RESEARCH

Towards standardising the collection of game statistics in Europe: a case study

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Abstract

In order to monitor wildlife populations in a manner that supports policy makers and natural resource managers, data must be collected using frameworks and methodologies that allow for comparisons between projects and across time. Though hunting statistics may represent a reliable data source for monitoring population trends in game species, a standardised framework for collecting and analysing this data has never been established in Europe, even within countries. Here we describe a case study on the use of hunting statistics in Spain in order to (i) describe the variability in big game statistics collection frameworks across mainland regions of Spain and (ii) propose a minimum common denominator for a standardised approach at the country level. The main differences in methodologies identified are that each region collects different variables, uses different spatial and temporal resolution, and follows different methodologies. We described spatial patterns by grouping regions based on similarities in the hunting data collection system and identified socio-economic factors as a potential driver of differences in methodologies among regions. Hunting effort-related variables and improved temporal resolution (to the event level) must be incorporated in order to achieve country-level standardisation of methodologies. The use of application software to collect information from the field in a standardised way is recommended, which necessitates engaging stakeholders as part of the monitoring process. Applications software should be designed intentionally, and only after clear objectives for the monitoring program have been defined. Making hunting data open access will improve collaboration and information transfer to scientific and professional sectors. Our recommendations can be adapted to other European countries, which would make hunting data more useful for population monitoring and wildlife policy-making at large spatial scales. Initiatives such as the "European Wildlife Observatory" (www.wildlifeobservatory.org), a network of wildlife observation and monitoring points in Europe, may improve data exchange and standardise protocols, leading to better utilisation of hunting statistics for European wildlife population monitoring.

Keywords Hunting statistics · Big game · Europe · Method standardisation · Hunting effort · Wildlife monitoring

Introduction

Wildlife monitoring is a fundamental part of sustainable population and ecosystem management. "Monitoring" in a wildlife management context means regularly observing and recording information on wildlife populations and the environment they inhabit to characterise change over time (Apollonio et al. 2010). Successful monitoring also requires considering a number of factors relevant for management, such as anthropogenic impacts, human-wildlife conflicts, and stakeholder and societal acceptance of management actions (Redpath et al. 2004). Management approaches are normally aimed at long-term feasibility, i.e. being sustainable over time. Wildlife population monitoring and the use of indicators supports understanding essential ecological, epidemiological, and

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socio-economic processes. Such knowledge is necessary to develop proactive management and to utilise the adaptive management model (Gamelon et al. 2012). Adaptive management is the process of making decisions supported by the best available knowledge, while continually adjusting objectives and resources to make management more efficient, effective, or practical over time (Riley et al. 2003).

Wildlife population monitoring should be approached in a rigorous and systematic way according to scientific and technical standards, and data must be managed and analysed in a standardised way to be able to credibly support management decisions and legal arguments, even in court (Thompson et al. 1998, Vicente et al. 2019). Only through this approach will the collected information be comparable among data collection frameworks, and useful in decision making. Selection of the monitoring framework and specific methods (study design) to be implemented depends on the goals and logistical capabilities of the monitoring system (e.g. Acevedo et al. 2008; Nichols et al. 2001). Even when a wide set of methodologies are suitable to monitor wildlife populations, the methods are constrained by the need to be applicable at large spatial scales for most monitoring systems (ENETWILD-consortium et al. 2021a).

Hunting statistics, in general terms, include variables related to the total number of animals seen and/or hunted during a hunting event or period, within a given area or time, and sometimes associated with other hunting effort and hunting effectiveness variables (Nichols et al. 2001). These data may offer a reliable alternative for monitoring population trends of big game species, and can be used to model their distribution and abundance patterns at large spatial scales (e.g. Gamelon et al. 2012; Imperio et al. 2010; Ruiz-Rodríguez et al. 2022). However, hunting statistics can be influenced by many factors not always measured in the datasets (such as regional hunting traditions and hunting regulations, hunting pressure, hunting ground size, hunting area characteristics, and hunters' availability, training, and engagement). When these factors are not taken into account, it makes it difficult to directly compare datasets across territories (e.g. Bosch et al. 2012; Vajas et al. 2021). However, when hunting statistics are recorded under a rigorous and systematic way, including relevant variables related to hunting effort (e.g. surface of the hunting area), they can be used as simple indicators of relative population abundance, even achieving estimations of population density (Artelle et al. 2018; ENETWILD-consortium et al. 2019), or may feed more complex models (Gamelon et al. 2012). This can support long-term and large-scale population monitoring systems that are in high demand by wildlife managers and epidemiologists (Aubry et al. 2020). As different interests and stakeholders may be in conflict with one another (e.g. urban *vs* rural, hunters *vs* animal rights activists), societies require science-informed policies. Therefore, it is essential to generate wildlife demographics data support policies and modern wildlife management (Delibes-Mateos 2015; Martínez-Jauregui et al. 2020).

Currently, there is not a standardised framework for hunting statistics collection in Europe at the country level (particularly for Federal or similarly decentralized countries where data collection depends on local/regional methodologies); each country/region typically collects this data using its own methods, and stores the data in repositories with variable accessibility (ENETWILD-consortium et al. 2018a). In addition, there are differences in hunting traditions and policies followed by countries/regions, which makes describing metadata essential to standardise the data. Differences in the way hunting statistics are collected among European countries are potential obstacles to the common use of hunting statistics at a large scale. As a result, there are calls in the literature for the creation of standardised data collection systems for all countries in order to obtain large-scale, quality data (Aubry et al. 2020; ENETWILD-consortium et al. 2018b). In order to create a proposal for a standard methodology to collect and manage hunting statistics, it is necessary to first know each country's current data collection systems for big game, and the limitations and advantages of these existing systems.

Here we aim to describe a case study in Europe, in order to (i) describe the variability in the big game statistics collection frameworks across mainland regions in Spain, and (ii) to propose a minimum common denominator among regions for a standardised framework of data collection that could be useful for wildlife managers and feasible to implement at the country level.

Material and methods

Spain is composed of 17 Autonomous Communities (AC hereafter; NUTS2 level), 15 of which are mainland communities composed of 47 provinces (NUTS3 level) where hunting legislation and management policies may be shared. Under the umbrella of the national legislation "Ley 1/1970, de 4 de Abril de Caza" (see Martinez-Jauregui et al. 2011), each AC has its own hunting regulations and data collection methodology.

We distributed a questionnaire (see Hunting Questionnaire in Supplemental information) to mainland Spain AC governmental hunting agencies, except for Basque Country, which had the questionnaire distributed to each of its three provinces (NUTS3, i.e. Araba, Bizkaia, Gipuzkoa), which operated independently in terms of hunting management and hunting statistics data compilation (regions hereafter, a total of 17). Questionnaires were designed with the purpose of collecting information about data collected in every region. This encompassed not just the statistics on hunted animals, but also general aspects of the hunting activity, such as the hunting grounds or management units, the number of animals seen during the hunting activity, the number of animals taken, carcass management, and data management. The questionnaire had a total of 20 questions (Table 1)

regarding the type of data available about big game hunting, and answers were coded as recorded/not recorded. Questionnaires covered different aspects of the information collected on big game species present in each region. The animals that were considered to be big game for the purposes of the questionnaire included all hunting species of wild ungulates: wild boar (*Sus scrofa*), red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), fallow deer (*Dama dama*), Iberian wild goat (*Capra pyrenaica*), Pyrenean Chamois (*Rupicapra pyrenaica*), mouflon (*Ovis musimon*), and Barbary sheep (*Ammotragus lervia*). In certain regions, the specific types or range of data collected varied depending on the game species. In such instances, governmental hunting agencies were requested to provide information that could be generalised and applied broadly, focusing on the records collected for the most widely distributed big game species in Spain, namely wild boar, red deer, and roe deer.

We distributed questionnaires in 2018–2019 to governmental hunting agencies, and we offered support via email and telephone. The information collected was updated in 2021, so this paper reflects the situation in that year. The responses from these questionnaires were compared to the responses from forms provided to hunters or managers of hunting grounds for reporting the results of hunts conducted by each region's governmental hunting agencies. This allowed for a comparison between the information gathered through the questionnaires and the data recorded through the official reporting system used by governmental hunting agencies in each region. However, in many cases, it is not mandatory to provide all the hunting statistics, and numerous hunting results are submitted without filling in all the variables requested by the regional hunting agencies. Consequently, the data collected through the questionnaires represent the best available data in Spain. We first used

Table 1 List and description of the variables used in the analyses collected through the questionnaires and grouped according to the level of information

Level of information	Variable	Variable description
Hunting ground characteristics and management	**Type ground**	Is the type of hunting ground recorded? (Public/Private/Protected area?)
	Fencing ground	Is whether the hunting ground is fenced recorded?
	Feeding ground	Is whether supplementary feeding is provided recorded?
	Presence livestock	Is data on the presence of extensive livestock recorded?
	Which livestock	Is the species of livestock present recorded?
	Livestock number	Is the number of herds/flocks per species known?
Game animals and hunting events	N$^{\text{o}}$. of hunted animals	• Is the n$^{\text{o}}$. of hunted animals per species and season recorded? • Same as above, but per event
	N$^{\text{o}}$. of observed animals per event	Is the n$^{\text{o}}$. of observed animals recorded, by species and event?
	Hunting modality	• Is the hunting modality used per season recorded? (Drive hunting/ still hunting/stalking) • Same as above, but per event
	N$^{\text{o}}$. of hunters	• Is the n$^{\text{o}}$. of hunters per season recorded? • Same as above, but per event
	Hunting area per event	Is the hunting area surface (in case of hunting drives) per event recorded?
	N$^{\text{o}}$. of dogs	• Is the n$^{\text{o}}$. of dogs used in each season in the hunting ground recorded? • Same as above, but per event
	Hunted animal sex	• Is the n$^{\text{o}}$. of hunted animals per season according to sex recorded? • Same as above, but per event
	Hunted animal age	• Is the n$^{\text{o}}$. of hunted animals per season according to age recorded? • Same as above, but per event
	Hunted animal fertility	Is the fertility condition of females per event recorded?
	Hunted animal weight	It the body weight of each hunted animal per event recorded?
Carcasses management	**Carcass search**	Is there an active search for carcasses of dead animals? (surveillance)
	N$^{\text{o}}$. of carcasses	If yes, is the n$^{\text{o}}$. of found carcasses known per time unit (week/ months, etc.)?
Data management	**Application**	Is there a mobile or web application software available for the collection of hunting data?
	Data accessibility	Are the hunting statistics data available online to be downloaded?

Variables that could be collected at different temporal resolutions (season vs hunting event) are underlined in the "Variable" column

descriptive statistics to identify differences among regions in the big game statistics data collection methodologies. We used multivariate statistics using a hierarchical clustering analysis with the packages "stats", "cluster" (Maechler et al. 2022), and "factoextra" (Kassambara and Mundt 2020) using R software (R Core Team 2021) to select the number of groups with similar data collection frames.

We conducted a comprehensive analysis using principal component analysis (PCA) in conjunction with a logistic regression model in order to analyse the underlying factors influencing the differences in hunting data collection systems across regions, Firstly, we collected data on various factors including economic outcomes, human resources, and hunting activity coverage from each AC (see Table 2) and summarized these descriptors in a PCA. The main sources for these data were the Forest Statistical Yearbook (Anuario de Estadística Forestal 2020) and the National Statistical Institute (Instituto Nacional de Estadística 2020). The data associated with human resources within each department was collected from the Spanish Association of Forestry and Environmental Agents (2005–2013) but was updated by reviewing the public job vacancies offered and published by each Autonomous Region and was complemented with additional surveys that were given to the heads of governmental hunting agencies in each region.

Secondly, we constructed a logistic regression model (binomial, logit link) using the "MASS" library (Venables and Ripley 2002) in R. PCA factors were treated as explanatory variables, modelling the probability of a region belonging to cluster 1 versus cluster 2 given its economic, logistic, and hunting characteristics. The best model was selected using likelihood ratio tests (LRT) and a step-wise procedure-routine based on the Akaike information criterion (AIC; Akaike 1974). This approach ensured the inclusion of relevant and influential variables in explaining cluster membership within the context of hunting data collection systems.

Finally, to propose a standardised and minimally complete data collection methodology at the country level, we identified the key variables that must be collected by the regional data collection frameworks.

Table 2 Variables used in the PCA to characterise each of the Autonomous Communities

Variable ID	Variable descriptor	Source
HuntGrounds	Number of hunting grounds (2020)	Forest Statistical Yearbook https://www.miteco.gob.es/es/biodiversidad/estadisticas/forestal_anuario_2020.aspx
HuntArea	Hunting grounds area (ha) (2020)	Forest Statistical Yearbook https://www.miteco.gob.es/es/biodiversidad/estadisticas/forestal_anuario_2020.aspx
PrivGrounds	Percentage of private hunting grounds in relation to the total area of hunting grounds	Forest Statistical Yearbook https://www.miteco.gob.es/es/biodiversidad/estadisticas/forestal_anuario_2020.aspx
HuntLicenses	Number of hunting licenses	Forest Statistical Yearbook https://www.miteco.gob.es/es/biodiversidad/estadisticas/forestal_anuario_2020.aspx
HunLinArea	Number of hunting licenses per area of hunting grounds (2020)	Forest Statistical Yearbook https://www.miteco.gob.es/es/biodiversidad/estadisticas/forestal_anuario_2020.aspx
EaArea	Number of environmental agents per area of hunting grounds (2005–2013)	Association of Forestry and Environmental Agents https://www.aeafma.es/policiamedioambiental/distribucion-territorial/comunidades-autonomas *Updated in this study*
TsArea	Number of technicians per area of hunting grounds (2022–2023)	*Updated this study*
HuntBG	Total number of big game animals hunted by year (2020)	Forest Statistical Yearbook https://www.miteco.gob.es/es/biodiversidad/estadisticas/forestal_anuario_2020.aspx
GDPpp	Percentage of Gross Domestic Product dedicated to primary production (2020)	National Statistical Institute https://ine.es/jaxi/Tabla.htm?tpx=31677&L=0
GDPpc	Gross Domestic Product per capita (2020)	National Statistical Institute https://ine.es/jaxi/Tabla.htm?tpx=31677&L=0

Variables considered for inclusion were economic, human resources, and the volume or coverage of hunting resources available in each of the regional administrations

Results and discussion

The data collection of big game hunting statistics in 2021 in Spain was highly heterogeneous among regions (Table 3; Fig. 1) which could be caused by differences in the way big game is managed and hunted. However, most of the regions included highly detailed spatio-temporal resolution, i.e. at the hunting event and hunting ground spatial resolution. In Spain, there are four main hunting modalities for big game species. Although they are practiced throughout the territory, there may be regional preferences for some modalities depending on the target species and local hunting culture: drive hunting with dogs, battue, stalking, and fixed point. "Drive hunting with dogs" is widely used throughout South-Central Spain. In this modality, the hunt area is surrounded by hunting posts and beaten with dogs. Although mainly used for hunting wild boar, battue can also be used for red deer, roe deer, fallow deer, and mouflon. "Battue" is similar to a drive hunt with dogs, with a smaller surface area and fewer hunters, typically resulting a smaller effort than a "drive hunt with dogs". Additionally, the dogs are usually replaced by people who battue the hunting area. "Stalking" here refers to a method where the hunter goes alone, tracks the animal, and moves slowly to a favourable position for shooting. In Spain, this modality is principally used for hunting roe deer, although it is also used for other species such as Iberian wild goat and Pyrenean chamois. "Fixed point" is a widely used modality for hunting wild boar, where the hunter stays at a fixed point, usually at night, at a location where the target species is expected to come. The diversity in hunting techniques and the absence of a standardised framework for collecting big game hunting statistics across all regions of Spain present significant challenges when comparing different territories. Furthermore, in the case of small game species, the implementation of management measures can vary even within distinct hunting areas (Arroyo et al. 2012), making it more complex to consolidate and standardise the collected data. Consequently, it is necessary to analyse hunting statistics separately for small game and big game species due to the substantial heterogeneity in management approaches, which can differ even within the same regions.

Table 3 Summary of the collected variables per region/province (red cells represent the variables collected in 2021)

Level of information	Regions	Andalucía	Aragón	Asturias	Araba *	Bizkaia *	Gipuzkoa *	Cantabria	Castilla-la Mancha	Castilla y León	Catalunya — Hunting Services	Catalunya — Monitoring Program of Wild Boar	Extremadura	Galicia	La Rioja	Madrid	Murcia	Navarra	Com. Valenciana	Score
Hunting grounds characteristics and management	Type of ground																			17
	Fencing ground																			15
	Feeding ground																			7
	Presence of livestock																			3
	Which livestock																			2
	Livestock number																			2
Game animals and hunting events	Nº of hunted animals																			17
	Nº of observed animals per event																			7
	Hunting modality																			13
	Nº of hunters																			13
	Hunted area per event																			10
	Nº of dogs																			9
	Hunted animals sex																			17
	Hunted animals age																			8
	Hunted animals fertility																			3
	Hunted animals weight																			4
Carcasses management	Carcass search																			3
	Nº of carcasses																			2
Data management	Application																			9
	Accessibility																			7
Total	Total per Region	12	4	11	8	13	13	7	10	9	8	16	10	12	11	10	11	13	6	
Total, event level variables	Nº of variables recorded at event-level	4	0	5	4	6	6	0	5	0	0	6	4	5	6	0	5	5	0	

Where variables could be collected at different temporal resolutions (underlined in the "Regions" column), we differentiated between regions where they were collected at the hunting season level (red cells) from those collected at the hunting event level (grey cells). Note that the 3 provinces [NUTS3] belonging to the Basque Country [NUTS2] are marked with *. For Catalonia, information is also detailed separately for the Wild Boar Monitoring Program
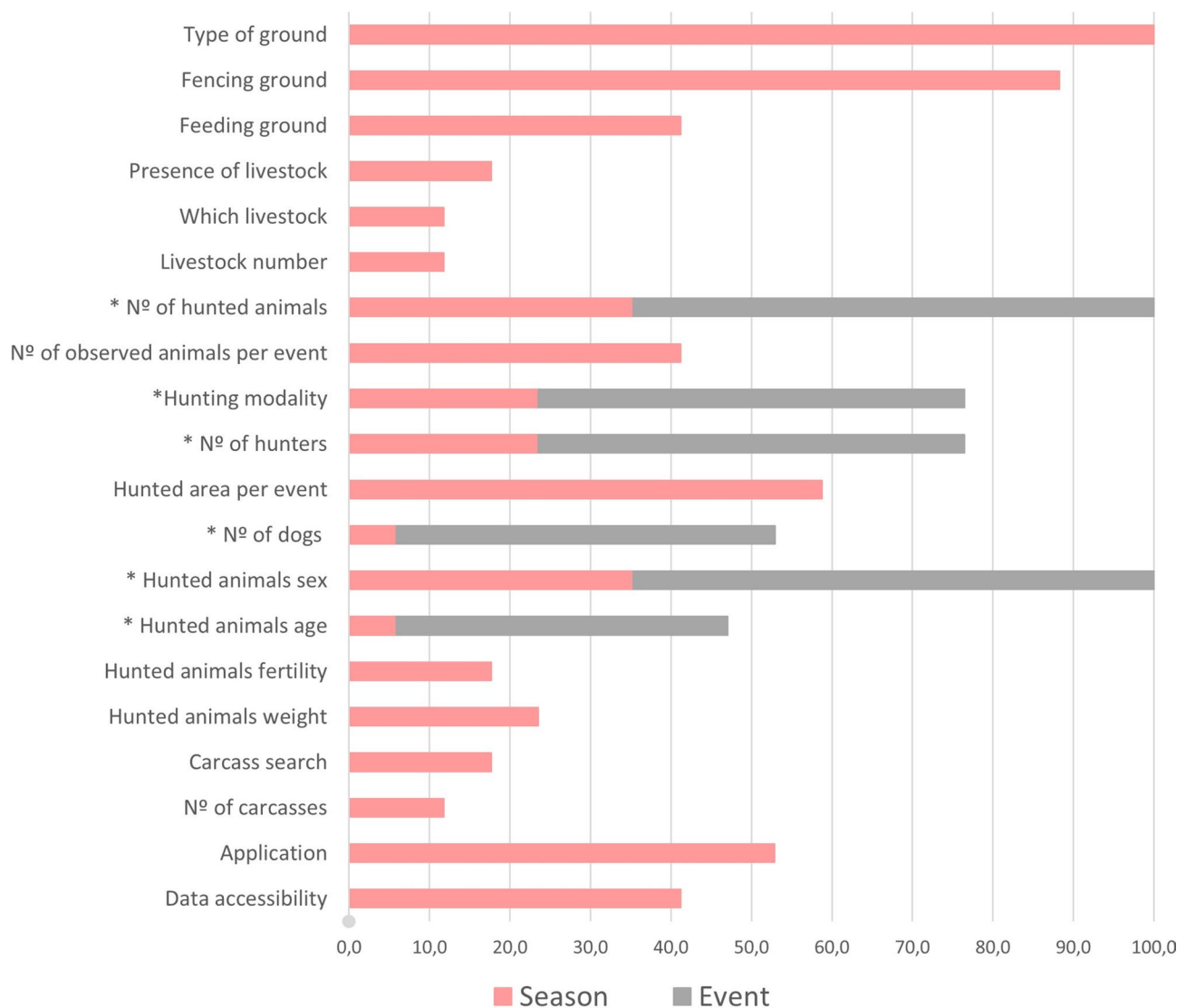
Fig. 1 Percentage of regions in mainland Spain that collected each hunting variable. Variables collected with different temporal resolutions between regions are marked with a "*" and represented with two colours: red represents variables collected at the hunting season level, and grey at the hunting event level

Although the main problem for comparing data across regions is that different information is collected, the resolution is also not equivalent and different methodologies for data collection were used (Martinez-Jauregui et al. 2011). However, despite these comparability issues, overall Spanish regions have relatively complete data collection frameworks (Fig. 1) in terms of the number of parameters collected when compared to other European countries. The number of hunted animals at the hunting ground and season levels was collected in all regions (ENETWILD-consortium et al. 2018b). Additionally, all hunting grounds perimeters have been characterised at the national level by georeferencing (ENETWILD-consortium et al. 2021b), which may be useful for both research and management purposes (i.e. in

case of disease outbreaks such as African Swine Fever; see Fernández-López et al. 2022 and ENETWILD-consortium et al. 2021b for examples of implementation at the national and international levels).

Patterns in regional data collection frameworks over mainland Spain

We grouped Spanish regions according to similarities in their hunting data collection systems based on the number and type of variables collected by each region. Results from hierarchical clustering analysis identified 2 main clusters (Fig. 2 top). The first cluster is made up of a larger number

of regions, where, with the exception of Madrid and Murcia, the regions are related to other spatially close regions. The second cluster is formed by regions located in the north and north-west of Spain (Navarra, Bizkaia, Gipuzkoa, Asturias, La Rioja, Araba and Galicia) and contains the regions with the most complete hunting data collection systems (see Fig. 2 bottom, map C). However, there are additional regions that collected the key parameter "number of hunted animals" at the event level, and other parameters at the event level (Fig. 2 bottom left map B in grey), that are distributed in South-Central regions of mainland Spain.

We conducted a PCA incorporating the ten variables characterising each region (see Table 2) in order to better understand the factors contributing to the clustering of regions. From this PCA, we selected the first two axes; PC1 and PC2 (based on criteria retention factors with eigenvalue higher than 1) that resulted in a cumulative explained variable of 73% (Table 4).

The PC1 explained 52% of the variance and may be interpreted as a workload gradient; this axis allows us to differentiate between regions with high GDP *per capita* and a high number of technicians working in governmental hunting agencies per hunting area, from other regions with fewer economic and technical resources but a high volume of hunters, hunting grounds, and number of hunted animals. The second, PC2 (21% explained variance), could be interpreted as a gradient within the hunting intensity that differentiates regions with a greater dedication to activities associated with hunting *vs.* regions more dedicated to primary production (agriculture and or livestock activities).

We also modelled the probability that these factors (PC1 and PC2) were associated with the likelihood of belonging to one of the two clusters. Following a likelihood ratio test analysis (LRT, $p < 0.005$), and AIC criteria ($\Delta AIC = 6.02$), the best logistic model included both principal component factors (PC1 and PC2), explaining 43% of deviance (pseudo-*R*). The model showed that cluster 2 was associated positively with PC1, indicating high economic and human resources. Simultaneously, it displayed a negative association with the number of hunting grounds, hunting area, and number of hunters. In contrast, for cluster 1, the situation was reversed, with a positive association observed with a higher workload associated to hunting activities (e.g. number of hunting grounds, hunting area, and hunting bags; see Table 5), coupled with higher values of PC2, representing a greater hunter density. This aggregation within cluster 1, comprising regions with a larger volume of information to manage (high numbers of hunters and hunting grounds), was also characterized by having a less complete hunting data collection system. This could be attributed to organisational issues, as the digitisation of information is not yet widespread in most regions, which could lead to regions with a larger

volume of data having difficulties in adequately managing high quality information. Despite the limitations of a small sample size, these results suggest that regions with a higher GDP *per capita* invested more in human resources, and this is associated with more complete hunting data collection systems. This is particularly relevant in regions with a large proportion of hunting surface in their territory. To improve data quality, it is recommended that hunting event data (such as group hunts) should be collected in those regions where they are only collected seasonally (ENETWILD-consortium et al. 2019). These data would potentially allow for more precise abundance estimation through the drive count methods (ENETWILD-consortium et al. 2018b, 2020a, 2021a). However, enhancing the quantity and temporal resolution of the collected data requires significant efforts from the hunting agencies. Unfortunately, some regional agencies face challenges due to insufficient financial and personnel resources. Therefore, it becomes crucial to motivate staff, to provide adequate training, to augment the budgets for staff in some regions, and to provide information technology tools to support data collection activities ("from the field to the desktop" strategy). By implementing these measures, it would be possible to address the proposed improvements effectively, and to establish a national big game data collection system capable of providing reliable data to support wildlife management and conservation efforts.

The fact that regions in cluster 2 have similar hunting data collection systems may reflect similarities in the hunting management and activities in these areas. In Northern regions, hunting is mainly a social activity, whereas in the South the economic and commercial components are more important. Hunting modalities (e.g. specific characteristics of driven hunts) may also differ between Northern and Southern Spain (López-Ontiveros and García-Verdugo 1991). These socio-cultural differences could also explain the differences in the way hunting statistics data are collected between the two clusters.

Different data sources can be essential for monitoring hunted wildlife populations in Spain and in Europe. Hunting statistics are essential, but not sufficient to adequately characterise the populations and the different management models that condition the level of hunting effort.

Accessibility, transparency, and improved spatial and temporal resolution of the information collected, as well as improved procedures to streamline the quality and speed of data collection, are key. This will allow for a rapid response to unforeseen scenarios such as new epidemiological challenges, and to activate early warnings or detect disease emergencies. The current Spanish data model has some strengths and limitations, and the description presented here allowed us to elaborate a proposal to improve hunting data collection systems (see below).
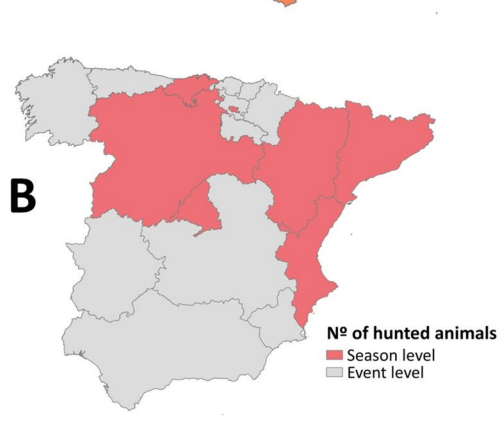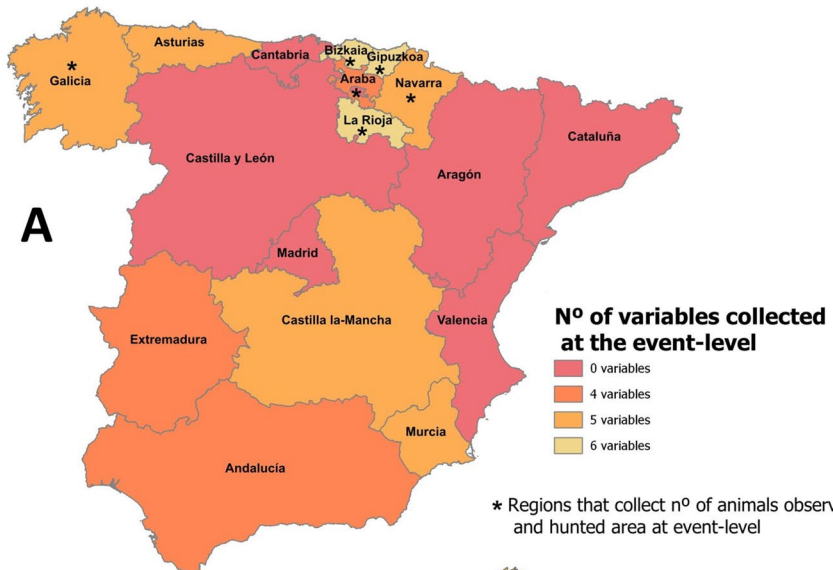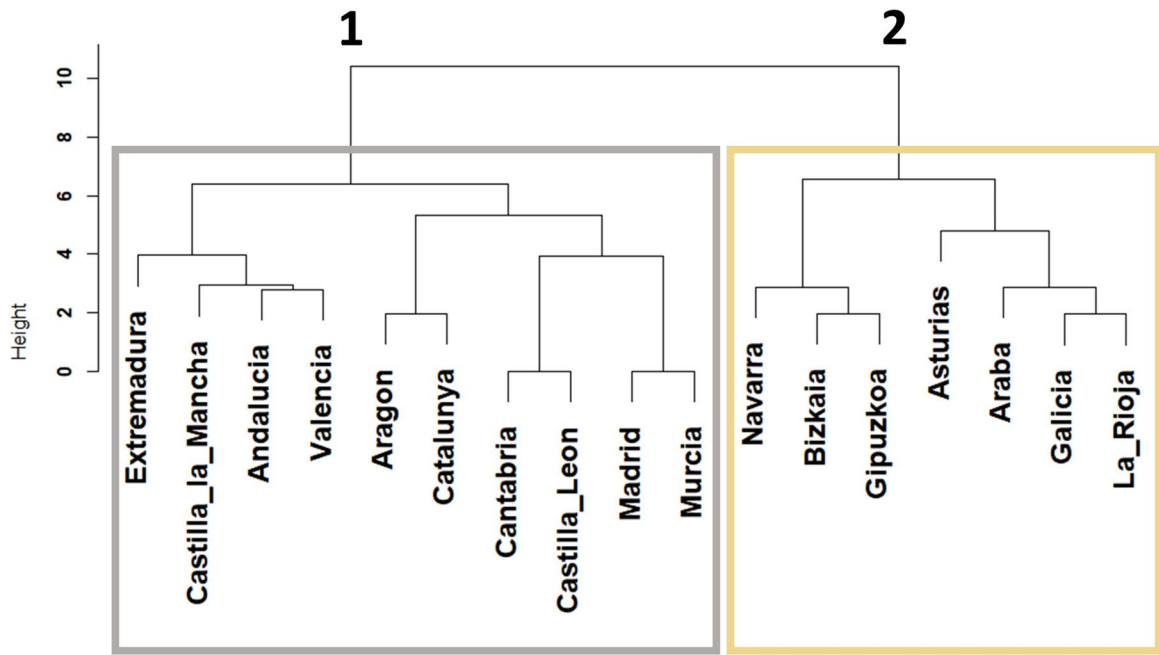
◄**Fig. 2** Top: Hierarchical clustering analysis dendrogram. The vertical axis represents the distance or difference between ACs or provinces. The horizontal axis represents all ACs and provinces. Bottom: map A of mainland Spain differentiates regions according to the number of variables collected at the event level, from 0 to 6 variables, regions in red did not collect any variables at the event level, and regions in yellow were where all six variables were collected at the event level. Map A also differentiates regions that collect data about the number of animals observed as well as the hunting area at the event level with (*). On the left bottom, map B of mainland Spain differentiates regions according to the variable "number of hunted animals": in grey, this variable is collected at the event level, and in red, at the season level. In Catalonia, the Monitoring Program of Wild Boar populations in Catalonia (Rosell et al. 2021) collects data at the event level in a network of 22 sites. On the right bottom, map C of mainland Spain, showing regions according to cluster (regions belonging to cluster 1 in grey, and cluster 2 regions in yellow)

Hunting ground characteristics and management

Collecting hunting statistics at the smallest possible management unit is key to guide management. It is noteworthy that in recent decades, many estates in mainland Spain (particularly in the Centre and South) have been fenced in order to allow more intensive management of big game populations with independence from the surrounding areas (Vicente et al. 2006). This implies that the relationship between the management unit (the surface of connected land subject to a common criterion of hunting management) and the ecological unit (the area of land that corresponds to an ecosystem that maintains a certain independence within the environment, Carranza 1999) may vary according to the region. Therefore, information on fencing is essential. The presence of perimetral fencing of the hunting grounds is widely recorded (15 out of 17 regions; Fig. 1), and the two cases which do not report fences are regions known to have an absence of big game fences (i.e., most Atlantic areas of Spain: Galicia, Asturias, Cantabria, Araba, Bizkaia, Gipuzkoa). Therefore, data collection on fencing can be considered complete in Spain. The variables with the lowest recorded rate are related to livestock presence within hunting grounds (Table 3; Fig. 1). This information (together with carcass management; see below) is relevant to characterise the epidemiological interface between domestic and wild species, and may help to improve our understanding on (i) shared diseases (du Toit et al. 2017; Gortázar et al. 2007; Siembieda et al. 2011) and (ii) determining the "stocking rate or grazing load" of ungulates (both wild and domestic) over management units. We are aware this information is available at regional administrations (animal health services), and therefore, an effort should be made to integrate information between Departments. Wildlife monitoring must be integrated since the inclusion of different animal types (such as domestic animals) can notably enhance our potential to understand and manage ecological and epidemiological processes (Cardoso et al. 2022; Vicente et al. 2019).

In regard to intentional artificial feeding (see Glossary in Supplemental information), seven of the 17 regions surveyed recorded information on any kind of feeding aimed at big game in hunting grounds. Not all regions interpreted the artificial feeding question in the same way. Different interpretations likely depended on the local/regional feeding practices and supplementary feeding was sometimes confused with baiting. Baiting can be defined as a strategy used prior to a hunting event or during stalking to attract animals, and thus increase the effectiveness of hunting (Inslerman et al. 2006). Though supplementary feeding in hunting grounds is forbidden by law in Spain (RD. 138/2020), there are exceptions in which supplementary feeding may be used with the prior authorisation of the regional hunting authority. Some of these exceptions that allow artificial feeding in hunting areas are to increase the effectiveness of hunts during emergency situations, such as during times of overpopulation of ungulates, and in particularly adverse climatic situations (e.g. severe drought). Only some regions recorded information on these exceptional cases. Exceptions to the prohibition by law are managed by each region individually. Because of the ambiguity between the interpretation of terminology regarding artificial feeding (supplementary vs baiting), a standardised collection of information on artificial feeding must be solved legislatively. One existing proposal is to regulate a maximum feeding quantity (kg of feed) per time and area, as in the "*Strategy approach to the management of African Swine Fever for the EU*" (SANTE/7113/2015-Rev12).

Game animals and hunting events

Here we refer to the total number of animals hunted and the number of animals hunted relative to the number of animals observed during hunting activities as the hunting effectiveness variables (see glossary). The number of animals hunted was a variable collected by all regions, and in most cases, at the best possible temporal resolution (collective hunting event, 11 regions; see Table 3). However, the number of animals observed per event was less frequently reported (collected only in 7 regions). These two variables can be used to precisely estimate abundance, applying the driven count method when the beaten surface area is also recorded (ENETWILD-consortium et al. 2019). However, the beaten area (see below) is only collected in nine regions and these regions are not always the same as the regions that record the number of animals sighted during collective hunts. It is important to note that in most regions, reporting hunting results at the event level is not obligatory. Consequently, despite providing the option to collect information at the event level in their data collection forms, the data received is frequently aggregated by season. Therefore, the

Table 4 Outcomes of the principal component analysis (PCA) performed on the hunting-related effort variables obtained for each region

Variable	PC1	PC2
HuntGrounds	− 0.41	0.14
HuntArea	− 0.40	0.00
PrivGrounds	− 0.18	0.30
HuntLicenses	− 0.30	0.38
HunLinArea	− 0.10	0.60
EaArea	0.26	0.49
TsArea	0.36	0.09
HuntBG	− 0.40	0.07
GDPpp	− 0.31	− 0.30
GDPpc	0.30	0.21
Standard deviation	2.29	1.45
Proportion of variance	0.52	0.21
Cumulative proportion	0.52	0.73

The table provides the correlation coefficients, standard deviation, proportion of variance, and cumulative proportion for each component (PC1 and PC2)

questionnaire results presented here represent, at best, the data collected by each region. The hunting modalities of "drive hunting with dogs" and "battue" are predominantly used for harvesting wild boar, as well as other species such as red deer, roe deer (in Northern Spain), fallow deer, and mouflon. In these modalities, the number of animals observed during hunting events is frequently recorded by hunters. It is noteworthy that in most regions, the recorded observations typically refer only to individuals of the same species being hunted. Only a few regions have implemented the practice of annotating observed animals of non-target species as well. Extending this annotation to include observed individuals of other big game species in these types of hunts (driven with dogs or battue), and correlating them with the hunting area's surface, could be an improvement applicable to other regions. This enhancement would aid in estimating the overall abundances of several species and provide a more comprehensive understanding of their populations. The ideal situation would be to have the three variables (no. of hunted animals, no. of observed animals, and the area of the hunted surface) available at the event level resolution for all regions to allow

Table 5 Results of the logistic regression model, including coefficients, standard error odds ratio, and 95% confidence intervals for the odds ratio

	Coefficient (β)	Standard error	Odds ratio (CI 95%)
Intercept	2.41	1.42	11.11 (1.33–489)
PC1	− 1.80	0.99	0.16 (0.01–0.69)
PC2	1.20	0.84	3.34 (0.84–33.1)

for abundance estimations. Also, statistical inference with these variables at this resolution guarantees greater objectivity and robustness of spatial predictive models (Aubry et al. 2020; ENETWILD-consortium et al. 2021b).

Information concerning hunting effort (hunting modality, number of hunters and beaten area) was collected at the event level in nine regions, and the number of dogs used was collected in eight regions (Table 3; Fig. 1). Recording these data at this resolution is relevant for characterising the hunting pressure and to evaluate hunting effectiveness. Several studies consider the relative abundance of hunting species by relating the total number of animals hunted to spatial variables, such as province, municipality, or hunting area (Acevedo et al. 2014; Bleier et al. 2012; Bosch et al. 2012; Imperio et al. 2010; Pittiglio et al. 2018). In Spain, all governmental hunting agencies in the surveyed regions have geospatial information on hunting grounds, which, together with the total number of animals hunted per hunting ground and hunting season, can be used for modelling relative abundances of big game species (Ruiz-Rodríguez et al. 2022). However, data on hunted animals at the highest temporal (hunting event) and spatial (area hunted per hunting event or battue) resolution would allow for better predictions, as hunting effort variables influence the number of animals successfully hunted (see Segura et al. 2014; Vajas et al. 2020).

Data on big game fertility and body weights (Table 3; Fig. 1) were rarely collected (four and three regions respectively, out of 17). However, this information is relevant to understand population dynamics (Clutton-Brock et al. 1997; ENETWILD-consortium et al. 2022) and management, such as quotas. The collection of this data at the individual level could be costly and labour-intensive and require certain expertise, but it should be considered a goal for a standardised methodology. The number of individual samples required to describe the reproductive status of the population may depend on the expected pregnancy rate. For example, according to Mayor et al. (2017), the minimum sample size required for a 10% confidence limit in the order Artiodactyla, assuming an expected pregnancy rate of 42% and an unlimited population size, would be 94 sampled individuals. In the case of the target ungulate populations in our study, we could propose collecting data for 20–30 individuals to describe the reproductive status at the hunting ground level, at a selection of 10% of the hunting grounds. In order to account for the regional variability (i.e. food availability, different management techniques, and diverse environmental conditions) it may be necessary to describe the performance at the regional level (Jovani and Tella 2006).

The Monitoring Program of Wild Boar populations in Catalonia merits special discussion (Rosell et al. 2021). This program has monitored wild boar populations for more than 20 years at the regional scale. The objective

is to quantify the demographic trends of wild boar populations utilising the expertise of a network of collaborators consisting of managers, technicians, and hunters. The program consists of a network of 22 sites (observatories) which represent different bioclimatic regions of Catalonia. Each observatory collects detailed data on all wild boar hunts. The same methodology has been maintained over time, allowing for comparison of results and the exploration of population parameters through time. Data collected are of high temporal (collected for each wild boar drive hunt or event) and spatial resolutions with registered information about: date, hunting area, the number of hunters and dogs, the number of wild boars observed and hunted, and the sex and weight of each hunted animal. Thanks to the quality and long-term maintenance of the data collected by this program, it is possible to estimate important parameters for wild boar management, such as hunting effectiveness, abundance estimates, and population characterisation in the studied areas. Its representative design also allows for inference at the regional level to inform policies and apply adaptative management.

Continuing along the lines of this program, the "European Wildlife Observatory" initiative (EOW, www.wildlifeobservatory.org) has recently been established as a network of wildlife observation and monitoring points at the European level. The aim of this project is to include different study areas representing all European countries and bioregions that collect data on wildlife (including high-quality hunting data) in order to monitor wildlife population trends. The EOW provides guidelines and tools for density estimation of wild terrestrial mammals such as ungulates (*ENETWILD*-consortium et al. 2018c, 2021a), support, and training for survey design and data analysis; facilitates data exchange; and generates information necessary to support monitoring of European wildlife populations.

Carcasses

We identified a low collection rate of variables related to the search and count of carcasses found in hunting grounds (Table 3; Fig. 1). This information is key to improving our knowledge on mortality and the epidemiology of diseases, as well as to generating risk analyses and the application of prevention and eradication protocols for diseases (Gervasi and Gubertì 2022; Lim et al. 2021; Morelle et al. 2019). Carcass finding is essential for early detection of diseases and preventing the spread of outbreaks, such as in the case of ASF in wild boar.

Data management

The hunting data collected in Spain are compiled by the responsible administrations of each region and are available upon request at the hunting ground resolution for scientific purposes. This accessibility contrasts with other existing models in Europe, where data are usually collected and archived by hunting associations, and the availability of this information is restricted or in many cases inaccessible at a spatial resolution suitable for incorporation into models of good spatial resolution (see ENETWILD-consortium et al 2021). Furthermore, in terms of accessibility, only 7 out

Table 6 Big game statistics (no. of hunted animals/species) openly shared by certain regions, and the link to the website or open document (access in October 2023)

AC	Spatial resolution	Time resolution	Link
Andalucía	Provinces	Hunting season	https://portalrediam.cica.es/descargas?path=%2F16_INDICADORES_ESTADISTICAS%2F01_IMA%2FIMA_2020%2FEstadisticas_indicadores%2F08_Espacios_forestales%2F08.07_Caza_y_pesca
Castilla La-Mancha	Provinces	Hunting season	https://www.castillalamancha.es/sites/default/files/documentos/pdf/20210813/memoria_anual_caza__clm_2020.pdf
Castilla y León	Provinces	Hunting season	https://medioambiente.jcyl.es/web/es/caza-pesca/resultados-temporadas-cinegeticas.html
Catalonia	Provinces	Hunting season	https://www.idescat.cat/indicadors/?id=aec&n=15201&t=2020&lang=es
Wild Boar Monitoring Program (Catalonia)	Hunting estate and hunting reserve	Hunting season	https://agricultura.gencat.cat/web/.content/06-medi-natural/caca/enllacos-documents/informes-tecnics/programa-seguiment-poblacions-senglar-sus-scrofa/fitxers-binaris/seguiment_senglar_cat_2020-21.pdf
Gipuzkoa	Management units	Hunting season	https://www.gipuzkoa.eus/documents/2946649/34957019/2021-22+Ehiza+larria.pdf/ce499399-64f3-d2d1-aeeb-8ed8c999e3fb
La Rioja	Type hunting ground	Hunting season	https://www.larioja.org/medio-ambiente/es/estadistica/materias/estadisticas-medioambientales
Murcia	Municipalities	Hunting season	https://cazaypesca.carm.es/documents/537485/1503356/Informe+de+capturas+cineg%C3%A9ticas+2020-2021/20f5aa78-be1f-46f3-a4f2-9d03fa6efd37

of 17 regions surveyed and the Wild Boar Monitoring Program in Catalonia share records openly on big game harvest, though at low spatial resolution (Table 6). Currently, less than half of the mainland regions have a platform for downloading hunting statistics, which makes it difficult for the scientific community or other users to access the data. The open (or under certain restrictions) availability of the hunting statistics of all regions at a high spatial resolution would be an important advancement for scientific and technical use (e.g. in case of ASF outbreak).

Although the reporting of hunting data is mandatory in Spain in most cases, most regions are far from having complete data collection. The availability of data at good spatial and temporal resolutions relies on more than half (9 of 17 regions) of the regional governmental hunting agencies, having a mobile or web-based application software, or an online form for hunting statistics data collection (Table 3; Fig. 1). In spite of several governmental hunting agencies intending to develop an application software in the short term, the use of paper forms is still the main method of hunting data collection in Spain, which requires manual digitisation by governmental hunting agencies staff. The general trend is an increase in the development and implementation of information technology tools (mobile or web-based software) to facilitate the collection and management of hunting information, as data can be digitised from the field. However, if applications software are going to be truly useful in wildlife monitoring, their design must follow an appropriate design of monitoring system and objectives. Otherwise, there is a risk that the collected information will not be standardised and useful for wildlife management decision-making. The structure and way of collecting the information must follow scientific-technical standards that even allow for comparisons between territories (ENETWILD-consortium et al. 2020b). If hunting agencies wish to incorporate the use of these applications software (which is highly recommendable), they should be designed to collect data on fine time and spatial scales, such as the hunting event, as well as collect data on hunting effort and effectiveness in a standardised way, using similar fields and vocabulary.

Recommendations

The main recommendations for the standardised improvement of hunting statistics include collecting variables at the smallest spatial and temporal scale and focusing on a few proposed variables presented below (see Table 7). This approach and data model can be adapted to other countries across Europe, considering the context of each country, which would notably improve the usefulness of hunting statistics data as a tool for sustainable management of big game species at large-spatial scales. More specifically:

Table 7 Number of regions (out of 17 included in the present study) where hunting effort and efficiency variables should be collected to achieve a complete standardisation of hunting statistics in mainland Spain at the event level

Effort and efficiency variables	No. of regions where they should be collected
N°. of observed animals per event	10
N°. of hunted animals per event	6
N°. of hunters per event	8
Hunting area per event	7
N°. of dogs per event	9

- It is essential to incorporate hunting effort-related variables of hunting statistics to allow for their use as indicators of abundance. In the case of Spanish regions, the most important variables are described in Table 7. The variables are related to the effectiveness and effort in hunting activity, such as number of seen/hunted animals, hunters, and dogs and the surface of the hunting area. They should be mandatory to be included in the standardised protocol to record hunting statistics at the hunting event level.

- It is recommended that regions increase the number of variables collected in a standardised way. Therefore, with the aim of being able to use high-quality data at the national (and international) level, we propose a template of a collection model for collective hunting, such as drive hunting with dogs and battue. This model identifies the variables that should be collected at the event level (Table 8). According to our results, some Spanish regions have a complete hunting data collection system; their data are highly disaggregated spatially and temporally and have the potential for population monitoring and modelling patterns of abundance of game species (e.g. Ruiz-Rodríguez et al. 2022). A strategy for "disseminating" these systems consists of promoting discussion among regions, sharing practical information, such as the effort required and best approaches (from sampling design to data collection and analysis) to carry out and maintain data collection at a high resolution. As an example for a standardised improvement of a data model, we discuss the proposed project ENETWILD, at the European level (ENETWILD-consortium et al. 2018b), available also in Excel format.

- The use of new information technology tools as a complement to collect information from the field in a standardised way is recommended, which implies engaging stakeholders as part of the monitoring process. Apps are practical and useful tools for implementing systematic data collection programs, and therefore should be designed intentionally for data collection, and not vice

Table 8 Proposed form to collect essential data during collective hunts (hunting drives with dogs and battues) at the hunting event level to achieve high quality, standardised data collection, capable of producing density estimates (doc available at http://wildlifeobservatory.org/wp-content/uploads/2022/01/Form.docx)

FORM TO COLLECT DATA DURING COLLECTIVE HUNTING EVENTS (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 cave red and/or consecutive number within the season):	
Start time:	End time:
Name and/or code of the stalking site:	
Nº of hunters (stalking sites):	Nº of beaters:	Nº of 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 of sighted wild boar (including those hunted):	
Total Nº of hunted wild boar:	
Total Nº of sighted red deer (including those hunted):	
Total Nº of hunted red deer:	
Total Nº of sighted roe deer (including those hunted):	
Total Nº of hunted roe deer:	
Total Nº sighted other species (including those hunted): indicate species and nº	
Total Nº hunted other species:	
Total Nº sighted other species (including those hunted): indicate species and nº	
Total Nº hunted other species:	
Total Nº sighted other species (including those hunted): indicate species and nº	
Total Nº hunted other species:	
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 coordinator of the drive count, who will fill in the form far 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.	

versa. One suggestion for the application software or online form design is to incorporate an alert system for missing data. In this way, if the hunting service identifies any uncollected data, they can contact the user who submitted the information and request they provide the missing details. Furthermore, for hunting events where the area can be delimited, such as driven hunts with dogs and battues, integrating a Geographic Information System (GIS) into the application would be beneficial. This feature would allow users to indicate the specific area where the hunting event is taking place. Lastly, we highly recommend ensuring interoperability between software application tools utilised by different institutions and adhering to international ecological standards (ENETWILD-consortium et al. 2020b).

- The open availability of data collected by governmental hunting agencies once standardised will greatly benefit the collaboration and transfer of information to the scientific and professional sectors. The standardisation of big game data collection systems would not be useful if access to data is limited. We found that only a small number of Spanish regions provide open hunting data for download (Table 6), the spatial-temporal resolution of the data was limited, and data was in different forms and resolutions, depending on the region.

- We propose the creation or improvement of a centralised annual publication detailing the data collection frameworks and statistics, providing demographic analyses and analysing trends. Hunting statistics of all regions should be adapted to a standardised data collection model progressively. This yearly book would be based on a national database agreed on by regional and national authorities.

Concluding remarks

Spain has a relatively complete data collecting "landscape" (as it is not a proper system developed for this purpose) for hunting data when compared to other European countries (ENETWILD-consortium et al. 2018b). However, it is composed of several disconnected regional systems, each using their own standards. The addition of several specific variables collected following consistent methodologies in alignment with international standards is required to achieve standardisation for the variables most relevant to the management of hunting effort in the short term. Namely, the spatial and temporal resolution of hunting effort and effectiveness data must increase. This would allow for the use of hunting statistics as reliable indicators of abundance of wild ungulates on a large scale. However, the feasibility of these proposed improvements in the hunting data collection systems requires further work on (i) determining the cost of implementing the proposed enhancements, including

the increase in the number of variables and resolution, (ii) identifying the barriers and difficulties of implementation (including the social component), and (iii) to develop/improve data collection applications capable of standardising different regions while meeting each regions' expectations, specificities, and confidentiality issues. Whereas this case study was focused on big game species in mainland Spanish regions, the recommendations provided here have the potential to be applied to other species and countries across Europe. The standardisation of hunting data at the national level, as a first step to achieve European standardisation, is essential for wildlife monitoring and wildlife informed management and conservation.

Declarations

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