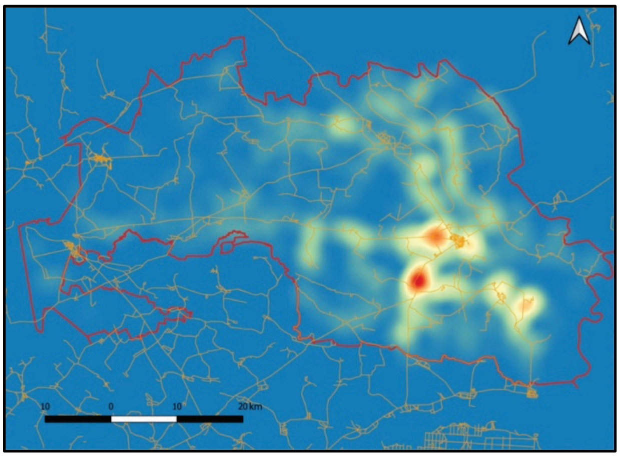


Fig. 3. Spatial distribution of records of the "Fauna" questionnaire (heatmap method)

The structure of the data has its own peculiarities, which consist in the uneven representation of different groups of animals. At the level of animal class, 65.8% of the observations are mammals, and 32.0% are birds, amphibians and reptiles account for 0.2% and 2.0% respectively.

Herpetofauna has minimal representation in the questionnaire. The amphibian class is represented by two species out of 11 species recorded in the Reserve's fauna (Table 2). In contrast, reptiles are represented by 7 out of 8 species. The representation of species is uneven – four species: *Natrix natrix* L., *Vipera berus* L., *Coronella austriaca* Laurenti, and *Emys orbicularis* L. – accounted for 90% of the records.

Table 2
Results of the "Fauna" questionnaire, herpetofauna

No.	Species	Observations	
		number	%
1	*Bufo bufo* (Linnaeus, 1758)	1	2
2	*Rana arvalis* (Nilsson, 1842)	1	2
3	*Emys orbicularis* (Linnaeus, 1758)	21	44
4	*Anguis fragilis* (Linnaeus, 1758)	2	4
5	*Lacerta agilis* (Linnaeus, 1758)	1	2
6	*Natrix natrix* (Linnaeus, 1758)	5	10
7	*Vipera berus* (Linnaeus, 1758)	7	15
8	*Coronella austriaca* (Laurenti, 1768)	10	21

The bird class includes 245 species, of which 78 are recorded in the Fauna questionnaire. The distribution is relatively even – dominants do not have a large weight in the sample (Table 3).

Table 3
Results of using the questionnaire "Fauna", birds

No	Species	Observations	
		number	%
1	*Tetrao tetrix* (Linnaeus, 1758)	110	15
2	*Perdix perdix* (Linnaeus, 1758)	59	8
3	*Tetrastes bonasia* (Linnaeus, 1758)	53	7
4	*Haliaeetus albicilla* (Linnaeus, 1758)	48	7
5	*Buteo buteo* (Linnaeus, 1758)	47	6
6	*Anas platyrhynchos* (Linnaeus, 1758)	36	5
7	*Ciconia nigra* (Linnaeus, 1758)	28	4
8	*Glaucidium passerinum* (Linnaeus, 1758)	28	4
9	*Falco Subbuteo* (Linnaeus, 1758)	25	3
10	*Pernis apivorus* (Linnaeus, 1758)	24	3
11	*Lanius excubitor* (Linnaeus, 1758)	19	3
12	*Cygnus cygnus* (Linnaeus, 1758)	18	2
13	*Falco tinnunculus* (Linnaeus, 1758)	15	2
14	*Ardea alba* (Linnaeus, 1758)	13	2
15	*Circus aeruginosus* (Linnaeus, 1758)	13	2
16	*Clanga pomarina* (Brehm, CL, 1831)	13	2
17	*Grus grus* (Linnaeus, 1758)	13	2
18	*Circaetus gallicus* (Gmelin, JF, 1788)	11	1

The mammal class includes 60 species, of which 23 are recorded in the Fauna questionnaire. The distribution is uneven – 50% of the observations are of two species: red deer and European elk (Table 4). Most of the observations are of animals of medium and large size class. In addition, these are species which are easy to identify. It should be noted that bats and mouse-like rodents are not available for direct observation. Their research requires special equipment. Mammals of the wetland complex have limited accessibility for direct observation. An equally important factor is the time activity of animals and observers. Data from camera traps show maximum animal activity in the dark (Vishnevskyi, 2021). However, the activity of the Reserve's employees fits into the daytime.

Table 4
Results of using the "Fauna" questionnaire, mammals

No.	Species	Observations	
		number	%
1	*Cervus elaphus* (Linnaeus, 1758)	451	30
2	*Alces alces* (Linnaeus, 1758)	310	20
3	*Capreolus capreolus* (Linnaeus, 1758)	190	13
4	*Equus ferus przewalskii* (I. S. Polyakov, 1881)	164	11
5	*Lepus europaeus* (Pallas, 1778)	68	4
6	*Castor fiber* (Linnaeus, 1758)	67	4
7	*Canis lupus* (Linnaeus, 1758)	59	4
8	*Vulpes vulpes* (Linnaeus, 1758)	43	3
9	*Nyctereutes procyonoides* (Gray, 1834)	34	2
10	*Sus scrofa* (Linnaeus, 1758)	30	2
11	*Meles meles* (Linnaeus, 1758)	17	1
12	*Lynx lynx* (Linnaeus, 1758)	15	1.0
13	*Lutra lutra* (Linnaeus, 1758)	15	1.0
14	*Mustela nivalis* (Linnaeus, 1758)	11	0.7
15	*Martes martes* (Linnaeus, 1758)	8	0.5
16	*Ursus arctos* (Linnaeus, 1758)	5	0.3
17	*Sciurus vulgaris* (Linnaeus, 1758)	4	0.3
18	*Erinaceus roumanicus* (Barrett-Hamilton, 1900)	4	0.3
19	*Talpa europaea* (Linnaeus, 1758)	3	0.2
20	*Mus musculus* (Linnaeus, 1758)	1	0.07
21	*Crocidura suaveolens* (Pallas, 1811)	1	0.07
22	*Martes foina* (Erxleben, 1777)	1	0.07
23	*Bison bonasus* (Linnaeus, 1758)	1	0.07

The next element of the data structure is the type of object that the observer records (Table 1). There are nine types of objects in the questionnaire that represent the presence of a species in one way or another. The vast majority of observers prefer to record animals directly (89%). Other types of animal fixations are not numerous: animal corpse (2.3%), traces (3.3%) and gnawing or scratching marks (1.6%). Other signs of animal presence (burrows, nests, dams, and huts) noted in isolated cases.

An important component of the structure of the questionnaire is its users, those who fill it with data. Among the staff working on the territory of the Reserve, the completeness of the questionnaire is rather uneven. Thus, the largest number of users is in the scientific department (66%), the smallest – in the department of security guards (12%). The department of reproduction and conservation of wildlife made only 459 records (19%). Other units of reserve were not involved in data collection. The number of users is related to the leveling index – in the case of small number of users, a large share of observations is made by a small share of employees.

Data structure of the iNaturalist platform. The spatial distribution of the iNaturalist platform data is generally similar to that of the Fauna questionnaire (Fig. 4). There are gaps in the western part, but the nature of the places with the highest concentration of observations is the same: these are places of concentration of staff (Chornobyl city with the floodplain), Prypiat city, and major transportation routes. The number of observations also increases from west to east.

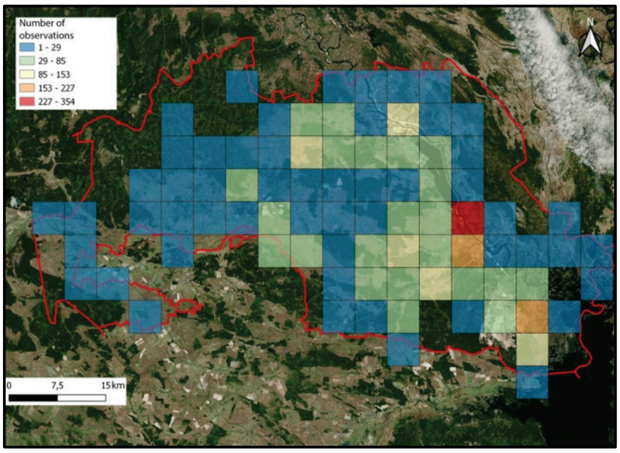


Fig. 4. Spatial distribution of iNaturalist platform records in the CEZ

The distribution of data by category has its own peculiarities. Thus, animals are represented by classes, all other protozoa, fungi and plants by kingdoms. Plants account for the largest number of observations, followed by birds, fungi, insects, and mammals (Table 5).

Table 5
Results of the iNaturalist platform application for the territory of the CEZ

No.	Systematic category	Number of species	Number of observations
1	Plantae	580	1904
2	Aves	108	430
3	Fungi	150	330
4	Mammalia	23	208
5	Insecta	125	186
6	Reptilia	6	21
7	Arachnida	7	10
8	Actinopterygii	4	9
9	Amphibia	5	8
10	Mollusca	5	5
11	Protozoa	1	1

In the bird class, 108 species were recorded, which is 30 more than in the Fauna questionnaire. However, most of these species are common species, which the Reserve's specialists do not include in the questionnaire due to professional deformation (Table 6). The distribution of observations has a uniform distribution – the index of evenness is 0.07.

The mammal class includes 21 species, which is less than in the Fauna questionnaire. In addition, there are small mammals and domestic dog (Table 7). The distribution is also uneven, with two species accounting for 50% of the observations: Przewalski's horse and European elk. Most of the observations also account for animals of medium and large size, with a high level of identification.

The reptile categories have fewer records, and amphibians have more records, but in general they are comparable to the Fauna questionnaire. Despite the large number of records, insects, plants, and fungi have a large percentage of abundant species.

Observations on the territory of the CEZ on the iNaturalist platform were made by 46 users. At the same time, almost 90% of observations were made by 5 users. Among them, one person has permanent access to the territory (an employee of the Reserve), two have systematic access, and two others were here for only two days. This shows the upper limit of the application's capabilities, which, however, is only possible for immovable objects such as plants and fungi.

Table 6
The most numerous bird species of the iNaturalist platform

No.	Species	Observations	
		number	%
1	*Haliaeetus albicilla* (Linnaeus, 1758)	30	7.0
2	*Parus major* (Linnaeus, 1758)	22	5.1
3	*Lyrurus tetrix* (Linnaeus, 1758)	19	4.4
4	*Buteo buteo* (Linnaeus, 1758)	18	4.2
5	*Circaetus gallicus* (Gmelin, JF, 1788)	14	3.3
6	*Cygnus cygnus* (Linnaeus, 1758)	10	2.3
7	*Ciconia nigra* (Linnaeus, 1758)	10	2.3
8	*Pyrrhula pyrrhula* (Linnaeus, 1758)	9	2.1
9	*Lanius excubitor* (Linnaeus, 1758)	8	1.9
10	*Dendrocopos major* (Linnaeus, 1758)	8	1.9
11	*Lanius collurio* (Linnaeus, 1758)	8	1.9
12	*Periparus ater* (Linnaeus, 1758)	7	1.6
13	*Anthus trivialis* (Linnaeus, 1758)	7	1.6
14	*Motacilla alba* (Linnaeus, 1758)	7	1.6
15	*Falco tinnunculus* (Linnaeus, 1758)	7	1.6
16	*Aegithalos caudatus* (Linnaeus, 1758)	7	1.6
17	*Poecile montanus* (Conrad von Baldenstein, 1827)	7	1.6
18	*Turdus viscivorus* (Linnaeus, 1758)	7	1.6
19	*Erithacus rubecula* (Linnaeus, 1758)	7	1.6
20	*Streptopelia turtur*(Linnaeus, 1758)	7	1.6

Table 7
Results of using the iNaturalist platform, mammals

No	Species	Observations	
		number	%
1	*Equus ferus przewalskii* (I. S. Polyakov, 1881)	59	28
2	*Alces alces* (Gray, 1821)	47	23
3	*Cervus elaphus* (Linnaeus, 1758)	18	8.7
4	*Capreolus capreolus* (Linnaeus, 1758)	14	6.7
5	*Sus scrofa* (Linnaeus, 1758)	14	6.7
6	*Vulpes vulpes* (Linnaeus, 1758)	9	4.3
7	*Lepus europaeus* (Pallas, 1778)	8	3.8
8	*Castor fiber* (Linnaeus, 1758)	7	3.4
9	*Canis lupus* (Linnaeus, 1758)	5	2.4
10	*Mustela nivalis* (Linnaeus, 1758)	3	1.4
11	*Sciurus vulgaris* (Linnaeus, 1758)	3	1.4
12	*Canis familiaris* (Linnaeus, 1758)	2	1.0
13	*Neogale vison* (Schreber, 1777)	2	1.0
14	*Talpa europaea* (Linnaeus, 1758)	2	1.0
15	*Sorex araneus* (Linnaeus, 1758)	2	1.0
16	*Apodemus* (Kaup, 1829)	2	1.0
17	*Ursus arctos arctos* (Linnaeus, 1758)	1	0.5
18	*Nyctereutes procyonoides* (Gray, 1834)	1	0.5
19	*Apodemus agrarius* (Pallas, 1771)	1	0.5
20	*Rattus norvegicus* (Berkenhout, 1769)	1	0.5
21	*Lepus timidus* (Linnaeus, 1758)	1	0.5

Comparison of different methods of collecting geospatial biodiversity data. For comparison, we chose one systematic group, the class Mammalia. As a control, we used studies conducted with camera traps. There are similarities here: camera traps, like humans, capture mostly medium and large animals. There are differences that reduce the factor of human influence: they do not frighten animals, work around the clock, record all animals that fall into the control zone of the motion sensor, and are not limited to open space (Table 8).

The calculation revealed that the Fauna questionnaire indicators are more similar to the results of large mammal monitoring by "Polissya without borders" project than to other samples, iNaturalist is the most different from other samples (Fig. 5).

It should be noted that the project "Polissia without borders" collected a large amount of data – 37,400 photo records. The location of 76 photo traps was on randomly selected 3.1 x 3.1 km grid cells within the CEZ.

Thus, this data set is the most representative of the group of medium and large mammals in this area. The closeness of the Fauna questionnaire data probably shows the importance of a large number of observations with the maximum possible coverage of the territory.

Table 8
Comparative table of mammalian species recording

Species	"Fauna"	"iNaturalist"	"Polissya without borders"	Low-resource study
Cervus elaphus (Linnaeus, 1758)	30.0	9.0	47.0	48.4
Alces alces (Linnaeus, 1758)	20.0	23.0	14.0	3.8
Capreolus capreolus (Linnaeus, 1758)	13.0	6.7	17.0	0
Equus ferus przewalskii (I. S. Polyakov, 1881)	11.0	28.0	6.0	23.8
Lepus europaeus (Pallas, 1778)	4.1	4.0	0	10.0
Castor fiber (Linnaeus, 1758)	4.0	3.4	3.0	0
Canis lupus (Linnaeus, 1758)	4.0	4.3	1.0	4.1
Vulpes vulpes (Linnaeus, 1758)	3.0	4.3	3.0	1.8
Nyctereutes procyonoides (Gray, 1834)	2.0	0.5	0	3.0
Sus scrofa (Linnaeus, 1758)	2.0	6.7	4.0	4.6
Meles meles (Linnaeus, 1758)	1.0	0	1.0	0.2
Lynx lynx (Linnaeus, 1758)	1.0	0	0.3	0
Lutra lutra (Linnaeus, 1758)	1.0	0	0	0
Mustela nivalis (Linnaeus, 1758)	0.7	2.0	0	0
Martes martes (Linnaeus, 1758)	0.5	0	0.6	0
Ursus arctos (Linnaeus, 1758)	0.3	0.5	0.1	0
Sciurus vulgaris (Linnaeus, 1758)	0.3	1.4	0	0
Erinaceus (Linnaeus, 1758)	0.3	0	0	0
Talpa europaea (Linnaeus, 1758)	0.2	1.0	0	0
Mus musculus (Linnaeus, 1758)	0.1	0	0	0
Crocidura suaveolens (Pallas, 1811)	0.1	1.0	0	0
Martes foina (Erxleben, 1777)	0.1	0	0	0
Bison bonasus (Linnaeus, 1758)	0.1	0	0	0
Rattus norvegicus (Berkenhout, 1769)	0	0.5	0	0
Apodemus agrarius (Pallas, 1771)	0	0.5	0	0

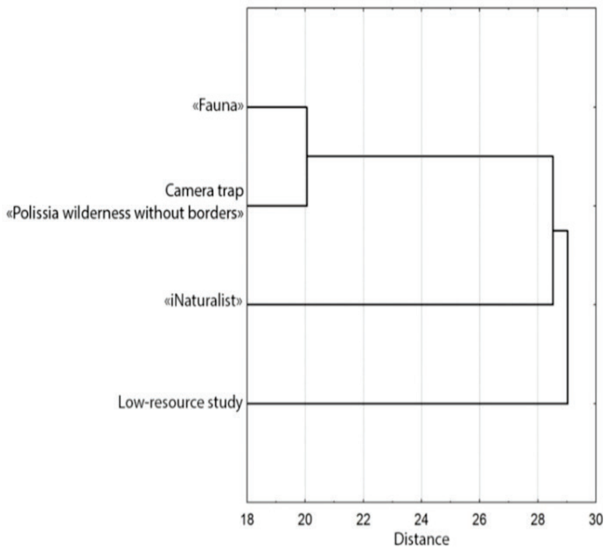


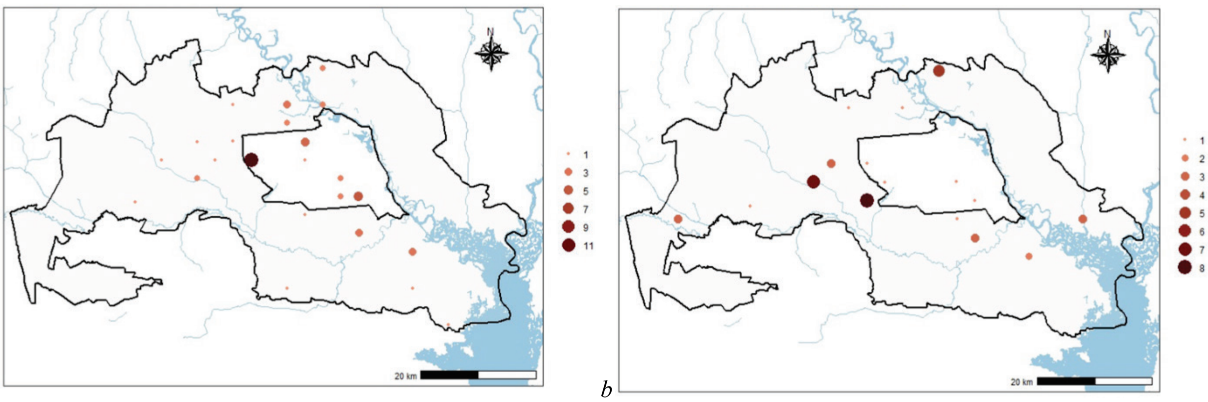
Fig. 5. Dendrogram of distances between samples of mammal species sets obtained by different methods (hierarchical cluster analysis)

Application of the research results in the operations of the reserve. Every year in the Kyiv region (and in Chornobyl Reserve as well), an oral vaccination campaign for wild carnivores is carried out in the fall (Barnett & Civitello, 2020; Dziuba, 2021). The vaccine in an edible shell is evenly scattered from an airplane over the territory. In 2023, due to wartime restrictions, the use of the aircraft was not possible. Within the framework of the vaccination campaign, the vaccine was distributed on the ground by employees of the Reserve, the State Forestry Enterprise "Pivnichna pushcha" and other services and enterprises.

In order to effectively conduct this vaccination campaign, the scientific department analyzed the results of long-term observations – the Survey123 database and monitoring of photo traps to identify places of concentration of predatory animals. A number of points of high animal concentration were found to coincide.

By overlaying the data, we were able to find out the places of the highest concentration and density of the animal population. For example, Figure 6 represents the spatial distribution and relative abundance of red foxes (a) and common raccoon dogs (b).

We also used this method to find out that carnivorous mammals mostly were more abundant in western part of reserve, which greatly helped us to conduct the vaccination campaign more effectively (Fig. 7). In this figure, we see that the areas with the highest concentration of predators are typical of floodplains, where the most productive ecosystems are located.



a *b*

Fig. 6. Spatial distribution and relative abundance: *a* – *Vulpes vulpes* Linnaeus, 1758; *b* – *Nyctereutes procyonoides* Gray, 1834

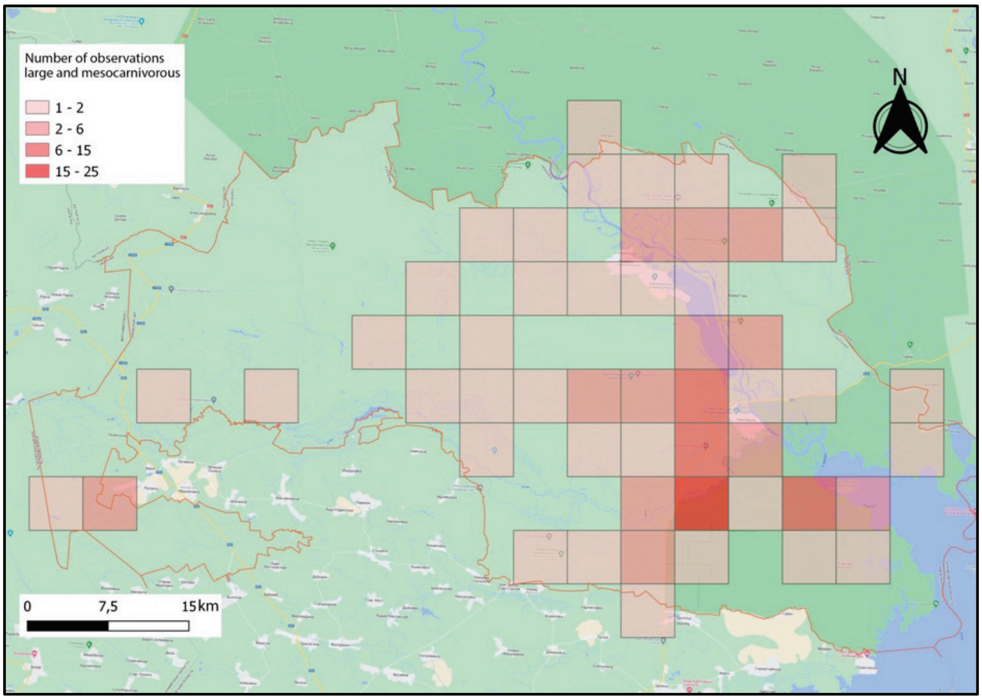


Fig. 7. Spatial distribution and relative abundance of carnivorous mammals

Discussion

Geospatial data services offer researchers a vast amount of information that was previously unimaginable (Wang et al., 2020). Through the integration of geospatial data and traditional methods of study, scientists have achieved a more profound comprehension of wildlife populations, their habitats, and the complex interrelationships between species and their environment (Rossi et al., 1992; Suhardiman et al., 2013; Tsvetkova et al., 2015; Lord et al., 2018). Currently, Geographic Information System (GIS) technologies, which have been recently integrated with remote sensing, are utilized in almost all environmental surveys and monitoring programs (Jezierski & Kabala, 2021; Skydan et al., 2022). Nowadays, geospatial technology is being used for wildlife census and monitoring (Palacio et al., 2021; Wild et al., 2023), detecting drivers and hotspots for disease transmission risk among wildlife (Barroso et al., 2023), wildlife crime investigation (Appleton et al., 2022), and evaluating the effectiveness of managing protected areas (Mileti et al., 2024). The rapid advancement of GIS technologies resulted in an increasing variety of tools that improve the efficiency of research, including biodiversity monitoring within protected areas (Goyal et al., 2020; Merry et al., 2022). Unfortunately, in most protected areas of Ukraine, the traditional method of field data collection is preferred.

Geospatial tools are actively used in the Chornobyl Radiation and Ecological Biosphere Reserve for various purposes: fire management (Fedoniuk et al., 2021; Matsala et al., 2023; Zymaroieva et al., 2023), promotion of international cooperation to protect endangered species and their habitats (Gashchak & Paskevych, 2019; Palmero et al., 2023), better understanding of species migration routes (Schlichting et al., 2020), general biodiversity monitoring (Cannon & Kiang, 2022).

The practice of using the “Fauna” questionnaire has shown a limited area of biodiversity recorded by the reserve's staff. These are large and medium-sized mammals that are easy to identify. Most of the entries in the questionnaire were made near roads and locations where personnel are constantly present. This introduces a systematic error in the results of the observations. The use of the questionnaire is not uniform – not all employees use it regularly and actively. The use of questionnaires is an important tool for managing protected areas (Fisher et al., 2023; Pu et al., 2023), and it is predicted that their use will only increase (White et al., 2005). Increasing the quantity and quality of results is possible by expanding the competence of staff in using the questionnaire and training aimed at identifying species by indirect signs such as traces, burrows, gnawing marks, etc. Despite the identified limitations of the questionnaire, the data set accumulated over several years can adequately describe the situation with the relative abundance and spatial distribution of large and medium-sized mammals, approaching such an accurate method as photomonitoring using photo traps.

A geospatial data source such as the iNaturalist platform can provide acceptable information on species composition, seasonal and topographic distribution. However, it has limitations in terms of the relative abundance and structure of species communities. Additionally, there is evidence suggesting that iNaturalist, a prominent database for geographic information regarding the distribution of species, intentionally adds uncertainty into precise records of endangered species occurrence data depending on two privacy policies: geoprivacy and taxon geoprivacy (Contreras-Díaz et al., 2023). However, this tool can be used as an additional resource for making decisions on prioritizing conservation and biodiversity monitoring (Callaghan et al., 2022; Beninde et al., 2023; Rocha et al., 2023).

The widespread use of questionnaires by reserve staff makes such surveys a cost-effective, less invasive and less time-consuming method of wildlife inventory, and they can be used to quantify the presence, abundance or density of many species of terrestrial mammals.

Conclusion

The use of geospatial data collection tools in a reserve is undoubtedly a powerful additional source of biodiversity information when incorporated into field research or inventories. The iNaturalist platform provides reliable data on species composition, as well as seasonal and topographic distribution. Nevertheless, it is constrained by limits regarding the relative abundance as well as the structure of species communities. Even though the data obtained using the Fauna questionnaire has some shortcomings, such as uneven distribution of records and dependence on the competence of observers, it reflects the real distribution of species quite precisely, approaching the accuracy obtained with the help of photo traps.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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