EXTERNAL SCIENTIFIC REPORT

APPROVED: 04 March 2022

doi:10.2903/sp.efsa.2022.EN-7214

Wild boar density data generated by camera trapping in nineteen European areas

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Abstract

This report presents the results of field activities in relation to the generation of reliable wild boar density values by camera trapping (CT) in 19 areas in Europe, mainly in East Europe. Random Encounter Model (REM) densities ranged from 0.35±0.24 to 15.25±2.41 (SE) individuals/km^2. No statistical differences in density among bioregions were found. The number of contacts was the component of the trapping rate that determined the coefficient of variation (CV) the most. The daily range (DR) significantly varied as a function of management; the higher values were detected in hunting grounds compared to protected areas, indicating that movement parameters are population specific, and confirming the potential role of hunting activities in increasing wild boar movement and contact rates among individual or groups. The results presented in this report illustrate that a harmonized approach to actual wildlife density estimation (namely for terrestrial mammals) is possible at a European scale, sharing the same protocols, collaboratively designing the study, processing, and analysing the data. This report adds reliable wild boar density values that have the potential to be used for wild boar abundance spatial modelling, both directly or to calibrate outputs of model based on abundance (such as hunting bags) or occurrence data. Future REM developments should focus on improving the precision of estimates (probably through increased survey effort). Next steps require an exhaustive and representative design of a monitoring network to estimate reliable trends of wild boar populations as a function of different factors in Europe. In this regard, the newly created European Observatory of Wildlife will be a network of observation points provided by collaborators from all European countries capable to monitor wildlife population at European level.

Key words: camera trap, wild boar, density estimation, network, harmonized protocol

Question number: EFSA-Q-2020-00677

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Acknowledgements: We acknowledge EFSA BIOHAW unit and ENETWILD partners for reviewing this manuscript. We are grateful to ENETWILD collaborators (listed on http://www.enetwild.com/collaborators).

Suggested citation: 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, 2022. Wild boar density data generated by camera trapping in nineteen European areas. EFSA supporting publication 2022:EN-7214. 21 pp. doi:10.2903/sp.efsa.2022.EN-7214

ISSN: 2397-8325

Summary

This report presents the results of field activities in relation to the generation of reliable wild boar density values by camera trapping (CT) in 19 areas in Europe (mainly in East Europe). The ENETWILD consortium trained several collaborators in applying the random encounter method (REM) to process data collected by CT and so to estimate wild boar density. We selected study sites representing the main bioregions[2] of Europe, and a diversity of habitats, management, and *a priori*, a wide range of densities.

The total effort consisted of 29,829 CTs*nights (number of CTs multiplied number of monitoring nights) average per study site 1540, range 130-4418). REM densities ranged from 0.35±0.24 to 15.25±2.41 (SE) individuals/km^2. No statistical differences in density among bioregions were found (17.33±5.45, 4.99±4.34 and 3.14±2.58 on average for Eastern, Southern and Western, respectively). The number of contacts was the component of the trapping rate that determined the coefficient of variation (CV). The daily range (DR) significantly varied as a function of management; the higher values detected in hunting grounds compared to protected areas, which indicate that movement parameters are population specific, and confirms the potential role of hunting activities in increasing wild boar movement and contact rates among individual or groups, with the subsequent epidemiological consequences.

The results presented in this report are very relevant since they illustrate that a harmonized approach to actual wildlife density estimation (namely for terrestrial mammals) is possible at a European scale, sharing the same protocols, collaboratively designing the study, processing, and analysing the data. For the first time, a range of reliable wild boar density values representing different European bioregions are available for comparison purposes based on the collaborative work developed by a harmonized network of professionals. This report adds density values that have the potential to be used for wild boar abundance spatial modelling, both directly or to calibrate outputs of model based on abundance (such as hunting bags) or occurrence data. Most importantly, we gained valuable experience and tuned the workflow of this pilot network, which is essential to success to produce a future long-term sustainable framework to monitor wildlife at the European level. The REM method and our field protocol proved to be adaptable to local conditions across Europe, and a range of professional's representative of European bioregions succeeded to collaboratively apply the density estimation protocols and to process the data after receiving online training.

In low-density situations, where low contacts are expected or population (and contact rates with CTs) are highly aggregated, a larger number of CTs and/or longer studies are required to obtain precise estimations of density because the coefficient of variations (uncertainty) estimated are usually large. These recommendations will be incorporated to our protocol for density estimation by CTs (without capture-recapture) studies. Future REM developments should focus on improving the precision of estimates (probably through increased survey effort). Next steps would require an exhaustive and representative design to estimate reliable trends of wild boar populations as a function of different factors in Europe. A professional network-based approach requires the inclusion of a larger number of study sites, and requires an improved coverage of the distribution range of wild boar across Europe to assure representation of reliable spatio-temporal populations trends. To facilitate their work and engagement, professionals must be equipped with tools capable to simplify and reduce efforts during field work, data processing and analysis. A CT based monitoring network is also applicable to other wildlife species since the presented CT protocol is multi-species and multi-method (i.e., REST and CT Distance sampling). In this regard, the European Observatory of Wildlife[3] an initiative run by ENETWILD and funded by the European Food Safety Authority (EFSA), will be a network of "observation points" provided by collaborators

2 See glossary
[3] https://wildlifeobservatory.org/

from all European countries capable to monitor wildlife population at European level in the long-term.

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1. Introduction

1.1. Background and Terms of Reference as provided by the requestor

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 implemented the EFSA-funded project "Wildlife: collecting and sharing data on wildlife populations, transmitting animal diseases agents", whose main objective is to collect wildlife density, hunting and occurrence data and model species geographical distribution and abundance throughout Europe. This subject is of particular concern due to the spread of pathogens like the continued advance of African swine fever (ASF). According to the specification for the present deliverable indicated as "Data generated by camera trapping in at least 15 areas in Europe including East and South Europe", a final report on activities done is due in December 2021.

1.2. Scope of the report

Reliable estimates of wild boar numbers, including densities, are needed for monitoring their population trends, for risk assessments, and to develop improved management strategies. A guidance provided by the ENETWILD consortium reviewed density estimation methods for wild boar, recommending the most robust estimation methods (ENETWILD consortium, 2018). The recommended methods also have the potential to be used for calibration and harmonizing 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 wild boar densities, not only with the aim of generating valuable density estimations, but to explore difficulties and refine our field protocol.

This report summarizes the estimation of reliable wild boar density values in 19 areas in Europe by CTs following a harmonized protocol. For this purpose, we selected study sites representing the main bioregions of Europe, and a diversity of habitats, management, and *a priori*, a wide range of expected populations densities. This study represents a relevant step forward towards harmonized monitoring of wildlife in Europe because, initially, beyond mere data generation, it is essential to generate networks and harmonize the approach among wildlife professional in as many European countries as possible. This study also contributes to develop the collaborative approach to harmonize wildlife density estimation in Europe, taking advantage of previous training activities, transferring methodology, and providing support during study design, field activities, data processing and analysis (the latter often represents a bottleneck to estimate reliable density values of wildlife by professionals).

Following this approach, in the long term, the analyses of population trends obtained by reliable methods will be able proactively to guide investigators and wildlife policy makers. The establishment of a network of collaborators, such as the one contributing to this report, must be done in a framework where data will be comparable, interoperable, and openly accessible at the European level.

2. Wild boar density estimation

2.1. Study areas

the ENETWILD consortium has offered training to 70 collaborators in order to improve the generation of wild boar abundance data following methodological standards (ENETWILD consortium 2019a, 2020). This activity was essential to enhance the network of wildlife professionals in Europe, especially, in previously identified gap areas for wild boar population data (eastern Europe). The animal health professionals and wildlife experts were recruited from national hunting and forest authorities, and some participants from organizations monitoring wild boar. The participantsreceived training on the methods for determining wildlife abundance and density (https://enetwild.com/2020/10/14/enetwild-camera-trap-course), and specifically on camera trapping, applying the random encounter method (REM, Rowcliffe et al. 2008) and random encounter staying time (REST, Nakashima et al. 2018) to improve estimation on wild boar density. Detailed explanations of field protocols to implement such methods were provided and are also available in the guidance produced by ENETWILD (ENETWILD consortium, 2018). The next step, presented here, consisted in involving several of them in the estimation of wild boar densities over gap regions of Europe.

We selected 19 study areas (in a North to South gradient in Europe, representing different bioregions, habitats, and management). The main characteristics of each study site and exact location are indicated in Table 1 and Figure 1, respectively. The list of 13 countries and 19 study sites involved in this trial, for which we present density values, are (number of study sites):

- Albania (1)
- Belarus (1)
- Bulgaria (2)
- Croatia (2)
- Czech Republic (1)
- Germany (2)
- Italy (2)
- North Macedonia (1)
- Poland (1)
- Portugal (1)
- Russia (1)
- Spain (3)
- Turkey (1)

Table 1. Detailed information on study areas

Name study site	Country	Institution	Adminstrative	Area (ha)	Habitat	Big animals present	Study design	CTs*day
1. Gora Kalwaria	Poland	Mammal Research Institute (MRI)	Hunting ground	4655	Forest-open mosaic (1396 ha of forests)	Eur. moose, wild boar, roe deer	15 study points	2611
2. Kirov-Semushino	Russia	B.M. Zhitkov Russian Research Institute of Game Management and Fur Farming of RAAS	Hunting ground and experimental plot	17400	Southern taiga subzone	Eur. moose, brown bear, wild boar, wolf, lynx, roe deer	17 study points	1135
3. Naliboki Forest	Belarus	Scientific and Practical Center of the National Academy of Sciences of Belarus for Bioresources	Hunting ground of the Naliboki State Landscape and Hydrology Reserve	14100	Pine and coniferous-deciduous forests, marshy rivers, and low-lying peatlands	Eur. moose, red deer, roe deer, wild boar, bison, wolf, brown bear	45 study points (15 CTs moved twice)	4418
4. Alt Oerrel	Germany	Institute for Terrestrial and Aquatic Wildlife Research-ITAW	Hunted forestry office grounds of Oerrel, Niedersächsische Landesforsten	4130	Mixed forest, dominated by pine, spruce and oak, surrounded by arable land	Wild boar, red deer, roe deer, wolf	48 study points (16 CTs moved twice)	1254
5. Süsing				2720			30 study points (15 CTs moved once)	1066
6. Niva	Czech Republic	Mendel University in Brno	Hunting ground	2000	Mainly coniferous forest, surrounded by open land	Wild boar, red deer, roe deer, fallow deer	15 study points	891
7. Voden-Iri Hisar	Bulgaria	University of Forestry, Sofia	Hunting ground (State hunting ranch)	8000	Broad-leaved mixed oak forest in lowlands, the most suitable for wild boars, surrounded by arable land	Red deer, fallow deer, roe deer, wild boar	30 study points (30 CTs not moved)	2069
8. Panagyurishte			Hunting ground	3600	Beach and spruce forests in mountain area, 1000-1500 m a.s.l.	Roe deer, wild boar	26 study points (13 CTs moved once)	858
9. Biokovo	Croatia	Faculty of Agriculture, University of Zagreb	Hunting ground	20000	Mediterranean scrubland, mountain rises vertically from the Adriatic Coast	Northern chamois, European mouflon, wild boar, wolf	40 study points (40 CTs not moved)	2645

10. Prolom			Hunting ground	7700	Mixed broad-leaved forest with grasslands & shrubs	Wild boar, red deer, roe deer, fallow deer, wolf	48 study points (24 CTs moved once), 15X1.5 km	4151
11. Mrezicko	North Macedonia	Hunting Federation of Macedonia (HFM)	Hunting ground	2500	Forest, pine, fir and beech	Roe deer; northern chamois; brown bear, wild boar	12 study sites	130
12. Çajupi Mountain(Gjirokastra region)	Albania	PPNEA (Protection and Preservation of Natural Environment in Albania)	Protected Area	24447	Mixed broad-leaved forest	Roe deer, wild boar, wolf, and brown bear, chamois	24 study points (12 CTs moved once)	719
13. Kartdag Wildlife Reserve	Turkey	University of Kastamonu	Protected Area	4420	Mixed broad-leaved forest	Brown bear, red deer, wild boar, roe deer, wolf	15 study points	705
14. La Mandria	Italy	Piedmont Forest Service, University of Torino	Regional Park, Protected area	1604	Broad-leaved forest dominated by oaks (*Farnia* and hornbeam)	Roe deer, wild boar, red deer, fallow deer, wolf	36 study points (12 CTs moved twice)	1156
15. CACN3		Comprensorio Alpino CACN, University of Torino	Hunting ground	73000	From broadleaved and coniferous forest to alpine meadows	Roe deer, northern chamois, alpine ibex, red deer, wolf, wild boar	37 study points (24 CTs, 13 were moved once)	963
16. Amudio (Araba)		Araba caza (hunting management company)	Lezama Hunting ground	6000	Atlantic forests, mainly Fagus sylvatica, scattered with farming and arable land	Roe deer, wild boar	57 study points (28 CTs moved once)	2023
17. Riglos (Huesca)	Spain	Aragon Hunting Federation	Riglos Hunting ground	2500	Transition Mediterranean to Atlantic forest	Roe deer, wild boar	30 study points (15 CTs moved once)	637
18. Parque Natural Sierra del Carche		Universidad de Murcia, Com. Auton. de la Región de Murcia	Regional Park, Protected area	2100	Mediterranean forest, mainly *Pinus halepensis*	Wild boar, rare Barbary sheep and Iberian wild goat	40 study sites (20 CTs moved once)	1531
19. ZCA Santulhão	Portugal	Palombar - Conservation of Nature and Rural Heritage	Associative Hunting Area	2948	Mediterranean shrubland and forests, fragmented with farming and arable land and meadows	Roe deer, wild boar, red deer, wolf	45 study sites (15 CTs moved twice)	867

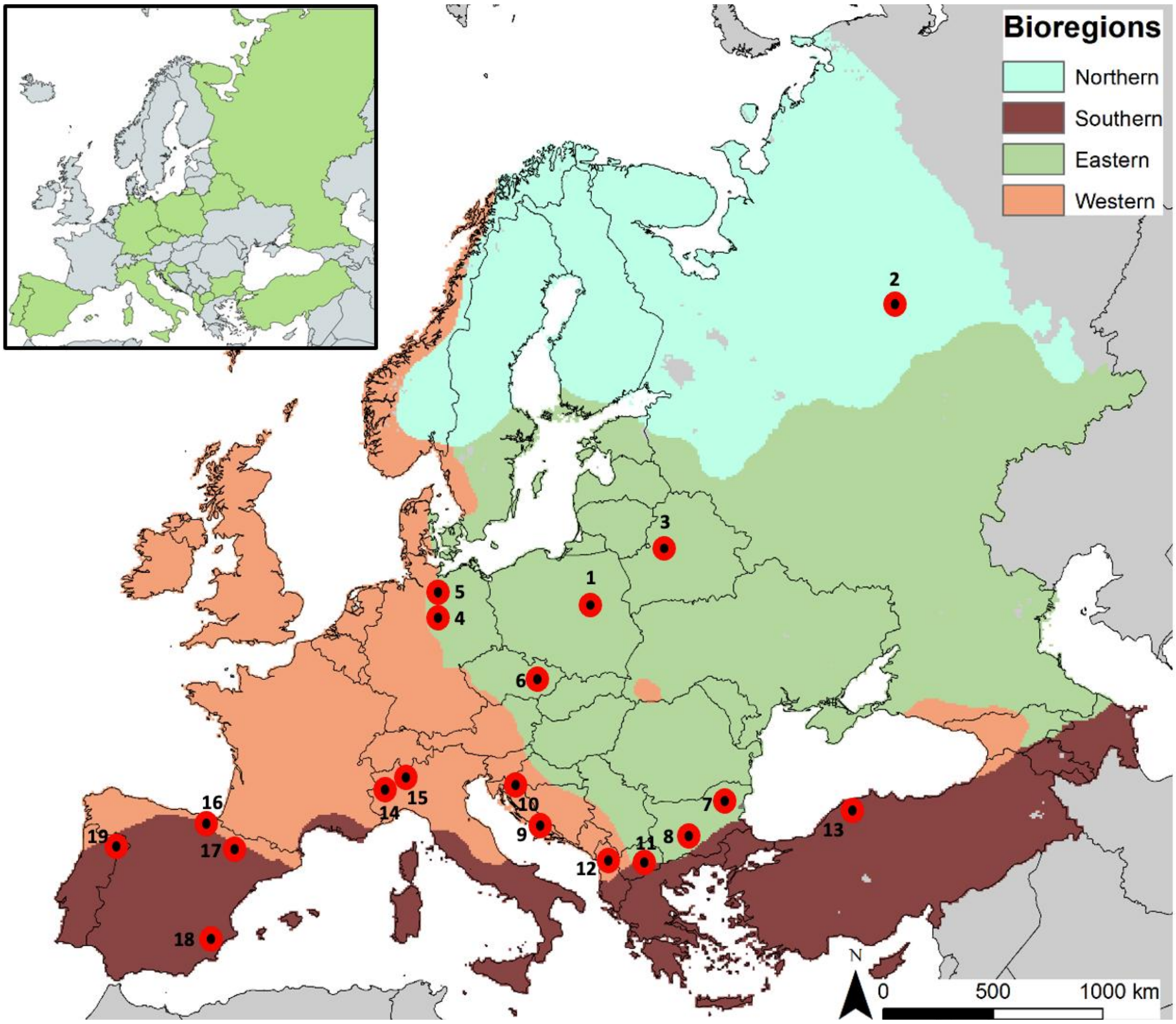

Figure 1: Distribution of study areas where wild boar density was estimated by camera trapping. The map shows the bioregion classification used by ENETWILD (ENETWILD consortium 2021). Population ID numbers correspond with Table 1. The distribution of countries where study areas where selected is shown in the top-left corner (green colour).

2.1.1. Instructions for the placement of cameras of phototrapping and estimation of wild boar density

This section presents the instructions followed by collaborators to estimate the density of wild boar using camera traps (CTs, ENETWILD consortium 2018, updated protocol in: https://enetwild.com/2021/03/20/ct-protocol-for-wild-boar/, see also Palencia et al. 2021a). Since different methods are available, we focused on a practical one that can generate 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, DR) of the species. 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.

- The work was developed during autumn/early winter 2019/2020 or 2020/2021, 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 2). 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 has. However, in case the study area is bigger, the distances between camera traps were larger than 1.5 km in order to enhance representativeness.
- We placed stakes in 2.5m intervals (Figure 3 A, B). Connecting the stakes with signalling tape helps to better visualize distances (Figure 3 C). Finally, we ensured that a photograph was taken from the CT where these stakes are evident. We put natural marks (stones, branches…) before remove the stakes for later identification of the path of the animals photographed (Figure 3 D).
- The CTs were placed on poles or vegetation 40 cm above the ground.
- The CTs were configured with 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. 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 is 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 that allows the detection of any wild boar 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).

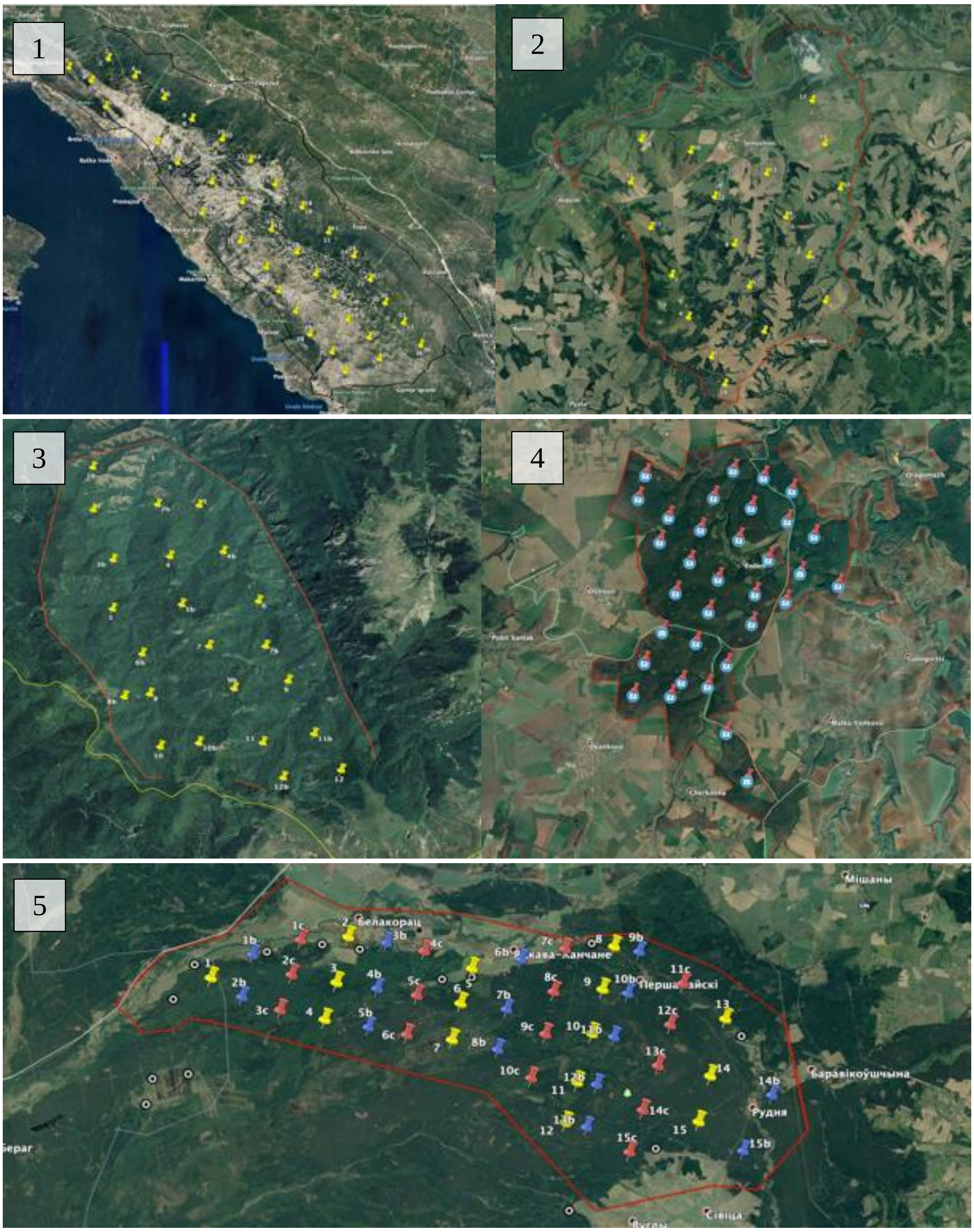

Figure 2. Examples of CT placements in different study sites: (1) Croatia, (2) Russia, (3) North Macedonia, (4) Bulgaria, and (5) Belarus.

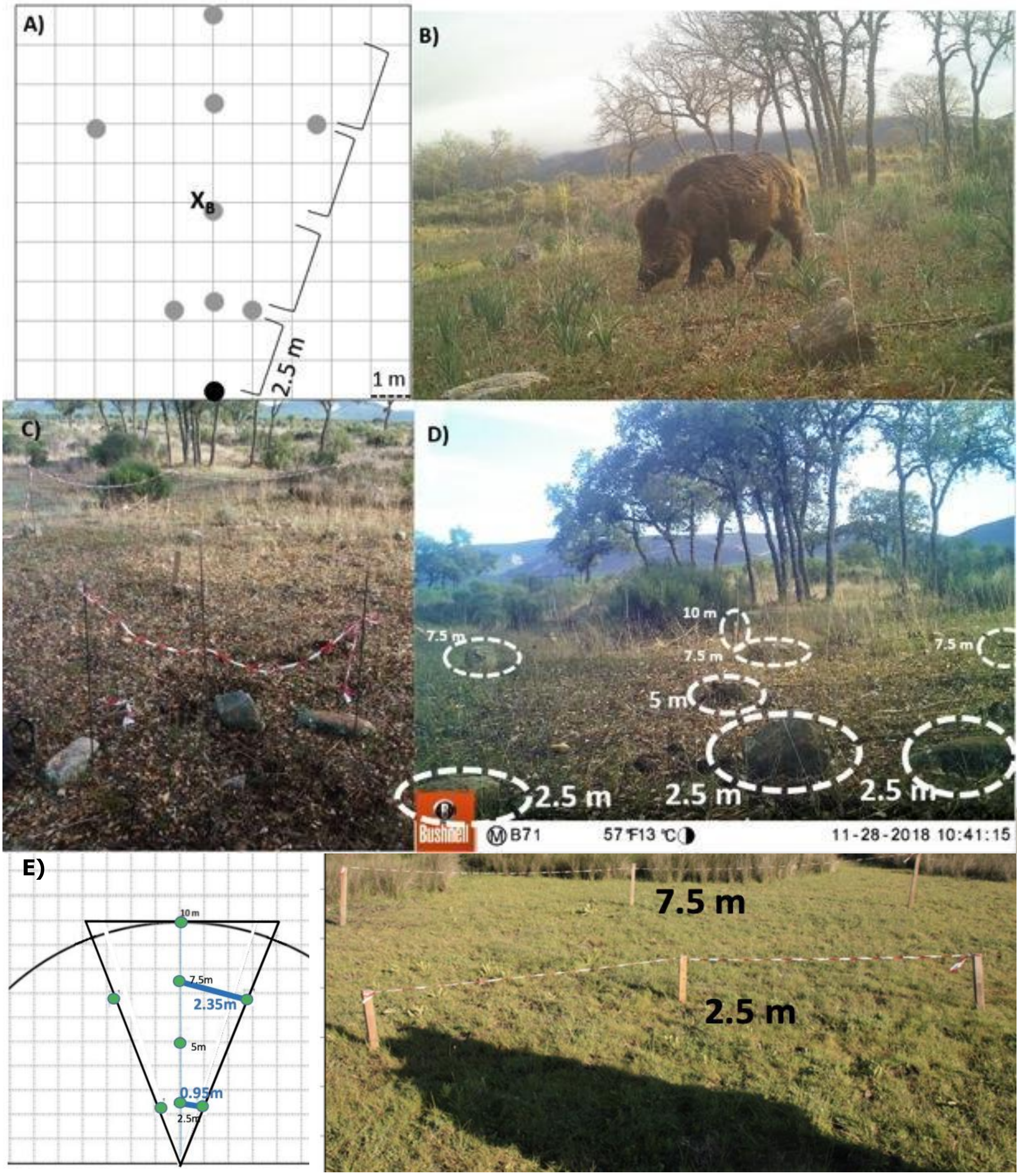

Figure 3. A) Scheme of the stick-structure (grey dots) used to reference the animal captured by the camera-trap (black dot). X_B indicates the position of the wild boar captured in the image B. B) Wild boar photo-capture. C) Photo of the structure installed in one photo-trapping sampling point. The camera should be oriented so that the well-centred sticks are displayed. D) Natural marks (stones) used as references after removing sticks. E) It is recommended to leave marks on the points marked in green, optimally natural (stones) after removing the sticks and taking the blank picture. To mark distances, it can be used a rope with knots or marks at 2.5, 5, 7.5 and 10 m, which is very practical. By turning it from the camera position and using the distances indicated in E), reference points can be easily marked. If for any circumstance the angle and radius of the marked field are modified (for example, adapting to the camera model or the terrain), these new distances must be indicated to perfectly define the field of study in the annotations sheet.

2.1.2. The random encounter model (REM) and data analysis

The REM models encounters between animals and passive detectors (here camera traps) without the requirement for individual identification of animals (Rowcliffe et al., 2008). The REM equation is:

$$D = \frac{y}{t} \cdot \frac{\pi}{v \cdot r \cdot (2 + \Theta)}$$

where y is the daily number of encounters, t is total survey effort, v is the day range and r and Ɵ refer to the effective radius and angle of the camera detection zone, respectively. To estimate encounter rate, we considered an individual of the target species entering and exiting the detection zone of the camera trap as an independent contact. Day range was estimated following Palencia et al. (2021b) using the *activity* and *trapping motion* packages in R (Palencia, 2020; Rowcliffe, 2019). Briefly, speed was measured on each sequence by dividing the distance travelled by the duration of the sequence; we subsequently identified different movement behaviours based on the speed measurements for the sequences. Secondly, we estimated activity level, following Rowcliffe et al. (2014). For each behaviour, we estimated the average speed and weighted the activity level, considering the proportion of time that the population spent on each behaviour. Day range was estimated as the sum of the product of the mean speed and the proportion of the activity level associated with each behaviour. To estimate detection zone, we recorded the position (radial distance and angle) of an animal when it first triggered the camera trap and then applied two distance sampling analyses to estimate effective radius and angle (Rowcliffe et al. 2011). The variance associated with the encounter rate was estimated by bootstrapping, resampling camera trap locations with replacements. The overall variance of density estimates was computed using the delta method (Seber 1982) and the emdbook package in R (Bolker 2019) and the variance of all the parameters considered (encounter rate, day range and detection zone).

We tested the statistical associations between density and DR and other variables by means of non-parametric Mann-Whitney tests or Pearson correlations. These variables included bioregion (southern, western, eastern), administrative figure (hunting ground *vs* protected areas), presence of African swine fever in the Country (Y/N), and presence of wolf in the area (Y/N). We also tested the association between the coefficient of variation and the number of study sites (CT*site), the number of contacts and the trapping rate (contact*CT*night). The level of statistical significance was set at $p < 0.05$.

3. Results

The REM parameter values for each population are shown in Table 2. The total effort consisted of 29829 CTs*nights (average per study site 1570, range 130-4418). REM densities ranged from 0.35 individuals/km^2 (Biokovo study site, Croatia) to 37.23 individuals/km^2 (Mrezicko, North Macedonia, but see below regarding the reliability of this value) in the 19 study sites. However, as discussed below, the results from the two populations showing the highest densities (27.90 and 37.23 individuals/·km^2 in Russia and North Macedonia, respectively) must be taken with caution. Therefore, the highest trustable density was estimated for la Mandria (Torino, Italy) with an estimated value of 15.25±2.41 (SE) individuals/km^2. Coefficients of variation (CV, %) ranged from 15.80 to 94.01 (Kirov-Shemushino study area).

As for the Kirov-Shemushino study area (Russia), the number of events registered was low (36), despite a large sampling effort (1135 CTs*nights), which impeded calculating reliable movement and detection parameters for wild boar. For instance, DR was unusually low; however, DR might be right due to harsh winter conditions (animals during winter are almost not moving). Therefore, the main problem in this area could be low density, which affected the overall calculations. In addition, contacts were highly aggregated since out of 36 records, 34 were in one point. In the case of North Macedonia study site (Mrezicko), no marks to determine distance, and subsequently DR and other parameters, were placed in site. Therefore, the statistical analysis included these parameters from the closest population (Croatia). Due to the abovementioned reasons, the following statistical comparisons excluded the Russia and North Macedonia study areas.

No statistical differences in density among Bioregions were found (7.33±5.45, 4.99±4.34 and 3.14±2.58 for Eastern, Southern and Western, respectively). No statistical difference was found as a function of other parameters, such as ASF presence or wolf presence.

The CV (%) ranged from 15.80 (La Mandria) to 68.57 (Naliboki Forest). Correlation tests evidenced a negative association between the CV and the number of events recorded per study area (Pearson coeff. corr= -0.61, p=0,01), but not with the sampling effort (in terms of CTs*nights). Therefore, the component of the trapping rate that determined the CV the most was the number of contacts.

The DR of wild boar per population averaged 5.97 km*day (ranging from 2.18 km*day in Gora Kalwaria, Poland to 15.99 km*day in Çajupi Mountain, Albania) (Mrezicko not included since DR was not calculated in this study area). When excluding the Kirov-Shemushino study area, the DR of wild boar per population averaged 8.11 km*day. The DR significantly varied as a function of management (U-Mann-Whitney=45, p=0.029), the higher values detected in hunting grounds (15.17±2.52 SE, n=13) compared to protected areas (10.38±5.09, SE n=4). No statistical differences were found as a function of other parameters, such as ASF and presence of wolf.

Table 2. Estimated random encounter model (REM) parameter values for each population, where *y/t* is the encounter rate (nº contacts/nº camera traps*days); v, the average distance travelled by an individual during a day (day range); r, the radius of detection; and Ɵ, the angle of detection. We present standard error, 95% confidence intervals and coefficient of variation (CV, %) for density.

Study site	y/t (ind/cam*day)	v (km/day)	r (m)	ϴ (rad)	Density (ind/km^2) ± SE	95% confidence intervals	CV (%)
1. Gora Kalwaria	0.07 (185/2611)	2.18	4.6	0.88	7.66 ± 4.63	3.03-12.29	60.44
2. Kirov-Semushino	0.03 (36/1135)	0.61	2.28	0.56	27.90 ± 26.25	1.65-54.15	94.09
3. Naliboki Forest	0.10 (460/4418)	3.59	5.96	0.06	7.41 ± 1.84	5.57-9.25	24.83
4. Alt Oerrel	0.07 (84/1254)	3.48	9.5	0.77	3.38 ± 1.19	1.05-5.71	35.21
5. Süsing	0.03 (35/1066)	3.48	8.0	0.81	2.31 ± 0.87	0.60-4.01	37.66
6. Niva	0.33 (295/891)	2.96	7.5	0.74	17.09 ± 7.42	2.55-31.63	43.42
7. Voden-Iri Hisar	0.09 (178/2069)	9.91	3.98	0.90	2.35 ± 0.86	0.68-4.03	36.59
8. Panagyurishte	0.05 (40/858)	5.08	3.69	1.11	2.51 ± 1.67	0.01-5.77	66.53
9. Biokovo	0.01 (14/2645)	4.15	6.12	1.13	0.35 ± 0.24	0.01-0.82	68.57
10. Prolom	0.12 (505/4151)	3.59	5.96	0.95	6.54 ± 1.14	4.31-8.77	17.43
11. Mrezicko	0.8 (104/130)	3.75*	6.00*	1.00*	37.23 ±10.74	27.49-47.97	28.85
12. Çajupi	0.16 (113/719)	15.99	5.41	0.95	1.45 ± 0.49	0.96-1.94	32.66
13. Kartdag	0.28 (199/705)	5.57	9.06	1,05	5.75 ± 2.40	3.35-8.15	41.74
14. La Mandria	1.00 (1159/1156)	13.35	7.07	0.96	15.25 ± 2.41	14.00-16.52	15.80
15. CACN3	0.23 (226/963)	6.47	6.99	0.78	5.84 ± 2.12	3.72-7.96	36.30
16. Amudio	0.05 (108/2023)	4.78	5.45	0.77	2.12 ± 0.83	0.49-3.75	39.15
17. Riglos	0.44 (284/637)	9.29	4.49	0.95	11.31 ± 4.11	3.25-12.13	36.34
18. Sierra Carche	0.08 (115/1531)	6.59	3.21	0.73	4.08 ± 1.63	0.88-7.27	39.95
19. ZCA Santulhão	0.35 (102/867)	8.21	4.96	0.79	3.07 ± 0.79	2.28-3.86	25.86

(*) Values based on average for Croatia (the closest study sites to North Macedonia)

4. Discussion

The results obtained in this report are very relevant since they illustrated that a harmonized approach to actual wildlife density estimation (namely for terrestrial mammals) is possible at European scale, sharing the same protocols, collaboratively designing the study, processing, and analysing the data. For this purpose, we used a reliable method to estimate population density: REM. This pilot experience revealed that good training and continuous support is needed to achieve data harmonization and density estimation by a European network of professionals since currently protocols are neither harmonized nor standardized across the distribution range of wild boar (ENETWILD consortium 2018). We detected that in some cases, protocols were not initially properly implemented in this study, leading to unreliable density estimations. However, for the first time, a range of reliable wild boar density values representing different European bioregions are available for comparison purposes based on the collaborative work developed by a harmonized network of professionals. Most importantly, we gained valuable experience and tuned the workflow of this pilot network, which is essential in view of a future long-term sustainable framework to monitor wildlife at European level is the aim.

The REM method proved to be adaptable to local conditions. However, we also evidenced technical aspects to improve the reliability of estimations and to optimize future efforts. This approach, still pilot, requires an expansion to a larger number of study sites and distribution range of wild boar in Europe to become representative, and to be able to indicate reliable spatio-temporal populations trends. 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 high quality hunting data, which have the potential to be comparable and used across Europe (ENETWILD consortium 2019b).

For comparison purposes, Table 3 shows validated densities (from 2015 onwards) in European study sites in the literature and based on the methods recommended by ENETWILD (ENETWILD consortium et al. 2018). Overall, excluding these two study areas where unreliable densities were obtained, we observe that our values are within the range of densities recently reported in Europe using methods, although this range refers to a few locations and is biased towards UK (where wild boar is expanding) and Spain. This report adds reliable wild boar density values that have the potential to be used for wild boar abundance spatial modelling, both directly or to calibrate outputs of model based on abundance (such as hunting bags) or occurrence data.

Table 3. Country, number of camera traps placements surveyed, and population density estimates obtained by random encounter model in recent published studies on wild boar in Europe (last 5 years).

Country	Nº camera trap placements	REM density (ind/km^2)	Reference density (ind/km^2)	Reference
United Kingdom	42	2.14	-	Massei et al. 2017
	38	4.48	-	
	34	2.62	-	
	35	5.54	-	
	35	0.71	-	
	35	6.99	8.7	
	33	5.41	-	
	32	5.63	-	
	27	1.66	-	
	29	4.90	8.7	
Spain	12	3.55	2.37	ENETWILD consortium 2019b
	15	3.12	5.71	
	15	19.80	13.99	
	37	0.62	3.6	
	10	3.24	3.69	
	19	1.89	1.61	
	14	1.7	3.24	
	8	8.31	9.5	

	17	2.19	5.24	
	20	7.21	8.56	
	20	6.19	8.24	Palencia et al. 2021a
	25	10.15	-	
Poland	57	8.6	-	Morelle et al. 2015
	15	7.8	-	
	42	0.4	-	
	9	0.3	-	
	25	10.15	-	

The average effort per study site was about 1540 CTs*night, which, overall, was sufficient to estimate the parameters required to determine wild boar density. However, as occurred in the Kirov-Shemushino study area (Russia), the number of events registered could be low (36) despite a large sampling effort (1135 CTs*nights), and this may impede calculating reliable movement and detection parameters for wild boar (for instance, DR was unusually low in this study area). The fact that the coefficient of variation negatively correlated with the number of events recorded per study area, but not with the sampling effort (in terms of CTs*nights, which was relatively standardized among study sites), suggests that in low density situations and/or where low number of contacts are expected, a larger number of CTs and/or longer studies are needed. This is important to improve our field protocol to estimate densities. Recently, it has been described in the literature (Palencia et al. 2021c) that more than 60 camera 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).

No statistical differences in densities among bioregions were evidenced, which may indicate that our sample size and study representativity is limited, and/or the fact that wild boar densities may greatly vary locally due to habitat, ecological and management factors irrespective of the bioregion. In view of future monitoring of wild boar population trends in Europe, our findings show that an exhaustive design of a monitoring program is needed to estimate reliable trends as a function of different factors.

The DR, i.e., the distance travelled by an individual during a day, is an important metric in movement ecology that recently gained interest by its relevance for estimating population density through the REM. Traditionally, DR has been estimated using GPS technology and considering raw straight-line distances between consecutive locations, which is an underestimation of the true path distance. In this work, we used camera trap data for the estimation of DR considering the animals' behaviour. Interestingly, the average DR of wild boar per population significantly varied as a function of management, with higher values detected in hunting grounds compared to protected areas (15.17±2.52 *vs* 10.38±5.09 km, respectively). Since our sampling partially overlapped in different areas with the start of the regular hunting season (in some, wild boar are hunted all year round), this finding may be a direct consequence of human perturbation. This is relevant because it demonstrates that wild boar behaviour is population specific and therefore the calculation of these parameters for different purposes (such as density estimation by REM) needs to be obtained locally. Also, this finding confirms the potential role of hunting activities in increasing wild boar movement and contact rates among individual or groups, with subsequent epidemiological consequences.

5. Conclusions and next steps

Conclusions:

- The REM method and our field protocol proved to be adaptable to local conditions across 19 study sites in Europe. A range of professional's representative of European bioregions succeeded to independently apply the density estimation protocols and to process the data after receiving online training.

- For the first time, a range of reliable wild boar density values representing different European regions based on harmonized estimations by a network of professionals is available. Beyond the estimation of density data, we illustrate that a harmonized approach to actual wildlife density estimation (namely terrestrial mammals) is possible at European scale by sharing the same protocols and collaboratively designing the study, and further processing and analysing the data.

- This report adds reliable wild boar density values that have the potential to be used for wild boar abundance spatial modelling, both directly or to calibrate outputs of models based on abundance (such as hunting bags) and occurrence data.

- In low density situations, where low contacts are expected or population (and contact rates with CTs) are highly aggregated, a larger number of CTs and/or longer studies are required to achieve precise estimations of density. These recommendations will be incorporated to our protocol for CTs studies (without capture-recapture) studies. Future REM developments should focus on improving the precision of estimates (probably through increased survey effort).

- The average DR of wild boar significantly varied as a function of management; the higher values detected in hunting grounds compared to protected areas. This indicates that wild boar movement parameters are population specific and confirms the potential role of hunting activities in increasing wild boar movement and contact rates among individuals or groups, with subsequent epidemiological consequences.

Next steps:

- Since wild boar densities may greatly vary locally due to habitat, ecological, epidemiological, and management factors, future monitoring of wild boar population trends in Europe requires increasing the number and representativeness of the study areas, so as exhaustive representative design to estimate reliable trends as a function of different factors.

- First, our network-based approach requires an expansion to a larger number of study sites and better distribution covering the range of wild boar in Europe, to achieve a good coverage and enough sampling sites to represent the different ecological and management situations occurring in Europe. This would ensure the determination of reliable spatio-temporal populations trends. Other reliable density methods are welcome, including high quality hunting data, which have the potential to be comparable and used across Europe.

- To facilitate their work and engagement, professionals must be equipped with tools capable to simplify and reduce efforts and costs during field work, data processing and analysis. In this regards, ENETWILD consortium is developing apps to collect data during field operations and to incorporate artificial intelligence to automatically process images. The development of these ITs will be complemented with a statistical easy-to-use interface for data analysis and density estimation.

- A CT based monitoring network is also applicable to other wildlife species since the presented CT protocol is multi-species and multi-method (i.e., REST and CT distance sampling, Howe et al. 2017). In this regard, the European Observatory of Wildlife will be a network of "observation points" provided by collaborators from all European Countries and funded by EFSA capable to monitor wildlife population at European level (https://wildlifeobservatory.org/).

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7. Glossary

Bioregion: Areas of Europe that result from reducing the dimensionality of the environmental variables into a set of linearly uncorrelated and independent components (see Pittiglio et al 2018). Bioregion has been included as predictor factor in previous ENETWILD wild boar abundance models, allowing the inclusion of new predictors which help to solve regional or local misleading predictions

Precision of an estimate: Degree of statistical error that entails an estimate. It can be measured by the coefficient of variation (CV).

Point transects using camera traps or Camera trap distance sampling (CT-DS): Recently, Howe et al. (2017) adapted standard point transect methods (distance sampling) to CTs (CT-DS). The strong point is that detection probability can be P<1, and this can be appropriate for rare species and low densities, where detections are sparse. Moreover, this method can have great potential in low-density scenarios because more than one distance of detection can be recorded for each detected animal. This optimizes the sampling effort.

Population density (d) is a measurement of population size per area unit, i.e., population size divided by total land area. The absolute density usually is expressed in heads per 100 ha or square km (km^2). Multiplying the population density by the studied surface, we obtain the population size. It can be calculated by different methods

Random encounter model (REM): This method to estimate wildlife density (Rowcliffe et al. 2008), is based on the gas model. This method rescales the trapping rate to population density using the day range (DR, i.e., daily distance travelled by an individual), and camera-related parameters (radius and angle of camera detection).

Random encounter rate and staying time (REST): REST is an extension of REM (Nakashima et al. 2018). The REST describes the relationship among population density, trapping rate and staying time (amount of time that detected animals remain within a specific area within the field of view of a CT) of animals in a predetermined detection zone. This allows a full likelihood approach and probably a good coverage of confidence limits (not available in REM). To estimate the detection zone, it is necessary to do a pilot study to estimate the area in which the probability of detect an individual of the target species (and with a specific cam-trap model) is 1.