EXTERNAL SCIENTIFIC REPORT

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Harmonization of the use of hunting statistics for wild boar density estimation in different study areas

Report based on comparison of case studies in different wild boar populations representative of the different management and habitat conditions across Europe

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Abstract

Hunting statistics can be suitable to determine wild boar density estimates if a calibration with an accepted rigorous method is performed. Here, densities calculated from drive counts during collective drive hunting activities are compared against density values calculated by camera trapping using the random encounter method. For this purpose, we selected 10 study sites in Spain, from North to South representing a diversity of habitats, management and hunting traditions without artificial feeding, plus one study site in Czech Republic where artificial feeding was practiced. Density values estimated from both drive counts and camera trapping were strongly positively correlated (R^2=0.84 and 0.87 for linear and non-linear models, respectively) and showed a good agreement. Drive counts data might be therefore used as a density estimate to calibrate models for estimating density in large areas and potentially, to compare densities among areas. For these purposes, there is still the need to harmonise hunting data collection across Europe to make them usable at a large scale. Our results need to be confirmed across a wider number of European populations to provide valid geographical wild boar density predictions across Europe.

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Key words: density, calibration, camera trap, density, hunting bag, random encounter model, drive counts, monitoring, population estimation, *Sus scrofa*, wild boar

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Summary

Reliable estimates of wild boar numbers, including densities, are needed for monitoring their population trend and for risk assessments, essential 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. The recommended methods also have the potential to be used for calibration and harmonizing hunting bag data to provide density estimates. In particularly, camera trapping (CT) was indicated as reliable, least disturbing and practicable method and independent from hunting activities to collect robust data of density, although this is difficult to apply at a large scale. There is now a need for compiling and validating wild boar abundance data at different spatial scales, but hunting data are still not currently sufficient to be used for abundance estimation without calibration with more accurate methods. In fact hunting data may not reflect real population densities, since they are influenced by numerous factors including weather conditions, nutrition, hunter's behaviour, population densities and visibility. For example a reduction in hunting bag may not reflect a real decrease in population, could be due just to a decrease in hunting effort, (i.e., the intensity of applied means, such as the number of dogs, beaters and shooters, which should be relativized to the area covered) and/or hunting effectiveness (the proportion between number of harvested animals and sighted animals), therefore they need to be corrected.

Wild boar hunting data of collected at local fine scale (e.g. at hunting ground level) are available for many European regions, as evidenced by previous reports of ENETWILD. Particularly, hunting bag or yield refers to the total number of animals harvested per unit of time and space, which is often referred to the management or administrative unit, up to national level. Hunting data can also include the total number of animals sighted during hunts (so called 'drive counts'), which are especially useful to interpret hunting data, as well as the hunting effort, a parameter that characterises the effectiveness of a certain hunting modality. This would include number of hunters, methods of hunting, weather conditions and even some economic parameters and it is used to make hunting bag data comparable across areas. For example, for drive hunt[2], the hunting techniques commonly used for wild boar, the hunting effort would take into account number of hunters, number of dogs, number of hours spent, beaten area, etc. Hunting statistics including the above-mentioned parameters collected at local scale can be considered high-quality hunting data. These can be calibrated by other reliable methods for density estimation, such as camera trapping, for density estimation across Europe.

The previous report by ENETWILD indicated that drive-counts can be conducted during drive hunts as a density estimation method. This report compares density estimations (animals sighted per surface unit) obtained during drive counts with density values calculated by the CT approach using the random encounter model (REM), a method which is independent from hunting activities in different study sites. We selected 10 study areas from North to South Spain, representing a diversity of habitats, management and hunting traditions, without artificial feeding, plus one population from the Czech Republic where artificial feeding was practiced.

The results of our study showed a wide range of densities across the study sites (from 1 to 20 wild boar/km^2). Density estimated by drive counts done during drive hunts and the REM were highly correlated (R^2=0.84 and 0.87 for linear and non-linear models, respectively, n=10 excluding the artificially fed population). We evidenced a good agreement between the two methods used to estimate densities of wild boar (no statistical significance in the mean difference).

This pilot study demonstrated that, in addition to the previously elaborated methods to estimate wild boar density, drive counts performed during drive hunts recorded following a harmonized protocol can reliably be used to estimate wild boar density at local level.

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[2] Collective hunting activities that consists of a line of drivers beating an area whose perimeter is guarded by hunters.

Hunting statistics including information on drive counts may already be sufficient for local density estimation because the calibration against CT method was good, and therefore it can be potentially used under our study circumstances. To be able to make calibrations at European scale, we require that hunters, administrators and wildlife managers use reliable methods of density estimation, such as camera trap based on REM, to calibrate hunting data in other regions, which should be systematically collected following our harmonized protocol.

In the single study where artificial feeding was practiced, density estimation by REM camera trapping was apparently not reliable due to the aggregated use of space and the pattern of activity displayed by wild boar in relation to feeders, and therefore, either the above methodology should be applied to hunting data in the absence of feeding, or other methods need to be used to estimate density.

In summary, our calibration study evidenced that hunting statistics that include information on drive counts can provide reliable density estimates. Since this measure may vary by country or region (with different hunting and licensing approaches), high quality hunting data should be calibrated in a number of countries, and the associated density estimates may then be used as inputs to calibrate a Europe-wide wild boar density model, and thus to compare densities among areas. For these purposes, we still need to harmonise hunting data collection framework across Europe to make it usable at a large scale. For that purposes, the ENETWILD consortium has already provided a previous report along with a list of priorities that must be assessed for each country. Good documentation to characterize the hunting effort should be made available in order to improve data harmonization. Here, we provide a form to collect data during collective hunts. As wild boar hunting effort is changing due to ASF prevention and control policies across Europe, hunting bag will probably not represent reliable indices of wild boar abundance anymore, but hunting effort will rather do. Therefore, quantifying hunting effort in terms of surface beaten becomes essential to derive wild boar densities estimated by drive counts. This approach also offers the possibility of calculating densities rather than abundance indices based on hunting bags.

Based on our results, the recommendations in order to improve comparability of data are:

- To adopt a standardized data collection model for wild boar hunting bag data across Europe.
- For drive hunts, a hunting method widely used in Europe for wild boar, it is possible to collect records of wild boar counts (number of animals sighted) at event level (individual drive hunt), including information on the beaten area. The existence of a quota should not affect these results if every wild boar is counted. Additionally, the effort (number of hunters, number of dogs and number of beaters) can be useful for further evaluation of factors determining hunting effectiveness (the ratio between hunted wild boar vs counted ones during the hunting session), an essential parameter to interpret hunting bag data.
- To compile geographical information of the hunting ground and hunted areas for each (collective) hunting event as precise as possible (e.g. shapefile of the hunting ground, or at least, total surface beaten per event).

Table of contents

Abstract 1
Summary 3
1. Introduction 6
1.1. Background and Terms of Reference as provided by the requestor 6
1.2. Scope of the report 6
2. Study areas 7
3. Methods to estimate wild boar density 10
3.1. Drive counts by collective hunts 10
3.2. Random encounter model 11
4. Results 14
5. Discussion 16
6. Conclusions 17
References 18
Glossary 20
Annexes 21

1. Introduction

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

This report is a deliverable of the specific contract 4 (D3.2) related to the above mentioned framework contract" Wildlife: collecting and sharing data on wildlife populations, transmitting animal disease agents" (Contract number: OC/EFSA/ALPHA/2016/01 – 01) awarded by EFSA to Universidad de Castilla-La Mancha. The deliverable is indicated in the signed amendment of the specific contract 4 as follows:

- Term of reference: Harmonization of the use of hunting statistics for abundance estimation in different study areas
- Deliverable: Report based on comparison of at least four case studies in different regions in Europe, representative of the different management and habitat conditions across Europe (report to be formatted according to provided EFSA template, revision of English language by native speaker and published on EFSA website).

1.2. Background and scope of the report

Hunting data refers to any statistics collected during or as a result of hunting activities, which can later be subject to different re-calculations. Hunting data (or statistics) collected at local fine scale (e.g. at hunting ground level) are available for many wild boar populations across its distribution range in Europe, as evidenced by previous reports of ENETWILD. Particularly, hunting data are mainly represented by (i) hunting bag or yield, which refer to the total number of animals harvested per unit of time and space (often referred to the management or administrative unit, ranging up to national level). Hunting data can also include the (ii) total number of animals sighted during hunts, so called drive counts, especially useful to interpret drive hunting statistics) and (iii) hunting effort (i.e., the intensity of applied means, such as the number of dogs, beaters and shooters, which should be relativized to the area covered during the hunt). Furthermore, hunt effectiveness (iv) can be calculated as the ratio between the harvested animals and the sighted ones or total number of animals that are present in the area. Hunting statistics including the above-mentioned parameters collected at local scale can be considered high-quality hunting data, and can be calibrated by (i.e. checked for agreement with) other reliable methods for density estimation, such as camera trapping, for density estimation across Europe.

Wild boar driven hunts are collective activities that consists of a line of drivers beating an area whose perimeter is guarded by hunters. The previous report by ENETWILD (2018a) indicated that drive counts (in terms of animals sighted per surface) can be conducted during drive hunts as a local density estimation method. This report compares density estimations (animals sighted per surface) obtained during drive counts, with independent density values calculated by the camera trapping approach using the random encounter model (REM[3]) in different study sites. We selected 10 study areas from North to South Spain, representing a diversity of habitats, management and hunting traditions) without artificial feeding, as well as a population from the Czech Republic where artificial feeding was practiced.

As demonstrated by the ENETWILD consortium review (2018a), no calibration of hunting statistics data with density has been done to date for wild boar, hence hunting bag data alone are not sufficient to estimates population density. Hunting bag data are influenced by several factors like weather conditions, nutrition, hunter's behaviour, wild boar population densities and visibility (e.g. a reduction in hunting bag may not be representative of a decrease in population, it can be just a decrease in hunting effort and/or effectiveness). It was concluded that hunting data and available information are

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[3] See Glossary

too variable and do not allow comparisons across areas, among countries and across time because they must be corrected for hunting effort.

Hunting statistics can be used as relative abundance, which means that they are a relative representation of the species in a particular ecosystem/area, as long as the hunting characteristics do not change over time. The relative abundance reflects the temporal or spatial variations of the size (N) or density (D) of a population but does not estimate these parameters. They are useful for monitoring animal populations over time, as well as for conducting large-scale studies on the factors that determine the abundance of species. For example, sometimes, due to financial, logistical, or time constraints, wild boar surveys can only deliver abundance indices instead of population size estimates. The best indices of relative abundance are those that have a linear relationship with the absolute density of the population, but often, this relationship will saturate at high abundance values (Figure 1, see ENETWILD consortium et al. 2018a).

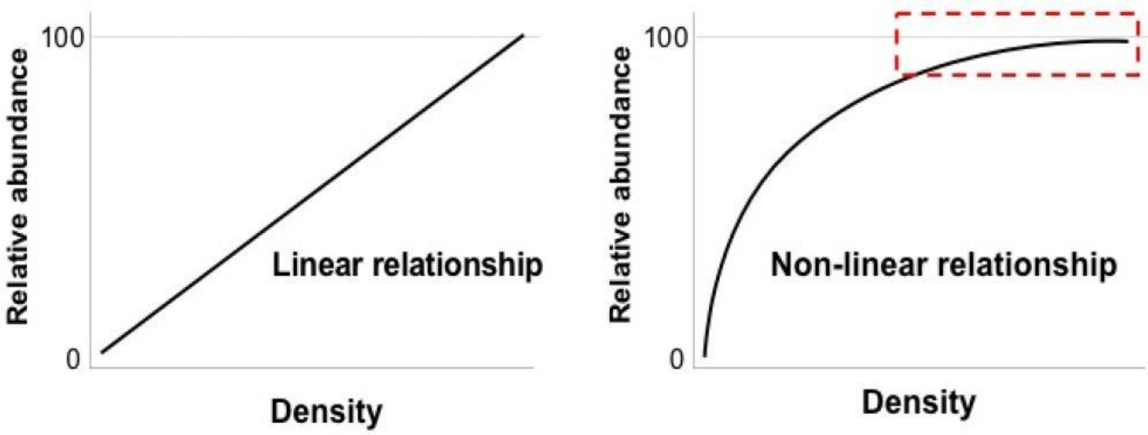

Figure 1. Interpretation of the relationships between density and relative abundance for calibration purposes.

The best indices of relative abundance are those that have a linear relationship with the population density (right) in a given area, but often, these relationships lead to saturate for high abundance values (left). The most critical quality of a relative abundance index is to be a monotonic function of the density. The Y-axes indicate the relative (expressed from 0 to 100) value of relative abundance.

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In light of the above, the aim of this report is to advance the harmonization of the use of hunting statistics for density estimation of wild boar in different study areas. For this purpose, we compared density estimations obtained by drive counts (animals sighted per surface) during collective hunting events, with density values calculated by the CT approach (using the random encounter model, REM), thus by a method independent from hunting activities, in 11 study sites.

2. Study areas

This report compares density estimates based on drive counts during collective hunts, against independent density values calculated by a reliable camera trapping (CT) method, i.e. by random encounter model (REM) for wild boar in different populations. We selected 10 case study areas from North to South in Spain, which represent a diversity of habitats, management and hunting traditions without artificial feeding, plus one population from the Czech Republic where artificial feeding was practiced. The exact location and main characteristics of each study site are indicated in Figure 2 and Table 1, respectively.

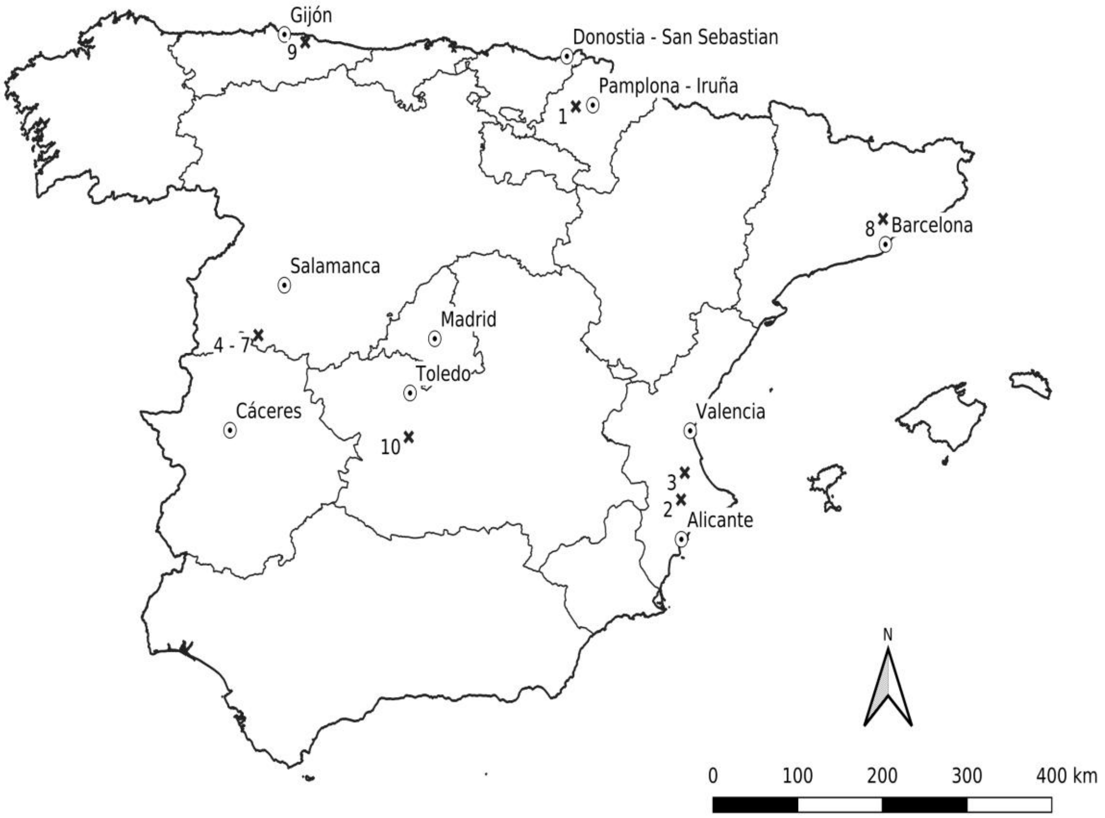

Figure 2. Map indicating the location of the study sites in Spain. Numbers correspond to Table 1. 4-7 (Ávila) consisted in two areas separated 12 km, which were sampled twice (2017/18 and 2018/19 seasons).

Table 1. Main characteristics of each study site included in this study. We also show the estimated densities (and error) for drive count during collective hunts and REM, respectively, in 11 study sites populations during the 2017/18 and 2018/2019 hunting seasons. 'Pasture' refers to extensive cattle farming.

ID	Region	Area (ha)	Main use	Nº driven hunts performed	Nº driven hunts performed /1000 ha	Artificial feeding	Density (Error) driven counts	Density (Error) REM	Nº CT placed	Nº CT placed /1000ha	Sampling effort (cam·day)	Sampling effort (cam·dray-1000ha)
1	Navarra	3500	Hunt	15	4.29	NO	2.37 (0.59)	3.55 (1.59)	12	3.4	768	219
2	Alicante	2450	Hunt	12	4.90	NO	5.71 (1.03)	3.12 (1.17)	15	6.1	1412	576
3	Valencia	4400	Hunt	30	6.82	NO	13.99 (3.20)	19.80 (9.00)	15	3.4	275	63
4	Avila1 2017	2700	Pasture	8	2.96	NO	3.6 (0.95)	0.62 (0.24)	37	13.7	831	308
5	Avila2 2017	2250	Pasture	2	0.89	NO	3.69 (1.75)	3.24 (1.12)	10	4.4	240	107
6	Avila1 2018	2700	Pasture	5	1.85	NO	1.61 (1.02)	1.89 (0.97)	19	7.0	554	205
7	Avila2 2018	2250	Pasture	3	1.33	NO	3.24 (1.37)	1.7 (0.61)	14	6.2	460	204
8	Catalunya	1500	Hunt	5	3.33	NO	9.50 (3.14)	8.31 (2.83)	8	5.3	350	233
9	Asturias	1800	Hunt/Pasture	24	13.33	NO	5.24 (1.33)	2.19 (0.5)	17	9.4	952	529
10	Toledo	6600	Hunt	3	0.45	NO	8.56 (2.85)	7.21 (2.85)	20	3.0	1160	176
11	Czech Rep.	2200	Hunt	2	0.91	YES	11.06 (1.97)	1.98 (0.95)	15	6.8	891	405
Avg. values		**2941**		**9.9**	**3.7**		**5.2**	**5.8**	**16.5**	**6.3**	**717.5**	**275**

3. Methods to estimate wild boar density

3.1. Drive counts by collective hunts

We collected hunting data from 11 wild boar populations and calibrated them against CT estimated densities. Rangers and/or hunters (the leader of the hunting team was tasked) acted as coordinators and recorded hunting data at each event and gave us all data needed for calculations (see Annex 1). The number of driven hunts performed during the 2017/2018 or 2018/2019 hunting seasons (a total of 115 for this study) are shown in Annex 2) as well as hunting effort hunting effectiveness, area covered and average values per location.

Drive counts during hunts were performed to estimate numbers of wild boar during winter according to a specified protocol (Figure 3).

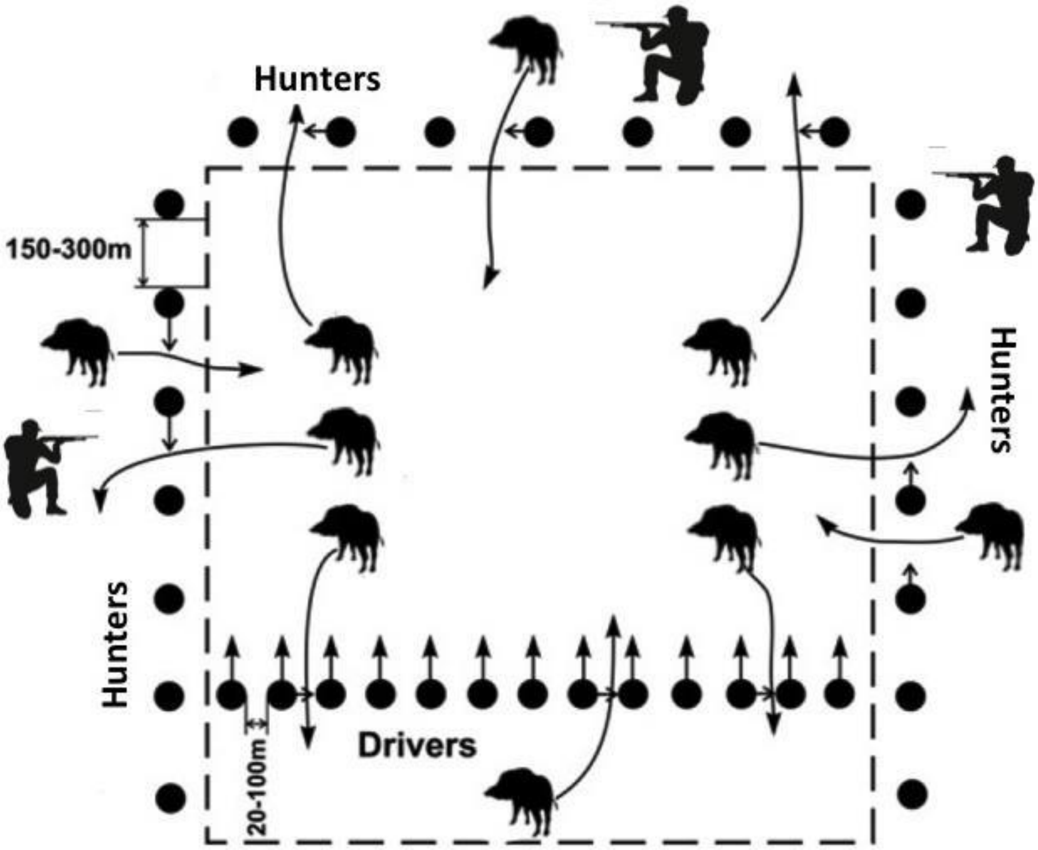

Figure 3. Outline of an ideal drive-count (taken from ENETWILD consortium et al.2018a), which was adapted for each driven hunt. The beaten area is enclosed in the dash line. At the bottom the line of drivers (beaters) is moving across the area, while the hunters are guarding the perimeter of the beaten area.

The number of beaters participating in the counts varied according to the local hunting event and local traditions (Annex 2). The hunters (observers) had sufficient experience to confirm the species and the count the number of individuals. Each hunter recorded on the observation from the species and number of individuals in each group (Annex 1). The coordinator collated then this information from all hunters, resolving any inconsistencies in order to minimize the likelihood of double counting and inaccurate group size estimates. The typical shape and size of the drive hunt area depended on the study area and location, which are adapted to the number of available hunters, beaters and terrain.

3.2. Random encounter model

The use of standardized approaches to estimate wild boar abundance requires optimizing efforts so that data collection is feasible. Camera trapping (CT), using a relatively recently developed method, provides key advantages to count such an elusive nocturnal species. We used a CT method, which is practical, does not require individual recognition, requires medium effort, and is able to generate reliable data over a wide range of situations across Europe (ENETWILD consortium et al., 2018a). The Random encounter model (REM) has been developed and tested in several species (Rowcliffe et al. 2008, Rovero & Marshall 2009, Rovero et al. 2010, Rowcliffe et al. 2011, Rovero et al. 2013, Rowcliffe et al. 2013). This is the only method already tested successfully in wild boar (Eversmann 2014, Keuling et al. 2014, Chauvenet et al. 2017, Massei et al. 2017, Palencia et al. 2019) and some unpublished data (C. Herbst, J. Vicente, O. Keuling, G. Smith). This method rescales the trapping rate (*y/t*) to population density using the daily range (DR, i.e. daily distance travelled by an individual), group size (i.e., the mean number of animals in a group) and camera-related parameters (radius and angle of camera detection) as in the formula below:

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

Where $\propto$ is the angle and *r* the radius of detection of the cameras (and, respectively), *v=DR, i.e.* the daily range of displacement.

The DR is the parameter that is most costly and time-consuming to determine. We estimated DR directly from the photo trapping data (Rowcliffe et al. 2016) rather than relying on fine resolution GPS or radio-tracking data from literature since comparative studies across regions, habitats and seasons are required to estimate a study site-specific DR value. The procedure to calculate DR is based on the key assumption that all individuals in the sampled population are active at the peak of camera trap recording, and that trap rate at other times of day is proportional to the level of activity in the population (i.e. the proportion of the day that the population is active, moving or feeding). A recent field trial (the authors, unpublished), has determined that the behaviour observed with the cameras can be classified into two categories with different movement speeds: i) feeding (i.e. exploiting resources) and ii) moving between habitats (i.e. searching for resources) to estimate a more precise DR. Six markers (wood sticks of 1m length) were placed in front of the camera forming an arc covering the angle of vision of the camera, three at 5 m from the camera, and the other three at 10 m (Caravaggi et al. 2017; Hofmeester et al. 2017; see Figure 4). After taking one photo of the structure, the sticks were removed. These marks were used later to place with greater precision the individuals captured with the cameras and to estimate their travel speed. We considered only those passages below 10 meters of distance to the camera.

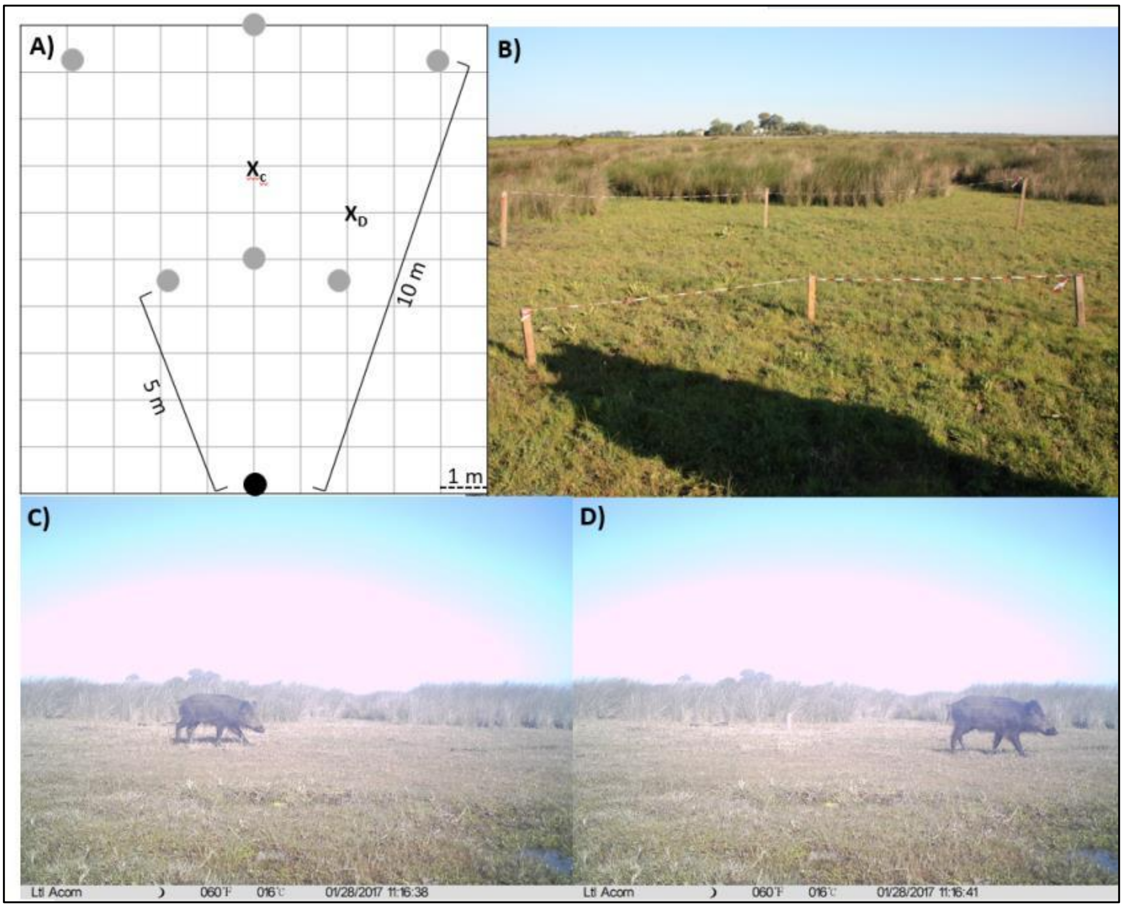

Figure 4. A) Scheme of the stick-structure (grey dots) used to reference the animal captured by the camera-trap (black dot). XC and XD indicate the position of the wild boar captured in the image C and D respectively. B) Photo of the structure installed in one photo-trapping sampling point. C) & D) Photographic sequence of a wild boar captured.

Design: placement and settings of camera traps

Infrared cameras (models Bushnell TrophyCam E3 and Aggressor, Browning Command OPS-PRO, and Little Acorn Ltl-5310 Series with LED IR Invisible) were placed in each point, without bait (Rowcliffe et al. 2016). Motion sensitivity in all cameras was set to medium. We followed the instructions recommended by ENETWILD Consortium et al. (2018a). Cameras were deployed on the tree nearest to a computer-generated point, 40 cm above the ground level, with the angle of view parallel to the overall slope and unobstructed by vegetation. If no trees were present, cameras were located within a 50 m radius of the corresponding generated-point on man-made poles. If necessary, vegetation in front of the camera was cut to reduce false triggers due to moving vegetation (see Meek et al. 2014; Hofmeester et al. 2017). Cameras were set to take pictures 24h per day, using an infrared flash at night, and the date and time of capture were automatically stamped onto each image. Cameras were triggered by passive infrared motion sensors and recorded a sequence of three or 4 consecutive (depending on the model) photos or 30s long video clips. In order to record the trajectory of the individuals in as much detail as possible, the minimum time lap between bursts was selected (0.5 seconds).

Field operations were deployed immediately pre-hunting, or during the hunting season (September-December 2017 and 2018), so that density estimates were comparable across sites and time. We randomly placed CTs (recording the coordinates) to obtain a regular uniform distribution (to guide the location using a buffer of 100 m around the nodes of the grid) at 1.5-2 km x 1.5-2 km (see Table 1). The random grid of CTs covered all the habitats of the study areas, so that the nº of CTs in each habitat were proportional to habitat availability. The overall sampling period was a minimum of one month (see exact duration in Table 1). The information on each CT was recorded during placement, with each receiving a unique number. All the information subsequently recorded ensured the traceability of the CT (and memory cards extracted) retaining this nomenclature in folders holding the images.

The Key CT settings were known (angle of detection and effective range) to determine the surveyed surface.

Image visualization and data base building

The average daily travelled distance can be calculated from trapping records, which requires determining movement distances compared to the initial picture (after taking this initial picture, wooden stakes and tapes were removed, see Figure 4). The collect data included the following fields:

- Point_ID: ID of the camera-trap location
- Sp: Species observed in each sequence (a number of consecutive pictures that belong to the same individual/group) until they exit the field of vision (if they come back, it is considered a new sequence).
- G_size: The total number of individuals observed in the sequence.
- Date: date of the sequence
- H_first: hour of the first picture of the sequence
- H_last: hour of the last picture of the sequence
- T: duration of the sequence (s): the duration of a number of consecutive pictures that belong to the same individual/group
- Dist.m: distance travelled by the animal/group in a given sequence
- Speed.m.s: Travel speed estimated for each sequence. Expressed in m/s
- Interval.min: Shorter distance between the animal and the camera. We consider the animal that is closer to the camera. Not necessarily the one that is consider to estimate speed. 5 intervals are considered: 1 (0-2.5m to the camera-trap), 2 (2.5-5m), 3 (5-7.5m), 4 (7.5-10m), 5 (>10m).
- Dist_det: Distance of detection. Distance between the animal and the camera in the first photo.
- Ang_det: Angle of detection. Angle of detection in the first photo of each sequence. Expressed in decimal grades
- Behaviour: Observed behaviour for each sequence: Moving: individuals are searching resources, moving among habitats. "High" travel speed; Feeding: individuals are exploiting resources, feeding. "Low" travel speed; Curiosity: Individuals react to the camera - travel speed for these sequences were discarded.

Estimations of trapping rate, daily range and activity

We used the procedure described by Rowcliffe et al. (2016) to estimate daily range (DR) from information obtained from CTs. Travel speed was estimated from the images of the animal. For this, the distance travelled was divided by the duration of the sequence (difference in time between the first and last picture). Following Rowcliffe et al. (2016), those sequences in which animal react to the camera were discarded. However, animals are more likely to contact cameras when they move faster (Hutchinson and Waser 2007). To solve this problem, a log-normal and Weibull distribution models were fitted to estimate the average travel speed (Rowcliffe et al. 2016) and AIC was used to select the most parsimonious models.

CTs only detect animals when they are outside of their refuges (i.e. active animals), so it is necessary to take into account the activity rate of the population. Activity was also estimated from CT data following Rowcliffe et al. (2014). This procedure is based on the assumption that all individuals in the sampled population are active at the peak trap rate, and that the trap rate at any given time of day is proportional to the level of activity in the population. Activity index was estimated using 'activity' R package (Rowcliffe 2016). Thus, it was estimated as the product of activity index (a) and travel speed (s). The standard error of this approach was estimated by Goodman´s (1960) variance of product formula. However, in wild boar, two different behaviours were observed, with two quite different movement speeds: i) some individuals are recorded by the cameras feeding (i.e. exploiting resources) and ii) others are recorded moving between habitats (i.e. searching for resources). Therefore, independent activity indices and travel speeds were estimated for each behaviour and then $DR = a_{search} \cdot s_{search} + a_{explo} \cdot s_{explo}$.

The contact rate (on a daily basis) was averaged for all CTs per study site after calculating for each CT as the number of independent contacts (sequences) relative to the number of days the CT was operative.

Calibration: relationship and agreement between the two density estimation methods

The relationships between densities calculated by drive counts and REM method was analysed by regressing the former on the later (linear and non-linear models) in order to evaluate the shape, and how predictable was the density calculated by drive counts from the independent variable (REM method as standard) by using the coefficient of determination (R^2. i.e. the proportion of the variance in the dependent variable, -the density based on drive counts, that is predictable from the independent variable, the density estimated by REM method). Bland-Altman plot was used to describe the agreement between the two measurements by constructing limits of agreement. These statistical limits were calculated by using the mean and 95% CI of the standard deviation (s) of the differences between two measurements. The statistical significance of the differences was tested by the *t*-test.

4. Results

The number of driven hunts performed (per 1000 ha) in our study sites ranged from 0.45 to almost 3 (average 1.4). The number of CTs-days per 1000 ha ranged from 107 to 405. Annex 2 shows data at the hunting event level. Hunting effectiveness per event (number of wild boar shot/total sighted) averaged 31% across the study populations.

Densities (by both methods) ranged from 1.6 to 19.8 ind./km^2 (Table 1) in the 11 populations during the 2018/2019 hunting season. In the single site where artificial feeding was provided (Czech Republic), density estimation by REM model was considered unreliable and excluded from subsequent analysis (11.06±1.97 and 1.98±0.95 for driven count and REM, respectively, discussed below).

Ten hunting data-based estimates (drive counts during drive hunts) and independent densities (REM model) for the populations in Spain, following the instructions of ENETWILD consortium et al. (2018a) guidance, were derived for comparisons purposes (Figure 5). The two density estimates measured by the two methods were strongly correlated and this correlation was statistically significant ($p<0.05$, best adjustments were $R^2=0.84$ and $R^2=0.87$ for linear and non-linear models, respectively, $n=10$).

The Bland-Altman graph (Figure 6) showed a good agreement between the two methods used to estimate densities of wild boar. Actually, the *t*-test yielded no statistical significance (mean difference REM minus drive counts was -0.58±2.63, $t=0.71$, P=0.49). The limits of agreement represented? (95% CI) indicated a trend towards negative values (density calculated by drive counts tended to be higher than by REM, although not statistically significant).

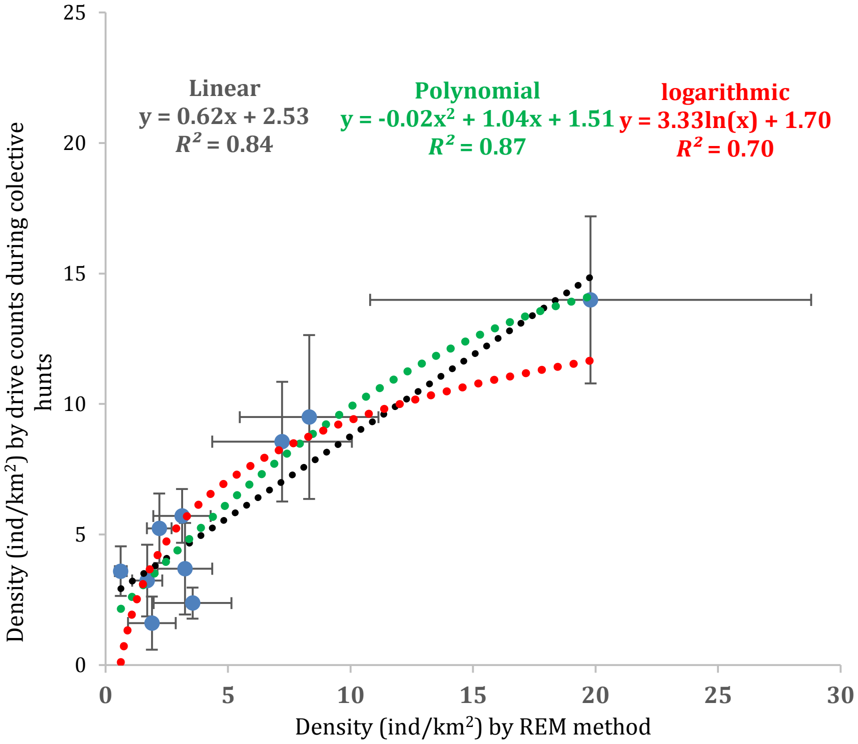

Figure 5. Relationship between wild boar hunting data-based densities (drive counts during drive hunts) and density estimates by REM model for 10 study sites in Spain. 95% CI standard errors are shown.

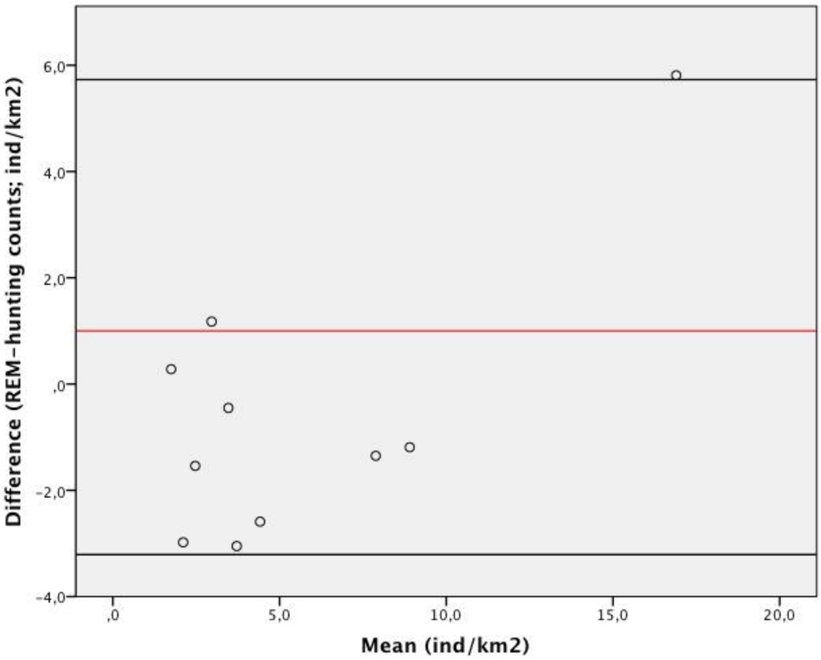

Figure 6. Bland-Altman graph showing the agreement between the two methods (drive counts and REM) used to estimate densities of wild boar (n=10). Y-axis is the difference between the values obtained by REM method and drive counts. X-axis displays the mean value. The limits of agreement represent the 95% CI of the standard deviation of the differences between two measurements. The average difference is showed in red.

5. Discussion

For the first time, we determined, for comparison purposes, the relationship and agreement between density estimates derived from drive counts during collective drive hunting (statistics based on the number of animals sighted per beaten area) and those calculated by random encounter model by using camera trapping.

We are aware this approach still requires an evaluation at a larger scale across the distribution range of wild boar in Europe and also in areas where disease (e.g. ASF) may have affected the population. Although our correlation seemed to perform well for a set of data representing a wide range of wild boar densities, the discriminative power of hunting statistic-based density estimates against independent values was not very evident at lower densities (<4 wild boar/km^2, see Figure 5).

However, we have demonstrated the potential comparability of this kind of density data, which makes them reliable to be directly used for modelling, population monitoring and management where validated, and therefore a strong effort is needed to collect comparable data across European countries. Hunting data collected during drive hunts, particularly the numbers of animals sighted per beaten area have the potential to be comparable and used across Europe.

The main advantages of conducting drive counts during collective hunts is that they are low cost (although it requires the engagement of hunters), adaptable to local conditions, and has the potential to be used also for regional (large scale) studies if proper hunting data collection is implemented. The later requires further calibration of the method in other parts of Europe.

We note that the calculations from hunting statistics may be strongly delayed; and that collective hunts are not performed all over the distribution of wild boar. In the latter case, drive counts without hunting, complemented with the CTs method, are recommended (ENETWILD consortium et al.

2018a). More research is needed across Europe to confirm our results, and to confirm the factors determining the relationship between hunting data-based density estimates and independent reliable density estimates. We remark that, as wild boar hunting effort is changing due to ASF prevention and control policies across Europe, hunting bag will probably not represent reliable indices of wild boar abundance anymore, but hunting effort will do, and therefore quantifying hunting effort in terms of surface beaten becomes essential to derive wild boar densities from counts conducted during drive hunts. This approach also offers the possibility of calculating densities rather than abundance indices based on hunting bags.

In the study where artificial feeding was practised, density estimation by the REM model was apparently not reliable, since one key assumption of REM is that pattern of activity of individuals should be random relative to the placement of CTs. We believe that the aggregated use of space and the pattern of activity displayed by wild boar in relation to feeders impacted our results for that population. Therefore, other methodologies should be used to calculate density or calibrate hunting data in such situations. The results obtained in this report are very relevant since hunting statistics are the most common source of potentially comparable data on wild boar abundance across Europe. Particularly, the total number of animals sighted during drive hunts and the size of the beaten area are only collected in certain regions (ENETWILD consortium et al. (2018b), but still in a sufficient number of sites that could be already used for spatial modelling of wild boar density. This has to be evaluated by the consortium in the context of future modelling activities. We demonstrated that drive counts performed during hunting activity, including basic parameters as suggested in the ENETWILD consortium et al. (2018b) protocol, could provide actual density estimates.. We have highlighted that the problem with using hunting data (collected during drive hunts) for density estimation can be overcome if the number of observed wild boar per beaten surface are collected during collective hunts, which can account for: (1) different hunting traditions and hunting methods in each hunting area; (2) changes in hunting effort; and (3) environmental conditions (e.g. weather, food availability and population density). Drive counts during collective hunts can be used across most of the distribution range of wild boar in Europe, and when applied following a robust study design, have the potential to provide unbiased estimates of wild boar density, and are useful for spatio-temporal comparisons. Detailed information on the general protocols to be implemented for this method are provided in a separate report by the Enetwild consortium et al. (2018b, see also figures 3, 4 and annexes).

Good documentation to characterize the hunting effort should be made available to improve data harmonization and density estimation. In addition to the number of animals hunted, basic information on hunting effort should be included when hunting is performed collectively (driven hunts). Currently protocols are neither harmonized nor standardized across the distribution range of wild boar (ENETWILD consortium et al. 2018a). Therefore, to overcome these barriers, hunting effort should be standardized and properly defined, for which the ENETWILD consortium provided a template (ENETWILD consortium et al. 2018b, see annexes); at least the number of animals sighted per known beaten area must be reported at the level of each hunting event. Harmonization of high-quality hunting data would not allow only for monitoring local wild boar populations over time, but their potential use in large-scale studies is a possibility, which is one of the main objectives of the ENETWILD project.

In view of our results, the recommendations for improving the comparability of data are:

- Adopt a standardized wild boar data collection model for hunting statistics across Europe (ENETWILD consortium et al. 2018a).
- For drive hunts, record data at event level (day), including hunting effort: surface of beaten area and nº wild boar sighted and hunted; and additionally, number of hunters, number of dogs and number of beaters. Indicate if a predetermined harvest quota is applied.

- Compile geographical information of the hunting ground and hunted areas for each (collective) hunting event as precisely as possible (e. g. shapefile of the hunting ground and total surface beaten).

6. Conclusions

- The number of wild boar sighted during drive hunts including some parameters related to hunting effort can provide reliable density estimates, and can be considered high-quality hunting data;
- These density estimates can be compared among areas. However, it is still necessary to calibrate wild boar density values based on hunting data against those derived by other methods across other regions of Europe;
- Density data obtained by high quality hunting data has the potential to be used in spatial modelling (e.g. to estimate the density of wild boar in all areas of Europe not just on specific hunting grounds), but they can also be used to validate model outputs based on abundance data;
- For these purposes, protocols of hunting data collection across Europe need to be harmonised to become usable at a large scale to account for differences in hunting methods used. For that purpose, a report of ENETWILD consortium has already provided a list of priorities each country must assess, as well as standardized protocols to collect data.
- As wild boar hunting effort is changing in Europe due to ASF prevention and control policies, hunting bag will probably not represent reliable indices of wild boar abundance anymore, hunting effort should be rather used. Therefore, quantifying hunting effort in terms of beaten surface becomes essential to derive wild boar densities from counts conducted during drive hunts. This approach also offers the possibility of calculating densities rather than abundance indices based on hunting bags.

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Glossary

Absolute population density or simply **population density** is a measurement of population size per areaunit, i.e., population size divided by total land area. The absolute density usually is expressed in heads per 100 ha. Multiplying the population density by the studied surface, we obtain the population size.

Abundance estimate: the number of individuals in a population calculated by statistical methods.

Activity rate of a population: the proportion of the day that the population is active; normally moving or feeding.

Collective hunts: are hunting modalities involving a group of hunters and drivers.

Drive counts method: Density estimation method based on the count of individuals displaced in the course of a beat in an area of known surface.

Drive hunts: the typical collective hunts (with local variations) practiced for wild boar (also other big and small game), that consists of a line of drivers beating an area (normally with dogs) whose perimeter is guarded by hunters.

Hunting bag or yield: total number of animals (game species) hunted in a given event, hunting area and period of time. Hunting bag may result in an indicator of population density or abundance, which requires standardized sampling effort.

Hunting data (statistics): any statistic collected during or as a result of hunting activities, which can later be subject of different re-calculations.

Hunting effectiveness: number of shot animals related to the sighted ones during the hunting activity.

Hunting effort: it is the parameters that characterise the effectiveness of a certain hunting modality. This would include number of hunters, methods of hunting, weather conditions and even some economic parameters. it is used to make hunting bag data comparable across areas. For example, for drive hunt the hunting effort should take into account number of hunters, number of dogs, number of hours spent, beaten area, etc.

Random Encounter Model (REM): It is a camera trapping method used to estimate animal density in a certain area. This method rescales the trapping rate to population density using the daily range (i.e. daily distance travelled by an individual), group size (i.e., the mean number of animals in a group) and camera-related parameters (radius and angle of camera detection).

Relative abundance or abundance index: It refers to the relative representation of a species in a particular ecosystem. Relative abundance can be calculated by different methods. The relative abundance reflects the temporal or spatial variations of the size (N) or density (d) of a population, but does not directly estimate these parameters (e.g. hunting bag). Since relative abundance covariates with the population density, it is useful for monitoring animal populations over time, as well as for conducting large-scale studies on the factors that determine the abundance of species. Nonetheless, this relationship is not linear (Figure 1). Sometimes, due to financial, logistical, or time constraints, wild boar surveys can only deliver relative abundance such as those obtained from camera trap surveys, instead of total population size or density estimates.

Annex 1- Form to collect data during hunting drives.

FORM TO COLLECT DATA DURING HUNTING DRIVES (one drive one form)		
Name and position (organizer, ranger, etc.) of count coordinator: /		
E-mail:	Telephone:	
Date:	Municipality:	
Hunting ground ID:	Hunting ground name:	
Hunting drive (name of the patch covered and/or consecutive number within the season):		
Start time:	End time:	
Name and/or name of the stalking site:		
Nº hunters (stalking sites):	Nº beaters:	Nº dogs
Did you look for tracks before?		
Did you bait the hunted area?		
Beaten area (has):	Is there GIS file available? (yes/no):	
Total Nº sighted wild boar (including those hunted):		
Total Nº hunted wild boar:		
Total Nº sighted red deer (including those hunted):		
Total Nº hunted red deer:		
INSTRUCTIONS TO FILL THIS FORM		
• Each stalked hunter must fill in this form for his position (fields indicated in grey) • Next, all data must be summarized in a single form by the co-ordinator of the drive count, who will fill in the form for the total count of the event. You should consider the possible double counting by neighbour hunting positions • It is very important to fill in the form even if no piece has been seen or hunted, in this case in the corresponding boxes it will be set 0		

Annex 2. Driven hunts performed during the 2018/2019 hunting seasons, their main characteristics of each hunting event (effort, effectiveness and area), and the average values per event.

Population	Nº hunters	Nº dogs	Nº beaters	Area beaten (ha)	Nº WB sighted	Nº WB shot	Effectiveness (%)
Navarra	43			256	22	10	45.45
	35			271	9	2	22.22
	36			159	6	6	100.00
	44			291	9	9	100.00
	37			283	11	5	45.45
	50			234	7	4	57.14
	23			212	0	0	
	40			271	2	0	0.00
	46			256	0	0	
	39			415	4	0	0.00
	31			371	2	1	50.00
	39			159	6	2	33.33
	40			234	2	0	0.00
	31			415	0	0	
	39			291	9	1	11.11
Navarra avg.	38.2			274	5.9	2.7	38.7
Alicante	11	12	11	130	1	0	0.00
	2	3	3	30	1	1	100.00
	5	12	5	50	7	2	28.57
	4	12	4	120	0	0	
	3	6	3	150	9	1	11.11
	4	12	4	50	2	1	50.00
	6	16	3	100	11	6	54.55
	4	12	4	75	7	1	14.29
	6	15	6	25	3	2	66.67
	5	12	5	75	4	2	50.00
	6	13	3	105	11	1	9.09
	5	11	5	100	0	0	
	4	12	4	50	1	1	100.00
	5	11	5	80	2	0	0.00
	11	10	2	120	2	1	50.00
	14	18	14	100	8	4	50.00
	9	14	3	170	7	0	0.00
	7	15	3	120	10	1	10.00
Alicante avg.	6.2	12.0	4.8	91.7	4.8	1.3	37.1
Valencia	5	10	5	40	2	0	0.00
	6	12	6	60	0	0	
	4	18	4	30	0	0	
	6	18	6	70	11	0	0.00
	3	17	3	50	8	1	12.50

	5	17	5	70	0	0	
	4	30	4	100	10	0	0.00
	6	6	6	10	0	0	
	6	6	6	8	0	0	
	3	5	3	2	1	0	0.00
	6	18	6	100	3	0	0.00
	5	11	5	35	5	2	40.00
	4	12	4	40	21	0	0.00
	5	18	5	90	0	0	
	1	11	1	60	0	0	
	5	16	5	80	6	1	16.67
	3	10	3	40	0	0	
	5	10	5	60	7	2	28.57
	3	11	3	30	21	1	4.76
	6	10	6	80	14	4	28.57
	5	11	5	40	2	1	50.00
	5	16	5	70	1	0	0.00
	7	22	7	70	16	8	50.00
	10	30	4	100	28	14	50.00
	1	14	2	25	7	1	14.29
	5	17	2	50	5	1	20.00
	4	17	2	80	8	0	0.00
	2	14	2	40	1	0	0.00
	2	13	2	30	9	2	22.22
	7	30	4	80	7	0	0.00
Valencia avg.	4.6	15.0	4.2	54.7	6.4	1.3	15.3
Avila1 2017				160	10	4	40.00
				101	4	2	50.00
				130	2	0	0.00
				300	28	2	7.14
				120	8	2	25.00
				250	20	3	15.00
				300	10	2	20.00
				200	16	4	25.00
Avila1 2017 avg.				195.1	12.3	2.4	22.8
Avila2 2017				100	4	0	0.00
				200	15	4	26.7
Avila2 2017 avg.				150	9.5	2.0	13.33
Avila1 2018				190	5	4	80.00
	82			450	20	15	75.00
	21			400	3	1	33.33
	15			280	15	1	6.67
	15			280	0	0	

Avila1 2018 avg.	33.3			320	8.6	4.2	48.8
Avila2 2018	17			160	5	1	20.00
	19			195	15	0	0.00
	24			300	13	9	69.23
Avila2 2018 avg.	20.0			218.3	11.0	3.3	29.7
Catalunya	43			157	31	13	41.94
	1			157	3	1	33.33
	32			181	24	9	37.50
	21			76	5	4	80.00
	18			150	9	1	11.11
Catalunya Avg.	23.0			144.2	14.4	5.6	40.8
Asturias	8	7	7	80	4	0	0.00
	8	7	7	56	10	0	0.00
	15	8	8	171	0	0	
	15	8	8	188	12	1	8.33
	14	8	8	246	17	1	5.88
	14	8	8	10	1	1	100.00
	15	8	8	29	1	1	100.00
	15	8	8	19	5	3	60.00
	15	8	8	29	0	0	
	10	8	4	246	12	3	25.00
	11	8	8	80	1	0	0.00
	11	8	8	101	0	0	
	13	8	8	39	0	0	
	13	8	8	83	0	0	
	14	8	8	108	11	8	72.73
	11	8	8	80	2	0	0.00
	11	8	8	29	4	3	75.00
	11	8	8	118	2	0	0.00
	11	4	4	246	10	5	50.00
	15	8	8	183	6	2	33.33
	10	8	5	183	12	5	41.67
	9	8	6	56	1	0	0.00
	9	8	6	56	0	0	
	9	8	6	112	0	0	
Asturias avg.	12.0	7.8	7.2	106.2	4.6	1.4	33.6
Toledo	33	460	46	836	111	25	22.52
	31	520	52	582	52	8	15.38
	48	340	34	674	36	8	22.22
Toledo avg.	37.3	440.0	44.0	697.3	66.3	13.7	20.0
Czeh Rep.	74	58	55	1056	96	37	38.54
	74	65	62	852	111	56	50.45
Czeh Rep.	74.0	61.5	58.5	954.0	103.5	46.5	44.5

avg.							
Total avg.	27.6	107.3	23.7	291.4	22.5	7.7	31.3
Total range	4.6-74	7.8-440	4.2-58.5	54.7-954	4.6-103.5	1.3-46.5	15.3-48.8

For better visualization, average values for hunting effort and effectiveness parameters per site are shown in a separate table (number of driven hunts performed per study site are indicated within parenthesis).

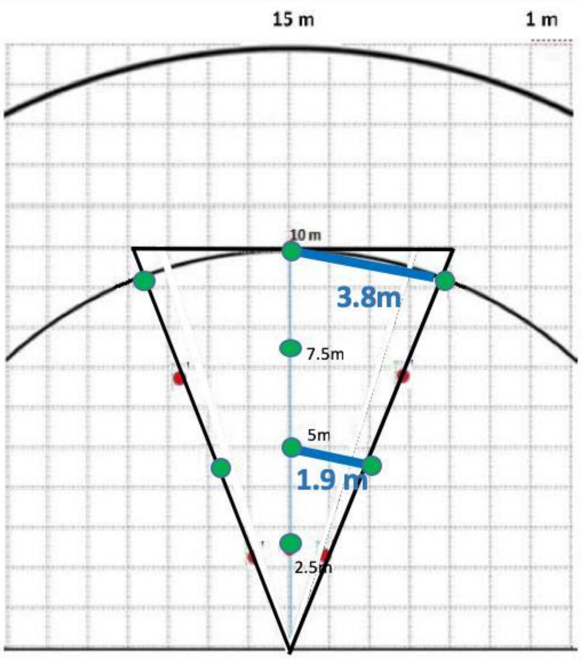
Population	Nº hunters	Nº dogs	Nº beaters	Area beaten (ha)	Nº WB sighted	Nº WB shot	Effectiveness (%)
Navarra (15)	38.2			274	5.9	2.7	38.7
Alicante (18)	6.2	12.0	4.8	91.7	4.8	1.3	37.1
Valencia (30)	4.6	15.0	4.2	54.7	6.4	1.3	15.3
Avila1 2018 (8)				195.1	12.3	2.4	22.8
Avila2 2017 (2)				150	9.5	2.0	13.3
Avila1 2018 (4)	33.3			320	8.6	4.2	48.8
Avila2 2018 (3)	20.0			218.3	11.0	3.3	29.7
Catalunya (5)	23.0			144.2	14.4	5.6	40.8
Asturias (24)	12.0	7.8	7.2	106.2	4.6	1.4	33.6
Toledo (3)	37.3	440.0	44.0	697.3	66.3	13.7	20.0
Czeh Rep. (2)	74.0	61.5	58.5	954.0	103.5	46.5	44.5

Annex 3- Form used to collect data during camera trap placement and checking visits.

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)	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.
1	/								
2	/								
3	/								
4	/								
5	/								
6	/								
7	/								
8	/								
9	/								
10	/								
11	/								
12	/								
13	/								
14	/								
15	/								
16	/								
17	/								
18	/								
19	/								
20	/								

Annex 4- Schematic representation of the field of vision of the camera trap to depict the movement of animals passing in front, to calculate the daily range (see Figure 4). The marks placed in the field (blank picture) are indicated. (a) Template proposed by ENETWILD consortium et al. (2018a). (b) Modified and more practical recommendation. Both templates are valid. The field of view of the CT varies according to the model, and adapted modifications of this template are recommended when needed.

(a)



(b)