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Wild ungulate density data generated by camera trapping in 37 European areas: first output of the European Observatory of Wildlife (EOW)

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Abstract

The European Observatory of Wildlife (EOW) as part of the ENETWILD project, aims to improve the European capacity for monitoring wildlife populations, implementing international standards for data collection, providing guidance on wildlife density estimation, and finally, to promote collaborative, open data networks to develop wildlife monitoring, initially focusing on terrestrial wild mammals. This report presents density estimates for species that are widely distributed (wild boar (*Sus scrofa*), European roe deer (*Capreolus capreolus*), red deer (*Cervus elaphus*)) by following a standardised camera trapping (CT) protocol, in 48 areas from 28 different countries in Europe, during 2022. Density values are provided for 37 areas from 20 countries, while an additional 9 locations from 8 countries are currently completing the data analysis. The EOW involved different stakeholders over most European countries, which resulted for the first time in a number of reliable (known precision) wild ungulate density estimates, from areas representing different European bioregions. These estimates are the result of a collaborative effort from the network to apply practical systematic and rigorous protocols. The results presented from the first pilot campaign of the EOW cannot be used to accurately describe wildlife population gradients and trends at European level but can be used as first baseline data for future trend analyses. Our

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results show data gaps, but also provide relevant insights into some of the main drivers of demographic evolution of wild ungulate populations in Europe. We will expand and improve the EOW in the future to include more representative sites. The Agouti app, including photogrammetry methods to estimate CT detection zone size and animal speed of movement using a computer vision process proved useful to reduce the workload and to improve objectivity of measurements for REM method. We discuss the results obtained by the 2022 campaign in relation to the specific objectives of the EOW and propose the next steps.

Key words: Agouti, camera trap, European Observatory of Wildlife, wild boar, red deer, roe deer, density estimation

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Summary

Background: The European Observatory of Wildlife (EOW), as part of the ENETWILD project, aims to improve the European capacity for monitoring wildlife populations, implementing international standards for data collection, providing guidance on wildlife density estimation and, finally, promoting collaborative, open data networks to develop wildlife monitoring. The EOW existing network of collaborators has developed field operations to estimate wild mammal density (wild ungulates and other medium to large mammals) in several areas of different European bioregions. A field camera trap (CT) based protocol provided by the EOW has been applied, and to a lesser extent, other protocols also recommended by the EOW (distance sampling). The CT field protocol is compatible with the subsequent application of artificial intelligence (AI) to process and analyse photos using the online application Agouti (https://www.agouti.eu). Participants were trained in applying the random encounter model (REM) and on other methods for automatically processing images and analysing data to obtain wildlife abundance and density (https://wildlifeobservatory.org/2nd-course-on-the-use-of-camera-trapping-for-monitoring-wildlife/).

Objectives: This report presents the generated density estimates for wild boar, as well as roe deer and red deer, species which are widely distributed in 48 areas from 28 different countries in Europe. Density values were estimated in 37 areas from 20 countries, while 8 countries are currently completing data analysis (densities will be provided in summer 2023). Using wild boar as reference species, we evaluated the population factors determining (i) the day range (ii), the density, and (iii), we also evaluated the precision of density estimations in relation to variations in the effort applied during sampling as a basis for future improvement of study designs.

Results and discussion:

General

- The EOW, as a collaborative approach, involved different stakeholders over most European countries: wildlife and/or game departments (at national and regional level), the academia, wildlife private professionals, national and regional hunting federations, NGOs and protected areas. For the first time, a number of reliable (known precision) wild mammals density values representing different European bioregions are available for comparison purposes based on the collaborative work developed by a network of wildlife professionals. This trial highlights that a harmonised "observatory" approach for the estimation of wildlife populations' densities is actually possible at a continental scale, applying practical systematic and rigorous protocols, not at odds with the fact that it is feasible, and demonstrated that can be applied routinely and easily after basic training.

- The use of the REM method allowed the adoption of a protocol that required few technicians for its implementation and limited equipment. Its implementation was made more practical and effective by the use of the photogrammetry approach (see below) and other tools provided by Agouti, which allowed to directly estimate animal speed and actual CT detection radius and angle, making REM extremely adaptable to the local conditions of each study site. This experience revealed that good training and continuous support are needed to achieve data harmonisation and density estimation by a European network of professionals.
- The application of the REM protocol in the field presented variability in effort parameters (Nº of CTs, Nº of CT deployment rounds, total Nº of deployments, Nº of deployments/area, CT*days, duration of deployments, overall duration) due to the variable availability of effort in several study areas and/or to logistic and technical constraints. However, this variability was excellent to test in real scenarios the factors determining the reliability (known precision) of density estimations, and to gain insight into what improvements are required in the protocol to achieve best cost (practical)/benefit (reliable) strategies in the future.
- The results presented here still cannot be interpreted to accurately describe wildlife population gradients at a European level but should only be interpreted in the context of the specific set of sampled populations. A larger number of study populations covering habitats representative of the main factors determining population dynamics, including management, is required. Our results showed gaps but also provided insights into some of the main drivers influencing wild ungulates populations at European level, which will be considered to expand and improve the EOW in the future in a more representative way.

New information technology tools (ITts)

- The CT image processing has been implemented using the online platform Agouti, which allows users to easily store and sequence the pictures in different projects for each study site. New Agouti functionalities based on the photogrammetry method to estimate CT detection zone size and animal speed of movement using a computer vision process proved useful to reduce the workload and improve objectivity of measurements. This requires some basic training and continuous assistance to solve local issues. After this first experience, EOW participants become self-sufficient and capable of applying the methodology and tools.
- Some collaborators faced difficulties during some of the crucial stages of the data collection, processing and/or analysis. Some of these difficulties were related to the correct calibration of the CT deployments. However, the experience gained this year will ensure a higher accuracy and precision in the implementation of the protocol which is going to lead to higher precision in future density estimates.

- The analysis scripts developed this year represent a fundamental part of the approach proposed by the EOW. In fact, they should provide to each collaborator a tool to independently perform the analysis required by the REM without being experienced with statistical programs. The tools provided by Agouti, as well as the analysis codes, are being continuously refined as the CT protocol is made more and more effective.

Density estimation

- Day range (wild boar): The parameters required to apply REM, such as the day range, presented high variability between study areas and species, indicating the need to specifically estimate these parameters in each study area; this means that the trapping rate cannot be directly scaled to obtain density estimates, but requires estimating these local parameters. We showed statistical differences in the wild boar day range as a function of the land use and the type of hunting method related to bioregion.
- Density (wild boar): The density estimations obtained are very valuable and have high potential to be applied to improve the spatial distribution of the species at continental level (e.g., calibrating abundance models into densities) and to evaluate risk factors associated with population abundance. Our results highlighted a tendency for protected areas in proximity to urban areas to have the highest wild boar densities. This is indicative of a growing problem at the European level since control methods (e.g., in the form of hunting) are more difficult to apply in these areas, and conflicts with humans (including disease transmission to humans or animals) are an increasing issue.
- Precision of density estimations (wild boar): As the number of rounds increased (for a relatively constant duration of the field trial), the CV did not improve, but on the contrary the higher the number of rounds (n=3), the lower the wild boar density estimation precision. Overall, for the number of CT available and duration of study, two rounds of CT deployments seemed to be an optimum balance. A higher number of rounds would only be recommended if the duration of CT deployment increases. Specific instructions on the study design to each study area will be provided for the next campaign in light of the effort produced in 2022 and the results achieved.
- Similarly to wild boar, the application of the REM protocol in deer species presented marked variability in parameters related to the implementation of the field protocol, such as the CT*days, or the duration of CTs deployments. As for wild boar, the practical evaluation of this variability in real scenarios requires increasing the number of deer populations assessed in the EOW. This will also allow us to interpret data to accurately describe population density gradients and trends (in the future) at a European level.
- <u>Conclusions relative to the progress of the EOW during the 2022 campaign and next steps</u>:

The conclusions and recommended steps are presented as a function of the main objectives of the EOW:

- Specific objective 1. To generate and provide information and unbiased gradients on population abundance for those developing, adopting, implementing, and evaluating environmental policy in Europe.

  Progress during the 2022: The first results of the EOW presented here cannot yet be interpreted to accurately describe wildlife population gradients at European level but should only be interpreted in the context of the specific set of sampled populations. However, they provided relevant insights to expand and improve the EOW in the future in a more representative way. The density estimations obtained are very valuable themselves and have high potential to be applied to improve the spatial distribution of the species at continental level (e.g., calibrating abundance models into densities) and to evaluate risk factors associated with population abundance.

  Next steps:

  - To continue supporting the current network of the EOW to generate long term data capable of providing gradients at European scale and for a wider range of species;
  - to make use of the generated data to show their practical applicability (e.g., improved abundance distribution models for ungulates at European scale, but also contributing to progress on ecological questions);
  - to involve new study areas and stakeholders (see below);
  - to match the EOW generated data and data collected through general data collection frameworks for less reliable data (for density estimation), such as local hunting statistics.

- Specific objective 2. To provide sound, independent guidance on methods and protocols for those involved in implementing wildlife monitoring, in close collaboration with European Institutions.

  Progress during the 2022: The EOW has previously offered training to all collaborators involved on the methods for determining wildlife density, and specifically on camera trapping, collaborating with institutions developing these methods and information technology tools (ITts). Detailed explanations of field protocols to implement such methods were provided, and they are available in the guidance produced by *ENETWILD,* and continuously updated at the EOW website.

  Next steps:

- To continue developing practical/reliable multi-species methods and protocols to determine density (but also presence and abundance indexes for certain taxa), mostly based on CTs, but also on new approaches, such as molecular techniques;
- to expand training activities to new participants and Institutions in close collaboration with European institutions.

- Specific objective 3. To develop a network for wildlife monitoring, incorporating different stakeholders, such as regional and national administrations, game, and wildlife managers, protected areas and research institutions.

  Progress during the 2022: A resounding success since we involved numerous stakeholders from most European countries.

  Next steps:

  - In addition to continuing to support the current network of the EOW, there is need to involve more stakeholders, including the network of European protected areas (e.g., Natura 2000 network), wildlife and game services (national, regional), and hunting federations;
  - to integrate/coordinate with monitoring efforts by European institutions and projects (e.g., EuropaBon), and putting data generated by this collaborative open data initiative at the service of policymakers and researchers.

- Specific objective 4. Supporting observation points, providing training, and facilitating field design, data processing and analysis.

  Progress during the 2022: EOW participants were capable to plan the study design together with *ENETWILD* coordinators, and subsequently develop data processing and analysis using the provided ITts, including the application of artificial intelligence.

  Next steps:

  - To incorporate to the lessons learnt during the first campaign of the EOW to optimise the limited effort and resources;
  - to continue training on new/modified density estimation protocols and tools: ITts, apps to collect and process data "from the field to the desktop";
  - making easier the final step of data analysis to obtain reliable densities with limited expertise on statistics (a relevant bottleneck during the process);
  - to facilitate and automate the data flow.

- Specific objective 5. Focused on mammals but looks to integrate other taxa and ecological variables and integrated monitoring (wildlife diseases).

  Progress during 2022: During 2022 we focused on terrestrial mammals. This report, as a pilot, focused on widespread species, i.e., wild boar and two deer species (red deer and roe deer). We already established the structure and the network to integrate other taxa and ecological variables and integrated monitoring (population and wildlife diseases).

  Next steps:

  - To integrate other vertebrate taxa: other carnivore species, micromammals, chiropterans, rodents and lagomorphs; which requires the integration and coordination of activities with current schemes on wildlife monitoring in Europe (e.g., wild birds, bats);
  - to develop integrated wildlife monitoring under the One Health (OH) approach: environmental detection of shared wildlife pathogens, such as zoonotic diseases of relevance to future OH policies in Europe, and to coordinate with initiatives such as Vectornet;
  - incorporating relevant Essential Biodiversity Variables (EBVs, e.g., invertebrates) and Essential Ecosystem Services Variables (EESVs), such as herbivory, which requires collaboration with other monitoring frameworks.

- Specific objective 6. To improve population abundance estimation protocols, calibration methods, incorporating ITts and citizen science.

  Progress during the 2022: The application of the REM field protocol resulted in a variability in field effort which allowed for the testing of factors determining the reliability (precision) of density estimations and what improvements are needed for the best practical/reliable strategy in the future. As the number of rounds of CT deployments increased for a relatively fixed duration of the field trials (averaging two months), the precision did not, but decreased. Two rounds of CT deployments seem to be an optimum balance, and a higher number of CT deployment rounds would only be recommended if the duration increases.

  Next steps:

  - To continue developing improved density estimation protocols and tools:
    - ITts such as AI for automatic recognition and refine the analysis codes as the protocol is made more and more effective;
    - evaluating the application of smart CTs capable of automatically pre-processing and sending information to servers in real time;

        - to develop apps to collect and process data "from the field to the desktop".
    - the future modification of the CT field protocol should balance practical issues (the higher the number of CT deployment rounds the higher the workload, efforts, and costs) and precision;
    - the lessons learnt in the citizen science project *MammalNet* (https://mammalnet.com/) should be put into practice to improve wild mammal data collection at European scale, for which the network of study areas of the EOW offers an excellent platform to promote and take advantage of the citizen science as complementary approach.

- Specific objective 7. Highlight areas and recommendations for action and reduce the inequalities existing in wildlife population monitoring over Europe.

  Progress during the 2022: As expected, the exploration of the patterns of densities for the three species considered in this report for the first campaign of the EOW (which can be considered a pilot), showed gaps in terms of areas and representativeness of certain relevant factors determining population gradients of wildlife.

  Next steps:

    - In general, an increase of the number of areas is required to better determine reliable population gradients at European level, a feasible objective would be to achieve a total of 60 areas by 2024 campaign;
    - we identified, at the bioregion level, gaps in terms of study areas representing certain land uses, management options (e.g., wildlife control options, such as hunting) and vertebrate community compositions (e.g., presence of large carnivores), which should be covered in future campaigns. Special attention should be paid to protected zones in vicinity to urban areas where wildlife associated conflicts are increasingly reported;
    - geographically, a higher representativity is required in Northern Europe and Eastern, and in certain countries;
    - We need to develop an informative dissemination campaign on coordinated wildlife monitoring and management at a European scale aimed at relevant international and national institutions, as well as to different stakeholders, for which the 2023 *ENETWILD* Annual General Meeting will provide an excellent opportunity.

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1. Introduction

1.1. Background and Terms of Reference

The contract entitled "Wildlife: collecting and sharing data on wildlife populations, transmitting animal disease agents" (Specific Contract number: OC/EFSA/ALPHA/2016/01 – 07) was awarded to the Universidad de Castilla-La Mancha by EFSA. The *ENETWILD* consortium is implementing the EFSA-funded project "Wildlife: collecting and sharing data on wildlife populations, transmitting animal diseases agents", whose main objective is to collect data on wild boar density, hunting and occurrence, and to model species geographical distribution and abundance throughout Europe. This subject is of particular concern due to the continued advance of African swine fever (ASF).

The specific objective 3 (SO3) of the *ENETWILD* framework contract 9 refers to data generation by camera trapping surveys density of wild boar (as part of TASK 3. Targeted wildlife population and health surveillance upon request, access to site, sampling, and processing). The deliverables 3.1 and D3.2 of SC9 specify to continue activities for generation of distribution and abundance data of wild animals by camera trapping in 30 countries, for which 18 countries have been incorporated to the new-born European Observatory of Wildlife (EOW, https://wildlifeobservatory.org/).

1.2. Scope of the report

This report presents estimated densities of wild boar, as well as two deer species that are widely distributed (roe and red deer) by following recommended methods (mainly by camera trapping using the random encounter model, REM) in 48 areas from 28 different countries in Europe during 2022. Density values are provided for 37 areas from 20 countries, while an additional 9 locations from 8 countries are currently completing the data analysis (densities will be provided early on 2023). No density was estimated in 4 countries in eastern Europe that were directly affected by war conflicts during 2022. This was compensated by increasing the number of study areas in other countries.

2. The approach of the European Observatory of Wildlife

The EOW was started as an international network of wildlife professionals that will benefit not only future risk assessment in relation to relevant pathogens, but the conservation and management of wildlife in Europe, and thus the European society. The collaborative approach of the EOW aimed at incorporating contributors from public administrations, the academia, wildlife managers, protected areas, and national and international frameworks monitoring wildlife and ecosystems. They all work in a network where data will be comparable, interoperable, and openly accessible, with continuous exchange of experiences and optimization of efforts. The EOW connects all the collaborators throughout Europe and provides them with: training, support, analytical tools (taking advantage of ITts) and the latest protocols for density estimation.

Reliable estimates of wildlife numbers, including densities, are needed for monitoring their population trends and trends, for risk assessments, and to develop improved management strategies. Several guidance provided by the *ENETWILD* consortium reviewed density estimation methods for medium to large mammals, recommending robust estimation methods (*ENETWILD* consortium, 2018, 2020, 2021a,b, 2022a, https://wildlifeobservatory.org/guides-and-population-density-cards). The recommended methods also have the potential to be used for calibration and harmonising hunting bag data to provide density estimates. In particular, camera trapping (CT) was preferred as an independent, least disturbing, and practicable method to collect robust data, although this is difficult to apply at a large scale. There is now a need to put into practice these recommended CT protocols over different European habitats, countries, management scenarios and a range of densities for wild boar and other species. This is not only with the aim of generating valuable density estimations, but to explore difficulties and continue developing optimum strategies in terms of cost/reliability of effort and results. All the above should help refine our field protocol and approach to expand the objectives and representativeness of the EOW in order to provide reliable gradients and trends of terrestrial wildlife monitoring in Europe. In this context, the EOW aims to continuously develop all its parts, from the network itself to the field protocol implemented for data collection, which is constantly updated to obtain the best possible standards. Continuous development of practical methods to estimate reliable wildlife abundance and training courses represents a fundamental part of the approach, as they assure a coherent implementation of the protocol throughout all the study sites, promote networking, and strengthen the relationships among collaborators (*ENETWILD* consortium 2022b, 2022c). Although the courses were recorded and constantly available, the collaborators were continuously supported throughout all the phases of the project, from the sampling design to the field work and the data processing and analysis. Furthermore, the adoption of the Agouti platform (*ENETWILD* consortium et al. 2022c), developed as a solution for CT surveys, provides effective features for species classification, image sequencing, parameters calculations and many others, making the data processing and analysis easier and more accessible.

3. Methods

The *ENETWILD* consortium has previously offered training to all collaborators involved in the EOW in order to improve the generation of reliable wildlife density data following methodological standards (*ENETWILD* consortium 2018, 2020, 2021a,b, 2022a,b,c). The animal wildlife experts were recruited from national wildlife, hunting and forest authorities, academia, the private sector and NGOs, and some participants from organisations already monitoring wildlife. The participants received training on the methods for determining wildlife density, and specifically on camera trapping, applying the random encounter model (REM; Rowcliffe et al. 2008) to improve estimation on wild boar density (other methods were also used, e.g., the random encounter staying time, REST; Nakashima et al. 2018). Detailed explanations of field protocols to implement such methods were provided, and they are available in the guidance produced by *ENETWILD* (*ENETWILD* consortium 2018) and updated at the EOW website (https://wildlifeobservatory.org/3rd-course-running-rem-analysis-on-camera-trap-data-packages-from-agouti/).

3.1. Study areas

A detailed summary of ongoing activities for all countries involved in this trial is indicated in Table 1. This report presents the progress and results in relation to the generation of wild ungulate density values by following recommended methods (mainly by camera trapping using the REM, https://wildlifeobservatory.org/guides-and-population-density-cards) in 49 areas from 28 different countries in Europe during 2022. To date, density values have been determined for wild boar in 37 areas from 20 countries (Tables 1, 2 and 3), and additionally, densities are reported for the other two most widespread wild ungulates (red deer and European roe deer) in 17 and 11 study areas, respectively. The study sites span Europe from north to south (also one study area in Israel is included), representing different bioregions, habitats, and management conditions (study areas where alpine/boreal habitat was present were classified together independently of the geographical location, see Table 2).

Table 1. Distribution of the 49 study areas in 28 countries. This report presents density values determined for wild ungulates (wild boar, European roe deer and red deer) in 37 areas from 20 countries, whereas 9 study areas (indicated in brackets) from 8 new countries (plus one area in Spain) will provide density estimations in summer 2023.

Country	Nº study sites	Country	Nº study sites
Albania	(1)	Lithuania	1
Andorra	1	Moldova	(1)
Belgium	2	Montenegro	1
Bosnia & Herzegovina	1	The Netherlands	1
Bulgaria	1	North Macedonia	(1)

Croatia	(2)	Poland	1
Czech Republic	1	Portugal	10
France	1	Romania	(1)
Georgia	(1)	Serbia	1
Germany	(2)	Slovakia	1
Greece	(1)	Slovenia	2
Hungary	1	Spain	5 (1)
Israel	1	Sweden	1
Italy	3	Turkey	1

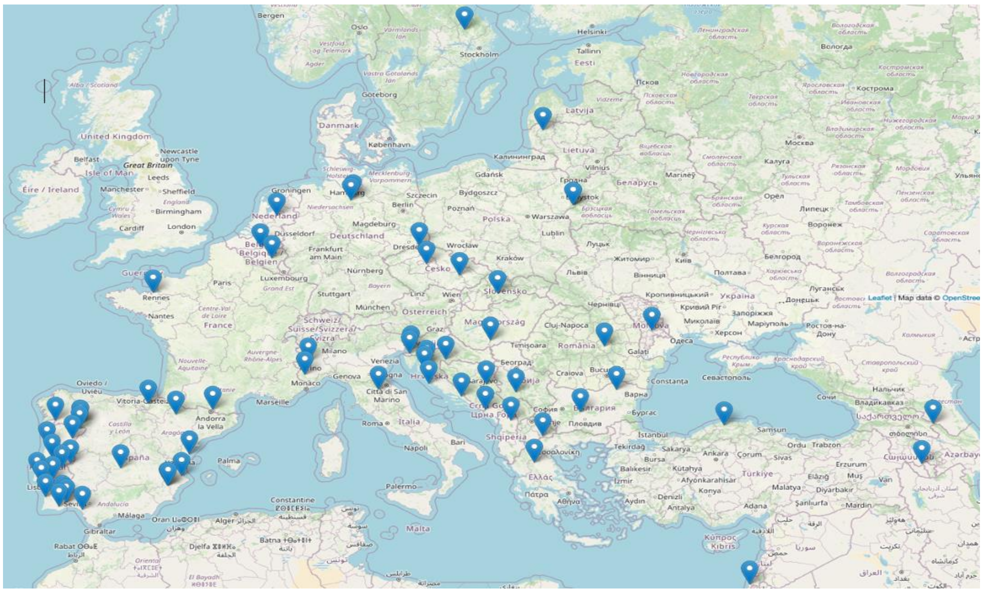

Figure 1. Map of the study areas included in the EOW to date (3/12/2022) (https://eow.wildlifeobservatory.org/).

Table 2. Participant institutions and main characteristics of the study areas providing density values for wild ungulates in this report.

Name study site	Country	Bioregion	Institution	Administrative figure	Use	Area (ha)	Habitat	Big animals present	Wolf present	Hunting	Hunting modality	Artificial feeding	Fencing
Vedat de caça de la Vall de Ransol	Andorra	Alpine/Boreal	Departement de Medi Ambient i Sostenibilitat, Govern d'Andorra	Hunting Reserve	Hunting	2813	*Aciculifolia* forests, Pinus sylvestris and *Pinus uncinata* scattered with moors, pastures and other low scrub and high mountains,	Roe deer, wild boar, Pyrenean chamois, mouflon, brown bear (very occasionally)	No	No	No	No	No
Game management unit 8	Belgium	West	Research Institute for Wildlife and Forest	Game Management Unit	Hunting	6000	Forest, shrubs, grassland, and swamps	Roe deer, wild boar	No	Yes	Individual & collective	No	No
Marche-en-Famenne	Belgium	West	Dept. Natural and Agricultural Environment Studies, Wallonia	Military camp	Protected	2500	*Quecus + Carpinus betulus*, scattered with meadows	Red deer, roe deer, wild boar	No	Yes	Individual & collective	No	No
Romanija	Bosnia & Herzegovina	Alpine/Boreal	University of Belgrade – Faculty of Forestry	Public estate (forest management company)	Hunting	6000	Mountain mixed forests, mainly *Abies alba* and *Picea abies*, scattered with pastures	Roe deer, wild boar, grey wolf, brown bear	Yes	Yes	Individual	No	No
Voden-Iri Hisar	Bulgaria	East	University of Forestry Sofia	Hunting ground (State hunting ranch)	Hunting	8000	Broad-leaved mixed oak forest in lowlands, the most suitable for wild	Red deer, fallow deer, roe deer, wild boar	No	Yes	Individual	Yes	Yes

Name study site	Country	Bioregion	Institution	Administrative figure	Use	Area (ha)	Habitat	Big animals present	Wolf present	Hunting	Hunting modality	Artificial feeding	Fencing
							boars, surrounded by arable land						
Dugi Otok island	Croatia	South	Faculty of Agriculture, University of Zagreb	Hunting ground	Hunting	3500	Island, 46% woods, 37% grass and small bushes, 9% of the habitat is scrubland, 5% agriculture	Mouflon, axis deer, feral goat, sheep	No	Yes	Individual	Yes	No
Marais Noir de Saint-Coulban	France	West	Fédération des Chasseurs d'Ille-et-Vilaine (FDC35)	Association	Hunting	1500	Farming and arable land, wet meadow, reed bed, willow, poplar plantation	Roe deer, wild boar	No	Yes	Individual	No	No
Gemenc	Hungary	East	Hungarian University of Agriculture and Life Sciences (MATE)	State forestry	Hunting	20000	Floodplain forests, mainly *Quercus robur, Fraxinus* spp,, *Populus* spp, and *Salix* spp,, scattered with some meadows and minimal arable plots	Red deer, wild boar, golden jackal	No	Yes	Individual & collective	Yes	Yes
Ramat Hanadiv Nature park	Israel	South	Ganei Ramt Hanadiv	Community interest company (CIC)	Protected urban	1160	Mediterranean *Garigue*, small conifer groves, vineyards, plantations, open fields	Mountain gazelles, wild boar, golden jackals, hyena	No	No	No	No	Yes

Name study site	Country	Bioregion	Institution	Administrative figure	Use	Area (ha)	Habitat	Big animals present	Wolf present	Hunting	Hunting modality	Artificial feeding	Fencing
La Mandria	Italy	West	University of Torino/Piedmont Forest Service	Regional Park	Protected	1604	Broad-leaved forest dominated by oaks, mainly *Farnia*, and common hornbeam	Roe deer, wild boar, red deer, fallow deer, grey wolf	Yes	Yes	Individual	No	Yes
Alpe di Catenaia	Italy	West	University of Sassari	Provincial Park	Protected	2700	Mostly covered by forested habitat (oak, chestnut, beech), with some areas with shrubs and agricultural patches	Red deer, roe deer, fallow deer, wild boar, grey wolf	Yes	No	No	No	No
CACN1/Val Maira	Italy	Alpine/Boreal	University of Torino/Comprensorio Alpino CACN1	Hunting ground	Hunting	34851	From broadleaved and coniferous forest to alpine meadows	Alpine ibex, southern chamois, red deer, roe deer, wild boar, grey wolf	Yes	Yes	Individual & collective	No	No
Model territory MMMPV	Lithuania	Alpine/Boreal	Lithuanian Research Centre for Agriculture and Forestry	National Park	Protected	5646	Mixed spruce forests, (spruce, pine, birch, ader, oak), incl. Western taiga, broadleaves mixed, Fennoscandian herb-rich forests with *Picea abies* scattered with	Wild boar, moose, roe deer, grey wolf, badger, red fox	Yes	Yes	Individual & collective	No	No

Name study site	Country	Bioregion	Institution	Administrative figure	Use	Area (ha)	Habitat	Big animals present	Wolf present	Hunting	Hunting modality	Artificial feeding	Fencing
							meadows, grasslands, swamps						
Orjen Mountain	Montenegro	Alpine/Boreal	NGO Wildlife Montenegro	Grahovo hunting society property	Hunting	6000	Highest mountain in Sub-Adriatic Dinarides, vegetation: macchia in the slopes of Bosnian pine, karstic meadows, *Fagus sylvatica* forests and *Pinus heldreichii*, small scale farming	Roe deer, wild boar, grey wolf, brown bear, northern chamois	Yes	Yes	Individual & collective	No	No
Central Veluwe	Netherlands	West	Wageningen University and Research	State Forest Service	Hunting	6000	Atlantic forests, mainly *Fagus sylvatica, Pinus sylvestris, Pseudotsuga menziesii, Quercus robur.* Drift sand and heathlands.	Roe deer, wild boar, red deer, grey wolf	Yes	Yes	Individual	Yes	Yes
Białowieża Forest	Poland	East	Mammal Research Institute (MRI)	State Forests Holding	Hunting	2947	Temperate lowland deciduous and mixed forest	Roe deer, red deer, moose, wild boar, European	Yes	Yes	Individual	No	No

Name study site	Country	Bioregion	Institution	Administrative figure	Use	Area (ha)	Habitat	Big animals present	Wolf present	Hunting	Hunting modality	Artificial feeding	Fencing
								bison, grey wolf, Eurasian lynx					
Castreja	Portugal	West	University of Aveiro	Associative hunting ground	Hunting	2470	Dominated by shrubs and rocky outcrops. Scattered agriculture and woods of pine and oak trees	Red deer, roe deer, wild boar, Iberian ibex, Iberian wolf	Yes	Yes	Individual & collective	No	No
Lombada	Portugal	South	University of Aveiro	National hunting ground	Hunting	21184	Dominated by shrubs and forest stands (pine, oak, chestnut) interspersed by semi-natural pastures and meadows	Red deer, roe deer, wild boar, Iberian wolf	Yes	Yes	Individual & collective	No	No
Murça	Portugal	South	University of Aveiro	Municipal hunting ground	Hunting	6404	Dominated by shrubs and forest (pine, oak, *Eucalyptus*). Scattered agriculture fields (subsistence)	Roe deer, wild boar	No	Yes	Individual & collective	No	No
Castelo Melhor	Portugal	South	University of Aveiro	Associative hunting ground	Hunting	3329	Dominated by shrubs. Vineyards, olive, and almond trees are very representative. Scattered agriculture fields	Roe deer, wild boar	No	Yes	Individual & collective	No	No

Name study site	Country	Bioregion	Institution	Administrative figure	Use	Area (ha)	Habitat	Big animals present	Wolf present	Hunting	Hunting modality	Artificial feeding	Fencing
Cubeira	Portugal	South	University of Aveiro	Touristic hunting ground	Hunting	1812	Dominated by shrubs and Montado (open canopy woodlands of mainly *Quercus* sp.)	Red deer, wild boar	No	Yes	Individual & collective	Yes	Yes
Tolosa	Portugal	South	University of Aveiro	Associative hunting ground	Hunting	4695	Montado (open canopy woodlands of *Quercus* sp.), scattered agriculture fields. Exotic plantations (*Eucalyptus*), urban and rural settlements	Red deer, fallow deer, wild boar	No	Yes	Individual & collective	No	No
Arrábida	Portugal	South	University of Aveiro	Natural Park	Protected	36283	Mixed and pine forests, and shrubs. Scattered agriculture fields, exotic plantations (*Eucalyptus*), urban and rural settlements.	Wild boar	No	No	No	No	No
Sudoeste	Portugal	South	University of Aveiro	Associative hunting ground	Hunting	6142	Sparse forest stands (pine, oak) and exotic plantations (*Eucalyptus*). Scattered agriculture (subsistence), urban	Wild boar	No	Yes	Individual & collective	No	No

Name study site	Country	Bioregion	Institution	Administrative figure	Use	Area (ha)	Habitat	Big animals present	Wolf present	Hunting	Hunting modality	Artificial feeding	Fencing
							and rural settlements. Sand dune system.						
Bicas da Serra	Portugal	South	University of Aveiro	Associative hunting ground	Hunting	1129	Montado (open canopy woodlands mainly *Quercus* sp.), pine forests and shrubs. Scattered agriculture fields (subsistence), strawberry trees and exotic plantations (*Eucalyptus*)	Red deer, wild boar	No	Yes	Individual & collective	No	No
ZCA Santulhão	Portugal	South	Palombar – Conservation of Nature and Rural Heritage	Associative Hunting Area	Hunting	2998	Mainly Mediterranean shrubland/forests, scattered farming and arable land, patches of coniferous and deciduous forest and semi-natural meadows	Roe deer, red deer, wild boar, wolf	Yes	Yes	Individual & collective	No	No

Name study site	Country	Bioregion	Institution	Administrative figure	Use	Area (ha)	Habitat	Big animals present	Wolf present	Hunting	Hunting modality	Artificial feeding	Fencing
Studenica	Serbia	East	University of Belgrade – Faculty of Forestry	Hunting ground	Hunting	11000	Mountain forests, mainly *Fagus sylvatica*, scattered with pastures and farming	Roe deer, red deer, wild boar, wolf, brown bear	Yes	Yes	Individual & collective	Yes	No
Javorie	Slovakia	East	National Forest Centre	state organization	Hunting	10000	Mixed forest spruce, beech, oak	Roe deer, red deer, fallow deer, wild boar, bear, grey wolf, lynx, wild cat	Yes	Yes	Individual	No	No
Rižana (Primorsko HMD)	Slovenia	West	University of Primorska, Faculty of Mathematics, Natural Sciences and Information Technologies	Hunting ground	Hunting	3657	Sub-Mediterranean forests: different associations with *Quercus* ssp, scattered farming and arable land	Wild boar, roe deer, red deer, golden jackal	No	Yes	Individual & collective	No	No
Vrhe Vrabče	Slovenia	West	Faculty of Environmental Protection	Hunting ground	Hunting	3950	Sub-Mediterranean and karst forests, different associations with *Fagus sylvatica* and *Quercus* ssp., scattered with farming and arable land	Wild boar, roe deer, red deer, golden jackal, grey wolf, brown bear	Yes	Yes	Individual & collective	No	No

Name study site	Country	Bioregion	Institution	Administrative figure	Use	Area (ha)	Habitat	Big animals present	Wolf present	Hunting	Hunting modality	Artificial feeding	Fencing
Cabanes-Torreblanca (Castellón)	Spain	South	Generalitat Valenciana (Regional Government)	Natural Park	Protected urban	850	Mediterranean humid grasslands of tall grasses and rushes and areas with Mediterranean and thermo-Atlantic halophilous scrubs,	Wild boar	No	Yes	Individual & collective	No	No
Parque Nacional de Doñana	Spain	South	Organismo Autónomo de Parques Nacionales / Junta de Andalucía	National Park	Protected	35600	Mediterranean Scrubland, scattered pine forest and cork oak, dunes, and marshland	Wild boar, red deer, fallow deer, cattle, horses	No	Yes	Individual	No	No
Riofrio	Spain	South	Junta de Comunidades de Castilla-La Mancha	Hunting ground (public)	Hunting	6141	Mediterranean forest and scrubland (*Quercus ilex*), and pine plantations, scattered croplands (rainfed)	Roe deer, wild boar, red deer	No	Yes	Collective	No	Yes
Arriola (Araba)	Spain	South	Araba caza (hunting management company)	Public Hunting ground	Hunting	4000	Atlantic forests: *Fagus sylvatica, quercus pyrenaica,* scattered farming and arable land	Roe deer, wild boar	No	Yes	Collective	No	No

Name study site	Country	Bioregion	Institution	Administrative figure	Use	Area (ha)	Habitat	Big animals present	Wolf present	Hunting	Hunting modality	Artificial feeding	Fencing
Parc Natural del Montgó	Spain	South	Generalitat Valenciana (Regional Government)	Natural Park	Protected urban	2086	Termo-mediterranean shrub and forests dominated by *Pinus* ssp,	Wild boar, Barbary sheep	No	Yes	Individual & collective	No	No
Stalbo	Sweden	East	University of Gävle	Hunting ground	Hunting	2500	Boreal forest: Pine and Spruce dominating, scattered deciduous trees: Birch, Aspen, Goat Willow	Moose, Roe deer, red deer, wild boar	No	Yes	Individual & collective	Yes	No
Kartdag Wildlife Reserve	Turkey	South	University of Kastamonu	Protected reserve	Protected	11000	Mixed broad-leaved forest	Brown bear, red deer, wild boar, roe deer, grey wolf	Yes	No	No	No	No
*Munella mountain/Center-North region in Albania	Albania	East	PPNEA (Protection and Preservation of Natural Environment in Albania)	Protected Area	Protected	24447,8	Mixed broad-leaved forest	Northern chamois, wild boar, Eurasian lynx, brown bear	Yes	No	No	No	No
*Lagodekhi National Park	Georgia	Alpine/Boreal	Ilia State University	National Park	Protected	24450	Highly rugged terrain covered with mesic temperate broad-leaved forests, sub-	Red deer, roe deer, wild boar, chamois, East Caucasian tur,	Yes	No	No	No	No

Name study site	Country	Bioregion	Institution	Administrative figure	Use	Area (ha)	Habitat	Big animals present	Wolf present	Hunting	Hunting modality	Artificial feeding	Fencing
							alpine vegetation, alpine meadows and sub-nival tops	bezoar goat, brown bear, grey wolf, lynx, leopard (possible)					
*Alt Oerrel	Germany	West	Institute for Terrestrial and Aquatic Wildlife Research- ITAW	2 hunted forestry office grounds, Forestry Office Oerrel, Niedersächsische Landesforsten	Hunting	4130	Mixed forest, dominated by pine, spruce and oak, surrounded by arable land	Wild boar, red deer, roe deer, grey wolf	Yes	Yes	Individual & collective	No	No
*Süsing	Germany	West	Institute for Terrestrial and Aquatic Wildlife Research- ITAW	2 hunted forestry office grounds, Forestry Office of Oerrel, Niedersächsische Landesforsten	Hunting	2720	Mixed forest, dominated by pine, spruce and oak, surrounded by arable land	Wild boar, red deer, roe deer, grey wolf	Yes	Yes	Individual & collective	No	No
*Kalambaka area	Greece	South	Faculty of Veterinary Science				Mediterranean Scrubland and forest	Red deer, wild boar, grey wolf, brown bear	Yes				

Name study site	Country	Bioregion	Institution	Administrative figure	Use	Area (ha)	Habitat	Big animals present	Wolf present	Hunting	Hunting modality	Artificial feeding	Fencing
*Forest-Hunting enterprize "Sil-Razeni"	Moldova	East	Institute of Zoology	Hunting Reserve	Hunting	7373,7	Central-European forest: *Quercur petraea, Q. robur, Fraxinus excelsior, Carpinus betulus*, scattered with farming and arable land	Roe deer, wild boar	Yes	Yes	Collective	Yes	No
*Mrezicko	North Macedonia	Alpine/Boreal	Hunting Federation of Macedonia / Lovecka Federacija na Makedonija	Hunting ground	Hunting	2500	Forest, Pine (Pinus), Fir (*Abies*) and Beech (*Fagus sylvatica)*	Roe deer; northern chamois, bear, wild boar, grey wolf	Yes	Yes	Individual	No	No
*Covasna	Romania	East	Covasna Environmental Protection Agency	Private Hunting Ground	Hunting	6000	Mixed forests, mainly *Fagus sylvatica* and *Quercus* species, spruce, pastures, and arable land	Roe deer, red deer, wild boar, wolves, brown bear, Eurasian lynx	Yes	Yes	Individual & collective	Yes	No
Parque Natural Sierra del Carche*	Spain	South	Universidad de Murcia, C.A. de la Región de Murcia	Regional Park, Protected area	Protected	5942	Mediterranean forest and scrub, mainly *Pinus halepensis*	Wild boar, rare Barbary sheep, Iberian ibex	No	Yes	Collective	No	No
Senj*	Croatia	South	Faculty of Agriculture,	Hunting ground	Hunting	3548	47% of habitat is covered with small bushes and grass,	Roe deer, wild boar, red deer, European	Yes	Yes	Individual & collective	No	No

Name study site	Country	Bioregion	Institution	Administrative figure	Use	Area (ha)	Habitat	Big animals present	Wolf present	Hunting	Hunting modality	Artificial feeding	Fencing
			University of Zagreb				43% is without vegetation cover and 10% is covered with forest	mouflon, brown bear, Eurasian lynx, grey wolf, golden jackal					
The Bohemian Switzerland National Park*	Czech Rep.	Alpine/Boreal	Mendel University in Brno	National Park	Protected	8000	Mainly coniferous forest strongly affected by the bark beetle calamity	Red deer, roe deer, wild boar, chamois, grey wolf, lynx	Yes	Yes	Individual	Yes	No

(*) Study areas which will provide density values in summer 2023 (ongoing data processing).

Table 3. EOW study areas providing density values for wild ungulates (wild boar, red deer, or roe deer) in this report: field effort parameters.

Name study site	**Country**	**Area** (ha)	**Nº CTs**	**Nº rounds**	**Nº deployments**	**Nº deployments/area** (km^2)	**CT*days**	**Start**	**End**	**Duration** (days)
Vedat de caça de la Vall de Ransol	Andorra	2813	12	3	36	1.28	720	15-6-22	14-11-22	148
Game management unit 8	Belgium	6000	32	3	96	1.60	2016	28-6-22	31-8-22	64
Marche-en-Famenne	Belgium	2500	12	3	35	1.40	1115	28-6-22	4-10-22	98
Romanija	Bosnia & Herzegovina	6000	12	3	32	0.53	469	29-7-22	6-10-22	69
Voden-Iri Hisar	Bulgaria	8000	28	2	56	0.70	728	5-7-22	29-8-22	55
The Bohemian Switzerland Nat. Park*	Czech Rep.	8000	37	1	37	0.46	2294	1-7-22	31-8-22	61
Marais Noir de Saint-Coulban	France	1500	17	1	17	1.13	817	3-6-22	26-10-22	145

Name study site	Country	Area (ha)	Nº CTs	Nº rounds	Nº deployments	Nº deployments/area (km^2)	CT*days	Start	End	Duration (days)
Gemenc	Hungary	20000	12	3	36	0.18	720	14-9-22	1-12-22	60
Ramat Hanadiv Nature Park	Israel	1160	19	3	24	2.07	528	27-10-22	6-12-22	40
La Mandria	Italy	1604	14	1	14	0.87	1156	1-7-20	4-10-20	95
Alpe di Catenaia	Italy	2700	20	2	40	1.48	1336	20-6-22	29-8-22	70
CACN1/Val Maira	Italy	34851	36	2	36	0.10	285	23-8-21	31-10-21	69
Model territory MMMPV	Lithuania	5646	24	2	36	0.64	564	3-10-22	6-12-22	64
Orjen Mountain	Montenegro	6000	12	3	36	0.60	540	12-8-22	25-9-22	44
Central Veluwe	Netherlands	6000	45	1	42	0.70	1703	26-10-22	6-12-22	41
Białowieża Forest	Poland	2947	16	3	48	1.63	2368	16-5-22	17-10-22	154
Castreja	Portugal	2470	25	1	22	0.89	1034	16-2-21	5-5-21	78

Name study site	Country	Area (ha)	Nº CTs	Nº rounds	Nº deployments	Nº deployments/area (km^2)	CT*days	Start	End	Duration (days)
Lombada	Portugal	21184	30	1	28	0.13	1963	19-1-21	12-4-21	83
Murça	Portugal	6404	25	1	23	0.36	1445	21-2-21	8-5-21	76
Castelo Melhor	Portugal	3329	25	1	24	0.72	1443	24-1-21	9-4-21	75
Cubeira	Portugal	1812	25	1	24	1.32	1212	9-3-21	13-5-21	65
Tolosa	Portugal	4695	25	1	22	0.47	825	10-8-21	19-10-21	70
Arrábida	Portugal	36283	25	1	24	0.07	940	24-7-21	8-9-21	46
Sudoeste	Portugal	6142	25	1	25	0.41	650	14-7-21	9-9-21	57
Bicas da Serra	Portugal	1129	25	1	24	2.13	744	16-11-21	17-12-21	31
ZCA Santulhão	Portugal	2998	15	3	45	1.50	1025	18-7-22	4-10-22	79
Studenica	Serbia	11000	12	3	36	0.33	969	31-7-22	18-10-22	79

Name study site	Country	Area (ha)	Nº CTs	Nº rounds	Nº deployments	Nº deployments/area (km^2)	CT*days	Start	End	Duration (days)
Javorie	Slovakia	10000	12	3	36	0.36	1251	1-8-22	7-12-22	128
Rižana	Slovenia	3657	12	3	32	0.88	1208	29-7-22	2-11-22	96
Vrhe Vrabče	Slovenia	3950	12	3	33	0.84	1011	28-7-22	27-10-22	91
Cabanes-Torreblanca (Castellón)	Spain	850	12	1	12	1.41	337	13-9-22	17-10-22	34
Parque Nacional de Doñana	Spain	35600	Distance sampling							
Riofrio	Spain	6141	19	1	19	0.31	744	22-9-22	2-11-22	41
Arriola (Araba)	Spain	4000	42	2	46	1.15	2304	20-7-22	30-11-22	133
Parc Natural del Montgó	Spain	2086	12	1	11	0.53	331	13-10-22	18-11-22	36
Stalbo	Sweden	2500	12	3	35	1.40	1104	3-8-22	5-11-22	94

Name study site	Country	Area (ha)	Nº CTs	Nº rounds	Nº deployments	Nº deployments/area (km^2)	CT*days	Start	End	Duration (days)
Kartdag Wildlife Reserve	Turkey	11000	12	3	36	0.33	756	23-6-22	25-9-22	94

(*) Distance sampling was applied for wild boar using thermal cameras.

The Figure 2 shows the bioregion classification used by *ENETWILD* (*ENETWILD* consortium 2021c), as well as the distribution of countries where the EOW has active study areas[1] (Fig. 2b), indicating those providing density values of wild ungulates in the present report (n=21), those providing density values in summer 2023 (n=7), and countries where density estimation in 2023 was not possible due political reasons (n=4).

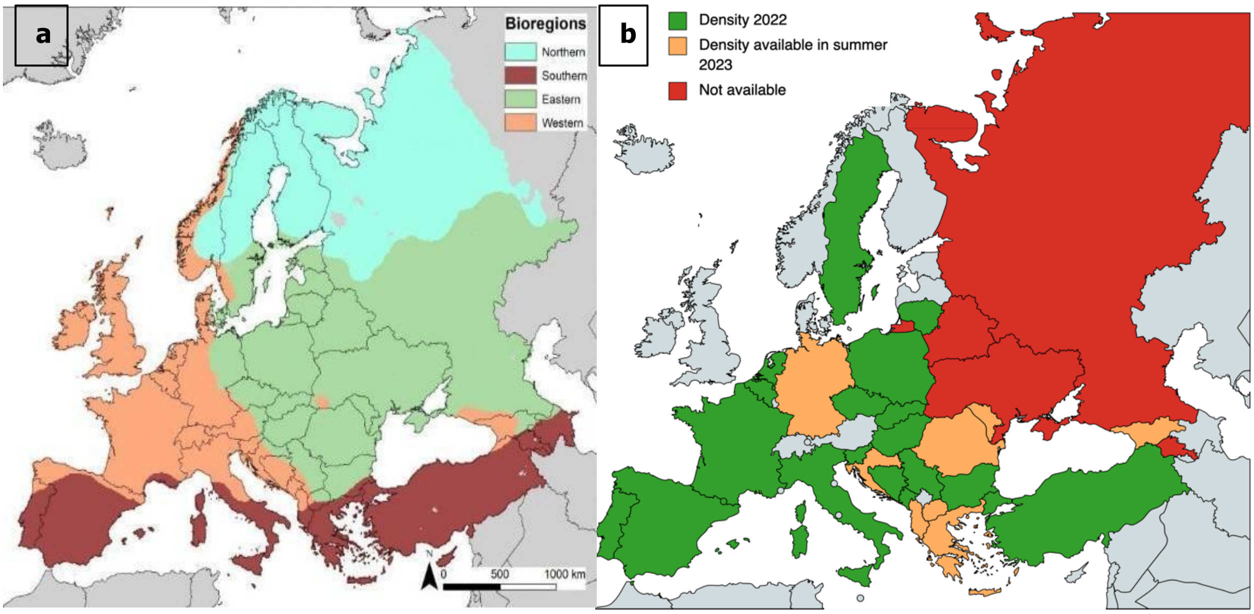

Figure 2. (a) Bioregion classification used by *ENETWILD* (*ENETWILD* consortium 2021). (b) Distribution of countries including study areas providing density values of wild ungulates in the present report (n=21, in green). Northern area was grouped with study areas placed in alpine regions (indicated as Alpine/Boreal in Table 2). Some study areas (N=9) are providing density values in summer 2023 (n=8 countries, in orange), whereas in 4 countries from eastern Europe (in red) it was not possible to deploy CTs.

3.2. The field protocol

Since different methods are available, the EOW focused on a CT-based, practical method that can generate reliable data in a wide range of situations and species throughout Europe. REM, as well as camera trap distance sampling and related methods for estimating the density of unmarked animals require data on animal positions relative to camera in order to estimate camera detection zone size and (specifically for REM) animal speed of movement. For the data collection of 2022, the EOW decided to allow the collaborators to choose between two different protocols to obtain the above mentioned data for REM: with natural marks structure like in the previous field season (*ENETWILD* consortium 2022b,c) or with the new developed photogrammetry method. Other methods considered as reliable (https://wildlifeobservatory.org/wp-content/uploads/2022/02/IREC-DOC-2022-final.pdf) were also used to a less extent, namely distance sampling in two study areas: in Doñana National Park (Spain, characterized by open habitats and scrublands, see Barroso et al. 2020), and the Bohemian Switzerland National Park (Czech Rep., incorporating thermal vision).

3.2.1. Sampling design and period

- Table 3 shows details on effort applied in each study area.
- The work was developed mainly during summer/autumn 2022, with the CTs placed for a minimum of 60 days.
- CTs were placed (registering the geographical coordinates) following a regular uniform distribution as a grid (Figure 3). The separation between CTs was approx. 1.5–2.5 km. The exact location can be within a diameter of less than 150 m around the points of the grid. The CTs were moved during the experiment to cover the minimum of, ideally, 40 locations per study area, although it was not possible in certain regions due to logistic constraints. For instance, 15 CTs moved twice (every 3 weeks) ideally fit a study area of approximately 2500–3000 ha. However, in case the study area is bigger, the distances between camera traps were larger than 1.5 km in order to enhance representativeness.
- The CTs were placed on poles or vegetation 50 cm above the ground.
- The CTs were configured with operation of 24 hours per day and to take the maximum possible number of consecutive images in rapid sequence, with the minimum waiting time (0 sec. if possible) between activations. We used medium sensitivity.
- The flash intensity was set at medium to avoid "overexposed photos".
- We checked that the date and time are correctly set, and automatically printed on each image.
- The CTs were reviewed at least halfway through the study period (ideally once a month) to check their functioning and placement. Normally it was not necessary to change the batteries and the memory cards, since the CTs were placed at random points and high wildlife activity was not expected.
- We chose a field of vision of the CT that was cleared of vegetation (it is not necessary to be totally clean, but it should be the detection of any animal that passes within the first 5 m), preferably facing north.
- A form was filled in, collecting the information of each CT during its placement. All the information that was subsequently extracted kept the traceability of the CT (we marked the source camera of each memory card extracted and kept this nomenclature in the folders that were created on the computer to archive the images).

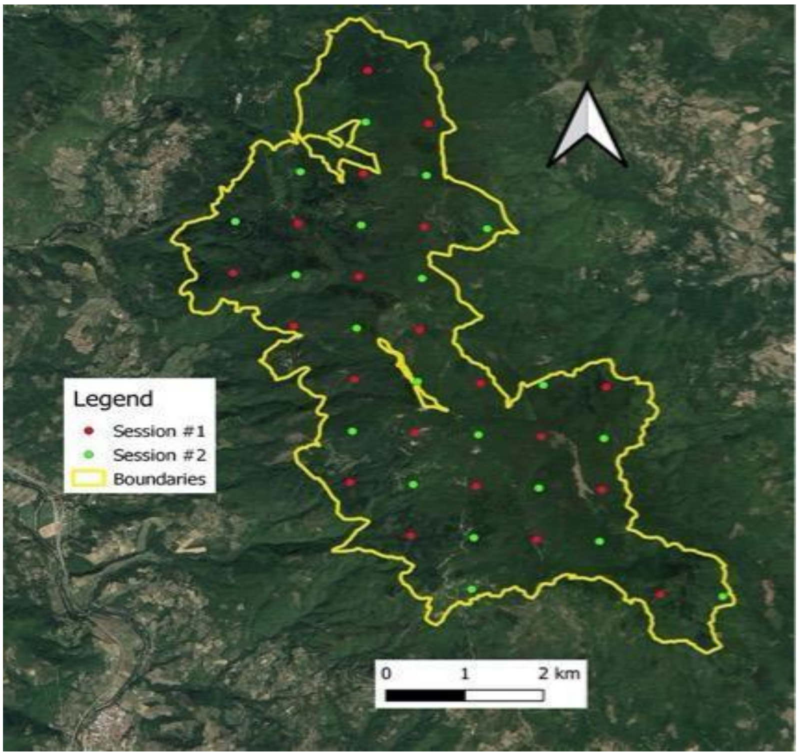

Figure 3. Example of study design (Alpe di Catenaia, Italy). Borders of the study area are shown by the yellow line and the dots show the camera position for each of the two deployment sessions.

3.2.2. Natural marks structure

This methodology requires the placement marks or stakes at a distance from the CTs that serves as a guide to subsequently mark the path followed by each animal, as indicated below.

We placed stakes in 2.5m intervals creating a grid of points (Figure 4, for details, see Annex 2). Connecting the stakes with signalling tape helps to better visualise distances. Finally, we ensured that a photograph where these stakes are evident was taken from the CT before starting the session. We put natural marks (stones, branches…) before removing the stakes for later identification of the path of the animals photographed. Such a structure allows to calculate the animal movements within each sequence and to evaluate the actual field of view of the camera.

Figure 4. Scheme of the stick-structure (green dots) used to reference the animal captured by the camera-trap. By turning it from the camera position and using the distances indicated, reference points can be easily marked (right).

3.2.3. Photogrammetry

This method estimates camera detection zone size and animal speed of movement using a computer vision process based on mapping image pixel positions to real world ground positions relative to the camera. This "map" can then be used to estimate the positions of animals in images with minimal effort. To create the map, images of calibration poles are required at each camera deployment in the field. The protocol was adopted:

We used a straight, strong pole (e.g., PVC electrical tube) at least 1 m in length, and marked it in a durable way with bands in a contrasting colour, e.g., white duct tape on a black pole (Figure 5). We placed five bands at 20 cm intervals from one end, from 0.2 to 1 m.

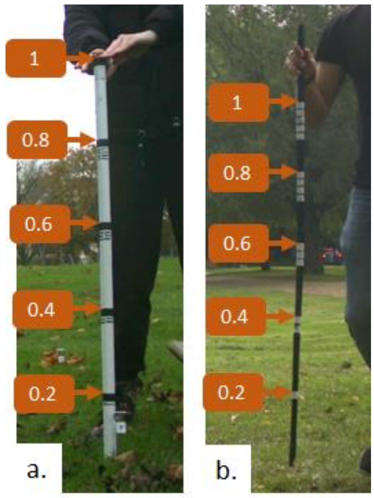

Figure 5. Two examples of calibration poles. The top of each group of bands is at a known height above ground at 20 cm intervals. Heights above ground are indicated in meters, with the number of bands in each group indicating the height increment.

Once the camera has been set up and switched on, we hold the pole with its base on the ground so that it is clearly visible to the camera. We ensured that the pole is held perpendicular to the camera's line of sight. On level ground with camera line of sight roughly parallel to the ground surface, the pole should be roughly vertical, but if the camera is angled to observe a slope the pole may need to be tilted accordingly (see Figure 6).

We hold the pole still long enough to ensure a clear image (generally 5-10 seconds). In order to indicate when the pole is resting on the ground, we give a distinctive hand gesture when this is the case. For example, in Fig. 5a, the pole is held by pressing on the top with outstretched fingertips. Closer to the camera, the pole top may not be visible, so it may be necessary to signal lower down, for example with a clenched fist held next to the middle of the pole.

We repeated this for further pole placements across the field of view and away from the camera, with placements spaced about 0.5 m apart. We continued away from the camera to the maximum extent that any animals are likely to be captured, or if possible, a bit beyond. As we reached greater distances, it helped to have a second person next to the camera to keep triggering it.

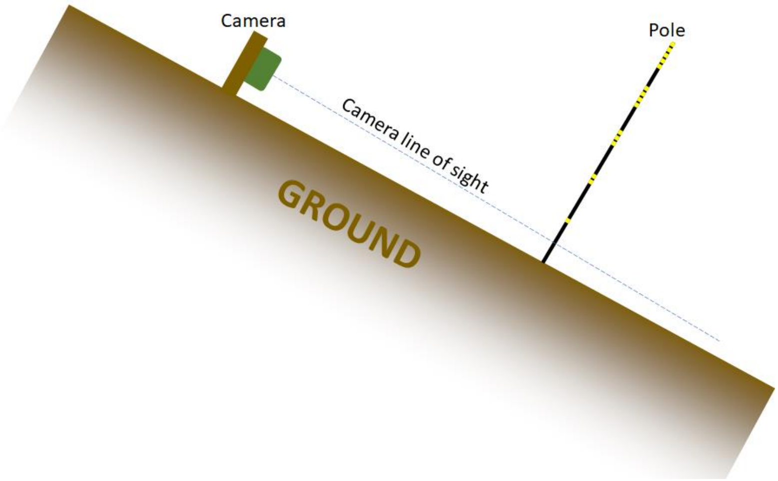

Figure 6. Diagram illustrating a camera set up to observe sloping ground, and the orientation of the calibration pole required to keep it perpendicular to the camera line of sight. Orientation can be judged by eye and need not be measured precisely in the field.

The photogrammetry method also requires taking camera calibration pictures (this is done once for every camera model and image resolution). In this case pictures of the calibration pole are taken at a range of known distances from the camera to calculate the camera model's intrinsic properties, which then allow us to calculate the distance of calibration poles in deployment calibration (Figure 7). This needs to be done for each combination of camera model and image resolution setting used in the field.

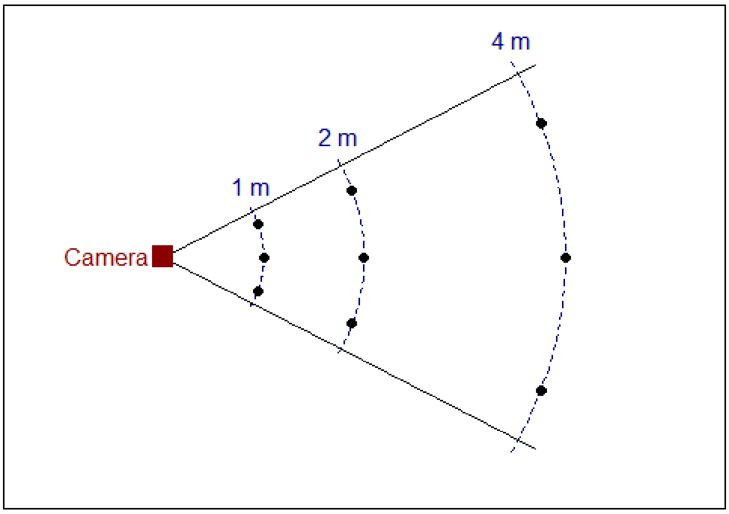

Figure 7. Plan view of an example layout for a camera calibration pole grid.

3.3. Image processing: Annotation

In 2022 the image processing has been implemented through the use of the online platform Agouti, which allows users to easily store and sequence the pictures in different projects for each study site. Once the pictures from each deployment have been uploaded the processing consists of three main steps: annotation, digitising of deployment calibration and digitising of animal movements.

The annotation process consists of recognising the species present in each sequence of pictures and counting the individuals specifying their age and sex class where known. Every time that an animal exits from the camera field of view and comes back in it is considered as a new individual and the behaviour categories (if used) can be defined by each collaborator as they were not included in this study.

Agouti also offers tools for the automatic annotation of the sequences, collaborators can choose between two main versions of Artificial Intelligence (AI), one is only annotating blank pictures, where that camera was activated without any animal in front of it, and those with humans, while the other version is actually recognising and annotating animal species.

3.3.1. Digitising of deployment calibration

The deployment calibration sequences are made of the pictures of the operator with the calibration pole as described in paragraph 3.2.3, and their digitising is fundamental for the estimation of the speed and camera field of detection parameters. Among the pictures of these sequences, the operator must choose those where the pole is clearly in the right position (touching the ground and perpendicular to the camera line of sight) and mark, using the specific Agouti function, the highest and lowest marked points on the pole. Each camera deployment must have its own deployment calibration in order to be included in the parameters' estimation.

3.3.2. Digitising of animal movements

This process consists in using the tracking function of Agouti to mark the animal position throughout the sequences. The foremost foot of the animal touching the ground is marked and is being tracked through the sequence. When the foot is not visible (e.g., behind an obstacle or just outside from the frame) but it is still possible to accurately guess its position the tracking can still be performed.

For those who adopted the natural marks method this function manual calculation of animal movements is required. In this case, the natural marks which are at known distances from the camera are used to calculate the animal movements through the sequences and the camera field of view parameters.

3.4. Data analysis to obtain density estimates

For the data analysis a simplified procedure in *R* software has been developed that allows every user to obtain density estimates from the data exported from Agouti. Once the data package has been exported from Agouti, following the step-by-step procedure collaborators can independently run the REM analysis and obtain density estimates for the target species present in their study areas (see *ENETWILD* 2022c; video: https://wildlifeobservatory.org/3rd-course-running-rem-analysis-on-camera-trap-data-packages-from-agouti/).

The range of species that can be included in this kind of analysis is very wide, however we focused on those more widespread ungulates: wild boar, roe deer and red deer. For them, densities are available over a large number of study areas which allows an evaluation of factors determining abundance. An added value of all participants focusing initially on a few species was the possibility to tune the image analysis process by using recently developed automatic tools with AI, since a number of methodological and technical issues arose during the process. For these purposes, the coordinators of the EOW (IREC, UNISS) and the developers of the ITts (WUR, IMBO, ZSL) were continuously available to answer questions and to solve technical problems related to the tools.

3.5. Evaluation of population factors determining the day range

Rowcliffe et al. (2008) described the REM (the method here applied for estimating animal density without the need of individual recognition), by using the distance travelled by one animal over the day (i.e., day range). While different approaches have been proposed to derive day range values, a recent development can estimate the day range based solely on the information derived from CT; in which, it is estimated as the product of travel speed (i.e., average speed while active) and activity level (i.e., the proportion of the day that the population is active) (Rowcliffe et al. 2016), which was applied in the field trial. To summarise, the parameters required to estimate density by the REM method include: y/t, the encounter rate; v, the average distance travelled by an individual during a day (day range); r, the radius of detection; and ϴ, the angle of detection). The day range is an essential behavioural parameter which contributes to scale trapping rates into density values, and it is population and context dependent. The 2022 campaign of the EOW provided the sufficient variability in day range to evaluate the determining factors of this important parameter.

3.6. Evaluation of population factors determining the wild boar density

We developed GLMzs (generalised linear models) for daily range (response variable) where bioregion was always used as explanatory variable to control for. The GLMzs, respectively, included as explanatory factors: the land use (protected, hunting, protected close to urban), the hunting modality (only single, only collective, single, and collective, no hunting), and hunting (yes/no). We included the respective interaction of these factors with bioregion. We used a gamma error and an identity link function. No model yielded overdispersion.

3.7. Evaluation of the precision of estimations in relation to effort variations in the application of the sampling protocol

The EOW promotes practical but reliable methods to estimate the density of wildlife. Under this approach, we must consider that the effort to determine density (e.g., measured in terms of number of CT deployments, duration of the field trial), as well as the study design and the distribution of the population over the study area greatly contributes to the precision of the final estimation. The usual aggregated distribution of wildlife and subsequently trapping rates by randomly deployed CTs, especially at low densities, requires sufficient sampling effort to obtain a suitable number of contacts to model the process of scaling the trapping rate to density. It also determines the precision of the density values, i.e., the coefficient of variation and confidence intervals. From a practical point of view and using the wild boar as reference species in this report, we analysed the contribution of parameters associated with the study design (number of CT deployments and their duration) to the precision of the estimation (namely, the coefficient of variation, CV, expressed as a percentage). In the present field trial, the application of the protocol was adapted to local logistic constraints and available human and technical means, and therefore it provided an excellent opportunity to test the impact of such parameters (number of CT deployments and their duration) on density precision. As we will see below, these two parameters did not collineate in our statistical models (Variance Inflation Factor always < 1.2).

The number of deployments refers to the total number of sites used (not to the instantaneous number of CTs). The duration of the study refers to the total, i.e., since CTs were deployed in the first round to the date CTs were removed after the last round.

We designed a GLMz where the CV per wild boar population was the response variable, and the number of CT deployments, their duration, and the trapping rate were the explanatory variables. We used a gamma error and a log link function. The model did not yield overdispersion. The results were interpreted as a function of the number of rounds of CT deployments used to apply the field protocol (which aimed to obtain a minimum of 40 CT deployments per study area).

4. Results

4.1. General

The efforts related to the application of the REM method per study area are shown in Table 4 (Nº CTs, Nº rounds, Nº deployments, Nº deployments/area, CT*days, duration). These results are summarised in Table 4 and are also visually represented in Figure 8. The observed variability in these parameters (Figure 8) resulted from the availability of CTs in each study area (apart from these provided by the EOW) and local logistic constraints, which affected the final number of CT deployments (also mediated by the number of rounds applied) and the duration of the study period (the majority of study areas applied more than 60 days of duration, as recommended).

Table 4. Summary of statistics on the effort related to the application of REM method per study area.

	Mean (median)	SE	Min	Max
Nº CTs	21.1 (19)	1.5	12.0	45.0
Nº deployments	31.9 (32)	2.3	11.0	96.0
Nº deployments per area (km^2)	0.9 (0.7)	0.1	0.1	2.1
Nº CT*days	1056.4 (969)	88.3	285.0	2368.0
Duration (days)	72.9 (70)	4.8	29.0	154.0

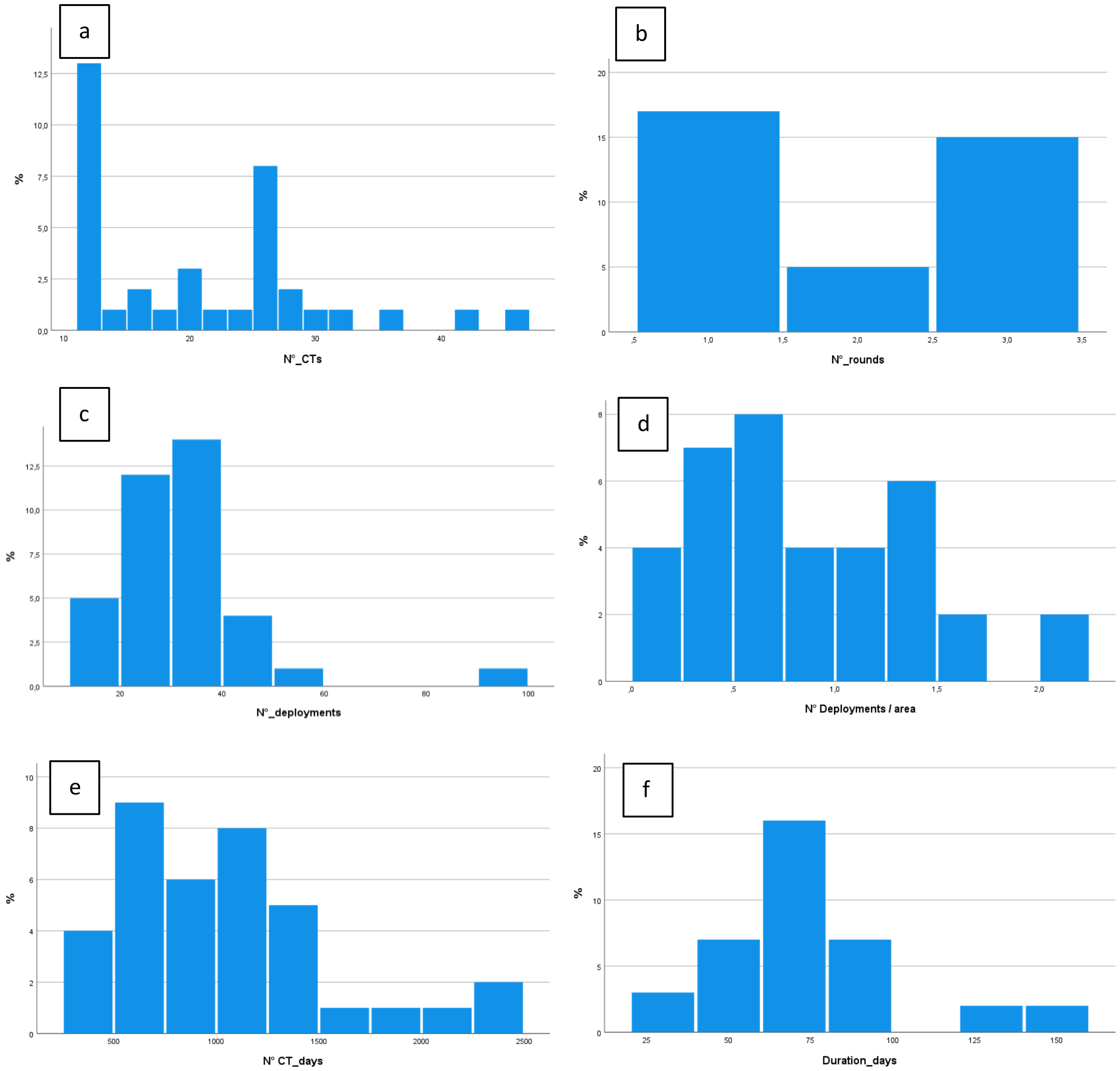

Figure 8. The distribution of efforts to apply the REM method per study area (a: Nº CTs used, b: Nº rounds, c: Nº CT deployments, d: Nº deployments/area, e: CT*days, f: duration of the field trial).

4.2. Wild boar

This section focuses on results obtained for wild boar.

4.2.1. Parameters estimated to determine density by REM

Table 5 shows a summary of the estimated REM parameters for each population of wild boar: y/t is the encounter rate; v, the average distance travelled by an individual during a day (day range); r, the radius of detection; and ϴ, the angle of detection. Their frequency distributions can be visualised in Figure 9.

The day range of wild boar per population averaged 9.14 km*day (ranging from 1.56 km*day in Model territory MMMPV (Lithuania) to 29.76 in Gemenc (the only remaining tidal area of the Danube in Hungary, followed by Białowieża, 27.20 km*day, a forest on the border between Belarus and Poland, one of the last and largest remaining parts of the European primaeval forest). The trapping rate values usually were below 0.6 ind·(cam·day)$^{-1}$ (Figure 9), however three populations presented remarkably higher values (Cabanes-Torreblanca-Spain, La Mandria-Italy, Alpe di Catenaia-Italy), which also showed some of the highest density values in this study (see below). The radius and angle of detection presented average values well centred (about 6.5 m and 2.8 radians, respectively, Figure 9c and d).

Table 5. Summary statistics of parameters estimated to determine wild boar density by REM method per study area (y/t is the encounter rate; v, the average distance travelled by an individual during a day (day range); r, the radius of detection; and ϴ, the angle of detection).

Parameter	Min.	Max.	Mean	SE
y/t: Trapping rate ((ind·(cam·day)$^{-1}$)	0.01	1.57	0.32	0.07
v: Daily range (km per day)	1.56	29.76	9.14	1.10
r: Radius of detection (m)	4.08	9.36	6.48	0.22
ϴ: Angle of detection (radians)	0.55	69.52	2.82	2.02

Table 6 shows the wild boar density values per study area and Figure 9e shows the density frequency distributions.

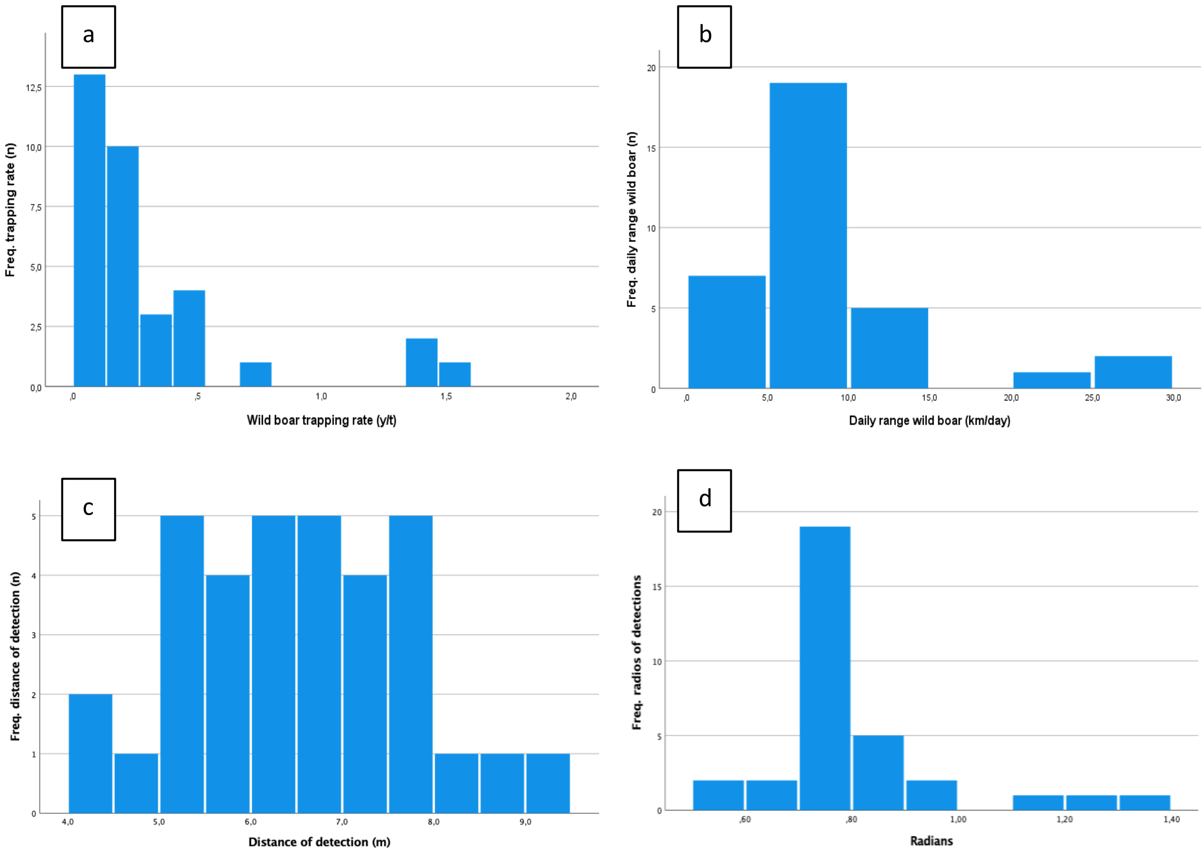

Figure 9. Distributions of the parameters estimated to determine density by REM method per study area: (a) y/t is the encounter rate; (b) the average distance travelled by an individual during a day (day range), v; (c) the radius of detection, r; (d) the angle of detection, ϴ; and (e) wild boar density.

The GLMzs for the wild boar day range (response variable, Table 7), where bioregion was used as an explanatory variable (Figure 10a), did not indicate statistical differences in the land use (Figure 10b) or hunting modalities (and absence of hunting, Figure 10c). No significant differences were seen by the binary explanatory variable hunting (yes/no, model not shown).

Table 6. Estimated random encounter model (REM) parameter values for each population of wild boar, where y/t is the encounter rate; v, the average distance travelled by an individual during a day (day range); r, the radius of detection; and ϴ, the angle of detection.

Study site	Country	y/t (ind·(cam·day)$^{-1}$)	v (km/day)	r (m)	ϴ (rad)	Density (Nº ind/Km^2)	SE	CV (%)	Nº sequences
Vedat de caça de la Vall de Ransol	Andorra	0.01	8.74	8.09	0.55	0.193	0.14	70.17	104
Game manag. unit 8	Belgium	0.44	9.76	5.95	0.80	8.60	2.93	34.06	697
Romanija	Bosnia Herzegovina	0.10	6.67	7.98	0.75	2.23	1.6	73.07	27
Voden-Iri Hisar	Bulgaria	0.22	10.57	4.81	1.13	4.38	1.84	42	809
The Bohemian Switzerland Nat. Park	Czech Rep.					1.24*		28.8	
Marais Noir St.Coulban	France	0.25	14.65	7.65	0.77	2.61	1.30	49.63	112
Gemenc	Hungary	0.76	29.76	7.36	0.72	8.07	5.72	71.5	746
Ramat Hanadiv Nat.P.	Israel	0.52	6.26	5.11	1.23	20.88	9.1	44	365
La Mandria	Italy	1.34	13.25	7.07	0.96	15.26	2.41	15.79	1569
Alpe di Catenaia	Italy	1.43	8.24	7.62	0.77	25.83	6.97	27	1300
CACN1/Val Maira	Italy	0.18	4.03	5.02	1.10	10.09	3.37	33.39	145
Model territory MMMPV	Lithuania	0.33	1.56	4.41	1.21	0.52	1.42	35.16	44
Orjen Mountain	Montenegro	0.2	10.47	6.28	0.79	2.85	1.68	58.82	96
Central Veluwe	Netherlands	0.20	22.52	6.58	0.81	2.05	1.02	50	334
Białowieża Forest	Poland	0.10	27.20	7.02	0.86	0.42	0.26	61.00	71

Study site	Country	y/t (ind·(cam·day)$^{-1}$)	v (km/day)	r (m)	θ (rad)	Density (Nº ind/Km^2)	SE	CV (%)	Nº sequences
Castreja	Portugal	0.08	2.72	8.71	0.73	6.39	2.65	41.44	87
Lombada	Portugal	0.04	6.6	5.18	0.73	2.79	1.12	40.12	90
Murça	Portugal	0.05	6.55	6.98	0.73	2.07	0.77	37.13	74
Castelo Melhor	Portugal	0.05	9.19	4.08	0.73	1.95	0.74	38.14	70
Cubeira	Portugal	0.15	9.08	6.78	0.73	6.75	1.46	21.67	183
Tolosa	Portugal	0.07	9.00	6.63	0.73	2.92	0.86	29.55	61
Arrábida	Portugal	0.2	5.14	5.87	0.73	18.45	6.36	34.46	186
Sudoeste	Portugal	0.19	3.84	7.97	0.73	19.95	8.42	42.21	122
Bicas da Serra	Portugal	0.13	4.04	6.3	0.69	16.26	6.45	39.65	99
ZCA Santulhão	Portugal	0.06	6.71	5.73	0.74	1.80	1.08	59.82	46
Studenica	Serbia	0.17	11.37	7.56	0.81	2.20	1.05	47.78	113
Javorie	Slovakia	0.22	9.83	5.33	0.74	4.73	2.18	46	253
Rižana	Slovenia	0.41	7.98	5.2	0.79	11.12	4.34	39.08	342
Vrhe Vrabče	Slovenia	0.33	8.48	6.12	0.82	7.131	2.49	35	161
Cabanes-Torreblanca	Spain	1.57	5.86	7.41	0.73	41.55	16.13	38.81	598
Parque Nac. Doñana	Spain					2.05*		38	
Riofrio	Spain	0.16	6.32	6.01	0.73	4.88	1.9	38.93	120
Arriola	Spain	0.30	12.91	6.21	0.76	4.27	0.76	17.82	693
Parc Nat. Montgó	Spain	0.25	3.22	5.08	1.36	14.47	9.59	66.28	81

Study site	Country	y/t (ind·(cam·day)$^{-1}$)	v (km/day)	r (m)	θ (rad)	Density (Nº ind/Km^2)	SE	CV (%)	Nº sequences
Stalbo	Sweden	0.05	2.27	9.36	0.64	2.81	3.23	114.79	20
Kartdag Wild. Res.	Turkey	0.09	7.98	5.51	0.55	2.45	1.55	63.31	54

(*) Estimated by distance sampling.

Table 7. GLMzs for wild boar daily range (response variable), where bioregion was used always as explanatory variable to control for, and hunting modality and land use as explanatory, respectively.

GLMz for hunting modality (as explanatory)					
	B	*B* (SE)	Wald Chi-sqr	gl	Sig.
Intercept	2.16	0.29	52.77	1.00	0.00
Bioregion= Alpine/Boreal	-0.25	0.31	0.64	1.00	0.42
Bioregion= East	0.42	0.27	2.64	1.00	0.10
Bioregion= South	-0.20	0.24	0.69	1.00	0.40
Bioregion= West	0.00				
Hunting modality= Collective hunting	0.31	0.44	0.49	1.00	0.48
Hunting modality= Individual hunting	0.38	0.33	1.33	1.00	0.24
Hunting modality= Individual & collective hunting	-1.12	0.26	0.21	1.00	0.64
Hunting modality= No hunting	0.00				
GLMz for land use (as explanatory)					
	B	*B* (SE)	Wald Chi-sqr	gl	Sig.
Intercept	2.00	0.38	27.4	1.00	0.05
Bioregion= Alpine/Boreal	-0.47	0.32	2.16	1.00	0.14
Bioregion= East	0.28	0.29	0.96	1.00	0.32
Bioregion= South	-0.37	0.23	2.51	1.00	0.11
Bioregion= West	0.00				
Land use= Hunting	0.42	0.34	1.53	1.00	0.21
Land use= Protected	0.02	0.39	0.004	1.00	0.91
Land use= Protected urban	0				

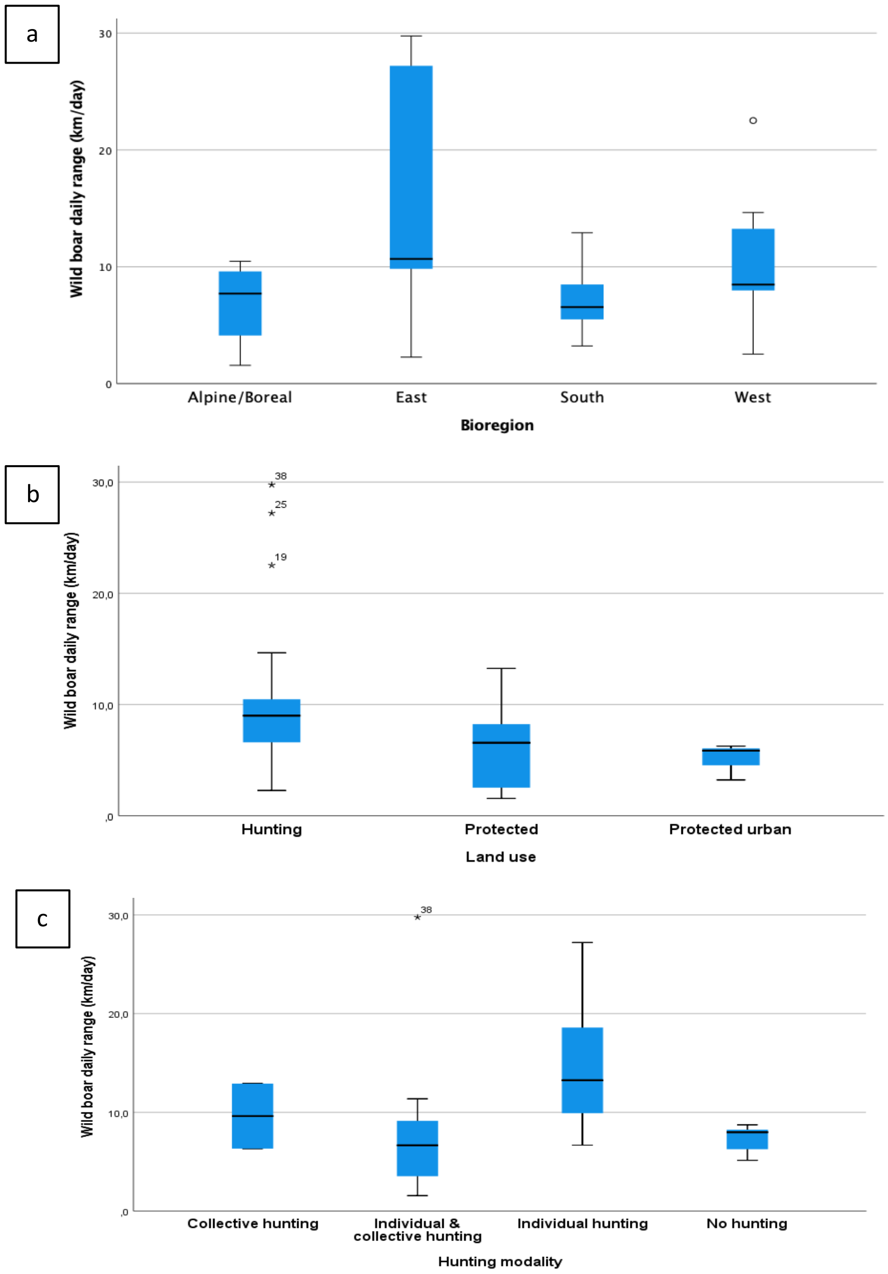

Figure 10. Boxplots representing the wild boar population day range (km/day) as a function of the bioregion (a), land use (b) and hunting modality (c).

4.2.2. Wild boar densities

REM densities for wild boar ranged from 0.19±0.14 individuals/km^2 in Vedat de caça de la Vall de Ransol (Andorra, Alpine habitat) to 41.55±1.13 individuals/km^2 Cabanes-Torreblanca, a small peri-urban natural area on the Mediterranean coast). Most values were below 5 individuals per square kilometre (Figure 11). Coefficients of variation (CV, %) ranged from 15.79 in La Mandria, Italy, to 142.42 in Gemenc (Hungary).

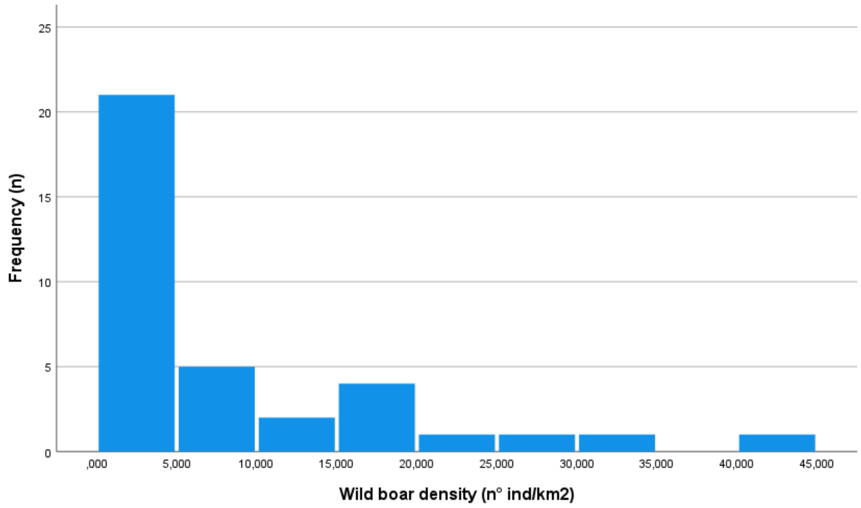

Figure 11. Distribution of wild boar densities (number ind/km^2) over the study populations (N=35).

Density values per bioregion, land use, hunting modality and presence of hunting (separately also for protected areas only), respectively, are shown in Table 8 and visualised in Figure 12 by means of boxplots.

Table 8. Summary of statistics for density by REM method per bioregion, land use, and hunting modality.

	N	Min	Max	Mean	SE
Bioregion					
Alpine/Boreal	5	0.2	2.9	**1.41**	0.5
East	6	0.42	8.08	**3.41**	1.09
South	16	1.8	41.5	**10.21**	2.76
West	9	2.05	30.8	**12.2**	3.36
Land use					

	N	Min	Max	Mean	SE
Hunting	25	0.2	19.94	**5.09**	0.96
Protected	8	0.52	30.8	**12.07**	4.29
Protected close to urban	3	14.47	44.5	**25.63**	8.17
Hunting presence					
Hunting absent	5	0.2	25.8	**13.55**	5.14
Hunting present	31	0.42	41.55	**7.5**	1.66
Hunting modality					
Collective hunting	2	4.27	4.88	**4.58**	0.31
Individual hunting	9	0.42	15.26	**3.64**	1.50
Individual & collective hunting	20	0.52	41.55	**9.55**	2.39
No	5	0.2	25.83	**13.56**	5.14

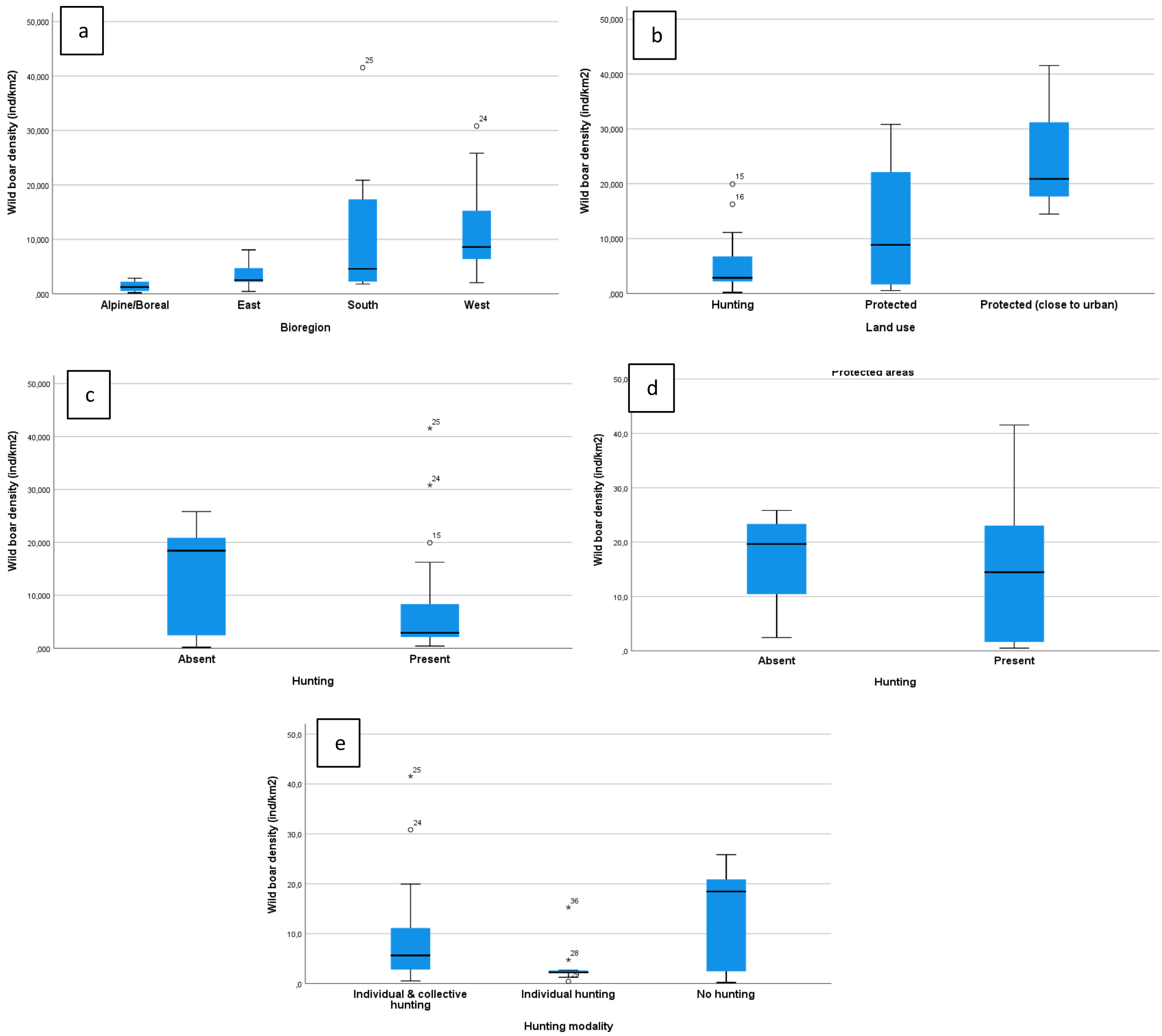

Figure 12. Boxplots representing the wild boar population density (nº ind/km^2) as a function of the bioregion (a), land use (b), hunting presence (c), hunting presence only in protected areas (d), and hunting modality (e).

The GLMzs for wild boar density (as response variable, Table 9), indicated always significant differences among bioregions, the highest densities being found in South and West bioregions of Europe (Figure 12a), the lowest in Boreal/Alpine areas. There was a significant effect for protected areas in proximity to urban zones to have higher densities (Figure 12b and see Figure 13a for bioregion South). Hunting presence model did not evidence statistical effects. However, hunting modality was significant, the lowest values were detected where individual hunting is practised.

Table 9. GLMzs for wild boar density (response variable), bioregion was always used as explanatory variable to control for, and hunting modality, and land use, respectively.

Parameters	Wald Chi-sqr	gl	Sig.
Land use model			
Intercept	16.610	1	0.0001
Bioregion	17.02	3	**0.001**
Land use	5.89	2	**0.05**
Land use*Bioregion	3.57	2	0.17
Hunting presence model			
Intercept	6.94	1	0.01
Bioregion	14.99	3	**0.00**
Hunting presence	0.66	1	0.42
Hunting presence*Bioregion	1.37	2	0.50
Hunting modality model			
Intercept	11.17	1	0.001
Bioregion	15.00	3	**0.002**
Hunting modality	7.19	2	**0.03**
Hunting modality*Bioregion	10.87	5	**0.05**

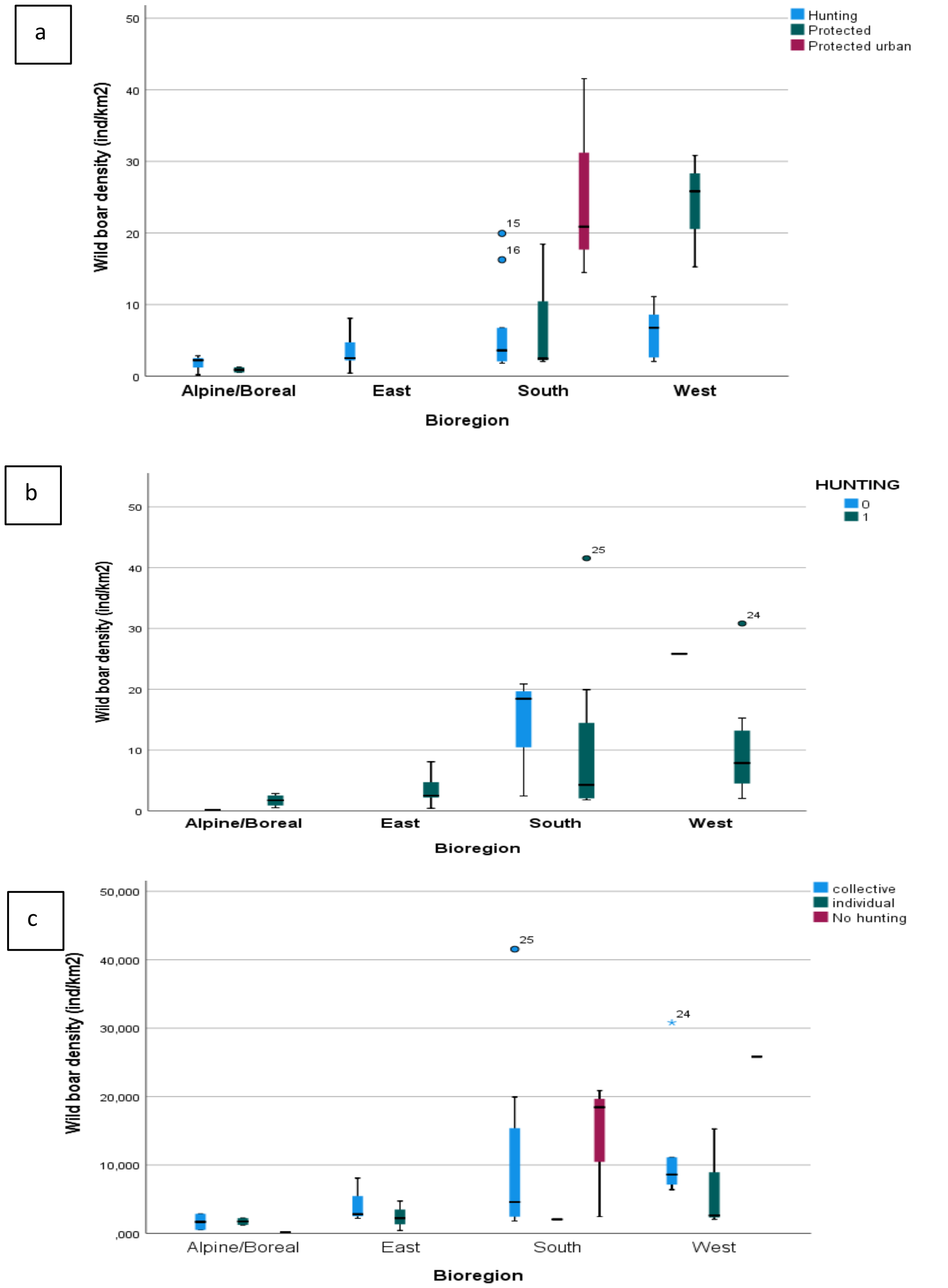

Figure 13. Boxplots representing the wild boar population density (nº ind/km^2) as a function of the bioregion and land use (a), presence of hunting (b), and hunting modality (c).

4.2.3. Precision of wild boar density estimations in relation to variations in the effort applied during sampling

We designed a GLMz where the CV per wild boar population density estimation was the response variable, and the explanatory variables were the number of CT deployments and the duration of deployments. The effect of the trapping rate was controlled for. The Table 10 displays the results of the GLMz. The variation of the inflation factor (<0.12) did not detect collinearity between the number of CT deployments and the duration of deployments (Figure 14). We detected a negative statistical relationship between the CV and the trapping rate (Table 10, Figure 14) but no effect associated to the number of CT deployments and the duration of deployments. Figure 15 shows the relationship between the CV (fitted values after the GLMz), and the trapping rates (a) and the duration of the CT deployment (b), and the number of deployments (c), respectively.

Table 10. GLMz where the CV per wild boar population density estimation was the response variable, and the explanatory variables were the number of CT deployments, the duration of deployments and the trapping rate.

	B	**SE (*B*)**	**Wald Chi-sqr**	**gl**	**Sig.**
Intercept	56.77	10.66	28.38	1	0.000
Duration of deployments	-0.09	0.09	0.97	1	0.324
Number of deployments	0.03	0.22	0.01	1	0.91
Wild boar trapping rate	-16.34	5.68	8.26	1	**0.004**

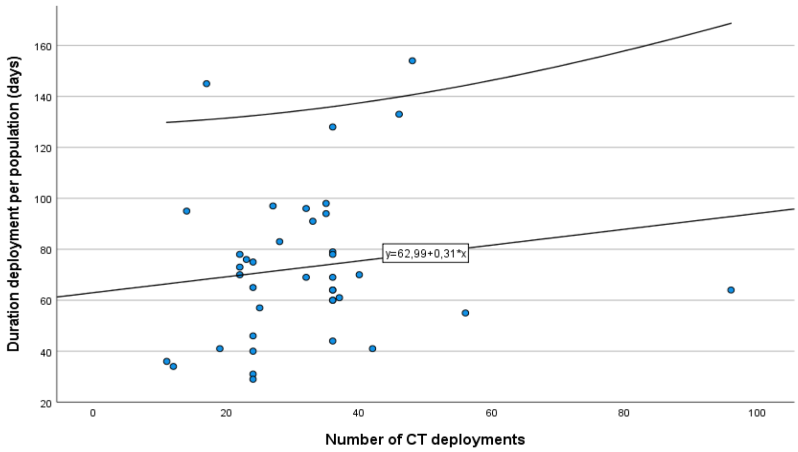

Figure 14. Relationship between the number of CT deployments and their duration per study site.

An additional GLMz evaluated the impact of the number of rounds on the wild boar density estimation CVs (Table 11), and it was evident that increasing the number of rounds (for a relatively constant duration of the field trial, Figure 16a) did not improve the CVs. Contrary, the higher the number of rounds, i.e. 3, the higher the CV (Figure 16b).

Table 11. GLMz where the CV per wild boar population density estimation was the response variable, and the explanatory variables was the number of rounds used to deploy a limited number of CT (which were removed and placed again in other locations). Reference parameter estimate value for variable "number of rounds" was established for level ="3 rounds".

	B	**SE (*B*)**	**Wald Chi-sqr**	**gl**	**Sig.**
Intercept	4.04	0.08	2286.76	1	0.000
Number of rounds (=1)	-0.38	0.12	9.94	1	**0.002**
Number of rounds (=2)	-0.59	0.18	10.41	1	**0.001**

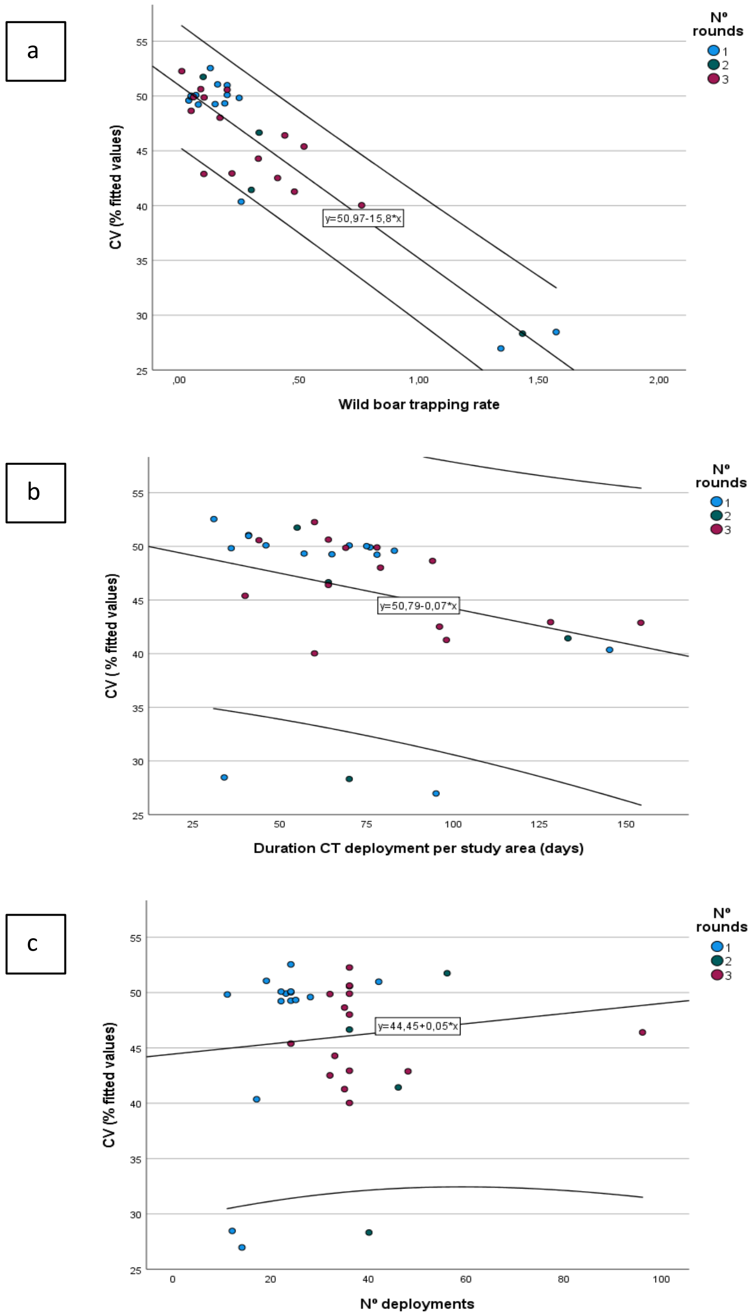

Figure 15. The relationships between the CV (fitted values after the GLMz) and the duration of the CT deployment (a), and the number of deployments (b) per study area, respectively. The number of CT deployment rounds performed in each study area is indicated by colour.

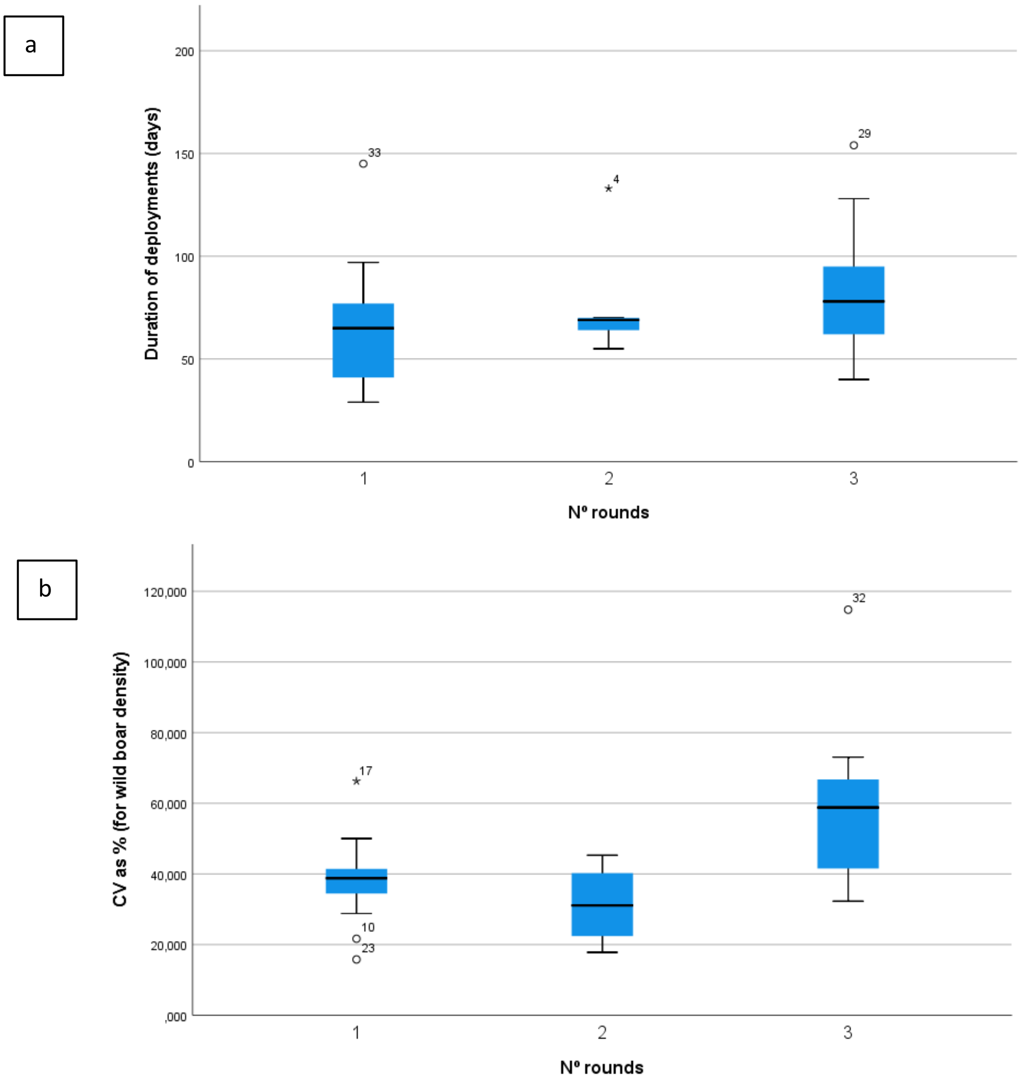

Figure 16. The relationship between the duration of the deployments per study site and the number of rounds (a), and between the CV (fitted values after the GLMz) and the number of rounds used to deploy the CTs (b).

4.3. Deer species

Regarding roe deer, REM densities (Tables 12 and 13) ranged from 1.15 ± 0.44 ind/km^2 in Stalbo (Sweden) to 17.34 ± 4.12 ind/km^2 in Marche-en-Famenne, Belgium. For red deer, REM densities ranged from 0.68 ± 0.54 ind/km^2 in Stalbo (Sweden) to 25.19 ± 7.84 ind/km^2 in Riofrio, Spain. Both species presented a similar frequency distribution of density values over the study populations (Figure 17).

Table 13 displays the estimated REM parameter values for each population of roe deer and red deer, where y/t is the encounter rate; v, the average distance travelled by an individual during a day (day range); r, the radius of detection; and ϴ, the angle of detection. The day range of roe deer per population averaged 9.18 km*day (ranging from 3.18 km*day in Marche-en-Famenne (Belgium), to 21.64 in Kartdag Wildlife Reserve (Turkey). For red deer, the day range per population averaged 7.81 km*day (ranging from 3.05 km*day in Javorie (Slovakia), to 23.81 in Gemenc (Hungary).

Table 12. Summary of REM densities (ind/km^2) for roe deer and red deer.

Species	N	Min	Max	Mean	SE
Roe deer density	20	1.15	17.340	6.36	5.15
Red deer density	14	0.68	25.19	6.80	6.51

Table 13. Estimated random encounter model (REM) parameter values for each population of **roe deer** and **red deer**, where y/t is the encounter rate; v, the average distance travelled by an individual during a day (day range); r, the radius of detection; and ϴ, the angle of detection.

Roe deer									
Study site	Country	y/t (ind·(cam·day)$^{-1}$)	v (km/day)	r (m)	ϴ (rad)	Density (Nº ind/km^2)	SE	CV (%)	Nº sequences
Vedat de caça la Vall de Ransol	Andorra	0.096	4.91	7.35	0.571	3.26	1.95	60.03	765
Voden-Iri Hisar	Bulgaria	0.16	12.6	5.15	0.84	1.34	0.51	37.81	314
Saint-Coulban	France	0.87	13.16	7.56	0.77	9.92	4.24	42.72	499
La Mandria	Italy	0.11	5.21	7.09	0.79	1.90	0.97	51.0	122
CACN3/**Val Maira**	Italy	0.36	6.08	5.04	0.69	15.9	4.38	27.55	356
Alpe di Catenaia	Italy	0.64	8.68	7.28	0.75	11.54	3.39	29.35	1015

Model territory MMMPV	Lithuania	0.74	10.85	6.13	0.91.	1.84	3.16	15.22	221
Orjen	Montenegro	0.3	11.25	7.6	0.74	2.22	0.96	41.3	135
Veluwe	Netherlands	0.15	13.6	7.5	0.86	1.30	0.65	50	245
ZCA Santulhão	Portugal	0.14	6.90	5.16	0.86	4.27	2.38	55.73	110
Studenica	Serbia	0.86	9.48	7.09	0.88	13.98	4.59	32.84	921
Javorie	Slovakia	0.17	9.07	8,84	0.73	2.49	1.048	42	253
Rizana	Slovenia	0.44	7.50	6.53	0.79	10.1	3.74	37	489
Riofrio- CLM	Spain	0.12	4.72	5.49	0.73	5.24	2.51	47.84	88
Arriola	Spain	0.33	6.6	5.94	0.85	9.16	1.83	20.02	753
Stalbo	Sweden	0.1	12.25	7.91	0.72	1.15	0.44	37.98	156
Kastamonu Kartdag	Turkey	0.13	21.64	3.85	0.55	2.05	1.84	90.03	145
Red deer									
Study site	**Country**	**y/t** (ind·(cam·day)$^{-1}$)	**v** (km/day)	**r** (m)	**ϴ** (rad)	**Density** (Nº ind/km^2)	**SE**	**CV** (%)	**Nº sequences**
Voden-Iri Hisar	Bulgaria	0.63	6.09	5.74	0.95	19.23	4.15	21.59	2754
La Mandria	Italy	0.46	6.33	7.3	0.78	11.03	3.17	28.74	529
Val Maira	Italy	0.27	3.12	12.24	0.79	0.79	0.77	97.47	51
Model territory MMMPV	Lithuania	0.07	5.16	5.2	1.24	2.86	2.72	23.7	3
Veluwe	Netherlands	0.24	12.79	8.11	0.86	3.34	2.03	61	395
Javorie	Slovakia	0.23	3.05	8.2	0.75	10.5	4.55	43	278

Doñana Nat. Park*	Spain					8.43		24	
Riofrio- CLM	Spain	0.39	3.57	4.67	0.94	25.19	7.84	31.12	293
Stalbo	Sweden	0.01	3.5	9.64	0.67	0.41	0.38	91.02	27
The Bohemian Switzerland National Park	Czech Republic	0.05	5.95	7.42	0.96	7.28	2.28	31.31	132
Gemenc	Hungary	0.787	23.81	9.78	0.87	5.44	3.66	67.3	765

(*) Estimated by distance sampling

When comparing the three species, overall, average density and dispersion patterns were similar (below 10 ind/km^2) (Figure 17), although some outliers stood out for wild boar, which represented protected zones in vicinity to urban areas in the South Bioregion.

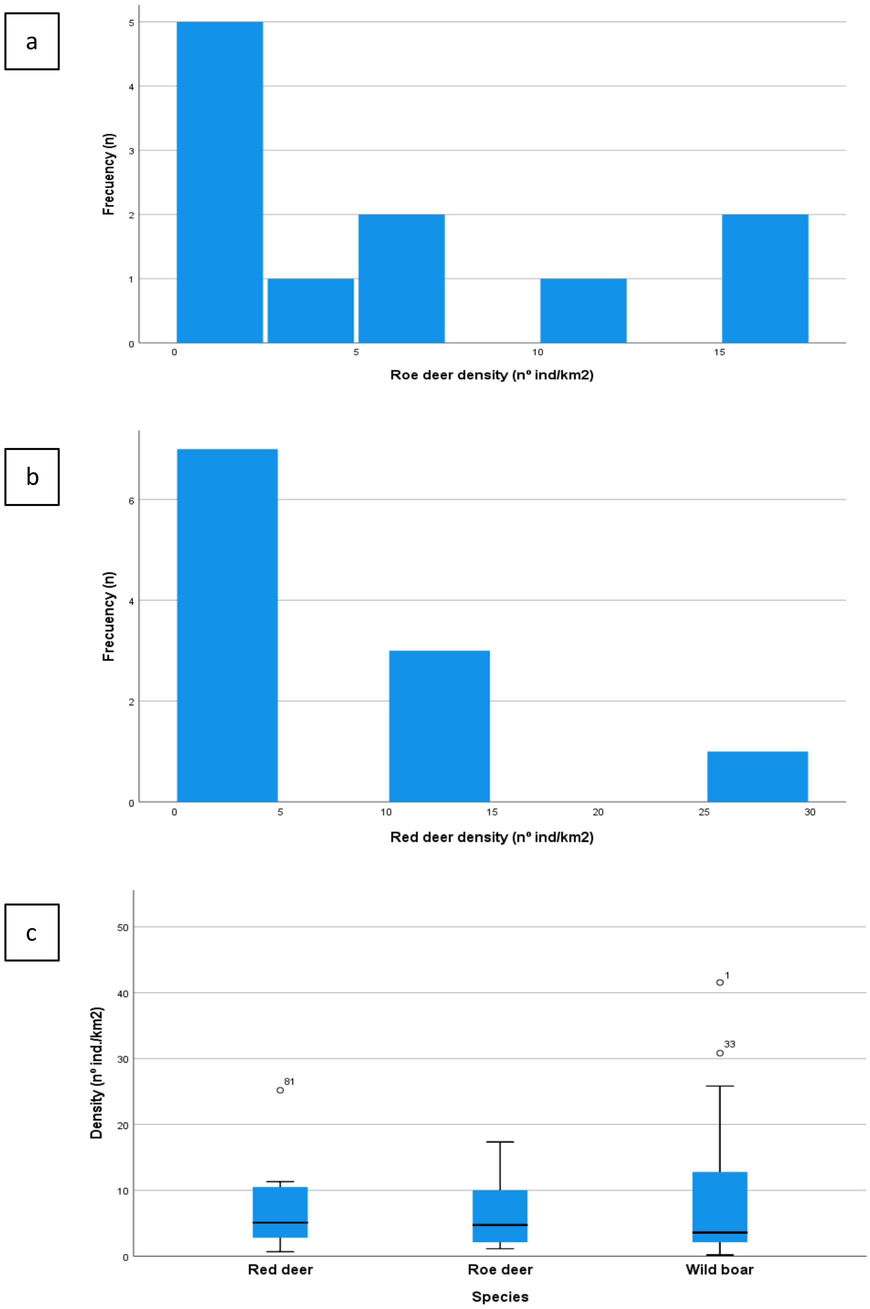

Figure 17. Frequency distribution of densities for roe deer (a) and red deer (b). Boxplots for red deer, roe deer and wild boar densities (number of ind/km^2) over the study areas (c). Note Y-axis for a and b present different scales.

4.4. Density patterns for all ungulates

In this section we visually and comparatively explore the pattern of densities for the three species considered in this report, with the aim of finding general gradients that may be useful for improving the EOW in terms of representativity of factors determining wild ungulate abundance in different bioregions. The Figure 18 represents the densities of the three species (wild boar, roe deer and red deer) by means of boxplots as a function of the bioregion (a), the land use (b), the presence of hunting (c) and the type of hunting (d). Alpine/boreal areas was the bioregion where the three species presented the lowest average density values. Red deer reached their highest average density values in bioregion South, while roe deer presented similar average values in bioregions South, East and West. On the other hand, the wild boar presented lower values in the East bioregion (comparable to that of Alpine/Boreal), the one most affected by ASF outbreaks during the last decade.

Regarding the land use, the more remarkable evidence was the high values reached by wild boar in natural protected peri-urban areas that occurred close to urban areas. This type of study area was only represented in the bioregion South in our set of sampled populations, and therefore we were not able to compare against other bioregions. As for the effect of hunting activity (practised or not), no visual patterns were evidenced for any species. However, when looking into more detail (considering the type of hunting modality), it was evident that red deer are more abundant where only single hunting is performed, and (iii) wild boar is less abundant where only individual hunting is performed.

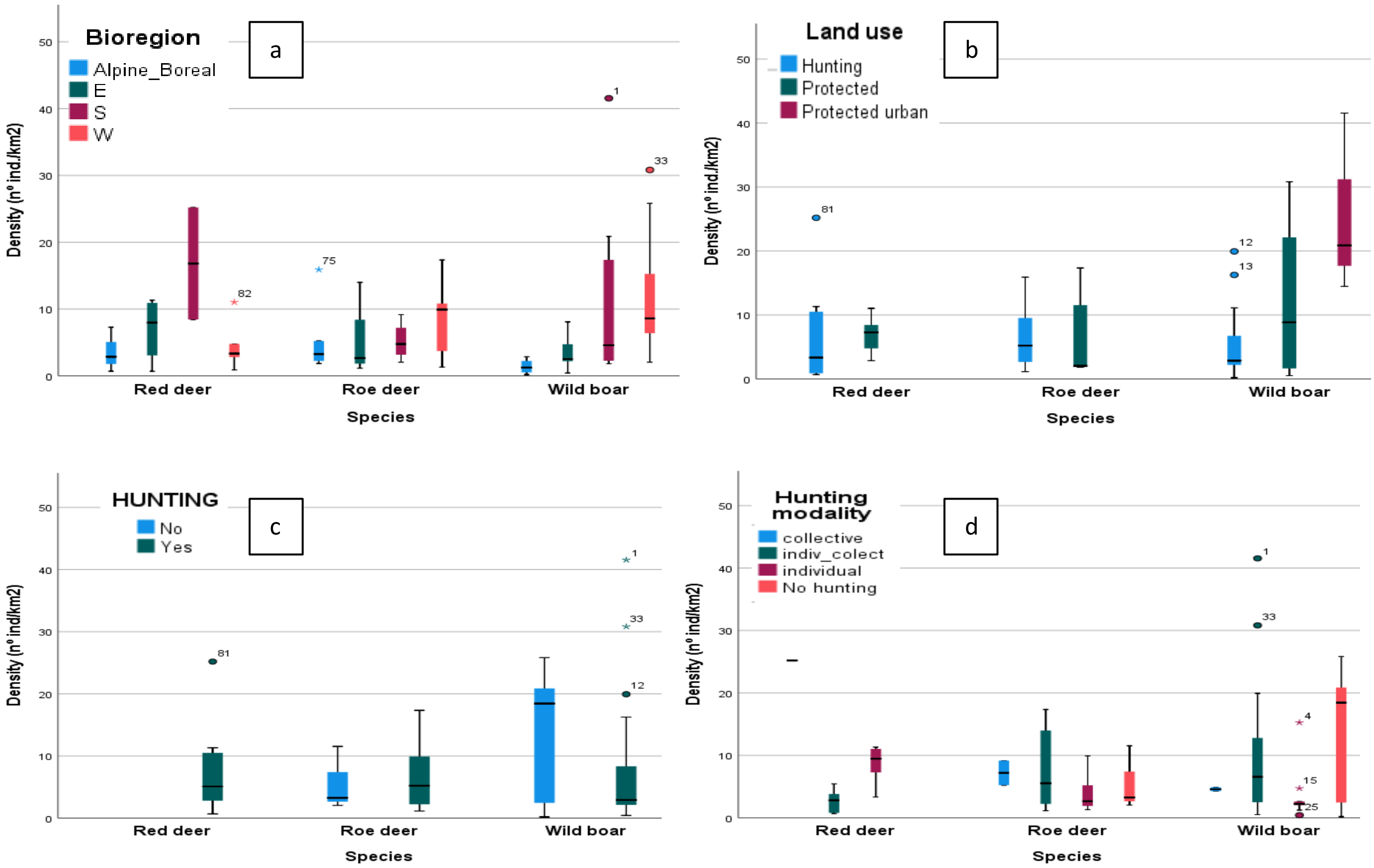

Figure 18. Boxplots for red deer, roe deer and wild boar densities (ind/km^2) over the study areas as a function of the bioregion (a), the land use (b), the presence of hunting (c) and the type of hunting (d).

5. Discussion

5.1. General

- The EOW, as a collaborative approach, bases its foundations on supporting observation points, providing training, and facilitating field design, data processing and analysis. We involved different stakeholders over most European countries: wildlife and/or game departments (at national and regional level), academia, wildlife private professionals, national and regional hunting federations, NGOs and protected areas. For the first time, a number of reliable (known precision) wild ungulate density values, representing different European bioregions, based on the collaborative work developed by a harmonised network of wildlife professionals are available for comparison purposes.
- The results described in this report demonstrate that a harmonised "observatory" approach for the estimation of wildlife populations' densities is actually possible at a continental scale, with a large number of collaborators sharing the same protocol for the data collection, study design, data processing and analysis. The growth of this network in one year demonstrates that the number of collaborators can be further increased, achieving a greater relevance for European wildlife management. The initial distribution of countries and study populations during the first campaign of the EOW primary aimed at generating a collaborative network, harmonising approaches to estimate wildlife density, improving the offered ITt, and training national participants in as many European countries as possible. This approach proved successful, given the diversity and number of participating countries and study areas.
- EOW monitoring applied practical systematic and rigorous protocols, not at odds with the fact that they were feasible and showed that they can be applied routinely and easily after basic training. However, a number of issues on the application of field protocols, data processing and analysis arose during the process, which required continuous support and supervision by the coordinators. Since the protocol adopted in 2022 was new and incorporated elements for further application of AI for image processing, sometimes it was not implemented correctly. However, the continuous support to participants to solve these problems and the experience gained this year will allow a more thorough implementation of each part of the protocol in future campaigns, which, we believe, is going to provide greater precision of the estimations. The coordination and supporting role is essential to keep such a big diverse network functional and efficient.
- The adoption of REM allowed the application of a protocol that requires limited staff effort and equipment for its implementation, representing an affordable tool for the estimation of wildlife densities. REM has been demonstrated to be a reliable methodology and its implementation was made more practical and effective by the use of the photogrammetry approach and the tools provided by Agouti. They were able to directly estimate animal speed and actual CT detection radius and angle, making REM extremely adaptable to the local conditions of each study site. This experience revealed that good training and continuous support are needed to achieve data harmonisation and density

estimation by a European network of professionals whilst previously, protocols were neither harmonised nor standardised across the distribution range of wild boar and other wild mammals (*ENETWILD* consortium 2018).

- The application of the REM field protocol presented certain variability in parameters such as the Nº of CTs, the Nº of CT deployment rounds, the total Nº of deployments, the Nº deployments/area, the CT*days, or the duration of deployments. duration). Apart from study area size, this was due to variable availability of means among participants (e.g., CTs), and/or to logistic and technical constraints. However, this variability provided an excellent scenario to test the factors determining the reliability (precision) of density estimations, and what improvements are needed in the protocol for best cost (practical)/benefit (reliable) strategies in the future.
- The results presented here cannot yet be interpreted to accurately describe wildlife population gradients or trends at European level but should only be interpreted in the context of the specific set of sampled populations. A larger number of study populations representatively covering the main factors determining population dynamics, including management, is required. Our results provided relevant insights into the relevance of some drivers of wild ungulates population at a European level, and they will be expanded to improve the EOW in the future to become more representative. Therefore, further effort is needed to train and equip professionals to collect comparable data across European countries. This approach may also rely on other reliable density methods, including, for instance, distance sampling or high-quality hunting data (e.g., drive counts), which have the potential to be comparable and used across Europe (*ENETWILD* consortium 2018, 2020). In view of future monitoring of wild mammal population trends in Europe, our findings show that an exhaustive design and increasing the number of study areas of a monitoring program are needed to estimate representative gradients and trends as a function of different factors, especially in the Northern and Eastern bioregions. Obtaining an even distribution of study areas will provide a more effective dataset for the evaluation of the factors affecting the densities of wild populations across the continent. Furthermore, we believe that a more accurate implementation of the protocol will ensure a higher precision of the density estimates and therefore a higher overall reliability of the results.

5.2. New information technology tools

- The CT image processing has been implemented using the online platform Agouti, which allows users to easily store and sequence the pictures in different projects for each study site. Once the pictures from each deployment have been uploaded, the processing consists of three main steps: annotation, digitising of deployment calibration and digitising of animal movements. Each CT deployment must have its own deployment calibration in order to be included in the parameters' estimation. The first two steps, which are done by the network of collaborators, were achieved satisfactorily.

- New Agouti functionalities based on the photogrammetry method to estimate CT detection zone size and animal speed of movement using a computer vision process proved useful to reduce the workload and improve objectivity of measurements. This requires only basic training and continuous assistance to solve doubts. After this first experience, EOW participants became self-sufficient and capable to apply the methodology and tools, and hopefully, to disseminate the use of reliable density methods in their respective countries.
- The protocol adopted by the EOW in 2022 can represent an important achievement for the future of wildlife monitoring, and it brought some fundamental improvements in terms of image processing. In fact, the adoption of Agouti allows the use of the latest processing tools providing support for sequencing, annotation, and digitising. Some collaborators faced difficulties during some of the crucial stages of the data collection and/or processing which delayed the analyses, preventing the inclusion of the results of some areas in the present report. Some of these difficulties were related to the correct calibration of the deployments, which is fundamental to obtain reliable parameters to estimate densities. However, we believe that the experience gained this year will ensure a higher accuracy and precision in the implementation of the protocol which is going to lead to higher precision in the density estimates.
- The analysis scripts developed this year represent a fundamental part of the approach proposed by the EOW. In fact, they are thought to provide to each collaborator a tool to independently perform the analysis required by the REM. This certainly ensured a higher accessibility to a methodology that is thought to be adopted not just within the Observatory, but also as a tool for managing wildlife in each context experienced by the collaborators.
- The tools provided by Agouti, as well as the analysis codes, are being continuously refined making the protocol more and more effective.

5.3. Wild ungulate density

- The parameters required to apply REM, such as the day range of wild boar per population (this also applied to other species, roe deer and red deer), presented high variability, indicating the need to specifically estimate these parameters in each study area, i.e., the trapping rate values cannot be directly scaled to obtain density values, but it requires estimates these parameters. We showed statistical differences in the day range as a function of the land use and the type of hunting strategy, after controlling for bioregion.
- The density estimations obtained are very valuable themselves and have potential to be applied to improve the spatial distribution of the species at continental level (e.g., calibrating abundance models into densities) and to evaluate risk factors associated with population abundance.

- We showed that protected areas in proximity to urban areas have the highest wild boar densities. This is indicative of a growing problem at European level since control methods (e.g., in the form of hunting) are difficult to apply in these areas, and conflicts with humans (including disease transmission to humans or animals) are an increasing issue.
- Overall, two rounds of CT deployments seemed to be an optimum balance in the context of this study, and a higher number of rounds would only be recommended if the duration of CT deployment increases (or at least does not decrease). Therefore, as the number of rounds increased (for a relatively constant duration of the field trial), the precision did not improve but worsened. Future modification of the field protocol should balance practical issues (large study periods, the higher the number of rounds the higher the workload, efforts, and costs) and precision. The latter would entail a longer study period, but a priory, not higher efforts. Recently, it has been described (Palencia et al. 2021b) that more than 60 CT placements should be sampled to achieve acceptable precision in the estimates (below 20% CV, which is a rule of thumb for monitoring programmes; Pollock 1990). This is because trapping rates are highly aggregated across CTs in most study populations. Future REM developments should focus on improving the precision of estimates (probably through increased survey effort). Specific instruction to each study area will be provided for next campaigns given the effort developed in 2022, and precision results obtained.
- Similarly to wild boar, for roe and red deer the application of the REM field protocol indicated marked variability in parameters related to the implementation of the field protocol, such as the CT*days, or the duration of CTs deployments. In order to use this variability to test in real scenarios the factors determining the precision of density estimations in deer species, there is a need to increase the number of deer populations in the EOW. This will also allow us to interpret data to accurately describe population gradients at European level.

6. Conclusions and next steps

Table 14 displays the main conclusions on the results obtained by the EOW campaign 2022 in relation to their specific objectives, as well as the proposed next steps.

Table 14. The main conclusions (EOW campaign 2022) in relation to objectives and proposed next steps.

Specific objectives	Progress during the 2022 *EOW* campaign	The road map: next steps
1. To generate and provide information and unbiased trends on population abundance for those developing, adopting, implementing, and evaluating environmental policy in Europe.	First results of the EOW, presented here, cannot yet be interpreted to accurately describe wildlife population gradients at the European level, but should only be interpreted in the context of the specific set of sampled populations. However, they provided relevant insights to expand and improve the EOW in the future in a more representative way. This report is the starting point to provide trends when future campaigns are implemented. The still the density estimations obtained are very valuable themselves and have high potential to be applied to improve the spatial distribution of the species at continental level (e.g., calibrating abundance models into densities) and to evaluate risk factors associated with population abundance.	1) To continue supporting the current network of the EOW to generate long term data capable of providing gradients at European scale and for a wider range of species; 2) to make use of the generated data to show their practical applicability (e.g., improved abundance distribution models for ungulates at European scale, but also contributing to progress on ecological questions); 3) to involve new study areas and stakeholders (see below); 4) to match the EOW generated data and data collected through general data collection frameworks for less reliable data (for density estimation), such as local hunting statistics.
2. To provide sound, independent guidance on methods and protocols for those involved in implementing wildlife monitoring, in close collaboration with European Institutions.	The EOW has previously offered training to all collaborators involved on the methods for determining wildlife density, and specifically on camera trapping, collaborating with Institutions developing these methods and information technology tools. Detailed explanations of field protocols to implement such methods were provided, and they are available in the guidance produced by *ENETWILD* and continuously updated at the EOW website.	1) To continue developing practical/reliable multi-species methods and protocols to determine density (but also presence and abundance indexes for certain taxa), mostly based on CTs, but also on new approaches, such as molecular techniques; 2) to expand training activities to new participants and interested institutions at European level in close collaboration with European institutions.

Specific objectives	Progress during the 2022 *EOW* campaign	The road map: next steps
3. To develop a network for wildlife monitoring, incorporating different stakeholders, such as regional and national administrations, game, protected areas and research Institutions.	A resounding success since we involved different stakeholders from most European countries (a total of 21, and some more which will produce density estimations shortly).	1) In addition to continuing supporting the current network of the EOW, there is need to involve more stakeholders, including the network of European protected areas (e.g., Natura 2000 network), wildlife and game services (national, regional), and hunting federations; 2) to integrate/coordinate with monitoring efforts by European Institutions and projects (e.g. EuropaBon), and putting the data generated by this collaborative open data initiative at the service of policy and research.
4. Supporting observation points, providing training, and facilitating field design, data processing and analysis.	EOW participants were capable to plan the study design together with *ENETWILD* coordinators, and subsequently develop data processing and analysis using the provided ITTs, including the application of artificial intelligence.	1) To incorporate into protocols the lessons learnt during the first campaign of the EOW to optimise limiting efforts and resources; 2) to continue training on new/modified density estimation protocols and tools: IT tools, apps to collect a process data "from the field to the destock"; 3) making easier the final stage of data analysis to obtain reliable densities with limited expertise on statistics (a relevant bottleneck during the process); 4) to facilitate and automate the data flow.

Specific objectives	Progress during the 2022 *EOW* campaign	The road map: next steps
5. Focused on mammals but looking to integrate other taxa and ecological variables and integrated monitoring (wildlife diseases).	During 2022 we focused on larger terrestrial mammals. This report, as a pilot, focused on widespread wild boar and deer species (red deer and roe deer). We already established the structure and the network to integrate other taxa and ecological variables and integrated monitoring (population and wildlife diseases).	1) To integrate other vertebrate taxa: micromammals, chiropterans and lagomorphs; which requires to integrate and coordinate activities with current schemes on wildlife monitoring in Europe (e.g., wild birds, bats); 2) to develop integrated wildlife monitoring under the One Health (OH) approach: environmental detection of shared wildlife pathogens, such as zoonotic diseases of relevance to future OH policies in Europe, to coordinate with initiatives such as Vectornet; 3) incorporating relevant Essential Biodiversity Variables (EBVs, e.g. invertebrates) and Essential Ecosystem Services Variables (EESVs), such as herbivory, which requires collaboration with other monitoring frameworks.
6. To improve population abundance estimation protocols, calibrating methods, incorporating information technology and citizen science.	The application of the REM field protocol presented certain variability in field effort parameters, which allowed the testing of the factors determining the precision of density estimations and what improvements are needed for best practical/reliable strategy in the future. As the number of rounds of CT deployments increased for a relatively fixed duration of the field trials (averaging two months), the precision did not improve. Two rounds of CT deployments seem to be an optimum balance, and a higher number of rounds would only be recommended if the duration of CT deployment increases.	1) To continue developing improved density estimation protocols and tools: 1a) IT tools such as AI for automatic recognition, and refine the analysis codes as the protocol is made more and more effective, 1b) application of smart CTs capable of automatically pre-processing and send information to servers in real time, 1c) to develop apps to collect a process data "from the field to the destock"; 2) The future modification of the CT field protocol should balance practical issues (the higher the number of CT deployment rounds the higher the workload, efforts, and costs) and precision; 3) the lessons learnt in the citizen science project *MammalNet* should be put into practice to improve wild mammal data collection at European scale, for which the network of study areas of the

Specific objectives	Progress during the 2022 *EOW* campaign	The road map: next steps
		EOW offers an excellent platform to promote and "exploit" the citizen science approach as complementary.
7. Highlight areas and recommendations for action and reduce the inequalities existing in wildlife population monitoring over Europe.	As expected, the exploration of the patterns of densities for the three species considered in this report for the first campaign of the EOW, which can be considered a pilot, showed gaps in terms of areas and representativeness of certain factors to determine population density gradient and trends of wildlife.	1) In general, an increase of the number of areas is required to better determine reliable population density gradients at European level, a feasible objective would be a total of 60 areas by 2023 or 2024 campaigns; 2) We identified, at the bioregion level, gaps in terms of study areas representing certain land uses, management options (e.g., wildlife control options, such as hunting) and vertebrate community compositions (e.g., presence of large carnivores), which should be covered in future campaigns. Special attention should be paid to protected zones in vicinity to urban areas where wildlife associated conflicts are increasingly reported; 3) geographically, a higher representativity is required in Northern Europe; 4) we need to develop an informative dissemination campaign on coordinated wildlife monitoring and management at European scale aimed at European and national institutions with competence on the matter, as well as to different stakeholders, for which the 2023 *ENETWILD* Annual General Meeting will provide an excellent opportunity.

7. References

Barroso P, Barasona JA, Acevedo P, Palencia P, Carro F, Negro JJ, Torres MJ, Gortázar C, Soriguer RC, Vicente J, 2020. Long-Term Determinants of Tuberculosis in the Ungulate Host Community of Doñana National Park. Pathogens 9, 6: 445.

ENETWILD consortium, Keuling O, Sange M, Acevedo P, Podgorski T, Smith G, Scandura M, Apollonio M, Ferroglio E, Body G, Vicente J, 2018. Guidance on estimation of wild boar population abundance and density: methods, challenges, possibilities. EFSA supporting publication 2018:EN-1449.

ENETWILD consortium, Grignolio S, Apollonio M, Brivio F, Vicente J, Acevedo P, Palencia P, Petrovic K, Keuling O, 2020. Guidance on estimation of abundance and density data of wild ruminant population: methods, challenges, possibilities. EFSA supporting publication 2020:EN-1876.

ENETWILD consortium, 2021a. Data generated by camera trapping in at least 15 areas in Europe including East and South Europe: Report of the field activities February 2021a, EFSA supporting publication 2021:EN-6771.

ENETWILD consortium, Acevedo P, Apollonio M, Bevilacqua C, Blanco-Aguiar JA, Brivio F, Casaer J, Ferroglio E, Grignolio S, Jansen P, Illanas S, Kavčić K, Keuling O, Palencia P, Plis K, Podgórski T, Rowcliffe M, Ruiz C, Smith G, Scandura M, Soriguer R, Šprem, N, Vada R, Zanet S, Vicente J, 2021b. A practical guidance on estimation of European wild ungulate population density. Enetwild Consortium, Spain, IREC.

ENETWILD consortium, Illanas S, Croft S, Smith GC, Fernández-López J, Vicente J,Blanco-Aguiar JA, Pascual-Rico R, Scandura M, Apollonio M, Ferroglio E, Keuling O, Zanet S, Brivio F, Podgorski T, Plis K, Soriguer R, Acevedo P, 2021c. Update of hunting yield-based data models for wild boar and first models based on occurrence for wild ruminants at European scale. EFSA Supporting Publication 2021:EN-6825.

ENETWILD consortium, Acevedo P, Aleksovski V, Apollonio M, Berdión O, Blanco-Aguiar JA, del Rio L, Ertürk A, Fajdiga L, Escribano F, Ferroglio E, Gruychev G, Gutiérrez I, Häberlein V, Hoxha B, Kavčić K, Keuling O, Martínez-Carrasco C, Palencia P, Pereira P, Plhal R, Plis K, Podgórski T, Ruiz C,Scandura M, Santos J, Sereno J, Sergeyev A, Shakun V, Soriguer R, Soyumert A, Sprem N, Stoyanov S, Smith GC, Trajçe A Urbani N, Zanet S and Vicente J, 2022a. Wild boar density data generated by camera trapping in nineteen European areas. EFSA supporting publication 2022:EN-7214.

ENETWILD consortium, Casaer J, Palencia P, Vicente J, Acevedo P, Jansen P, Rowcliffe M, Guerrasio T, Scandura M, Apollonio M, Blanco JA, 2022b. ENETWILD training: "First online course on the use of camera trapping for monitoring wildlife and density estimation in the framework of the European Observatory of Wildlife (5th May 2022). EFSA supporting publication 2022:EN-7405.

ENETWILD-consortium, Guerrasio T, Blanco-Aguiar JA, Casaer J, Palencia P, Acevedo P, Jansen P, Rowcliffe M, Guerrasio T, Scandura M, Apollonio M, Preite L, Vicente J, 2022c. Report of the ENETWILD training "Second online course on the use of camera trapping for monitoring wildlife and density estimation in the framework of the European Observatory of Wildlife-EOW", 28th September and 21st November 2022. EFSA supporting publication 2022:EN-7708.

Nakashima Y, Fukasawa K, Samejima H, 2018. Estimating animal density without individual recognition using information derivable exclusively from camera traps. J. Appl. Ecol. 55: 735-744.

Palencia P, Barroso P, Vicente J, Hofmeester TR, Ferreres J, Acevedo P, 2021. Random encounter model is a reliable method for estimating population density of multiple species using camera traps. Remote Sensing in Ecology and Conservation 8, 5: 670-682.

Pollock KH, Nichols JD, Brownie C, Hines JE, 1990. Statistical inference for capture-recapture experiments. Wildlife Monographs 107: 3-97.

Rowcliffe JM, Field J, Turvey ST, Carbone C, 2008. Estimating animal density using camera traps without the need for individual recognition. J. Appl. Ecol. 45: 1228-1236.

Rowcliffe JM, Jansen PA, Kays R, Kranstauber B, Carbone C, 2016. Wildlife speed cameras: measuring animal travel speed and day range using camera traps. Remote Sens. Ecol. Conserv. 2: 84-94.

8. Annexes

8.1. Annex 1. Instructions for the survey design and set up

Unmarked camera trap density estimation methods require representative sampling, placing cameras randomly with respect to animal movement. This is best achieved by preselecting camera deployment locations using computer-generated random points. Usually these points should be in a systematic grid with fixed spacing between them across a defined study area (if you don't have the necessary GIS skills in your team, this web app provides an accessible tool for doing this: https://marcusrowcliffe.shinyapps.io/mapping).

In cases where the study area covers more than one clearly distinct habitat, and especially when animals of interest are strongly attracted to a relatively rare habitat, it may be useful to stratify your grid, selecting a similar number of points in each habitat, rather than planning a single consistently spaced grid across the whole area.

Survey designs that cannot be used to estimate the density of unmarked populations include preferentially placing cameras on animal or human trails, targeting spots preferred by the animals such as water sources, mineral licks or high value foods, and using bait to attract animals. Using unmarked density estimation analysis on data gathered in these ways will give results that are biased to an unpredictable extent, and therefore of no value.

In the field, find or make a suitable attachment point for the camera as close as possible to the computer-generated point. If using pre-existing attachment points (rather than placing your own), this will almost inevitably require moving away from the computer-generated point to some extent. When choosing a location away from the computer-generated point, keep in mind the microhabitat in which it fell and aim to place the camera in the same habitat. Do choose a camera viewpoint with sufficient open ground to give some prospect of clear animal images but resist the temptation to choose spots that seem good for animals when doing this. To the extent possible, point cameras at ground that is reasonably even, not extremely rough.

8.2. Annex 2. Instructions for the placement of camera traps and calculation of density of medium to big size mammals - June 2022

This annex presents basic instructions to estimate the density of wild boar through the use of camera traps (CTs). Since different methods are available, we will focus on a practical one that is capable of generating reliable data in a wide range of situations (and species) throughout Europe. The random encounter (REM) model does not require individual recognition. However, it is necessary to collect certain information to determine the speed of movement (average daily movement range) of the wild boar. Therefore, it is necessary to place marks or stakes at a distance from the CTs that serves as a guide to subsequently mark the path followed by each animal, as indicated below. These instructions also apply to REST and Distance sampling methods.

During 2022 the European Observatory of Wildlife will implement the use of artificial intelligence tools available on Agouti to automatically process and analyse images. Since 2022 is a transitional year, from manual processing (see the recording of the training course https://wildlifeobservatory.org/course-on-the-use-of-camera-trapping-for-monitoring-wildlife/) to automatic image processing, this field protocol is compatible with both approaches.

General

- The work should be developed during summer/early autumn, with the CTs placed for a minimum of 60 days.
- They will be placed (registering the geographical coordinates) following a regular uniform distribution as a grid with a minimum of 36 CT placements. The separation between CTs will be approx. 1.5 km. The exact location can be within a diameter of fewer than 100m around the points of the grid. If the number of CTs available is not enough to sample the 36 placements at the same time, the CTs should be moved during the experiment to cover a minimum of 36 locations. For instance, 12 CTs moved twice (every 3 weeks), which fits a study area of approximately 2500-3000 has. In case the number of CTs is 15, the final sampling will be 45 CT placements.
- However, in case the study area is bigger, the distances between camera traps can be larger than 1.5 km, and if possible, it is recommended placing more camera sites.
- The grid must cover at least one patch beaten for hunting big game during the hunting season, if possible, more or several grids for several patches. This is not compulsory (there are study sites of the EOW where hunting is not practiced)
- The CT will be placed on poles or vegetation 50 cm above the ground.

- The CT is configured with the operation of 24 hours per day and to take up to three consecutive images (the maximum number possible), with the minimum waiting time (0 sec. if possible) between activations. Use medium sensitivity. If the time lapse between consecutive photos of the same burst is high (>2-3 sec.), video mode is recommended.
- The flash intensity should be set at medium (if possible) to avoid "overexposed photos".
- Check that the date and time are correctly set, and that they are printed automatically on each image.
- The CT should be reviewed at least in half of the study period (ideally once a month) to check its functioning and placement. Normally it will not be necessary to change the batteries and the memory cards, since the CTs are placed at random points and high wildlife activity is not expected.
- Choose a field of vision of the CT that is cleared of vegetation (it is not necessary to be totally clean, but that allows the detection of any wild boar that passes within the first 5 m), being better a north orientation.
- A form must be filled in, collecting the information of each CT during its placement (see below). All the information that is subsequently extracted must keep the traceability of the CT (mark the source camera of each memory card extracted and keep this nomenclature in the folders that are created on the computer to archive the images). Shortly, *ENETWILD* will provide an app based on *Smart* which will be useful to collect this information in the field.

Manual processing set up

- Place stakes in 2.5m intervals (Figure 1). Connecting the stakes with signalling tape helps to better visualize distances. Finally, ensure that a photograph is taken from the CT where these stakes are evident. Also take one picture with your mobile device from a standing position. These two pictures will later help to position animals observed in the pictures. Put natural marks (stones, branches…) before removing the stakes for later identification of the path of the animals photographed. **This part is not needed if the photogrammetry methodology is adopted** (see annex 3)

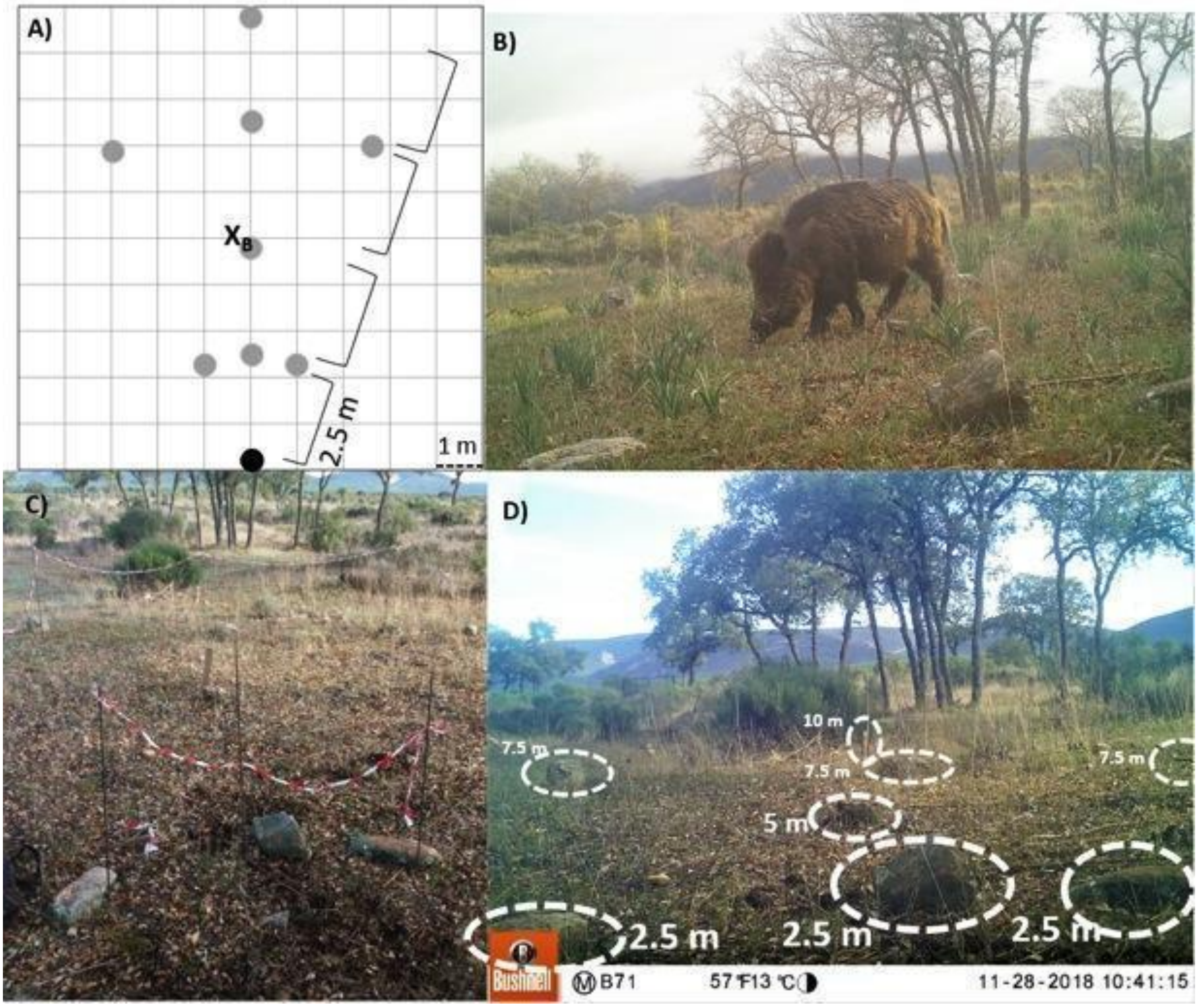

Figure 1 (annex 2). A) Scheme of the stick-structure (grey dots) used to reference the animal captured by the camera-trap (black dot). X_B indicates the position of the wild boar captured in the image B. B) Wild boar photo-captured. C) Photo of the structure installed in one photo-trapping sampling point. The camera should be oriented so that the well-centred stakes are displayed. D) Natural marks (stones) used as references after removing stakes (based on Palencia et al. 2021).

8.3. Annex 3. Field protocol for camera trap surveys with camera calibration for measuring animal positions for unmarked density estimation (Photogrammetry)

Background

The random encounter model (REM), camera trap distance sampling and related methods for estimating the density of unmarked animals require data on animal positions relative to camera in order to estimate camera detection zone size and (for REM) animal speed of movement. These positions can be efficiently estimated using a computer vision process based on mapping image pixel positions to real world ground positions relative to the camera. This "map" can then be used to estimate the positions of animals in images with minimal effort. To create the map, images of calibration poles are required at each camera deployment in the field. This protocol sets out field methods for generating the necessary calibration images.

Making calibration poles

Take a straight, strong pole (e.g., PVC electrical tube) at least 1 m in length, and mark it in a durable way with bands in a contrasting colour, e.g., white duct tape on a black pole (Fig. 1 annex 3). Place five bands at 20 cm intervals from one end, from 0.2 to 1 m. Indicate height by adding additional bands below the height marker, with the number of bands indicating height increment, so that 1 band = 0.2 m, 2 bands = 0.4 m etc.

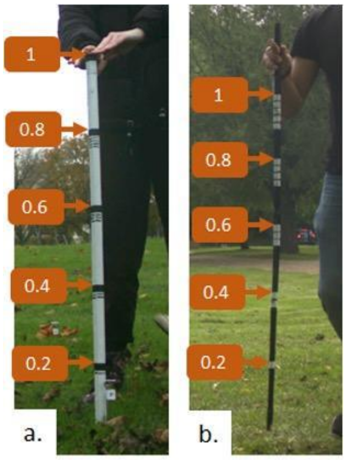

Fig. 1. (annex 3) Two examples of calibration poles. The top of each group of bands is at a known height above ground at 20 cm intervals. Heights above ground are indicated in metres, with the number of bands in each group indicating the height increment.

Taking deployment calibration images

Carry out the following procedure at each deployment:

1. Set up the camera firmly to minimize risk of subsequent movement, and in position ready to capture wildlife images. Switch it on ready to trigger photos.

2. Starting about 1m directly in front of the camera, hold the pole with its base on the ground so that it is clearly visible to the camera. Take care to ensure that the pole is held perpendicular to the camera's line of sight. On level ground with camera line of sight roughly parallel to the ground surface, the pole should be roughly vertical, but if the camera is angled to observe a slope the pole may need to be tilted accordingly (see Fig. 2 annex 3).

3. Hold the pole still long enough to ensure a clear image (generally 5-10 seconds). In order to indicate when the pole is resting on the ground, give a distinctive hand gesture when this is the case. For example, in Fig. 1a, the pole is held by pressing on the top with outstretched fingertips. Closer to the camera, the pole top may not be visible, so it may be necessary to signal lower down, for example with a clenched fist held next to the middle of the pole.

4. Repeat this for further pole placements across the field of view and away from the camera, with placements spaced about 0.5 m apart. Continue away from the camera to the maximum extent that any animals are likely to be captured, or if possible, a bit beyond. As you reach greater distances, it may help to have a second person next to the camera to keep it triggering.

Note that if the camera position is moved, even slightly (for example when checking batteries), the calibration process should be repeated for that deployment. If possible, it should also be repeated when removing the camera, as well as when setting and checking it.

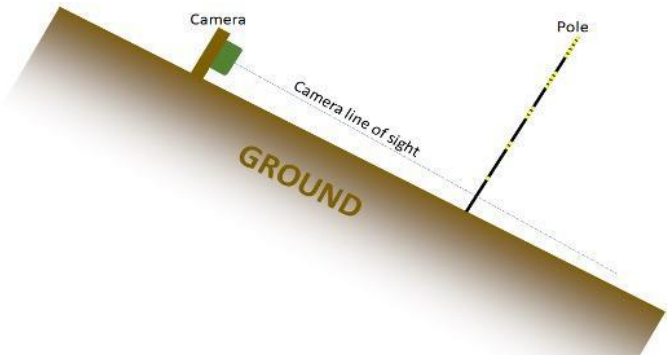

Fig. 2. (annex 3). Diagram illustrating a camera set up to observe sloping ground, and the orientation of the calibration pole required to keep it perpendicular to the camera line of sight. Orientation can be judged by eye and need not be measured precisely in the field.

Training and trialling

Before going to the field, it is important to run trials of the deployment calibration process. Complete the deployment calibration process described above (taking deployment calibration images) in a convenient location and inspect the images. Check that you have taken at least 10, and ideally 20 or more useable images of the pole resting on the ground, distributed reasonably evenly across the surface visible to the camera, ranging from very close (1 m or less) to at least as far as the furthest distance you expect to record animals. Fig. 3 (annex 3) shows an example of a good set of calibration pole images for a deployment. If at first you don't obtain enough usable images, or your coverage of the detection zone is poor, modify your process to obtain a better set of images, for example by waiting a little longer at each pole placement, or taking more pole images at greater density. Do this with your deployment team to ensure that all team members understand the process fully.

Fig. 3. (annex 3). A set of deployment calibration images showing 28 pole positions with good coverage of the detection zone.

Taking camera calibration images

The goal is to take pictures of objects of known size at a range of known distances from the camera to calculate the camera model's intrinsic properties, which then allow us to calculate the distance of calibration poles in deployment calibration. This needs to be done for each combination of camera model and image resolution setting used in the field. It's best to keep image resolution consistent throughout deployments; if you do this, and use a consistent camera model, you only need to calibrate one camera, once. The steps are as follows:

1. Set up the camera in a convenient location in front of a level surface, either indoors or outside.

2. Mark out nine positions at a range of radial and angular distances from the camera, measuring the distances from camera accurately. Fig. 4 annex 3 gives an example of placement positions, with poles at three distances (1, 2 and 4 m), and a range of angles. It's not necessary to measure angle, but it should be variable, and within the camera's field of view (usually about 20 degrees either side of the midline), but you may need to check the field of view for your camera.

3. With a camera positioned in front of the arena and switched on, take images of a calibration pole (making instructions above: Making calibration poles) at each position on the array, holding up some visible marker of the distance. For example, in Fig. 5 (annex 3), the pole is placed at 2 m from the camera, with distance indicated in metres by the number of fingers displayed. As in the deployment calibration process, care should be taken to hold the pole perpendicular to the camera's line of sight.

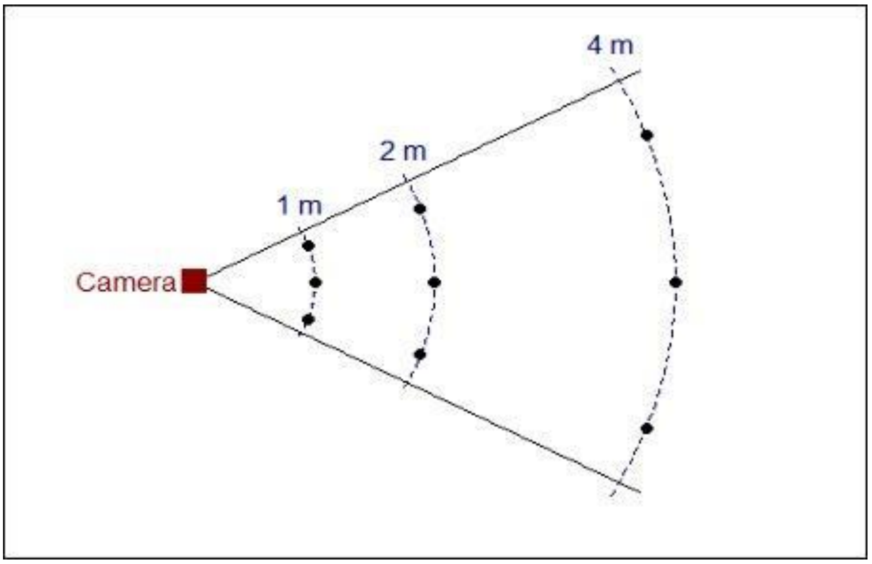

Fig. 4. (annex 3). Plan view of an example layout for a camera calibration pole grid.

Fig. 5. (annex 3). A camera calibration image with pole in position 2 m from the camera.

Nº of the study point	Nº CT and memory card	Coordinate X	Coordinate Y	Date setting-up CT in the field	Time setting-up CT in the field	Picture of vision field with marks taken? (Y/N)	Calibration is done when setting the camera (Y/N)	Calibration is done before remove the camera (Y/N)	Date CT removal	Time CT removal	Observations: any eventuality, indicate if revision is made, the date of this, aspects of functioning of the CT, if it dropped down, if still correctly attached, any failure, change of memory or batteries, etc.
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Nº of the study point	Nº CT and memory card	Coordinate X	Coordinate Y	Date setting-up CT in the field	Time setting-up CT in the field	Picture of vision field with marks taken? (Y/N)	Calibration is done when setting the camera (Y/N)	Calibration is done before remove the camera (Y/N)	Date CT removal	Time CT removal	Observations: any eventuality, indicate if revision is made, the date of this, aspects of functioning of the CT, if it dropped down, if still correctly attached, any failure, change of memory or batteries, etc.
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