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Research protocols for designing studies/pilot trials to evaluate and to improve effectiveness of wild boar management in relation to African swine fever virus

Enetwild consortium[1]

Abstract

The ecological plasticity of wild boar and their growing populations can generate conflicts with human activities and can be a threat to livestock and public health. Particularly, the emergence of African Swine Fever in Europe is of major importance. However, there are gaps in knowledge about wild boar ecology, population monitoring, management and population control that prevent the design and application of the best science-based ASF control policies, and/or adaptive evaluation of the actions taken. The effectiveness of wildlife policies is known to be directly proportional to their acceptance by stakeholders. However, it is unknown how the acceptance of these policies and different management scenarios vary among stakeholder groups, in different socio-economic and cultural contexts. Acceptance by stakeholders in different contexts determines the success of management strategies. Finally, factors that influence wild boar abundance and disease spread are not bound by national borders. Thus, there is need to coordinate national and international decision-making. In this context, this report presents research protocols to address a number of knowledge gaps previously identified by EFSA, and aims to improve the strategy to control ASF in the short-term. Twelve research objectives grouped into six categories address aspects of: (i) wild boar ecology, i.e. studies on basic aspects of wild boar population dynamics and assessment of the factors that determine the presence of wild boar near outdoor pig farms; (ii) wild boar monitoring, i.e. implementation of practical methods to estimate wild boar density and strategies to promote their application; (iii) wild boar management and population control, i.e. effect of feed availability, role and efficacy of recreational hunting and professional culling, efficacy of wild boar trapping and different fencing methods and the use of trained dogs in ASF affected areas; (iv) social acceptance by the stakeholders; (v) assessment and management of risk factors (biosecurity awareness and implementation among backyard pig farmers, evaluation of passive surveillance and carcass removal); and (vi) national and international decision-taking. We propose protocols for each specific research objective, their study design, implementation methodology, required time frames and budget limitations. We comparatively summarize the protocols and discuss them in terms of solving overlaps and interactions among protocols that address different research objectives, which eventually can be combined to optimize the use of resources and budgets and to reduce the required time needed to achieve objectives.

Keywords: Research protocols, research objectives, wild boar, management and population control, African swine fever, monitoring, social acceptance, national and international decision-taking

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Summary

The ecological plasticity of wild boar (WB) and their growing populations generate human-ungulate conflicts, and may cause livestock and public health threats. Particularly, the emergence of African Swine Fever (ASF) in Europe is of major importance. However, there are relevant gaps in knowledge of the WB ecology, population monitoring, management and population control that prevent designing and applying best science-based ASF control policies, and/or adaptively evaluating the actions. This knowledge is also essential to develop risk assessment. The effectiveness of wildlife policies is known to be directly proportional to their acceptance by stakeholders. Nevertheless, it is unknown how this effectiveness varies among stakeholder groups and different management scenarios, or socio-economic and cultural contexts. This variability of stakeholders and contexts determines the success of management strategies. Finally, factors that govern WB abundance, their impacts and disease spread are not bound by national borders and there is need to coordinate national and international decision-making. In this context, this report proposes research protocols (ROs) to address a number of gaps previously identified by EFSA, aiming at improving the strategy to control ASF in a short-term perspective.

These protocols here proposed may eventually be combined (in case different ROs are finally addressed within the same time frame) to optimize the use of resources and budget, and to improve the quality and applied value of results. Regarding protocols requiring WB telemetry, they normally are first choices in the respective ROs. However, they can exceed the time-fame required for short-term assessment. In most cases, several years are required to generate reliable and sufficient data to evaluate the specific question (e.g., mortality) and not only seasonal, but interannual fluctuations are so relevant (even they may impede comparisons among study sites if not accounted for). In other cases, telemetry is especially recommended because it provides a complete picture and sufficient detail of WB spatial behaviour to develop control strategies. By contrast, camera trapping (CT) provide really high resolution data but are limited to monitoring specific areas. Actually, both approaches are complementary and are often used to characterize risk at the wildlife/livestock interface. In some cases, CT could replace telemetry, which reduced costs, but monitoring is limited to what the camera traps (CTs) photograph/record. Short-term telemetry also demands a high budget as devices (e.g., GPS collars) can hardly be re-used on several animals. It also requires studies conducted simultaneously in several areas. It is therefore recommendable to explore already-existing data on telemetry available from European collaborative initiatives. However, we provide alternative protocols in all ROs that included telemetry-based protocols.

Within each specific RO, different protocols, in most cases complementary rather than exclusive, were proposed. In total, eighteen protocols have been developed, and we remark the following considerations for each of them:

Wild boar ecology

- RO1. Studies on basic aspects of WB population dynamics all over Europe.

  Protocols can be addressed separately, optimally, consecutively

- RO2. Holistic assessment of the factors that determine the presence of WB near to different pig farm types, including outdoor farms and extensive production systems.

  Although telemetry added values provides practical information to develop specific management, as mentioned above, telemetry can be efficiently replaced by CTs to provide short term assessment.

Wild boar population monitoring

- RO3. Implementation of practical methods to estimate WB density.

  The activities proposed are well aligned with current activities developed by Enetwild project.

Wild boar management and population control

- RO4. Effect of food availability on WB population dynamics in natural areas in relation to baiting and feeding

  Protocols can be addressed separately, although the first one (data compilation) can be useful for the selection of study sites for telemetry protocol. Telemetry added values provides practical information to develop specific management. It is recommendable to check already-existing data on telemetry by European collaborative initiatives.

- RO5. Role and efficacy of recreational hunting and professional culling for WB population control.

  It is recommendable to collect data on hunting and culling statistics in selected management areas of Europe where recreational hunting and professional culling are being/were performed.

- RO6. Assessment of the efficacy of WB trapping methods including welfare implications and social acceptability.

  It is recommendable to check administrations involved in the management of local ASF WB outbreaks about data availability.

- RO7. Assess the efficacy of different fencing methods with GPS- collared WB, considering also the effect on non-target species.

  CTs and video recording alone are cheaper solutions but not optimum approach to make robust conclusions on the effectiveness of fencing. It is recommendable to check with administrations involved in the management of ASF outbreaks about data availability. Recommendable to check already-existing data on telemetry by European collaborative initiatives.

- RO8. Use of trained dogs in ASF affected areas to detect WB carcasses.

  It is recommendable to check with administrations involved in the management of local ASF WB outbreaks about data availability.

Social acceptance

- RO9. Social acceptance of WB management measures and animal welfare (qualitative and quantitative approaches).

  These are two protocols to assess acceptability of WB management options by different stakeholders (qualitatively and quantitatively, respectively) which should be developed consecutively in order to provide a complete assessment of the requested issue, even in parallel.

Assessment and management of risk factors

- RO10. The WB/pig interface: Raising awareness about biosecurity and its implementation among backyard pig farmers.

  The first protocol will produce a detailed guide on the implementation biosecurity in outdoor and backyard pig farms, covering the vast majority of outdoor management contexts existing in Europe, while the second protocol would provide a tool to facilitate the assessment of the level of biosecurity on the farm. Therefore, the priority is the first protocol.

- RO11. Evaluation of the measures of passive surveillance and carcass removal on the spread of the disease.

  Two protocols based on data collected in selected management areas of Europe are proposed, and we recommend addressing both at once using the same study areas (this would reduce total costs). It is recommendable to check administrations involved in the management of local ASF WB outbreaks about data availability.

National and international decision-taking

- RO12. Assess how to improve coordinated national and international decision-taking.

  The proposed protocol is based on establishing organized and well-prepared working sessions by specific groups and putting together their inputs following a pre-defined agenda, to finally elaborate a first draft for a WB Pan-European management plan. In this plan, not only scientific and technical issues, but organization and coordination aspects involved in WB management will be key. The format/s adopted (several can be combined) to develop discussions are really flexible, and therefore, current COVID19 pandemics should not impact its normal course.

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1. Introduction

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

This contract was awarded by EFSA to Universidad de Castilla-La Mancha, contract title: Wildlife: collecting and sharing data on wildlife populations, transmitting animal disease agents, contract number: OC/EFSA/ALPHA/2016/01. As stated in Specific Contract 8 (deliverable 3.1), the terms of reference for the present report were: Literature review and research protocols for designing studies / pilot trials to evaluate i) the impact of reducing wild boar (WB) *Sus scrofa* population densities in relation to transmission of African swine fever virus (ASFV); (ii) the natural ecology and behaviour of WB to improve effectiveness of WB population management (the exact list and definition of research topics to be considered in the protocols will be provided in June 2020. Deliverable: report and research protocols. Deadline: Jan 2021.

The WB is a widespread native palearctic ungulate whose population has sharply increased in the last decades (Keuling et al., 2013; 2017; Massei et al., 2015; Sáez-Royuela & Tellería, 1988). It has one of widest geographical ranges of all the terrestrial mammals in Europe (Apollonio et al., 2010; Keuling et al., 2017). Considering bioclimatic variables, vegetation cover and topographic covariates, we can identify four homogeneous bioregions in Europe (Fig. 1, Enetwild 2019a). These bioregions can be used to describe WB population dynamic and to select representative study areas/populations resembling the European diversity of environments. Particularly, South, West and East bioregions present the highest WB densities, whereas in the North bioregion this species is less distributed and abundant. For this reason, South, West and East bioregions are considered as the main areas to develop the proposed protocols and to stratify sampling.

Figure 1. Map showing the bioregions. The different colours correspond to the different bioregions: South (yellow), West (pink), East (green) and North (blue). Extracted from Enetwild 2019a.

WB ecological plasticity and population growth have generated human-ungulate conflicts (Putman et al., 2011), as the WB can cause significant damage to crops and natural vegetation (e.g. Barrio et al., 2009; Schley et al., 2008; Welander, 1995), biodiversity (e.g. Carpio et al., 2014; Oja et al., 2017), road traffic (e.g., Lagos et al., 2012; Thurfjell et al., 2015) and livestock and public health (e.g. Gortázar et al., 2007; Ruiz-Fons, 2017). WB may be a carrier of many pathogens (Ruiz-Fons et al., 2008) that threaten livestock (Gortázar et al., 2007) or humans (i.e., zoonosis, e.g., Ruiz-Fons, 2017). For example, the emergence of African Swine Fever (ASF) in Eastern Europe is of major importance. However, there are knowledge gaps in WB ecology, population monitoring, management, and population control that prevent the designing and application of science-based ASF control policies, and/or the adaptive evaluation of on-going actions. This lack of knowledge is also essential for risk assessment, which requires proper parameterization with reliable data. For instance, it is indicative that most current European wildlife shared pathogen surveillance programs, including ASF, lack integration with appropriate population monitoring (i.e. the denominator data). The efficiency of policies is directly proportional to their acceptance by stakeholders. Therefore, improvement in the acceptance of policies and reduced conflicts is important in the decision-taking process for wildlife management (Ansell & Gash, 2008; Beierle & Konisky, 2001; Fulton & Manfredo, 2004). This acceptance determines the success of management strategies. Finally, factors that govern WB abundance, their impacts and disease spread are not bound by national borders (Vicente et al., 2019). However, in Europe we lack a cross-border approach. International collaboration is essential to achieve sustainable wildlife management from a holistic and integrated point of view, and to design informed adaptive decision-taking strategies (Linnell et al., 2020).

This report proposes research protocols (see the summary Table 1) to address gaps aimed at improving the strategy to control ASF in the short-term (e.g., outcomes expected in approx. 1 year after the onset of the study). We note that WB telemetry added values provides fine resolution and complete practical information to develop specific management. However, this approach normally requires long term approaches and high budget. In certain cases, telemetry can be efficiently replaced by CTs conducted simultaneously in several areas to provide valuable short-term assessment with reduced costs.

Table 1. Summary table of protocols included in each RO.

Topic	RO	Protocol	Methodology
WB ecology	1. Studies on basic aspects of WB pop. dyn.	WB pop. dynamics & drivers, & data gaps identification	Long-term data compilation on WB pop. parameters and drivers. Identification of data gaps by multivariate statistical analysis.
		Field research	To estimate density, pop. structure, piglet mortality, reproductive performance
	2. Factors determining presence of WB in outdoor farms & extensive pig	Use of outdoor farm resources by WB and study of interactions with pigs	Assessment of WB visits to outdoor farms, use of resources and characterization of interactions with pigs by CT and questionnaires to farmers
WB monitoring	3. Practical methods to estimate WB density	WB density estimation	Enhancing the network of wildlife professionals and researchers, WB monitoring based on CT, hunting statistics and development of density analytical tools (app).
WB management and population control	4. Effect of natural resources & artificial feeding on WB pop. dynamics & management	Impact of nat. resources, crops and artificial feeding on WB pop.	Data collection on WB pop. dyn under different food availability conditions, complemented with diet determination by fecal barcoding
		Impact of natural resources, crops and artificial feeding on WB social and spatial behaviour	Comparative study using GPS-collared WB under different conditions: natural without crops access vs natural with crops access vs artificial feeding
		Eval. of baiting strategies to improve collective hunting efficiency	Contrasting baiting strategies in relation to WB hunting/culling efficiency
	5. Role & efficacy of recreational hunting & professional culling for WB pop. Control	Analyse and comparison of the effectiveness of recreational hunters and professional hunters on wild boar populations	Data collection on hunting and culling statistics to compare effort and costs of recreational and professional hunters in selected management areas of Europe where recreational hunting and professional culling are being/were performed
	6. Efficacy of WB trapping & welfare	Evaluation of effectiveness and welfare impact of WB trapping	Assessment of effectiveness and welfare impact of trapping during culling activities on selected management areas where trapping operations are being performed, alone or in coordination with other pop-control activities
	7. Efficacy of fencing, incl. non-target spp.	Efficacy of fencing with GPS-collared WB, and non-target spp.	WB tracked close to fences. CT to check WB actions against fences and specificity for non-target spp.
	8. Use of dogs in ASF affected areas	Field trials on detection of WB carcasses and analysis of dog training, testing and certification procedures.	Literature review, questionnaires and field trials.
	9. Social acceptance of WB management & welfare	Qualitative: short-term ethnographic research	Ethnographers contact with stakeholders to explore their lifeworld
		Quantitative: Acceptance of stakeholders of different management tools	Questionnaires to stakeholders about WB management tools and ASF spread
Assessment and management of risk factors	10. WB/pig interface: biosecurity backyard & outdoor pig farms	Development and test on-farm WB risk mitigation protocol	Visiting farms to develop a protocol for on farm evaluation of risk and implementation of Action Plan
		Development of information technology tools	Developing an app to collect data to apply the on-farm Wildlife Risk Mitigation Protocol
	11. Evaluation of passive surveillance & carcass removal on ASF spread	Eval. of passive surveillance for carcass detection	Questionnaires and description about passive surveillance in ASF affected and at-risk areas
		Eval. of carcass removal impact	Questionnaires and monitoring carcass removal in ASF affected areas
National and intern. decision-taking	12. Improve national & internat. decision-making	European exchange of information on current management	Internat. discussion organized in workshops/working groups, draft a proposal for a WB Pan-European management plan

Data and Methodologies

The research objectives (ROs) are listed below, and they have been organized and sorted as follows:

Wild boar ecology

- RO1. Studies on basic aspects of **WB population dynamics** all over Europe
- RO2. Holistic assessment of the factors that determine the **presence of WB near to different pig farm** types, including outdoor farms and extensive production systems
-

Wild boar monitoring

- RO3. Implementation of practical methods to estimate **WB density**.
-

Wild boar management and population control

- RO4. Effect of **food availability** in natural areas in relation to baiting and feeding in WB population dynamics.
- RO5. Role and efficacy of **recreational hunting and professional culling** for WB population control.
- RO6. Assessment of the efficacy of WB **trapping methods** including welfare implications and social acceptability.
- RO7. Assess the efficacy of different **fencing methods** with GPS- collared WB, considering also the effect on non-target species
- RO8. Use of **trained dogs** in ASF affected areas to detect WB carcasses.
-

Social acceptance

- RO9. Investigate acceptability of farmers and public to **fences**.
- RO10. Acceptance of measures for WB management by **hunters**.

After discussion with EFSA, these two ROs have been rearranged as follows:

RO9. Social acceptance of WB **management measures** and animal welfare (qualitative and quantitative approaches).

-

Assessment and management of risk factors

- RO10. The WB/pig interface: Developing **biosecurity** awareness and implementation among backyard pig farmers.
- RO11. Evaluation of the measures of **passive surveillance and carcass removal** on the spread of the disease.
-

National and international decision-taking

RO12. Assess how to improve coordinated national and international decision-taking

The structure of the proposal for each specific RO is:

- Background.
    - Evidences available in Europe and worldwide.
    - Current situation for the particular research objective in the EU.
    - The potential impact of the results obtained for ASF management in the EU.
- Objectives
- Methodology: this section includes the protocols (one or more by specific RO) for proposed works, indicating to which objectives they correspond.
    - Methods
    - Study design
    - Sample size
    - Spatial range
    - Budget limitations
    - Expected duration
- Deliverables, which align with protocols and objectives.
- Literature (provided in a separate Endnote file).

The conclusion section of this report includes a summary of the proposed protocols, their time frames and budget limitations to facilitate further discussion on the interactions/overlaps between protocols that address different research objectives, which eventually can be combined to optimize the use of resources and budget.

2. Assessment/Results

2.1. Wild boar ecology

2.1.1. RO1. Studies on basic aspects of wild boar population dynamics all over Europe

2.1.1.1. Background

• Currently, the lack of standardized information on wild boar (WB) population dynamics covering the necessary range of biogeographical, management, socio-economic and cultural factors prevent data from being reliably used at the European level, hampering risk assessments (Enetwild et al., 2018b; 2019b, 2020a). Biased, incomplete or simulated parameters are normally used for these purposes, and their regional variation is not considered. The situation is further complicated by two factors:

- There exists a wide diversity of parameters to describe WB population dynamics and different methods are applied, which are not always appropriate and/or comparable (Enetwild 2018a, 2019b, 2020a).
- The temporal frame of available data does not always represent the current situation. WB populations have been increasing over during the last decade in the absence of ASF, and in certain regions the direct impact of ASF and/or reactive and proactive policies have led to very different scenarios (EFSA et al., 2020a).

• Compiling and generating valid up-to-date information on WB population dynamics is needed, following harmonised methods and filtering by standards of quality. Recent activity has been restricted to density and distribution data but not to population dynamics (Enetwild 2019a, 2019b; 2020a).

Evidence available in Europe and worldwide

• There is a large body of literature describing basic aspects of WB population dynamics (see table S1 in annex A). However, the literature is extremely biased towards certain regions of its native range (Central Europe) and certain parameters (reproduction and spatial ecology).

• WB population parameters are largely determined by different drivers including natural and human-related extrinsic factors influencing ecological processes and population dynamics (see table S2 in annex A). Population models addressing the drivers that may affect WB populations depend on the local and regional variation, and the scarce literature mainly refers to Central European WB populations (Bieber & Ruf 2005, Vetter et al. 2020).

Current situation for the particular research objective in the EU

• WB is ecologically very plastic, with potentially rapid population growth rates. WB populations still growing and expanding despite high mortality rates. They are also able to adapt to a wide array of climatic conditions (Enetwild 2019b). All of this makes WB population dynamics highly variable across the continent, requiring a deeper understanding of local and regional variations over its distribution range.

• Essential steps to guide ASF control policies are considered to be: (i) defining which basic parameters of WB population dynamics are most relevant, (ii) understanding them in a context-dependent manner, on the basis of their variation in given geographical, ecological and management contexts (hereafter called "WB population bioregions") and conditioned by drivers, and finally (iii) quantifying these parameters (once data gaps are identified).

Potential impact of the results obtained for ASF management in the EU

- The steps (i), (ii) and (iii) described previously will allow:
  - Planning integrated and harmonized (comparable) monitoring of WB population dynamics trends and impacts over space and time under different scenarios and drivers occurring in Europe (e.g., protected areas, agricultural land, hunting grounds; management schemes such as artificial feeding or not), and epidemiological situations (pre-ASF, during or post-ASF; at a local outbreaks scale and over large frontlines and regions affected by ASF).
  - Monitoring the effects of ASF management actions under an adaptive approach, that is, information is collected continuously, and this is used to improve biological (including the human dimension) understanding and to inform future decision-making. For example, changing hunting strategies to achieve the most effective method WB population reduction (Massei et al., 2011).
  - Parametrizing population dynamics models (disentangling factors regulating population dynamics such as compensatory growth, density dependence, top-down control by predators, stochasticity) and epidemiological models (e.g., risk analysis, control options). Only science-based modelling should be accepted to guide policy, for instance, to develop most efficient cost-benefit strategies: control and eradication of ASF in different scenarios (ASF affecting large areas, local outbreaks, ASF-free zones) and epidemiological stages of ASF (epidemic, endemic).

2.1.1.2. Objectives

1. To produce a comprehensive compilation and description of data on WB population dynamics throughout Europe (table S3 in annex A) for further understanding disease dynamics and improving science based ASF management.

2. To identify and prioritize data gaps over the (bio)regions and contexts of Europe.

3. To to determine the main drivers of WB population dynamics.

4. To propose the approach and design of short-term field research to address these gaps.

2.1.1.3. Methodology

Protocol 1 addresses objectives 1, 2 and 3. Protocol 2 addresses objective 4.

Protocol 1: Comprehensive compilation and description of data on WB population dynamics and the main associated demographic drivers throughout Europe following a standardised data model and subsequent assessment and identification of WB population bioregions (in relation to population dynamics and management regions) and identification of data gaps.

Method: Compilation and description of data on WB population dynamics and long-term data on the drivers (e.g., management strategies, density dependent and stochastic factors, which vary by region) following a standardized data model (Enetewild 2020a). Description of parameters and regions where there are data gaps.

Study design:

- Objective 1: Compilation of population dynamics data using a narrative literature review: A published and unpublished literature review and data collection on WB population dynamics and drivers throughout Europe through networking (including researchers, administrations and wildlife managers). Data collection should be done by the applicant following Enetwild standards (Enetwild 2020a), which guarantees that sufficient information (e.g., on methods) is collected to validate data. Data collection should be adapted to the list of parameters indicated in table S3 in annex A. The data model also allows collecting metadata to make an inventory of the WB information that is being collected.

- Objective 2: Identify gaps in data per bioregion in the EU based on population dynamics parameters identified in the previous point and environmental and management data. The compilation of data on drivers will allow a comparison of the population parameters among study areas, or over time in given areas across European WB population bioregions under different ecological and management conditions (predators presence vs. no predators; ASF presence vs. ASF-free region; different management strategies applied, global warming) (Morelle et al., 2016; Nores et al., 2008; Tanner et al., 2019a).

- Objective 3: Analysis of the main drivers of population dynamics across the European continent: (i) transversal (O'Neill et al., 2020) and (ii) long-term correlational (Barroso et al., 2020) (including delayed effect) analyses.

Sample size: The guidelines of systematic reviews (e.g. Pullin and Knight, 2009) must be followed. However, since there may be a large amount of reviewable literature (including grey literature), as WB populations have grown markedly in recent years, and methods (e.g., telemetry) have greatly developed, it would be advisable to limit the bibliographic search to the last twenty years. Unpublished and grey literature available throught contact with researchers, administrations and wildlife managers.

Spatial range: all of Europe.

Budget limitations: No (< 144,000 euro).

Expected duration and study viability: 8 months (if an expert network is already available, e.g. Enetwild).

Protocol 2: Short-term field research to address scarcity and/or lack of data on wild boar population dynamics data (gaps).

Although research protocols have already been developed to investigate the following parameters, based on the identification of knowledge gaps under objective 1,2 and 3, additional field studies may be needed in specific bioregions (minimum of 5 sites per parameter and type of site (WB population bioregions, i.e., clusters, established in protocol 1):

- Densities: This work is currently ongoing by Enetwild (Enetwild 2018a) but an increase in the sampling size and coverage of Europe is needed (30 sites in gaps areas, i.e. in countries where data about WB density is not available, such as European Eastern countries), as is the validation of hunting statistics (as a proxy of population density). Protocols, effort required, and sampling size are already available on the Enetwild website, being recommendable camera trap-based protocols (Enetwild et al., 2018; https://enetwild.com/2021/03/20/ct-protocol-for-wild-boar/).

- Population structure and social behaviour (group size): for population structure sex by age class protocols are available (hunting at least 30% of the population and randomly selected;Sáez-Royuela & Tellería, 1988); group size to be determined by CTs (number of CTs according to study surface area, protocol, effort, sampling size available at https://enetwild.com/2021/03/20/ct-protocol-for-wild-boar/) in different seasons to obtain data about group size evolution across the year.

- To evaluate mortality in <3 month-old individuals (piglets), it is necessary to first determine reproductive performance (i.e., litter size), and then compare to the juvenile population (i.e., surviving piglets >3 months and <1-year-old) by CT. - Reproductive performance: direct inspection of litter size (number of foetuses/female) and proportion of pregnant females after hunting event (Fernández-Llario & Carranza, 2000; Fonseca et al., 2011). Minimum 40 hunted female WB per population.

Sample size: depending on specific parameter and protocol (detailed above). At least one data set per bioregion.

Spatial range: throughout Europe, attending to data gaps in specific WB bioregions.

Budget: approx. 150,000 euro.

Expected duration and on study viability: 1 year .

2.1.1.4. Deliverables

Protocol 1

- Deliverable 1: Data on WB population dynamics throughout Europe.
    - Comprehensive compilation and description of data on WB population dynamics (S3 on anex A) and demographic drivers throughout Europe following a standardized data model.
    - The completion of this deliverable influences the subsequent deliverable, because the collected data will allow the identification of WB population bioregions.
- Deliverable 2: Identification of WB population bioregions.
    - Report describing patterns of WB population dynamics (bioregions) which should guide data gapcollection.
    - Validation of classification, limitations and uncertainties: sample size and representativeness of available data.
    - Completion of this deliverable influences the subsequent deliverable because drivers of population dynamics will be analysed considering and/or within the bioregion.
- Deliverable 3: Report on the analysis of the main drivers of population dynamics across the continent.
    - Analysis of the main drivers of population dynamics across the continent.

Protocol 2

- Deliverable 4: Report on short-term field research to address data gaps
    - Report on the values of population dynamics parameters after short-term field research to address gaps. Results discussed in terms of fulfilment of objectives and representativeness of data.
    - Limitations and uncertainties: need for efficient local collaborators in gap areas (mainly Eastern Europe).
    - Report on the potential and estimated impact of obtained results on ASF management and risk assessment

2.1.2. RO2. Holistic assessment of the factors that determine the presence of wild boars near to different pig farm types, including outdoor farms and extensive production systems.

2.1.2.1. Background

• In the context of WB population growth and the presence of ASF in Europe (EFSA, 2014b), it is urgent to understand intrinsic and extrinsic factors affecting the presence of the species in areas close to pig farms. These areas, also known as the wild/domestic interface, are key in the appropriate, rapid and effective control of ASF outbreaks due to the risk of transmission between domestic pigs and their wild relatives (Boklund et al., 2020; Enetwild et al., 2020b).

• Across Europe, pig farms vary according to their production system, herd management and/or size (Enetwild et al., 2020b). In many cases, these differences are related to local practices, climatic conditions (e.g., cold winters require pigs to be kept inside) and the legislation in each country (e.g., biosecurity measures to avoid ASF spread in risk areas or where the disease is present).

• Outdoor pig farms, backyards and extensive production systems are relevant socio-economic activities in some areas of Europe, particularly in Eastern Europe (Enetwild et al., 2020b). The current ASF epidemiological situationpresents a huge threat for disease spill-over at the wild/domestic pig interface (Barasona et al., 2014; Kukielka et al., 2013).

Evidence available in Europe and worldwide

• At a large scale (continental), the main factors affecting WB presence are environmental factors such as climatic variables, land cover, topography and human footprint (e.g., human population density, proximity to urban areas, roads) (Enetwild et al., 2019a).

• At a local scale, however, the presence of WB in certain areas is associated mainly with vegetation (i.e., some specific plant communities that offer cover and are a source of food) and water availability in natural areas (Barasona et al., 2014; Keuling et al., 2017; Wu et al., 2012). Moreover, WB presence is affected also by human factors such as socio-economic conditions and management strategies (Massei et al., 2015; Oja et al., 2014). Thus, increasing access to anthropogenic food resources and some hunting strategies are positively related with WB presence and local abundance (Table 2). The resource-limited season in South Europe is summer, and in North and Central Europe it is winter (Gortázar et al., 2007; Kukielka et al., 2013). Thus, WB/pig interactions could vary spatially and temporally across Europe. Local husbandry practices for pigs (e.g., in situ seasonal feeding on the mast) also determine the frequency and intensity of these interactions (Jori et al. 2017b; Triguero-Ocaña et al. 2020).

Current situation for the particular research objective in the EU

• The interest focuses on outdoor farms, which are defined as establishments in which pigs are kept temporarily or permanently outdoors (Working Document SANTE/7113/2015; Rev 12 /Apr 2020). Outdoor farms allow any type of outdoor access to the pigs (e.g., to pastures, forests, runs/yards, open air buildings or buildings that allow the pigs to have access to open air or to the external environment as defined by: https://ec.europa.eu/eusurvey/runner/Pig_Outdoor_Farming#page1). The following types of outdoor pig farms have been reported to EFSA by EU MSs: a) animals have access to woodlands/forests without any fencing, b) animals have access to fenced areas in woodlands/forests, c) animals have access to fields or pastures without any fencing, d) animals have access to fenced areas in fields or pastures, e) animals are held in open buildings that are fenced with no access to outside forests, and f) animals are held in closed buildings with access to a fenced concrete outdoor run/yard (https://ec.europa.eu/eusurvey/runner/Pig_Outdoor_Farming#page2). The types of farms that are considered outdoor farms in several MSs are: free ranging farms, backyards, kept WB farms, organic pig farms, farms with specific (native) breeds and pigs kept as pets or for hobby.

• Definition of distribution and characteristics of the WB and pig interface at a large scale is being addressed by Enetwild (Enetwild, 2020b). This will allow the quantification of the overlap of WB and pigs therein on different production systems. To date, the interface has been finely (spatially) depicted in only a few countries, and considering the typology of pig farms, only in Romania (Enetwild et al. 2021).

• The presence and visits of the WB to pig farms could be related to farm type and resource access, such as food or water points (Table 2). It has been determined that proximity of forest to the farm and distance between pig enclosures and houses (where farmers live) are factors that influence WB intrusions (Wu et al., 2012; Kukielka et al., 2013). Moreover, physical barriers such as fences of minimum height or electrified fences could be measures to reduce or avoid direct WB-pig interactions.

• Even though direct contact is uncommon (Cadenas-Fernández et al., 2019; Triguero-Ocaña et al. 2020), indirect contact could be an important factor in disease transmission (Kukielka et al, 2013).

• It has been found that WB are generally more attracted to sows in oestrus than to other resources such as food (Wu et al., 2012; Wyckoff et al., 2009). Thus, mating purposes could be a factor of attraction for the WB to the pig farms.

Table 2. Main factors related to WB presence near pig farms already identified

Variable		Hypothesis	Reference
Farm management and structures	Water/ feeding points	Aggregation points could favour diseases transmission. WB visits these points for eating, drinking water or wallowing, especially during resource-scarce seasons/periods (attractive factor).	Kukielka et al., 2013; Carrasco-García et al., 2016
	Carrion	Carcasses (as attractive factor) can be removed from the farm area or left in nature.	Jori et al., 2017a
Mating purposes		Male WB attracted by sows in oestrus, increasing contacts among WB and pigs. Hybridisation as a consequence and an indicator.	Wu et al. 2012; Nikolov et al. 2017
Farm location		Pigs located away from buildings and/or close to forests (refugee effect) could be at risk for indirect contact with WB.	Wu et al. 2012
WB artificial feeding in proximity of pig farms	Artificial feeding for big game hunting	WB at high densities (favoured by hunting management, such as artificial feeding) in farming areas could favour contacts and disease transmission. Artificial feeding aimed at big game may attract pigs when farming and game uses are not separated.	Vicente et al., 2007

Potential impact of the results obtained for ASF management in the EU

- Determining which factors affect the presence of WB close to pig farms will allow:
  - The establishment and improvement of management measures to reduce pig farm attractiveness to WB and to minimise the risk of disease transmission, especially under different epidemiological scenarios (recent ASF outbreak, endemic stage of ASF, ASF free areas).
  - Demonstration to stakeholders, such as pig farmers and hunters, of the necessity for avoiding and minimising WB and pig interactions through structures and human behaviour changes (i.e., fencing or carcass removal) to reduce ASF risk transmission. This is an essential step toward developing biosecurity awareness and further implementation among backyard and outdoor pig farmers.

2.1.2.2. Objectives

1. To determine which environmental and human factors (e.g., farm structure, building characteristics, open-air access, land use in and around farm, see Table 2) attract WB to pig farms or farming areas, and to assess spatial behaviour of WB and domestic pigs at pig farms, and how they interact spatially and temporally.

2.1.2.3. Methodology

Protocol 1: Use of outdoor farm resources by WB in a set of farms representative of different typologies across Europe, and study of the interspecific interactions between WB and pigs (where, when, how and how often).

Method: Assessment of WB visits to pig farms and characterisation of interactions with pigs by CT. Previous studies have demonstrated the practical value of CTs when they are used in pig management systems where there is a priori understanding of where potential WB-pig interactions may take place (Kukielka et al., 2013, Carrasco-Garcia et al. 2016, Payne et al., 2016, Cadenas-Fernández et al., 2019).

Study design: Among the types of outdoor farms that have been reported to EFSA by EU MSs, the farms included in this study are those fulfilling any of these characteristics (four types): i) where pigs have access to woodlands/forests without fencing, ii) pigs have access to fenced areas in woodlands/forests, iii) animals have access to fields or pastures without fencing, iv) animals have access to fenced areas in fields or pastures. Four study regions will be selected as follows:

- Poland and Romania (or Hungary): East Bioregion (Enetwild et al., 2019a), abundance of backyards farming including outdoor conditions part of the year
- North Spain and Germany (or France), representative of the Atlantic Bioregion.

We exclude the Mediterranean areas, since comparable information is already available (Kukielka et al., 2013, Carrasco-Garcia et al. 2016, Cadenas-Fernández et al., 2019).

- Farmer questionnaires: structured into sections including (a) farming characteristics (number of pigs, typology of farm, following our classification, surface area, description of outdoor practices and grazing management along the year, hunting activities inside and/or around the farm, feeding and wallowing practices, management of carcasses); (b) observation of WB (Jori et al., 2017b); (c) identification by the owner of the "risk points" (facilities or areas attractive to WB and areas of animal congregation where WB can directly or indirectly came into contact with pigs such as feeders, troughs or fences) (Cadenas-Fernández et al., 2019; Payne et al., 2016); (d) socio-demographic characteristics (sex, age) following the classification by ELSTAT (2011, www.statistics.gr).

- WB abundance, as an index, based on hunting data in the area (Enetwild et al., 2018b).

- CTs: placed at farm facilities at a priori attraction points (e.g., water/feeding points, feed stores) and risk contact areas (e.g., resting areas) (Kukielka et al., 2013; Payne et al., 2016; Podgórski et al., 2018; Triguero-Ocaña et al., 2020). CT also placed in unclassified areas that could be used by WB but are not, apparently, aggregation points (random points are those where food and water are not present), which will be used as control CTs for comparison purposes (following Carrasco-Garcia et al. 2016). The number of CTs depends on farm size and number of risk points. CT should cover the farm proportionally following these criteria: 50% of plots (fenced areas), 33% of "risk points", and a minimum 3 CTs in control sites. Control CTs should be distributed to cover the range of distances from the furthest point to the nearest woodland to the farm (or vegetation covered area), then at least one at the woodland-grazing plot ecotone, and finally, one inside the woodland (at least 100 m from the grazing plots). CT must be operative for at least 15 days at each farm (revised weekly) covering the four seasons, especially when pigs are outside. Control CTs will be operative for at least 30 days each season, even when pigs are not outside . CTs will allow the characterisation of sex and age WB/pig contacts (mainly indirect, see Kukielka et al, 2013). Details of the protocol: Kukielka et al., (2013) and Carrasco-García et al., (2016). CTs set up to collect 3 pictures and a 1 minute time delay, except on control sites, where no time delay will be set. Quantification of farm resource use and number of interactions as specified in Kukielka et al., (2013) and Carrasco-Garcia et al., (2016).

Sample size: a minimum of 10 farms per study region, of which 5 are type i or ii (pig access to woodland/forest) and 5 are type iii or iv (outdoor access to field or pastures). At least 15 CTs per farm. This is about 75-90 CTs placed at one time at 5 farms in each region, and a second round where CTs can be moved to the remaining 5 farms within a given season.

Spatial range: at least Atlantic and East European bioregions (Enetwild 2019a) as described above.

Budget limitations: approx. 160,000 euro.

Expected duration: 15 months (1 year data compilation, but likely need more than 1 year for data analyses).

2.1.2.4. Deliverables

Protocol 1

- Deliverable 1: Use of key outdoor farm resources (e.g., attraction points and risk contact areas) by WB in a set of farms representative of different bioregions and pig outdoor management typologies, and identification of their potential for interspecific interactions between WB and pigs (e.g., number of contacts per day; related to risk of disease transmission for specific areas and seasons).

2.2. Wild boar monitoring

2.2.1. RO3. Implementation of practical methods to estimate wild boar density

2.2.1.1. Background

• Relative abundance is commonly estimated for a species in a particular ecosystem, but this is a proxy of the density or the population size, which only indicates the trend of the population size (O'Brien, 2011). Accurate and unbiased estimates of real population size can only be achieve by calculating the absolute abundance (total number in the population) or the density (population size per area unit). Since counting WB on a large regional scale is unfeasible, estimations of density and abundance are reliable only at a local scale in specific habitats.

Evidences available in Europe and worldwide

• WB density is not easy to estimate. Generally, the density estimates of the species are based on hunting bags, and from different sources and scales (Enetwild et al., 2018). Moreover, data collection does not follow any scientific or harmonised methodology (Melis et al., 2006).

• Given the diversity of available methods and the geographical diversity of Europe, harmonisation of such methods is essential. A recent report reviewed the accuracy and comparability of methods to estimate relative abundance and density of WB populations and guidelines for their implementation (Enetwild et al., 2018). Three methods (CT, drive counts, and distance sampling with thermography) were recommended to estimate WB density on a local scale.

• CT allows an easy and non-invasive way to study the WB population, including density. This methodology, which usually includes many cameras and multiple people , generates thousands of images that must be stored and processed, which delays and limits efficiency of projects. In spite of the potential of CT methods to generate harmonised and comparable density values over a wide range of situations, difficulty in data processing and analysis of CT methods limits their use.

• However, different computational tools are being developed to organise and process images automatically and through collaborators (e.g., Norouzzadeh et al., 2018). These systems can facilitate and accelerate research projects, overcoming the bottleneck that prevents most wildlife professionals from calculating reliable CT-based densities of WB and other mammals.

Current situation in the EU for the particular research objective

• WB population density values for Europe are scarce in the literature (Enetwild et al., 2018). Enetwild is already and partially (as a pilot) addressing WB population density in a number of locations, 15-20 in total, 1-2 sites per country (in red below), during 2020 and 2021, and practical protocols to estimate reliable values are available (Palencia et al., 2019; Rowcliffe et al., 2008):

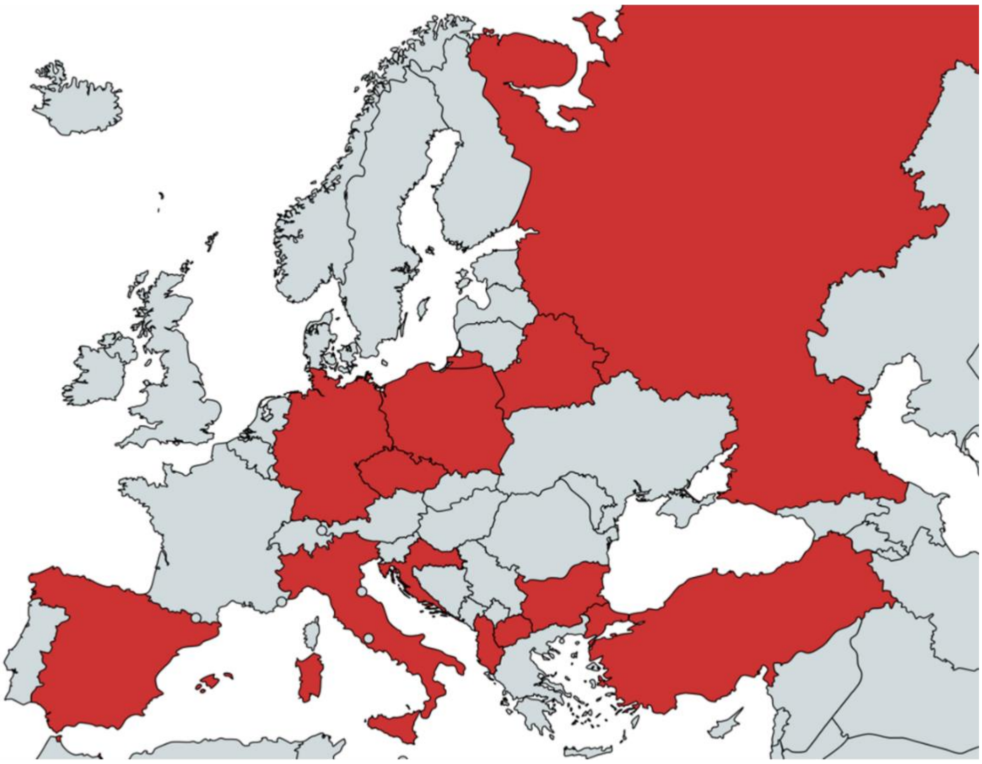

Figure 1: Representation of the countries where reliable values of WB density are being calculated (as a pilot), by CT in a number of WB populations (15-20) during 2020 and 2021 by Enetwild (www.enetwild.com).

• However, it is necessary to increase the number of study sites, expanding into areas represented in the figure in grey to ensure representative values across Europe: Portugal, France, UK, Belgium, The Netherlands, Switzerland, Slovenia, Austria, Slovakia, Serbia, Bosnia & Herzegovina, Montenegro, Greece, Romania, Moldova, Ukraine, Hungary, Latvia, Estonia Lithuania, Norway, Sweden, and Finland .

• Some recently developed CT methods without the need for individual recognition provide an independent, low disturbance, and practical way to collect robust data (Enetwild et al., 2018; Palencia et al., 2019; Rowcliffe et al., 2008). They are usable across most of the distribution range of WB in Europe, and when applied following a robust study design, they provide accurate and unbiased estimates of WB density, which are useful for spatiotemporal comparisons (Howe et al., 2017; Nakashima et al., 2018).

• Tools for processing images captured with CT are in development, and first steps have been taken in Europe for organizing images, developing automated animal recognition and solving associated challenges, e.g., adverse environmental conditions, partially visible animals, etc. (Hoebeke et al., 2018).

Potential impact of the results obtained for ASF management in the EU

• In the case of ASF, values of absolute abundance or density are needed for robust risk assessment, essential to improve management strategies, which have now been successful in two locations (Czech Republic and Belgium).

• We need to know the numbers and distribution of WB across Europe and in specific areas (e.g., in case of outbreak) for conducting and assessing efficient WB population management for disease prevention and control.

• Density values will also enable the validation of hunting statistics (the most available data with potential to be compared across Europe) to estimate density, which will make possible the use of a large amount of available data.

2.2.1.2. Objectives

1. To improve WB density estimation and to increase the number of study sites in those areas where knowledge gaps exist across Europe, through facilitating the use of CTs analytical tools by professionals.

2.2.1.3. Methodology

Protocol 1: WB density estimation through facilitating CT analytical tools by professionals.

Gap countries/regions (mainly in Eastern Europe, see map above) already identified. CT protocol available at: https://www.efsa.europa.eu/en/supporting/pub/en-1449 (see annex B for updated protocol, currently applied in countries displayed in Fig. 1).

Methods: establishment of a network of wildlife professionals and researchers, data compilation through harmonised monitoring of WB population throughout Europe based on CT methods without individual recognition (Random Encounter Model CT-REM, Random Encounter rate and Staying Time CT-REST, and Distance Sampling CT-DS). This network is based on collaborative science facilitating CT analytical tools by professionals. In parallel, high quality hunting statistics are collected in study areas during collective hunts (see annex B) (Enetwild et al., 2018; https://enetwild.com/2021/03/20/ct-protocol-for-wild-boar/). A sufficient sample size (see below) will make the calibration of both methods possible and will improve spatial abundance models.

Study design:

- A study network of WB populations must be composed of organizations, such as research centres and wildlife management professionals, which will apply the CT protocol designed by Enetwild to determine WB density. This protocol is compatible with CT-REM, CT-REST and CT-DS methods to estimate WB density based on CT data without the need for individual recognition. Details of the protocol: Enetwild et al., (2018); Rowcliffe et al., (2008); Rowcliffe et al., (2013); https://www.efsa.europa.eu/en/supporting/pub/en-1449; see annex B.

- Development of analytical tools to harmonize procedures and promote collaborative science:

    - Harmonising the generation of databases prior to analyses will be done by means of CT image management app (e.g., Agoutí). This requires (i) the development of a web platform for participants of the wildlife network to create their own CT projects, and (ii) incorporating functionalities to generate standardised CT databases ready for statistical analyses using at least CT-REM, CT-REST and CT-DS methods. This app will allow the easy export of CT records into a format that can be used to analyse and estimate density.

    - Data visualisation and automated measurement of distances.

    - Development of an external interface for running CT density models (CT-REM, CT-REST and CT-DS).

- Create interactive online maps in an institutional portal.

- Hunting statistics: high-quality hunting statistics (i.e., sampled at high spatial resolution) should also be collected by participants of the network at sampling sites during collective hunts. Hunting statistics will then be calibrated against reliable CT density data following Enetwild et al. (2019b) (see annex B). In this way, the density data generated by this network will be key to evaluating if density data calculated from high quality hunting statistics is reliable.

Organization: coordinate methodological approach (placement of CTs, hunting data collection) with local collaborators (academia, administrations).

Study sites: at least 15 WB populations in total, ranging from 1000 to 5000 ha..

Sample size: 35-45 CTs at each study site over a study period of 2 months during autumn/early winter (Enetwild et al., 2018; Rowcliffe et al., 2008; Wearn & Glover-Kapfer, 2017).

Spatial range: all across Europe, particularly covering the gaps in Figure 1 and WB population bioregions/clusters identified in RO1, mainly in Eastern Europe. Countries are listed in Fig. 1.

Budget: approx. 200,000 euro (15 populations).

Expected duration: 1 year. All is feasible in the short term and economically viable.

2.2.1.4. Deliverables

Protocol 1

- Deliverable 1: Density values estimated by CT for at least 15 populations in gap countries and calibration with density values obtained from high quality hunting statistics.
- Deliverable 2: Development of a web platform to manage photo-trappings and generate standardised CT databases, and an external interface for running CT density models (CT-REM, CT-REST and CT-DS).

2.3. Wild boar management and population

2.3.1. RO4. Assess the effect of natural resources and artificial feeding on wild boar population dynamics and managing

2.3.1.1. Background

• WB is an opportunistic omnivore feeding on all types of organic matter (plant, animal and fungi),of natural or anthropogenic origin (Ballari & Barrios-García, 2014). Natural food availability is a strong factor influencing WB population dynamics, which, in turn, is related to environmental conditions (Oja et al., 2014; Touzot et al., 2020). However, human presence and activities have facilitated WB population access to vast amount of food resources (e. g. crops or artificial feeding; Fruziński & Łabudzki, 2002; Rosvold & Andersen, 2008). WB's highly plastic feeding behaviour explains its particularly high adaptability to different ecological conditions and thus its wide geographical distribution (Ballari & Barrios-García, 2014).

Evidences available in Europe and worldwide

• Food availability can affect WB demography mainly in three ways: reducing juvenile mortality, increasing fertility and litter size, and advancing reproductive age (Tack, 2018). • Even when natural resources are available, WB use anthropogenic resources (e.g., agricultural products, supplementary feeding for hunting or management purposes, garbage in urban areas).It has been found that, even during years characterised by abundant mast productivity, populations receiving artificial feeding have higher recruitment than populations receiving no artificial feeding (Groot Bruinderink et al., 1994).

• WB or wild pig population control activities (e.g., trapping, shooting, or toxic baiting) frequently involve the deployment of bait to attract wild pigs (Snow & VerCauteren, 2019). When the supply of feed is limited (to not affect WB population dynamics) and the objective is to increase contact with WB for hunting or culling, then we use the term baiting. The main differences between baiting and feeding are the required quantities of food employed, but there is no exact threshold to distinguish these (EFSA, 2015). Reducing the number of wild pigs following baiting as an effective strategy for population control (Snow & VerCauten, 2019).

Current situation for the particular research objective in the EU

• Recent literature addressing the effect of natural resources and artificial feeding on WB population dynamics and management is scarce and not representative of WB population bioregions. Artificial feeding policies applied to WB management and their purposes vary (and its normative) across European countries, from obligatory to banned.

• At the European level, it has been reported that the WB diet consists primarily of vegetation, including aerial parts, roots, bulbs, fruits and seeds. Different studies have related mast productivity with a greater WB female breeding proportion (Gamelon et al., 2013; Touzot et al., 2020). Even if the proportion of animal matter was reported to be relatively low in the WB diet, it is thought to be an essential dietary component (Ballari & Barrios-García, 2014).

• Crops also represent a key food resource for WB in Europe. For instance, maize is one of the most important crops at the European level, and it has increased drastically over the last decades (Oja et al., 2014; Tack, 2018). The range of cultivations WB can feed on are diverse and occur in different seasons, making use of what is available wherever and whenever they can be accessed.

• As there is no clear boundary between baiting and feeding, European countries have developed different regulations and recommendations limiting the quantity of food to bait, particularly in areas where ASF is present (EFSA, 2015; EFSA, 2017; SANTE/7113/2015 – Rev 12). Table 3 shows some examples of these limitations.

Table 3. Bait limitations at the European level and in some European countries.

Country	***Bait limit***	***Other information***
All Europe	10 kg/km^2/month	
Latvia	40 L/km^2	Spatial restrictions; WB limited access to food.
Poland	10kg/km^2/month	Restricted areas; 143 million tonnes/year for the entire country and all ungulates.
Lithuania	100kg per baiting place (specially designed content)	20kg/ha is allowed (apples or vegetables).
Estonia	100kg/WB or 100kg/month per place	Locations separated by at least 1 km.
Czech Republic	5 kg/km^2	

• Different baits and attractants have been employed in Europe (Geisser & Reyer, 2004; Massei et al., 2010; Ballesteros et al., 2011) to attract WB for hunting/culling or to reduce crop damage (i.e., diversionary feeding; Massei et al., 2011) There is no information about the most effective baits or WB preferences, although WB show particular preference for sweet flavour and chemicals such as monosodium-glutamate (Lavelle et al., 2017).

Potential impact of the results obtained for ASF management in the EU

• Limiting food availability is of direct application to reduce WB population size and growth rate.

• A better understanding of how feeding resource availability (natural or artificial) affects WB social-spatial behaviour is fundamental to the strategy of population control based on providing resources to reduce animal movements, for instance, during ASF outbreaks reducing access of WB to food resources. Crop management and protection from WB are also directly involved.

• To explore effectiveness of baits (quantity and type) and baiting strategy, in combination with attractants would allow increased efficacy and optimisation of efforts on culling to reduce WB populations.

2.3.1.2. Objectives

1. To determine, over different scenarios across Europe (ASF situation, bioregion, social), how different available feed resources affect:

   i. population dynamics parameters

   ii. social and spatial behaviour (this could be quantified to assess the associated risks, very relevant in the epidemiological context)

2.

To assess the efficacy of contrasting baiting strategies developed previous to collective hunts to concentrate WB in the area.

2.3.1.3. Methodology

Protocol 1 addresses objective 1.i. Protocol 2 addresses objective 1. ii. Protocol 3 addresses objective 2.

Protocol 1: Quantify the impact of natural resources, crops and artificial feeding on WB population dynamics.

Method: Correlational study of WB population dynamics under three different food availability conditions: natural resources vs agriculture resources vs artificial feeding based on available data, controlled by WB population bioregion (see Enetwild et al., 2019a). Together with a cross-sectional study to determine diet using barcoding techniques over different representative contexts of Europe.

Study design: Collecting information on parameters such as density, female breeding proportion, growth rate or recruitment on WB populations under these different conditions: natural without crop access vs natural with crop access vs artificial feeding (Miloš et al., 2016; Oja et al., 2014; Touzot et al., 2020). This will be done by analysing already published information on population dynamics. Non-invasive faecal sampling over different seasons in study populations to determine diet will complement this by barcoding (Ando et al., 2020; Monterroso et al., 2019).

Sample size: minimum 10 sites or WB populations per bioregion (see Enetwild et al., 2019a for regions), including the three conditions mentioned (if possible, four study sites per situation). Thirty faecal samples per study population (at least from 15 populations) and season which must be spatially independent (Ferreira et al., 2018; Robeson et al., 2018).

Spatial range: across all of Europe in different WB population bioregions (artificial feeding practices, crops and WB population dynamics vary across the continent).

Budget limitations: 160,000 euro.

Expected duration: 1 year.

Protocol 2: Quantify the impact of natural resources, crops and artificial feeding on WB social and spatial behaviour.

Method: At each study site, to track as many animals as possible, at least 15 females, with GPS collars (protocols available at: Barasona et al., 2014; Baubet et al., 2004; Morelle et al., 2014; Triguero-Ocaña et al., 2020) in three situations: natural resources vs agriculture resources vs artificial feeding, controlled by WB population region (see Enetwild et al., 2019a). Assessment of spatial behaviour in similar environments with and without artificial feeding.

Study design: Comparative studies including these conditions: natural without crop access vs natural with crop access vs artificial feeding. Assessment of spatial parameters such as home range, daily activity, habitat selection, interactions among groups (Podgórski et al., 2013; 2014). This issue has been rarely assessed for WB as a study species (i.e., to assess the effect of artificial feeding on WB spatial behaviour) (EFSA, 2014a; Keuling et al., 2008; Thurfjell et al., 2009), but has for other ungulates (Guillet et al., 1996; Pascual-Rico et al., 2018; Williams & DeNicola, 2000). Minimum three sites or WB populations in one of the main bioregions.

Sample size: minimum 15 individual collared in each condition (females) for six months.

Spatial range: across all of Europe at different bioregions (artificial feeding practices, crops and WB population dynamics vary across the continent).

Budget limitations: 270,000 euro for three WB populations (3 different conditins and 15 individuals collared in each).

Expected duration: 1 year.

Protocol 3: Evaluation of baiting strategies to improve collective hunting efficiency

Method: Comparison of different baiting strategies (amount, duration and surface baited) on WB hunting/culling (collective events) efficiency.

Study design:

- Cafeteria experiment: as a preliminary study, to determine the most effective attractant using a cafeteria experiment (e.g. Martinez-Guijosa et al., 2020). This consists of offering to WBs several attractants and assessing their preferences, which is monitored by CT (video mode to analyse detection time, time spent smelling the bait or near the bait, number of individuals, reaction to the bait). Different baits are deployed in a small area and separated from each other by 100 m (i.e., four different baits in one hectare). To check if accessibility to the attractant point or WB density is conditioning the experiment, it is recommended to rotate the position of baits weekly. Baits to test: naturals such as cinnamon-truffle (Ballesteros et al., 2009), strawberry-flavoured and fish-flavoured (Campbell & Long, 2009). Develop the cafeteria experiments in three countries (one per main bioregion) before the hunting season.

- Baiting comparative study:

    - Corn as bait with the most effective attractant (established in the previous cafeteria experiment) covered by medium-large stones to hinder access to the bait (Ballesteros et al., 2009).

    - Amount of bait employed: 25 kg of corn/250 ha * week (resembling current EU advice in the context of ASF) vs. 100 kg of corn/250 ha * week vs. a control area where there is not baiting.

    - Surface area baited (or under study in the control site): twice the size of a typically large beaten area (minimum 500 ha).

    - Number of baiting points: all of those that fit in the area, separated by 500 m and visited once per week (20-25 baiting points in a typical 500 ha area).

    - Duration of baiting: three weeks previous to hunting. The first and second weeks, baiting points must be regularly distributed across the study area (twice the size of beaten area). The third week, baiting points must be placed only in the area to beat, creating corn trails (in the second week) leading to this area from the area that received bait in the first two weeks, using bait and attractant for the trials (see annex C).

- WB density in the study areas (approx. 2500 ha) should be calculated by CT (by a random encounter model, CT-REM, REST or DS-CT Enetwild et al., 2018; https://enetwild.com/2021/03/20/ct-protocol-for-wild-boar/) before and during the baiting period, not only to estimate WB density, but to detect changes in WB spatial behaviour due to attractive effect of baiting. One third of baiting points monitored by CT (video mode) to assess bait detection time, consumption time, or the number of individuals. Baiting places should be moved each week, because according to some experts, it increases the efficiency and decreases the need for large amounts of bait (EFSA, 2015).

- If in any study area baiting and WB data are available from previous years, then results could be compared to detect trends and effectiveness.

Sample size: minimum three countries for the cafeteria trial and field baiting experiences, one per main bioregion (Enetwild, 2019a), including the three treatments mentioned during the regular hunting season. 35-45 CTs at each study site over a study period of two months (Enetwild et al., 2018; Wearn & Glover-Kapfer, 2017).

Spatial range: across all of Europe at different bioregions, at least in the three main bioregions. Budget limitations: 150,000 euro.

Expected duration: 1 year.

2.3.1.4. Deliverables

Protocol 1

- Deliverable 1: Description of WB population dynamics and diet in relation to three different conditions across Europe: natural resources only, crops and artificial feeding. Management recommendations.

Protocol 2

- Deliverable 2: Quantification of the impact of natural resources only, crops and artificial feeding on WB spatial behaviour relevant to disease transmission. Management recommendations.

Protocol 3

- Deliverable 3: Evaluation of bating strategies to improve hunting efficiency.

2.3.2. RO5. Role and effectiveness of recreational hunting and professional culling for wild boar population control

2.3.2.1. Background

• Recreational hunting is linked to culture across the globe including Europe, and is considered an important management tool to control WB populations and to reduce disease prevalence (Boadella et al., 2012; Cowled et al., 2012; García-Jiménez et al., 2013; Mentaberre et al., 2014). The ability of recreational hunters to control ungulate populations is of increasing concern, particularly when facing severe wildlife disease epidemics, such as ASF, and the effectiveness of hunting plans to control ungulate populations is still debated (Brown et al., 2000; Lebel et al., 2012; Stedman et al., 2004).

Evidences available in Europe and worldwide

• There are few empirical studies about the benefits and limitations of using recreational hunters (RH) to achieve specific management objectives, in general, and in WB in particular (Solberg & Saether, 1999; Mysterud et al., 2019; Strand et al., 2012; Hothorn & Müller, 2010;Boadella et al., 2012; Keuling et al., 2010; Massei et al., 2015; Quirós-Fernández et al., 2017).

• Harvest simulations have been carried out to investigate the effects of varied culls among animal categories on growth rate and total harvest levels (Magnusson, 2010; Quirós-Fernández et al., 2017). However, the implementation of theoretically developed strategies normally collides with the reality of limitations, such as practical, cultural and legislative aspects. Therefore, culling strategies need to be assessed in real situations.

• On the other hand, professional culling is a complementary management strategy to control wildlife populations and carried out by professional hunters (PH). No data about effectiveness of this management option is easily available, and there are not recent examples of this strategy to manage WB, although it has been applied to different species (e.g., Hampton et al., 2017; Hodnett, 2006; Mysterud et al., 2019).

Current situation for the particular research objective in the EU

• Several studies detected an important effect of hunting on WB population dynamics (Keuling et al., 2013; Quirós-Fernández et al., 2017), since hunting is its main cause of mortality (Bassi et al., 2020; Nores et al., 2008). However, others pointed to the fact that recreational hunting, as it is currently practiced, is not enough to control WB population and could be improved (Massei et al., 2015; Massei et al., 2011; Vajas et al., 2020). A key point is that if ordinary hunting is practiced in a programmed sustainable way it could be able to control WB populations over the long-term across Europe. This requires scientific-technical expertise, resources and the willingness of society (hunters) to be involved (see ROs on social acceptability).

• In the case of professional hunting, Mysterud and Rolandsen (2018) showed that this was effective to eradicate an entire population of reindeer affected by Chronic Wasting Disease. Thus, this methodology deserves evaluation for its application to manage ASF in WB populations.

Potential impact of the results obtained for ASF management in the EU

• The combination of these different strategies (e.g., recreational hunting and professional culling) to reduce WB populations may be more effective than recreational hunting alone.

- Preventive and feasible drastic reduction of WB boar population by recreational hunting and professional culling hunting should prevent the risk of ASFV establishment and subsequent spread.

2.3.2.2. Objectives

1.To assess effects on WB populations of recreational hunting and professional culling (e.g., density reduction or growth stabilisation) and to compare the effectiveness of these approaches.

2.3.2.3. Methodology

Protocol 1: Analyse and compare the effectiveness of recreational hunters and professional hunters on WB populations in selected management areas of Europe.

Method: Analyse and compare the effectiveness, effort required and costs by recreational hunters (recreational hunting practiced with restrictions) and professional hunters (the number of harvested WB per time) during the culling activities in selected management areas of Europe. Effectiveness can be calculated based on the number of animals sighted and shot and local density. Local density calculated by CT (REM method, Enetwild 2018, Annex B). This approach needs high quality hunting and culling statistics, for the calculation of reliable pre-harvest densities to enable a comparison: the number, age group, sex, and kill date of harvested WB (reported by hunters using a standard reporting system).

Study design: The factors to consider are: type of culling (recreational hunters-professional hunters), type of day (weekend-workday) and visibility (e.g., related especially to weather conditions; protocol by Mysterud et al. 2019).

Sample size and spatial range: minimum two study sites where recreational hunting and professional culling are performed, respectively, in each of the three main WB bioregions (Fig 2).

Budget limitations: 144,000 euro.

Expected duration: 1 year.

2.3.2.4. Deliverables

Protocol 1

- Deliverable 1: quantification and comparison of effectiveness of recreational hunters (recreational hunting practiced with restrictions) and professional hunters (in terms of the number of harvested WB per time) in the context of current WB management schemes across Europe.

2.3.3. RO6. Assessment of the effectiveness of wild boar trapping (professional culling tool) methods, including welfare implications.

2.3.3.1. Background

• Trapping, in the current context of ASF management to remove WB offers more biosecurity and little risk of disease dispersion than other strategies (e.g. those that may favour the movement of animals to other areas). However, trapping also has some limitations, such as is being associated with economic cost and being time consuming in revise traps and manage captures (Guberti et al. 2019).

• The characteristics of WB trapping techniques (and their specificity) are variable (e.g., corral traps, cage traps, funnel traps; Hampton et al., 2019; Seward et al., 2004; Torres-Blas et al., 2020) and present different advantages.

• Trap capture of WB should minimise negative effects on animal welfare, irrespective of whether the animals are trapped for hunting, research, or management purposes.

Evidences available in Europe and worldwide

• Trapping has been used to control/eradicate *Sus scrofa* (including WB and feral swine) globally (McCann & Garcelon 2008; Alexandrov et al. 2011; Ballari et al. 2015). Trapping is more effective if it is used in conjunction with other methods, such as hunting/culling or tracking dogs (McCann & Garcelon 2008) due to learned response (Saunders et al., 1993) and to the fact that other management tools are necessary to increase WB captures.

• Trapping efficiency is better at higher WB density, and thus, varies by ASF-epidemiological situation in each area, since ASF-free areas have higher WB densities (Licoppe et al. 2020). Moreover, its effectiveness can vary seasonally, because of food availability fluctuations, being more effective the scarcer the feeding resources (Barret & Birmingham 1994).

• While trapping is a common management tool, the data and literature available on trapping normally report effort and trapping success, but not effectiveness in terms of the proportion of the population controlled (i.e., proper population monitoring is not performed) (Licoppe et al. 2020).

• Comparisons of the performance of trapping systems have been conducted in feral pigs (e.g., Gaskamp 2012, Bodenchuk 2014), but not for European WB in non-urban environments. Method selection may be based on the size of the area available for control, time necessary to successfully implement control, access to the habitat, and costs; and the performance of different traps cannot be always extrapolated to other areas or to newly established populations).

Current situation for the particular research objective in the EU

• At the European scale, trapping has been demonstrated as a useful management strategy to mitigate the spread of WB disease. For instance, trapping facilitated Classical Swine Fever (CSF) eradication in a WB population in Bulgaria (Alexandrov et al., 2011). However, live-trap capture of WB followed by killing inside the trap (e.g., by gunshot) may be considered a controversial hunting method (Fahlman et al. 2020).

• The assessment of the effectiveness of WB trapping as a sustainable culling method has yet to be done in the EU, particularly, in non-urban or peri-urban environments (Torres-Blas et al. 2020). The key point is if WB trapping practiced in a programmed and sustainable way can control WB populations over the long term across Europe. Trapping does probably not interfere in any way with other depopulation techniques, but the opposite effect may be true. Therefore, its effectiveness should be evaluated in the context of other measures (e.g., artificial feeding, hunting).

• European trapping regulations vary among countries. In ASF-affected areas trapping requires strict biosecurity measures to avoid disease spread to non-affected areas through fomites (e.g. traps, clothes) (Guberti et al. 2018; 2019).

• The most common types of traps used in the field include (Fenati et al. 2008, Barasona et al. 2015, Torres-Blas et al., 2020):

- Cage (box) traps (individual or small group capture method) from wood and/or metal, which are easily transportable, size 2-3 m^2.

- Corral traps (collective physical capture method), ranging from medium-size pens (size5-15 m^2), which can be fix or transportable (metal or combining wood and metal) and large-size pens (up to 60-70 m^2 ,metal or combining wood and metal, fix). To minimize injuries to caught animals, the internal side of corral traps should be covered with wood panels or branches.

- Drop-net (collective physical capture method) may show less trap shyness and the ability to capture large numbers in a single drop. However, this also complicates the management of many animals at once (which should be shot or anaesthetised), and normally, requires continuous camera monitoring systems, and sophisticated drop triggering devices. Similarly to physical capture methods (corral traps), it requires habituation of complete family groups, and normally it should be displaced to other placement after capture events.

• Behavioural (during and post-release), pathological, haematological and bio-chemical assessments after capture events of WB (Fenati et al. 2008, Barasona et al. 2015, Fahlman et al. 2020, Torres-Blas et al. 2020) are required to evaluate capture-induced stress in WB. Trap-related pathological findings due to trauma and other indicators reveal that, under appropriate management conditions (e.g., impeding escape behaviours and severe reactions to external stimuli, like charging against the mesh walls of the trap or long exposure to adverse climatological conditions, such as severe heat), capture-induced stress and physical injuries would be minor, and therefore, compatible with ethical capture and management procedures (Decision 98/142/CE).

Potential impact of the results obtained for ASF management in the EU

• Trapping can contribute to long-term, sustainable depopulation or control of WB populations synergistically with other means. In areas where no other population management methods are available (e.g., hunting in urban areas or public parks), trapping is a feasible option for controlling WB population (Cahill et al. 2012; Torres-Blas et al. 2020).

• The proper and timely use of trapping in the context of ASF disease may avoid dispersive behaviour as happen with some hunting modalities (Artois et al., 2001; Moennig, 2015).

2.3.3.2. Objectives

1. To assess efficiency (in terms of population proportion captured) in different WB population bioregion scenarios, considering how different population and environmental factors, such as WB density, season, habitat or local management practices could affect the effectiveness of this management tool.

2.3.3.3. Methodology

Protocol 1: assessment of effectiveness and welfare impact of trapping during culling activities on selected management areas of Europe where trapping operations are being performed, alone or in coordination with other population control activities (relative and total effects).

Method: field design to analyse the absolute effectiveness (proportion of population captured) of trapping during WB population control on selected management areas of Europe, where trapping operations (different methods and intensity, and their combinations with other methods) are being performed. The study must cover several representative areas (bioregions, landscape, habitat, management); including "control areas" (no trapping or hunting) to monitor WB population located in areas with similar environmental conditions to trapping areas. Monitor population density is needed (Enetwild et al., 2018; https://enetwild.com/2021/03/20/ct-protocol-for-wild-boar/).

Study design:

- The aim is to install a network of traps targeting a density of 1 trap/300 ha while ensuring the best possible distribution (Licoppe et al. 2020). Four methods under study for comparison in areas of similar size (3000-4000 has), WB density, management and environmental factors: use of corral traps, use of drop-nets, use of cage traps, and control (no trapping or hunting), respectively. The factors to consider affecting the number of animals caught relative to population size, and how this compares to other methods (culling), are: type of trap, season, local practices, intensity and modality of culling.

- Type of traps used in the field should include minimum 10 cage (box) traps (minimum separation 500 m from each other), 3 corral traps (separated by 1 km) and 3 drop nets (separated by 1 km) per study site. The bait (corn) is used following Licoppe et al. (2020). The drop-net is installed, monitored and triggered following Torres-Blas et al. (2020), and cage and corral trap as Barasona et al. (2015). If remote triggering is not applied, traps must be deactivated at latest 1 h before sunrise.

- Performance measures and variables to assess the methods: WBs captured per operation, proportion of population captured, time spent working, cost per capture event, cost per individual captured, safety for operators and animals, ease to cull animals, specificity, ability to conduct trapping with few operators, among other measures.

- Performance measures to assess animal welfare: At least 20 WB per study site selected to be comparable in terms of age and sex and methods are sampled after euthanasia following Fahlman et al. (2020) and Decision 98/142/CE.

Sample size: minimum of two study sites with four treatments each (drop trap, corral trap, box trap and control) , in the same European bioregion for comparison.

Spatial range: throughout Europe.

Budget limitations: 160,000 euro.

Expected duration: 1 year.

2.3.3.4. Deliverables

Protocol 1

- Deliverable 1: effectiveness of trapping as a management tool to control WB population, and analysis of the factors determining the relative number of animals caught.

2.3.4. RO7. Assess the efficacy of different fencing methods with GPS-collared wild boar, considering the effect on non-target species

2.3.4.1. Background

• Different kinds of barriers can affect the movement wildlife species. Some are installed deliberately to limit spatial behaviour and interactions among WB populations and/or with domestic pigs, such as WB-proof fences (Mysterud & Rolandsen, 2019).

• In recent cases, in Belgium, Czech Republic and Germany the use of permanent, mobile and already present fences (such as highway fences), has been shown to play a key role in the reduction and spatial containment of the disease to specific areas (Dellicour et al., 2020). More in-depth investigation is needed to understand the aspects of fences that make the effective barriers to WB.

Evidences available in Europe and worldwide

• Integrated research investigating the impact of these different barriers on wildlife, and particularly WB, has thus far been scarce (Rosell 2019; Rosell et al., 2018)particularly at a fine scale using telemetry.

• The efficacy of fencing for WB containment is variable (Geisser & Reyer, 2004; Honda et al., 2009; Vidrih & Trdan, 2008), and results depend on the scale (large fences of hundreds of km are highly vulnerable to WB at weak points), environmental conditions (e.g., snow could lead to lowering the barrier) and fence structure (Mysterud & Rolandsen, 2019). Moreover, fencing may have an effect on non-target species movement, or may conflict with conservation policies (Jakes et al., 2018; Mbaiwa & Mbaiwa, 2006).

• Different types and designs of fences are available, varying by fence height, single or double fence line, electrification, woven or barbed wire, and other aspects (Mysterud & Rolandsen, 2019; Paige & Stevensville, 2008). Associated costs for fence construction and maintenance are also variable (e.g., Honda et al., 2009;2011).

Current situation for the particular research objective in the EU

• WB-proof fences have mainly been used to reduce agricultural damage or ecological impacts in Europe (Geisser & Reyer, 2004; Rosell, 2019; Rosell et al., 2018; Vidrih & Trdan, 2008). Different MSs have built fences to avoid ASF spread among countries, for instance between Belgium and France, Denmark and Germany, Germany and Poland, or around affected areas within a country, such as Czech Republic, Belgium and Germany to control ASF outbreak. The efficiency of this measure to stop ASF in Europe by limiting WB migration/movement is not yet fully evaluated, although it is unlikely that fences alone can solve the problem if other measures are not employed (Blenkinsop & Trompiz, 2018).

Potential impact of the results obtained for ASF management in the EU

• Management is vital to restrict European WB populations in relation to controlling ASF spread, because it can reduce the likelihood of contact among individuals between different zones of intervention (e.g., an ASF outbreak) or between different populations by reducing spatial movement. Moreover, fences in ASF-areas could be used for capturing WB, if used as guiding structures and leading them to traps.

• Investigating more accurately the relative role of different types of barriers on WB movement is a crucial component of an integrated approach to control the disease once an outbreak has occurred in a particular area.

2.3.4.2. Objectives

1.

To assess and evaluate the effect of different types of fences on the movement of WB.

2. To determine which non-target species interact with fences and how they could be affected.

2.3.4.3. Methodology

To properly evaluate the efficiency of fencing as a management tool in terms of permeability to WB, it is necessary to use the available movement data (GPS-VHF, earmark, CTs) and to combine this information with existing fences/barriers (natural and human-made).

Protocol 1: Assess the efficacy of different fencing methods with GPS-collared WB, considering the effect on non-target species.

Methods: It is recommended that an evaluation of fence efficacy at small scales be used to extrapolate results to large scale fencing. The study consists of a field design to assess the effectiveness of different types of fences and barriers for preventing WB access to certain areas. Tracking of WB by telemetry from areas close to the fences will be used to analyse their movement and to detect passage points (if they cross the fence). CT is used to check WB interactions with the fence as well as non-target species (e.g., other ungulates and carnivores). It is recommended already installed fences on international borders be leveraged.

Study design:

- Fence: include different types of fences: single/double line fence (commercial fencing advertised as big game proof; Mysterud & Rolandsen, 2019), electrified fences, and dig fences.

- Telemetry: tracking WB where artificial passive barriers are already present, including some installed to restrict WB access, such as the fence constructed between France and Belgium (already built to prevent ASF spread). GPS monitoring for 6 months, including the hunting season (i.e., August-January). Calculation of fence crossings by WB are estimated considering GPS positioning error.

- Camera trap: installation of CT (video) to monitor specific points that are more appropriate for wildlife passage (e.g., in streams, or where underpasses are detected or signs of ungulate presence) to check interactions of non-target species with fences and WB interactions with the fence (Laskin et al., 2020). This is complemented with weekly visits to fences to check breaks caused by WB or other species, identify new underpasses and subsequent placement of CTs to monitor wildlife behaviour. In specific points where there is evidence of suspected overpasses by other ungulates, CTs must also be placed. Although CTs can be moved based on evidence of passage, they must remain for a minimum of 2 weeks in the same location. It is important to pay special attention to fence efficacy when hunting is practiced, especially with dogs. Wildlife behaviour at the fences is assessed by the crossing success (cross/not-cross) and crossing method (over/under/through).

Sample size: select one study site where the different types of abovementioned fences are present, including at least big game proof and WB proof fence types. To track at least 15 animals (half males and half females) with access to fences (captured <2 km from fences). Thirty camera traps installed at fences at each study site for 6 months in parallel to telemetry.

Spatial range: across Europe, where big game fences are pre-existent. e.g., in fenced hunting grounds of Spain and Hungary, installed fences on international borders.

Budget limitations: 170,000 euro.

Expected duration: 1 year, including at least six months of field monitoring (Aug-Dec).

2.3.4.4. Deliverables

Protocol 1

- Deliverable 1: report on fence permeability to WB by different types of fences,
- patterns of fences crossing by WB (when/where and animals' characteristics, age/sex).
- Deliverable 2: report on non-target species affected by different types of fences assessed by CT.

2.3.5. RO8. Use of trained dogs in ASF affected areas to detect wild boar carcasses

2.3.5.1. Background

• In areas where ASF is present, WB carcasses are a potential risk of transmission to WB that interact with carcasses, especially in European regions where environmental temperatures are low and persistence of carcasses are prolonged (Probst et al., 2017; 2019). Presence of infected carcasses allows the persistence of ASFV even after the WB population is reduced to very low numbers It is considered that this contact is more important for ASF spread than direct contact between live infectious individuals. Models suggest that reduced hunting effort is required in the intensive hunting area (in the context of ASF outbreaks) to reduce spread of disease, when carcass removal is being implemented in the core area (Lange et al., 2018). Thus, carcass detection and removal in ASF-affected areas could be an effective strategy to reduce ASF transmission (EFSA et al., 2018; Morelle et al., 2019).

Evidences available in Europe and worldwide

• • Detection of carcasses in natural areas is difficult due to low accessibility of the terrain and/or lack of visibility of carcasses, especially for human searchers. Scientific literature regarding WB carcass localization in ASF-affected areas is almost absent, although carcass localization has been tested in other species and contexts. ASF-infected WB deathbeds are mostly found in cool and moist habitats (Morelle et al., 2019), underlining the difficulties of carcass detection under real conditions in the field. Among the detection methods and techniques to find WB carcasses, the use of detection dogs is promising.

• Well-trained dogs are the most portable and versatile tools in use today for odour detection (Bálint et al., 2020; Marchal et al., 2016; Rosell, 2018; Schüler & Kaul, 2019). Surveillance and searching techniques, such as active searching by humans or aerial surveillance to eliminate operator fatigue and many other approaches, are not 100% effective. None of the detection options have been able to match canines' abilities (Smallwood et al. 2020). Nevertheless, the use of the dogs has disadvantages. For example, operational working under field conditions is limited and the efficiency to locate an odour is highly variable from dog to dog.

• The search for carcasses by dog handlers with specially trained dogs is an effective tool for carcass detection, even in closed vegetation environments and for small carcasses (Barrientos et al., 2018; Dahlgren et al., 2012; Domínguez del Valle et al., 2020; Homan et al., 2001; Mathews et al., 2013). Detection dogs have been employed to find chamois (*Rupicapra pyrenaica*) carcasses during a sarcoptic outbreak (Alasaad et al., 2012). There are also working groups using dogs to detect disease-infected animals (https://wd4c.org/our-work/biosecurity-invasives) and humans (for covid-19 see Federal Government of Germany, 2020; Grandjean et al., 2020; Jendrny et al., 2020).

• Biosecurity measures should be considered if detection dogs are being used. For instance, the South Korean Ministry of Environment identified ASFV in a hunting dog used to find WB carcasses.

Current situation for the particular research objective in the EU

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• From the ASF control-and-prevention phase to the ASF eradication-and-control phase (Guberti et al., 2019) dogs can be used to a) control or reduce the WB population (searching for and chasing game at driven hunts, searching for wounded individuals etc.), b) detect carcasses (found by accidental occurrence or systematic surveys), and c) detect ASF-infected meat or meat products. In some ASF-affected areas (e.g., eastern Germany) detection dogs are already in use for carcass searches in field operations.

• Scientific evidence is lacking and urgently needed to assess the potential benefit of detection dogs for ASF eradication strategies. First experiences under real operating conditions are available as unpublished reports from dog-handler teams (e.g., for dog-handler teams from the federal state of Schleswig-Holstein which worked in ASF affected areas in 2020; Karsten & Orlowski, 2020; Niemann, 2020, 2021).

• It is necessary to identify the pros and cons of using dogs in ASF management and compare their use with other techniques under different environmental conditions. As a result of such a cost-benefit analysis, a model should be available to provide the best carcass detection solution for decision makers in ASF prevention and eradication management.

• Private organizations or individuals step into the ASF carcass-detection-dog business without defined and harmonised standards for training, testing, certification, and practical field work. Defining common international standards for decontamination procedures of detection dog teams after fieldwork do not exist. Up to now, there is no scientific evidence to support the development of best practices regarding:

- The use of extensive tests on detection rates and searchable area sizes under various terrain and weather conditions in different European bioregions.
- Assessment of different detection dog searching strategies, such as free-area-search (off-leash) *versus* transact-orientated-area-search (on-leash).

Potential impact of the results obtained for ASF management in the EU

- • A faster and more effective intervention in early ASF epidemic stages to stop/mitigate disease spread through contacts between carcasses and live WB.

• The development of a decision matrix for a best practice approach in carcass detection: carcass detection method or combinations of different methods for given environmental conditions to achieve optimal WB carcass detection rates in ASF-affected areas.

• It will be feasible to elaborate a proposal to form a European-K9-carcass-detection unit operational for ASF management.

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2.3.5.2. Objectives

1. To investigate the use of detector dogs in ASF management to identify best practice options for their use in ASF prevention and eradication programs. For this purpose:

- Define standards for training, testing and the certification of reliable carcass detection dogs used in ASF-affected areas.

- Compare different carcass detection techniques.

- Develop a draft proposal for harmonised training, testing, and certification standards of carcass detection dogs used in ASF management in Europe.

2.3.5.3. Methodology

Protocol 1: Field trials of detection of WB carcasses and analysis of current detections dog training, testing and certification procedures.

Method:

- First, a literature review will be performed on available practical experiences and scientific approaches in the use of detection dogs in ASF management. Moreover, interviews/questionnaires will be sent to organizations and individuals involved in training and use of carcass detection dogs in current ASF management throughout Europe to assess the current situation regarding WB carcass detection (training of dogs and handlers, operational experiences, quality assurance, coordination, testing of different detection options etc.).

- In parallel, field trials developed to evaluate biological (dogs, humans) versus technical (drones with thermographic sensors and optical imaging) WB carcass detection under different environmental conditions (different habitat, seasonal and weather conditions, and also different decomposition stages). Different detection methods will be characterised in terms of precision, sensitivity, effort, and cost. In the field trials, data on habitat conditions, weather, performance of dog-handler teams, time consumption, detection rates, costs, human influences and decontamination procedures must be collected to model best practice approaches.

- Analysis of current detection dog training, testing and certification procedures (interviews, literature, participation in trainings and field operations). This analysis will allow the drafting of a proposal for harmonised training, testing, and certification standards of carcass detection dogs used in ASF management, and a proposal for a sustainable structure of detection dog use. The interviews with experts will be used to evaluate dual-use possibilities of trained carcass detection dogs in wildlife and conservation management or in disease control projects; the implementation of a European-K9-carcass-detection unit operational for ASF management, and voluntary versus professional dog-handler-teams used for WB carcass detection in ASF-affected areas.

Study design:

Field trial : Monitoring of the dog search to estimate detection time and search area (dogs and dog handlers equipped with GPS collars or trackers), and other parameters affecting detection success (wind conditions, carcass density etc.). A comparison between the tracked versus the untracked area of the complete search area allows the calculation of the detection effectiveness in an area where a predefined number of WB carcasses (1-5 per dog/search) are previously laid out. This will be compared to human searchers and other detection techniques (drones). The searching methods (human chain, systematic area search) and the given searching times could be varied as well to identify optimal searching routines. The sample size per field trial should contain 10 detection dog teams with varying working times and predefined area sizes searched per each trial. Analyses must control for the dog-handler team.

Sample size: Up to 10 search repetitions should be made in each of the 5-10 different study areas representing different habitats in the same bioregion (Enetwild et al., 2019a).

Spatial range: where specifically trained dogs are available (e.g., Germany).

Budget limitations: approx. 200,000* euro (only field trial: 120,000 euro; this calculation does not include travel and accommodation expenses).

Expected duration: 1 year .

2.3.5.4. Deliverables

Protocol 1

- Deliverable 1: Report on practical experiences and scientific approaches in the use of detection dogs in ASF management: (i) literature review of available scientific papers and grey literature/experiences reports dealing with detection dog use in ASF management, and (ii) interviews/questionnaires to collect standardised data and information from organizations and individuals involved in different ASF detection dog programs in European countries.
- Deliverable 2: Scientific analysis of field trials on the detection of WB carcasses under different habitat, seasonal and weather conditions including a comparison of different biological (dogs, humans) and technical detection systems (drones with thermographic sensors and optical imaging).
- Deliverable 3: Report on current detection dog training, testing and certification procedures containing (i) a draft proposal for harmonised training, testing, and certifying standards of carcass detection dogs used in ASF management in Europe, (ii) analysis (based on expert interviews) of dual-use possibilities of trained meat and carcass detection dogs in wildlife and conservation management or in disease control projects beyond use in ASF management, and (iii) proposal for the implementation of a European-K9-carcass-detection unit operational for ASF management and a sustainable structure to administer detection dog use in ASF management in Europe.

2.3.6. RO9. Social acceptance of wild boar management measures and animal welfare (qualitative and quantitative approaches)

2.3.6.1. Background

• Wildlife impacts often lead to the so-called "human–wildlife conflicts", which are conflicts among humans over wildlife management issues (Redpath et al., 2013). To successfully address such conflicts, a management strategy should be effective at reducing wildlife impacts and, at the same time, interested parties should support, or at least tolerate, its application (Redpath et al., 2015). This is closely linked to the existing wider debate over the need for human intervention to manage nature (Deary & Warren, 2017; Linnell et al., 2015).

• Acceptability is a judgement or decision regarding the appropriateness of a particular action or policy (Bruskotter et al., 2009). This acceptability in relation to wildlife management varies among stakeholder groups and different management scenarios (i.e., depending on the species, proposed management actions), or socio-economic and cultural contexts (e.g., it has become important in modern societies; Dandy et al., 2011; Delibes-Mateos et al., 2013; Wallach et al., 2018).

• It is necessary to establish who the stakeholders are in relation to wild boar management, and what exactly is 'at stake' by embedding human-wildlife conflicts. The question of acceptance of various wildlife management policies by stakeholders must also be addressed. The ethnographic approach extends the usual concept of 'social acceptance' from a mere fixed statement of opinion into a dynamic stance taken up in daily life, socially enacted, and publicly performed in different settings and encompassing multiple dimensions (social, cultural, economic, ecological, political). Rather than imposing a pre-conceived set of questions 'top-down' from outside stakeholders' life worlds, such an approach is primarily 'bottom-up', explorative, and explicative.

• The quantitative approach allows a quantitative analysis of the acceptance and preferences of different stakeholders about different management scenarios to control African Swine Fever (ASF). The ethnographic perspective and the quantitative approach are complementary as the qualitative findings will be very helpful in designing the questionnaires and in the interpretation of the responses. On the other hand, the quantitative approach will allow estimates of the representativeness of opinions, perceptions and preferences that stakeholders express during the ethnographic interviews and discussions.

Evidences available in Europe and worldwide

• Currently, short-term theoretically informed ethnography is emerging as an approach useful for applied research projects designed to lead to informed interventions, which saves time and resources. It is characterised by forms of intensity that lead to deep and valid ways of short-term knowing (Knight 2000, Pink 2006, Pink & Morgan 2013).

• Management tools are usually more acceptable when the impacts or damage caused by wildlife increase in severity (Liordos et al., 2020). In addition, acceptability of wildlife management options generally decreases with increasing invasiveness of management strategies; e.g., from the less invasive fencing to the highly invasive culling (Heneghan & Morse, 2019; Martínez-Jauregui et al., 2020; Treves et al., 2006). In general, in developed countries, hunters and farmers are more positive towards wildlife management strategies, including lethal actions, than the general public (Frye, 2006; Keuling et al., 2016). Nevertheless, some studies in Europe showed that farmers and the general public are in favour of preventive measures against wildlife conflicts, such as fencing (Frank et al., 2015). Moreover, farmers consider these types of management tools effective to protect livestock from wildlife (Liordos et al., 2020).

Current situation for the particular research objective in the EU

• The WB is one of the most popular game species across Europe and WB hunting has deep historical and cultural roots. WB feature regularly in European public discourse, because their numbers and impacts have been rising spectacularly across the continent (e.g., González-Crespo et al., 2018; Jansen et al., 2007; Torres-Blas et al., 2020).

• Currently, fencing and trapping are common management tools for WB in the specific case of ASF outbreaks and control of other diseases in Europe (Alexandrov et al., 2011; Rosell, 2019). However, their acceptability is limited or has not been evaluated, and possible consequences for animal welfare are often disregarded (for example see Cassidy 2019 for similar issues relating to badger culling in the context of Bovine TB in the UK). In the current scenario of ASF spread, these management tools, among others, could be employed to manage WB populations. Animal welfare during capture is addressed in other RO.

• Hunters may be less willing than farmers and the general public to accept the management of game WB than of non-game species (e.g., European badger *Meles meles* in Greece; Kontsiotis et al., 2020). However, little literature is available on the issue, and therefore, a better understanding of differences in the acceptability of WB management strategies between and within public groups is necessary.

Potential impact of the results obtained for ASF management in the EU

• This study will allow to characterise the stakeholders in WB management (current and alternative strategies) in different European contexts, and it can indicate which policies are likely to be positively accepted – where and by whom. This, in turn, can lead to differentiation of those policies so they are adjusted to particular contexts rather than pursuing a "one size fits all" approach.

• To quantitative evaluation of the acceptability and preferences of different ecological management scenarios to control WB/ASF, including lethal control and indirect methods, like fencing. These results are essential to incorporate social acceptability and animal welfare issues into the process of decision-making in regards to WB/ASF management. So, it will guide to a better communication with stakeholders in relation to WB and ASF management in addition to enhancing their awareness and making them (the feel) part of decision-making process.

• The results of this study can help to promote a scenario of "high acceptability" and positive social attitudes towards WB management, contributing to meeting the established objectives and increasing management success.

2.3.6.2. Objectives

1. To obtain a great detail of information about the group/s, problems and their perceptions by conducting ethnography. This allows researchers to qualitatively describe the actions, interactions and social situation of stakeholders by detailed observation (farmers, hunters and general public), learning about their ways of life in relation to WB management activities, and to compare perceptions among stakeholders and/or study areas on their implications for questions regarding WB management activities.

2. To determine the degree of acceptability (quantitative approach) of different management strategies (including ASF-specific strategies) among different stakeholder groups in different contexts (as a case), and the level of agreement and potential for consensus both between and within stakeholder groups.

2.3.6.3. Methodology

Protocol 1 addresses objective 1. Protocol 2 addresses objective 2.

Protocol 1. Focused/ Short-term ethnographic research (qualitative approach)

Through the presence in the field, applied Ethnography will mobilize mixed-methods and a variety of data in a holistic approach to understand the complexity of peoples' lifeworlds. Specifically, a 'focused' (Knoblauch, 2005)/ short-term ethnographic research strategy (Pink, 2006) takes account of such applied contexts and compensates for the necessary short-term nature of the fieldwork with a stronger emphasis on extensive documentation, especially through audiovisual means. The researchers conducting the project should be ethnographers already familiar with the respective country, including language skills and, ideally, with previous research experience in rural economies and on hunters and/or farmers. This should enable the ethnographers to gain access and build the rapport and trust with stakeholders necessary to conduct fieldwork.

Methods:

Ethnographic research values ecological validity over methodological rigidity. As it cannot be expected that stakeholders will fully adhere to protocols of scientific research, ethnographers need some flexibility in the range and application of methods applied during fieldwork. The research design should, therefore, leave room for adjustments in the field when necessary and not be predetermined.

- Desk Research: In preparation for field research, ethnographers start by reviewing existing anthropological/social scientific literature about the field, complemented by researching and collecting 'grey literature' from the field (including media reports, social media, local and regional newspapers). In addition, research into stakeholders' social networks and the local institutional infrastructure is conducted (What are relevant stakeholder organisations? What institutions are involved in WB management/ASF management?).

- Field Research: Each ethnographer conducts fieldwork for a period of three months. They contact and establish rapport and trust with a number of stakeholders (hunters, farmers) and local residents (local villagers) to explore their everyday lifeworld through a range of methods, including participant observation, informal conversations and semi-structured interviews, focus groups, and audiovisual documentation.

Study design: A pilot ethnographic fieldwork is grounded in the prolonged, continual participant observation of stakeholders' everyday activities which are described and documented in written field reports and, where possible, through audio and video recordings. Ethnographers distribute their time in the field to get to know local hunters, farmers and other residents (the general public) in the area, initially focusing on local experts and gatekeepers before branching out.

Sample size: sample size is irrelevant as qualitative research is not meant to be representative but explorative. 2-4 case studies per country.

Spatial range: 3-4 case studies. As this is a pilot, the aim is not to be completely representative of the diversity of situations across Europe, but select a few countries with contrasting realities. The minimum countries to include are:

- a Baltic state: small country affected by ASF since the virus arrived in Europe, but with a non-significant pork industry.

- Poland: large country affected by ASF since the virus arrived in Europe. This country has a significant pig industry, and outdoor and backyard pig farms greatly affected by ASF and the latter tend to disappear. Social conflict emerged because the government proposed massive WB culling and the general public objected (Schmidt et al. 2019; Walker 2019).

- Romania: ASF present since 2017. Important backyard farming production, related to the significant rural population.

- Germany or Spain: large countries and relevant pork producers, the former recently affected by ASF (September 2020).

Budget limitations: 150,000 euro.

Expected duration: 1 year

Protocol 2. Case study: collection and analysis of perceptions, opinions and preferences of different stakeholders on the practicability and acceptability of fencing, trapping, culling with different methods, and other management options to control ASF in WB populations (quantitative approach).

Method: questionnaires (in the local language) administered to farmers (pig industry), hunters and the general public (including the general population, animal welfare organisations and NGOs) to determine attitudes towards tools used to manage WB and ASF spread, and the level of agreement and potential for consensus both between and within stakeholder groups.

Study design: Survey participants classified into general public and specific stakeholder group: farmers and hunters. Questionnaires should include questions about (a) knowledge on the ASF situation in Europe; (b) perception of the ASF problem; (c) general perception about the need for intervention; (c) opinion about acceptability of a range of interventions, (d) opinion about effectiveness of a range of interventions; (e) preferences for different management interventions under different scenarios; (f) socio-demographic characteristics (gender, age) following the classification by ELSTAT (2011, *www.statistics.gr*). Selection of participants is detailed below.

An online questionnaire will be designed using available information about WB and ASF management in the scientific literature and EFSA reports. In addition, findings obtained in the qualitative approach will help identify key issues, e.g., to define a complete list of potential management interventions. This list will be redefined in consultation with experts (i.e., researchers, wildlife managers, etc.) on WB and ASF management. The questionnaire should be adapted to each group (i.e., general public, hunters and farmers). A stratified consumer's panel attending to rural-urban areas, age and gender will be used to achieve the best representation of society in each of the countries involved in the study (see an example in Martínez-Jauregui et al. 2020). It is strongly recommended that formal contacts with national representatives of farmers and hunters be established for collaboration in the distribution of the questionnaires (hardcopies and online) among those collectives in addition to enhancing their willingness to participate in the survey (Redpath et al., 2013). The questionnaire, once designed, must be pre-tested to optimise subsequent data collection, reduce bias and improve the reliability of the questions. The analysis of preferences requires the use of discrete choice experiments (e.g., Delibes-

Mateos et al., 2014). Analyses will test whether attitudes, perceptions and preferences vary in relation to age, social group (rural/urban), activity (hunting, farming, etc.), education and nationality.

Sample size: Answers from 440 people (including 10% of the sample for a pilot study) will be used in each country to obtain a representative sample of the general public. This sample will attend to rural-urban areas, age and gender (see above). 220 questionnaires will be implemented for other stakeholder groups (farmers and hunters), including a subsample of 10% for the pilot study.

Spatial range: 3-4 case studies. As this is a pilot, the aim is not to be completely representative of the diversity of situations across Europe but select a few countries with contrasting realities (selected among a Baltic state, Romania, Poland, Germany or Spain).

Budget limitations: 150,000 euro.

2.3.6.4. Expected duration: 1-1.5 years.Deliverables

Protocol 1

- • Deliverable 1: Each ethnographic study should lead to a separate in-depth report that will analyse in detail the studied context with its WB management practices. A separate report should compare the socio-ecological variability (perceptions) among pilot countries. The comparative report should also formulate which findings can lead to a meaningful quantitative survey.

Protocol 2

- Deliverable 2: report on hunters, farmers and general public acceptance and preferences about ecological and management scenarios to control ASF in WB populations, identifying the level of agreement and potential for consensus both between and within stakeholder groups.

2.4. Assessment and management of risk factors

2.4.1. RO10. The wild boar/pig interface: Developing biosecurity awareness and implementation among backyard and outdoor pig farmers

2.4.1.1. Background

• The WB/pig interface is the environment close to farming areas, where they both can interact (directly or indirectly, often human-mediated), and presents a risk for the spread of disease, such as ASF. The EU pig meat sector alone accounts for nearly half of total EU meat production [over 150 million pigs reared in 2018 (EPRS & Augère-Granier, 2020)]. The sector is highly diverse, with huge differences in rearing methods and farm sizes across the European countries: from backyard farming (non-commercial) to industrial indoor installations with thousands of animals.

• In terms of numbers of heads, while only 3% of the pigs in the EU are kept in backyard farms, there is a large number producing meat for home consumption or the local market (EPRS & Augère-Granier, 2020), and this presents an important risk for the pig industry. Backyard farms present particular challenges in the context of an ASF eradication programme, including uncontrolled movements of pigs and people, poor biosecurity and the identification of holdings (EFSA et al., 2020b). It is difficult to differentiate between backyard and outdoor production systems, because in some cases backyard herds are not completely fenced and pigs are not isolated (Enetwild et al., 2020b).

• In outdoor production, pigs have access to places outside the rearing structure, with contact to the external environment, regardless of the amount of time spent outside (generally speaking, we will use the term backyards to also refer to outdoor).

• The characteristics of domestic pig production together with other influences (geographical, land uses and habitats conditions, WB populations), determine local specific WB/pig interfaces. At that interface, indirect interactions due to behaviour of stakeholders, such as hunters and farmers (e.g., carcass manipulation or swill feeding) can also contribute to maintaining and spreading infections (Pozio, 2014).

Evidences available in Europe and worldwide

• Among the strategies to control ASF, reducing the risks of direct and indirect interaction (as well as human-mediated) at the WB-domestic pig interface in Europe is a key (Prodanov-Radulović et al., 2018). Biosecurity in backyard farms, and often in commercial outdoor farms, is usually scarce and the owners lack knowledge about animal disease control and preventive measures (Blome et al., 2010).

• Some government authorities have developed communication campaigns to promote awareness about ASF, targeting to pig owners and other stakeholders (such as hunters and the general public) as a preventive ASF control strategy (Bellini et al., 2016; Cwynar et al., 2019). These campaigns work to get farmers and other stakeholders involved in ASF management and to become part of the solution, while at the same time, increasing management acceptability and the likelihood of successfully achieving management objectives (Ansell & Gash, 2008; Beierle & Konisky, 2001).

Current situation for the particular research objective in the EU

• Detailed protocols to assess and implement farm-specific biosecurity to protect against WB (wildlife in general) are lacking in backyards and/or outdoor production systems. Biosecurity plans for protection from WB diseases at farms must be developed applying a standardised protocol that guides assessment of risks for wildlife-livestock interactions *in situ*.

• Such protocols must be designed so their application is practical and feasible in different contexts, easily transferable to professionals and adapted to epidemiological systems. After applying this protocol, the implementation of specific plans is proposed to farmers to reduce the risk of interaction and transmission of pathogens at the interface.

• Using our own terminology, on-farm wildlife risk mitigation protocols are scientifically based and standardised technical procedures to (i) gather information, identify and evaluate risks for wildlife-livestock interaction and pathogens transmission, and (ii) develop farm-specific actions to reduce the probability of interaction and transmission of pathogens between wildlife and livestock. This leads to a Farm-specific Action Plan (FsAP), which consists of management measures to reduce interactions at the wildlife-livestock interface, and is farm-specific. The subsequent evaluation of such plans in terms of efficacy, cost-effectiveness, and acceptance by farmers, are necessary for further development of ASF Risk Mitigation Programs at national and Europe-wide levels.

Potential impact of the results obtained for ASF management in the EU

• Developing for the first time a systematic protocol for on-farm ASF risk assessment at the WB-backyard pig interface in different scenarios across Europe is needed to:

- describe the most relevant and specific epidemiological features of the farms, their management and risks, attending to their variability across Europe;
- standardise the development of FsAP, key to improving general farm management, and specifically localised risks;
- rank the priority of alternative management options as a function of their expected efficacy and practical value, essential to focus limited resources and efforts on those actions that better reduce risk of interaction at the WB/pig interface and that are welcome by farmers.

• All of this will facilitate farmers' understanding of the need to avoid and minimise WB and pig interactions through active management, structures and human behaviour changes (i.e., fencing, carcass removal, swill feeding) to reduce ASF risk transmission.

2.4.1.2. Objectives

1. To develop and test an on-farm WB risk mitigation protocol in backyard/outdoor pig farms under different management and epidemiological scenarios across European environments:

- To evaluate the risks of WB-pig interactions and ASF transmission at specific farms;
- To develop an on-farm wildlife risk mitigation protocol that is flexible and adaptable to the existing range of characteristics of backyards/outdoor pig farms across the continent;
- To test the protocol by generating FsAP at these farms, evaluate their potential implementation in terms of practical feasibility and acceptability by farmers.

2. To develop information technology tools to facilitate the standardised generation of science-based FsAP in backyard/outdoor pig farms across Europe.

2.4.1.3. Methodology

Protocol 1 addresses objective 1, and protocol 2, objective 2.

Protocol 1: To develop and test an on-farm WB risk mitigation protocol in backyards/outdoor pig farms under different management and epidemiological scenarios across European environments.

Method: By visiting backyard/outdoor pig farms under different management and epidemiological scenarios across European environments, to develop a protocol for on-farm specific evaluation of risk and implementation of FsAP, adaptable to local circumstances, including informative campaigns about ASF and the transmission risk at the WB/pig interface.

Study design (steps):

- Selection of backyard and outdoor pig farms (see below)

- On-farm Wildlife Risk Mitigation Protocol. The protocol consists of three steps:

a. -Before farm visit: gathering information from veterinary and/or the forestry/wildlife authorities: census, sanitary status, origin of movements, georeferenced information including farm size, perimeter, location, and land uses, including information on neighbouring properties, information on wildlife (WB abundance, density, hunting records) at the farm and/or surrounding areas.

b. On-farm visit: to conduct an interview (questionnaire) to gather information on livestock, wildlife, land use, feed and water distribution and management to identify potential sources of risk. Use a printed map to locate plots, land uses, "a priori" risk sites and any other management issue of relevance. To place CTs at four risk points on three farms per study site for one month during the season that risk is perceived as highest.

c. After the interview, to visit each plot and each potential risk point accompanied by the responder. Each potential risk point georeferenced, photographed, and its characteristics and signs of use by wildlife described in detail. To score the risk based on available information on farm resource uses by WB and/or epidemiological evidence (e.g. Barasona, 2015; Barasona et al., 2017; Cadenas-Fernández et al., 2020; Carrasco-Garcia et al., 2016; Payne et al., 2016). For this purpose, a risk scoring system needs to be developed and tested for application at each specific risk point. This approach will help in the scoring of risk as objectively as possible, and to design the appropriate specific actions to minimise interaction risk with WB. The final action during the field visit consists of summarising in a concise description of the main risks detected and any observations that would later be helpful to develop the action plan. Estimated duration of field visits about 2-3 hours.

- To develop the FsAP, which is a detailed report for each farm, including the general background on ASF and farm biosafety, listing and ranking the specific risks identified, as well as the mitigation actions proposed. Mitigation actions listed as "Priority actions" (preferred) or "Alternative actions". "Priority actions" refer to those that, with a minimum a priori cost have the greatest potential to prevent interaction between WB and pigs. "Alternative actions" are those that, despite being useful for controlling interactions, are theoretically less efficient than "Priority actions". Mitigation actions were also classified into "general" and "specific". "General actions" refer to those that involve comprehensive management of the farm, or at least affect the management of resources or pigs; "Specific actions" refer to those that focus on controlling the interaction at a single point (e.g., a feeder or waterer).

- To deliver the report within two months after the on-farm visit and establish permanent contact with farmers (telephone and e-mail) to report any incidents, ask any pending questions and convey their concerns. Six months after the report is delivered, to ask the farmers which of the proposed actions has been implemented, the difficulties encountered and the estimated costs of the implementation. To report which alternatives or new actions farmers adopted in each case, and their motivations. The interviewers will visit 20% of the farms again to verify the implementation of actions, including changes in habits (how frequently an action has been performed). To ask farmers about their general perceptions on the FsAP (effectiveness, practicability and acceptability; Ciaravino et al., 2020).

- To elaborate informative/dissemination material, including the protocol, which can be used at European and/or national scales for campaigns through different communication channels to raise awareness about ASF control and biosecurity at the WB/pig interface.

Sample size: minimum 20 farms per type of production (backyards and outdoor). They should be selected randomly (but where WB is present) in collaboration with national veterinary authorities.

Spatial range: across Europe in four European countries covering the three bioregions (Enetwild et al, 2019a), respectively, and at least one country in the Balkans area.

Budget limitations: 170,000 euro.

Expected duration: 1 year.

Note: collaboration with international organisations (e.g., FAO) is highly recommended.

Protocol 2: To develop information technology tools to facilitate the standardised generation of science-based FsAP in backyards/outdoor pig farms across Europe.

Method: To develop an app (for tablet and/or mobile devices) to collect information *in situ* to apply the on-farm Wildlife Risk Mitigation Protocol when visiting the backyard/outdoor pig farms under different management and epidemiological scenarios across European environments. This is complemented with a computer screen app to draft the FsAP. The apps should be flexible to easily adapt to local characteristics of backyards and outdoor farms across Europe, and languages.

Study design:

- To format the On-farm Wildlife Risk Mitigation Protocols (protocol 1) as an app (optimally to be used in a tablet in the field) to record information on maps and collect information from the questionnaire conducted during the on-farm visit: information on livestock, wildlife, land use, feed and water distribution and management to identify potential sources of risk. The app must be able to incorporate the pictures of risk points taken *in situ* during the field visit.

- To develop an interface, such as a computer screen app, to draft the FsAP report. This app is connected to the tablet/mobile app. As described above, the FsAP is a detailed report for each farm including the general background on ASF and farm biosafety, listing and ranking the specific risks identified, as well as the mitigation actions proposed. Mitigation actions listed as "Priority actions" (preferred) or "Alternative actions" (explained above).

Sample size: the apps will be tested on 20 farms.

Spatial range: app translated into national languages across Europe, initially at least in English and in four European countries from NW, NW, SW and SE regions, respectively, two of which are ASF-affected.

Budget limitations: approx. 144,000 euro.

Expected duration: 1 year.

2.4.1.4. Deliverables

Protocol 1

- Deliverable 1: An On-farm WB risk mitigation protocol based on 40 farms (20 per type of production; written report and protocol, including the FsAP and dissemination material) for backyard/outdoor pig farms under different management and epidemiological scenarios across European environments.

Protocol 2

- Deliverable 2: Information technology tools (apps for tablet/mobile, and computer screen, respectively) to facilitate the standardised generation of science-based FsAP in backyard/outdoor pig farms across Europe.

2.4.2. RO11. Evaluation of the measures of passive surveillance and carcass removal on the spread of the disease

2.4.2.1. Background

• Epidemiological investigations and disease surveillance of wildlife populations are essential to enhance our capacity to detect and control infectious diseases that are currently spreading or that may emerge in wild and domestic animal populations (Artois et al., 2009).

• Early detection of ASF and its effectiveness increase when stakeholders collaborate, particularly hunters, since the species of interest is hunted (Guberti et al., 2014) or the general public and professionals reporting road-killed animals (Schulz et al., 2020). These animals must be tested for ASF, for instance, using PCR (blood samples are requested, or organs in case blood samples are unavailable).

• Carcass removal consists of the elimination of carcasses and visceral remains (e.g., buried, cremated or any other method of destruction on the spot) from the environment to reduce probabilities of disease transmission, ASF virus in this case, to living individuals (Jennelle et al., 2009). This strategy includes the elimination of WB carcasses found as a result of passive surveillance, and those found actively (taking blood or organ samples to test for ASF) through search teams and/or trained dogs (see RO8) using a defined protocol (Alasaad et al., 2012; Hoinville et al., 2011).

Evidences available in Europe and worldwide

• Passive surveillance has been a useful strategy for early detection of emerging diseases globally (e.g., Schmitt et al., 1997; Hadorn & Stärk, 2008; Rivière et al., 2015). Early detection in disease-free areas, particularly at-risk countries, greatly determines the effectiveness of disease control actions (OIE, 2010). Wildlife disease programmes need to be supported by communication to ensure that all components of the surveillance are coordinated and function together. This includes education initiatives for people working within the programme.

• ASF can be transmitted by several routes, such as contact with carcasses of infected animals, or via fomites and food (Carrasco-Garcia et al., 2018; EFSA, 2014a; Probst et al., 2017; Vicente et al., 2016). Carcass removal is considered a highly effective method for controlling ASF outbreaks in Europe. At the same time, this option is often unpractical (Guinat et al., 2017) due to the difficulty and required effort, especially in forests, dense scrub areas or ravines. However, effective ways to detect WB carcasses could be developed (Alasaad et al., 2012; Dahlgren et al., 2012; Cukor et al., 2020; Morelle et al., 2019).

Current situation for the particular research objective in the EU

• Passive surveillance has shown, by simulations, high efficiency (i.e., the performance under controlled circumstances) for detecting the presence of ASF in WB populations, and following the epidemic phase in an infected population (Gervasi et al., 2020). Simulations have shown that carcass removal has an important effect on controlling ASF, increasing effectiveness in combination with other control measures [e.g., depopulation, (EFSA et al., 2017; Lange, 2015)], especially in areas with low temperatures (ASF virus persists longer in frozen carcasses) and obligate scavenger scarcity (O'Neill et al., 2020). The sooner the carcass is removed, the better (EFSA et al., 2017).

• However, regarding its effectiveness (i.e., performance under real conditions), there is no empirical data available in the scientific literature for ASF, and the effectiveness of early detection and removal has not yet been evaluated under natural conditions.

Potential impact of the results obtained for ASF management in the EU

• To evaluate the impact of passive surveillance and rapid carcass removal on the spread of ASF would help to quantify the effectiveness of this strategy and to estimate the necessary effort to invest. Early detection of ASF-affected carcasses, particularly in at-risk countries and where first outbreaks occur, greatly determines the effectiveness of subsequent disease control actions:

- Permits early assessment and decisions about how to respond, i.e., delimiting areas where a battery of management actions should be implemented;
- Management actions taken early in an ASF event are more likely to succeed and cost less than management actions taken at a later time;
- Allows for rapid communication to ensure that all components of the wildlife disease surveillance programme are coordinated and function together. This is very relevant at an international level for such a transboundary disease.

2.4.2.2. Objectives

1. To evaluate effectiveness of carcass removal to control ASF spread.

2.4.2.3. Methodology

Protocol 1: evaluation of carcass removal impact during ASF outbreaks on the spread/control of the disease

Method: questionnaires and monitoring about carcass removal in ASF-affected areas (where outbreaks happened).

Study design:

- Questionnaires: to describe carcass removal strategies, protocols (including the use of dogs and technology such as drones) and effort applied by authorities in areas where ASF outbreaks occurred. To evaluate the impact of carcass removal strategies on the spread and control of the disease, information is needed on other control strategies/measures and parameters indicating the spread and control of the disease in WB over space and time, and to evaluate their associations (see below). Face-to-face or web based (Guinat et al., 2017; Vergne et al., 2016).

- Monitoring carcass removal: in areas where different strategies for detection of WB carcasses (e.g., human effort, using trained dogs), elimination processes (e.g., buried, cremated, transported for destruction) and intensity of carcass removal are being implemented, and evaluate their impact on spread/control of disease (Gervasi et al., 2020). Buffer zones should be considered (i.e., ASF-free areas, but at risk because they are adjacent to infected areas, and in which control measures should be implemented to increase effectiveness (Lange, 2015)). Provision of a mobile app to report carcasses in real time in the future, including a warning system for authorities collaborating in monitoring. Detailed evaluation of hunting statistics in the area to determine relative abundance pre-outbreak, and if possible, density (Enetwild et al., 2019b). In conjunction with data collected from questionnaires, to evaluate the impact of carcass removal strategies on the spread and control of the disease; the associations between management and the spread and control of the disease in WB over space and time should be analysed.

Sample size: at least 20 WB population areas, optimally, the locations where ASF was first detected in a given region, implying a geographical advance of ASF. Distributed along areas where different strategies and intensities were applied (all affected and at-risk countries).

Spatial range: across Europe where outbreaks occurred and buffer zones.

Budget limitations: No (<144,000 euro).

Expected duration: 1 year.

Difficulty: basic population parameters are often unknown, but it is necessary for proper evaluation.

2.4.2.4. Deliverables

Protocol 1

- Deliverable 1: Report on effectiveness of carcass removal for controlling ASF outbreaks under different scenarios (i.e., different elimination strategies and search intensity) to optimise the process.

2.5. National and international decision-taking

2.5.1. RO12. Assess how to improve coordinated national and international decision-taking

2.5.1.1. Background

• Factors that govern wildlife abundance, their impacts and disease spread are not bound by national borders (Vicente et al., 2019). This means that, at an international level, the spatial and temporal scale of wildlife management must be compatible with the ecological and socio-economic scales of the drivers that affect wildlife, and human-wildlife interactions. This approach is essential to develop sustainable wildlife management from a holistic and integrated point of view (Linnell et al., 2020).

• Wildlife management is evolving from population management, based on population estimates and population models, towards impact management, focussed on those impacts (positive and negative) resulting from interactions between and among species, habitats and humans, that matter to stakeholder groups (Decker et al., 2014; Riley et al., 2002). Given the need to manage impacts without knowing all possible consequences, wildlife managers need to act with the information, knowledge and opinions on hand. Adaptive impact management is the most logical approach combining management, monitoring and knowledge gathering simultaneously (Reidinger Jr & Miller, 2013).

Evidences available in Europe and worldwide

• Wildlife management in the international context is normally not scaled and proportional to ecological and socio-economic relevance, and institutional decisions are not always coordinated both vertically (i.e., from local to international levels) and horizontally (i.e., among interest or sectors at each level) to generate collective action (Ansell & Gash, 2008; Beierle & Konisky, 2001; Sandström, 2012). For instance, a lack of coordination among countries has been shown in Europe scale with the management and conservation strategy of European Turtle-dove (*Streptopelia turtur*), a migratory bird whose population has severely decreased (Hanane, 2017; Lormée et al., 2019).

To address to the challenging task of managing wildlife in complex socio-ecological systems while engaging stakeholders and being transparent, wildlife managers are increasingly using decision support frameworks, and decision tools are being tailored to wildlife problems (Runge et al., 2020). Structured Decision Making (SDM) (Gregory et al., 2012) is based on decision theory and risk analysis. The PrOACT analytic sequence (standing for Problem framing, Objectives, Alternatives, Consequences and Trade-offs) is key for decomposing the problem and guiding the decision process, allowing both scientists and policy-makers or managers to play their own role.

• WB and feral pig populations are widely distributed and increasing in most areas of their distribution range, which concurs with increasing negative impacts, such as pathogen/vector spread, environmental and agricultural damage, and road accidents. Worldwide, this situation requires an effective, rapid and coordinated national and international response. International approaches and information exchange also favour proactive wildlife management models, instead of reactive (Jacobsen et al., 2016).

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• To improve coordinated national and international decision-taking (Biegus & Bueger, 2017) (i) the international community must assume a common focussed approach; (ii) the approach taken should be inclusive, created in a forum where all relevant stakeholders (e.g., regional, states and international organisation representatives, technical experts, wildlife authorities, game managers, wildlife ecologists, hunters and veterinary professionals) participate and share their agenda, activities and analysis; (iii) from the created forum and its participants, ideas and strategies emerge due to information exchange, and the development of collaborative guidelines and concrete projects; and (iv) finally, an institutional structure and plan to respond to the problem is needed.

Current situation for the particular research objective in the EU

• The Birds (1979) and Habitats (1992) Directives are the pillars of nature legislation and protection at the EU level. The legislation on hunting in the EU differs by country. However, these regulations should comply with these previously adopted EU directives. The European Charter on Hunting and Biodiversity defined sustainable hunting as the use of wild game species and their habitats in a way and at a rate that does not lead to the long-term decline of biodiversity or hinder its restoration (Council of Europe, 2007). This means that when hunting is conducted in such a sustainable manner, it can positively contribute to the conservation of wild populations and their habitats and also benefit society.

• Most wildlife population monitoring structures at the European level are implemented for waterbirds and/or migratory species, where hunting is viewed as a variable that is easy to adjust based on credible and adaptive strategies, and only periodic estimates of population abundance are needed. However, apart from migratory species, Europe-wide distributed species also need cross-border approaches and the creation of an appropriate legal, administrative, and financial framework to be managed. The WB is the perfect paradigm.

• The conservation status of WB is not of concern. On contrary, its impacts have been increasing with no signs of a solution in the context of decreasing numbers of hunters in Europe (Massei et al., 2015). The EU aims nature back to agricultural land (European Commission, 2020) to step up the protection and restoration of nature, improving and widening the network of protected areas and developing an ambitious EU Nature Restoration Plan. This can even favour the expansion and growth of WB populations in the future.

• This context indicates that, in parallel to the EU Nature Restoration Plan, key actions must be taken by the EC in relation to WB management. An appropriate Pan-European WB management plan would contribute to the EU 2030 nature protection targets (European Commission, 2020). This plan must be intended to serve as a guiding framework on the Pan-European level, and not to replace national or regional plans in existence; and shall serve as a guiding framework for their development. National and/or regional WB plans on the level of smaller regions or areas can provide more detailed analyses of measures to be taken as well as milestones, addressing progress on specific results. They can also address and incorporate the roles of responsible organisations in more detail. The management of WB also needs to secure long-term funding for priority management measures to suit these widely distributed species, still increasing in numbers and impact. A coordinated approach for adaptive WB management does not require uniform regulations (i.e., hunting legislation), since adaptive management is only part of the process of a sustainable management process, which can differ among contexts. However, hunting is an essential tool within a broader wildlife management system, and to revert this situation, hunters need to be trained and motivated to regulate wild boar, which should be part of the plan.

Potential impact of the results obtained for ASF management in the EU

• Improving vertical and horizontal coordination on decision-making at national and European level will permit a science-based WB proactive management model. This is the most cost-effective strategy in the long term to prevent WB impacts, namely, to address emergency disease response in relation to ASF outbreaks.

• The revision of the distribution of responsibilities between national and international governmental authorities that work with wildlife management (WB in particular), so that stakeholders will allow (i) adjustments to clarify and refine their commissions to operate as efficiently as possible, as well as (ii) to engage a broad range of stakeholders with clear responsibilities for the implementation of necessary measures.

• A Pan-European approach towards decision-making in WB management can support political decisions.

2.5.1.2. Objectives

1. To improve, at national and international levels, the coordination of European decision-making among involved institutions and social actors in relation to WB.

2. To provide the basis for a comprehensive and integrated Pan-European WB management plan.

2.5.1.3. Methodology

Protocol 1 addresses objectives 1 and 2.

Protocol 1: European exchange of information on current wildlife national management schemes and discussion to improve coordinated national and international decision-taking, focused on WB as a paradigm species; and to draft a proposal for a WB Pan-European management plan supported by the main national decision-taking agents and stakeholders.

Method: First, heterogeneities in WB management across Europe must be analysed using questionnaires. This will be complemented by an international discussion (physical convention, which can be replaced by small in-person workshops and/or online workshops). The participants, specific topics, format (workshops=working groups) and expected outcomes are discussed below. The analysis of the outcome of the convention, data analyses (questionnaire), literature review, and subsequent work meetings with key stakeholders and European policy makers will inform the drafting of a proposal for a WB Pan-European management plan supported by the main national decision-making agents and stakeholders, which will be presented to the EU.

Study design: As for the questionnaire, respondents will represent the administrations and hunting sectors of all European Countries. Participants invited to workshops will be representative policy makers of the EU national governmental institutions (who also answered the questionnaire), as well as the sectors involved in WB management, all connected in the framework of Europe. All participants, previously allocated to different working groups, will receive detailed information in advance on the different topics that will be analysed and presented at the convention by the organizers, and expectations of their participation. They will be asked to prepare a short presentation (following templates for the working group), and will fill out a questionnaire to record data on their respective WB management system. The first results of the questionnaire and a brief report with the main scientific evidence and statistics (objective data) will be provided in advance to participants to have a common evidence-base starting point for discussion. The main expected outcomes are:

i. Inter-institutional and inter-sectorial coordination at the international level

- A review of nature and wildlife management legislation at the European level and the distribution of responsibilities between national and international governmental authorities that work with wildlife management; how to adjust this distribution to clarify their commissions to operate as efficiently as possible; how to engage the broad range of stakeholders with clear responsibilities for the implementation of necessary measures; how to improve vertical (from local to European level) and horizontal (different sectors) coordination on decision-making.

ii. Decision-making by wildlife managers and politicians based on scientific knowledge and interdisciplinary research into all aspects of management

- A review of the measures taken that disregard the science of wildlife management in relation to WB; to agree to a general scheme of coordinated wildlife management adhering to the principles of modern wildlife management and to ensure that the results of research inform and guide international, national policies and decisions; how to promote interdisciplinary research into all aspects of WB management and design exchange programs/committees in scientific and technical areas.

iii. Wild Boar population monitoring and analysis to determine best approaches

- Defining the structure of a realistic European WB population monitoring scheme, where information is constantly or at least regularly updated (iterative, timely and transparent feedback from monitoring); how to apply progress already made (e.g.; Enetwild project) on harmonised and accurate population data collection, but also sanitary and socio-economic impacts, following international standards (Enetwild 2020b); how sound reporting performance can be achieved.

iv. Coordinated management across jurisdictional borders and adequate national and international, mutually compatible legislative frames

- Determine what legislative needs are for coordinated management across jurisdictional borders; how harvest levels for particular populations and areas are determined, as well as hunting seasons, and harvest methods; does legislation mandate specific scientific methods, are quotas science-based by low or demand-driven? It is important to consider the conflicts (with other sectors) that can occur if too few animals are harvested, such as the case of WB, or if measures like supplementary feeding lead to exceedingly high densities, or aggregations in undesirable areas.

v. Education and public awareness programmes

- Education and public awareness programmes on sustainable and effective methods of communication are also part of the plan; how to develop and establish communication among stakeholders, managers and the general public; how to engage people in education and awareness of the opportunities and constraints of sustainable use; how to develop effective means for communication between stakeholders.

vi. Draft a proposal for a WB Pan-European management plan to be presented to the EU supported by the main national decision-taking agents and stakeholders.

- The aspects to be included in a Pan-European WB management plan, which will support political decision makers, are: scope, objectives, results, activities, time lines, evaluation, priorities, main actors/organisations responsible for coordinating, implementing or supporting actions; how to link this plan to a system for information-gathering and monitoring for effective wildlife management planning based on an ecosystem approach; apart from the agricultural (and veterinary) and forestry sectors, identify which sectors are required to be coordinated for planning; how much cost does this management and conservation plan incur? How to develop European capacity-building to adapt in a fast-changing world to the present reality of WB management. This outcome is not immediate to the convention, but it consists of the analysis of their outcomes (also questionnaire), literature review and subsequent working meetings with key stakeholders and European policy makers. This plan will propose how to apply a science-based WB proactive management model, as the most cost-effective strategy in the long term to prevent WB impacts, namely, to address emergency disease reaction in relation to ASF outbreaks.

Sample size: all involved institutions, 150 participants involved through online workshops/working groups.

Spatial range: across Europe.

Budget limitations: 150,000 euro if mostly developed online.

Expected duration: 1 year.

2.5.1.4. Deliverables

Protocol 1

- Deliverable 1: Description of local, national and European differences in the management system of WB.
- Deliverable 2: Outcome of the International discussion on WB management, as guidance to improve, at national and international levels, the coordination of European decision-making among involved institutions and social actors in relation to WB.
- Deliverable 3: To provide a proposal for a comprehensive and integrated Pan-European WB management plan

3. Discussion and conclusions

Table 4 summarises the proposed protocols, time frames and budget limitations, to facilitate further discussion on the **interaction between protocols addressing different ROs**. These protocols may eventually be combined (in case different ROs are addressed within the same time frame) to optimise the use of resources and budgets, and to improve the quality and applied value of results:

- As for ROs based on collecting already existing data, RO1 and RO4 could be combined by addressing the same study areas. The use of barcoding is essential to RO4.
- In relation to protocols based in data collection on selected areas, particularly ASF affected zones, it would be a wise strategy to combine RO4, RO5 and RO6.
- As for field-work-based ROs (excluding telemetry), the combination of protocols does not always offer advantages since they address specific situations, however RO2 and RO10 include the use of CTs in similar areas (outdoor/extensive pig farms).
- Regarding protocols requiring WB telemetry, all of these are the top choices according to researchers drafting the present report for the respective ROs. However, they exceed the time-frame required for short-term assessment. In most cases, several years are require to generate reliable and sufficient data to evaluate the specific question (e.g., mortality) and not only seasonal, but interannual fluctuations are also relevant (they may impede comparisons among study sites if not accounted for). In other cases, telemetry is especially recommended, because it provides a complete picture and sufficient detail of WB spatial behaviour to develop control strategies. In contrast, CTs provide high-resolution data but are limited to monitoring specific points (in fact, the two approaches are complementary, and are often used to characterise risk at the wildlife/livestock interface; Triguero-Ocaña et al., 2021). Short-term telemetry also demands a large budget as devices can rarely be re-used for multiple animals. This also requires on-going studies in several areas at the same time. It is therefore recommended to explore already-existing data on telemetry through European collaborative initiatives. However, we provide alternative protocol in RO4 that included telemetry-based protocols. Guidelines specifically stated that the RO7 should be based on telemetry.
- There are two protocols (RO9), which are based on applying social sciences to case studies to assess acceptability of WB management options by different stakeholders (qualitatively and quantitatively, respectively). They should be developed consecutively, in order to provide a complete assessment of the issue. In case they select the same study cases (which is recommended in the protocols), they could be carried out at the same time (in parallel), or with a short lag (few months) between them.
- Finally, the protocol to assess national and international decision-making processes presents relevant interactions with other ROs, but can be addressed independently. For instance, aspects related to WB monitoring (RO3), or factors determining WB population dynamics across Europe (RO1) are relevant. Also, data collected on WB management experiences (population or ASF management, RO5, RO6, RO10) are relevant, especially in transboundary contexts. Finally, social aspects associated with stakeholders and their variability across countries (RO9) are relevant to international decision-making. However, as management plans for wildlife must be adaptive, any relevant output obtained from other ROs can be later incorporated.

Within each specific RO, several protocols, in most cases complementary rather than exclusive, were proposed, and we would note the following considerations:

Wild boar ecology

- RO1. Studies on basic aspects of WB population dynamics throughout Europe: Protocols can be addressed separately, optimally, consecutively (first, identification of data gaps, and then, collection of data to fill these gaps).
- RO2. Holistic assessment of the factors that determine the presence of WB near different pig farm types, including outdoor farms and extensive production systems.

Wild boar monitoring

- RO3. Implementation of practical methods to estimate WB density.

  The activities proposed are well aligned with current activities developed by the Enetwild project.

Wild boar management and population control

- RO4. Effect of food availability in natural areas in relation to baiting and feeding in WB population dynamics.

  Protocols can be addressed separately, although the first (data compilation) can be useful in the selection of study sites for the telemetry protocol. Telemetry added value is providing practical information to develop specific management plans. It is recommended to check already-existing data on telemetry through European collaborative initiatives.
- RO5. Role and efficacy of recreational hunting and professional culling for WB population control.

  It requires a comparison of already-existing data on recreational hunting and professional culling and CT.
- RO6. Assessment of the efficacy of WB trapping methods including welfare implications and social acceptability.

  It is recommended to check with administrations involved in the management of local ASF WB outbreaks about data availability.
- RO7. Assess the efficacy of different fencing methods with GPS-collared WB, considering the effect on non-target species.

  CT and video recording alone are not an optimal approach to make high quality conclusions on the efficacy of fencing, but they are cheaper. It is recommended to check with administrations involved in the management of local ASF WB outbreaks about data availability. It is recommended to check already-existing data on telemetry through European collaborative initiatives.
- RO8. Use of trained dogs in ASF affected areas to detect WB carcasses.

  It is recommended to check with administrations involved in the management of local ASF WB outbreaks about data availability.

Social acceptance

- RO9. Social acceptance of WB management measures and animal welfare (qualitative and quantitative approaches).

  As mentioned above, there are two protocols to assess the acceptability of WB management options by different stakeholders (qualitatively and quantitatively, respectively) that should be developed consecutively to provide complete assessment of the issue, or even in parallel.

Assessment and management of risk factors

- RO10. The WB/pig interface: Developing biosecurity awareness and implementation among backyard pig farmers.

  The first protocol will produce a detailed guide on implementation of biosecurity among outdoor and backyard pig farmers, probably covering the vast majority of outdoor management contexts existing in Europe, while the second protocol would provide a tool to facilitate assessment. Therefore, the first protocol is the priority.

- RO11. Evaluation of the measures of passive surveillance and carcass removal on the spread of the disease.

  Two protocols based on data collected in selected management areas in Europe are proposed, and we recommend addressing both at once using the same study areas (this would reduce total costs). It is recommended to coordinate with administrations involved in the management of ASF outbreaks about data availability.

National and international decision-taking

- RO12. Assess how to improve coordinated national and international decision-taking process

  The proposed protocol is based on establishing organised and well-prepared working sessions by specific groups and putting together inputs following a pre-defined agenda, to ultimately develop a first draft for a WB Pan-European management plan. In this plan, not only are scientific and technical issues considered, but organisational and coordination aspects will be key. The format/s adopted (several can be combined) to develop discussions are flexible, and therefore, current SARS-CoV-2 pandemics should not impact its normal course.

(yellow)	Complilation of data
(light blue)	Telemetry
(orange)	Data on selected manag. areas
(light yellow)	Field rearch
(light green)	Social science (cases studies)
(grey)	Internationaldiscussion and manag. plan

Table 4. Summary of the proposed protocols by research objectives, main methodologies (see legend on top right corner), budget and time frame.

	1. Studies on basic aspects of WB population dynamics all over Europe	2. Factors determining presence of WB near to outdoor farms & extensive pig	3. Implementation of practical methods to estimate WB density	4. Effect of natural resources & artificial feeding on WB pop. dyn. & manag.	5. Role & efficacy of recreational hunting & professional culling for WB pop. control	6. Efficacy of WB trapping methods & welfare implications	7. Efficacy of fencing methods incl. non-target spp.	RO8. Use of dogs in ASF affected areas	RO9. Social acceptance of WB manag. & welfare	RO10. WB/pig interface:biosecurity backyard & outdoor pig	RO11. Eval. of passive surveillance & carcass removal on ASF spread	RO12. Improve coordinated national & internat. decision-making
Protocols based on complilation of data	Compilation & description of data on WB pop. dyn. & drivers, & data gaps identificaton, **<144k, 8 m**			Impact of natural resources, crops & artificial feeding on WB pop. dyn. (correlat.) & diet (barcoding),**160k, 1 yr**								
Protocol based on data on selected manag. areas of Europe				Evaluation of baiting strategies to improve collective hunting efficiency, **150k, 1yr**	Effectiveness of recreational & profes. hunters on selected areas, **144k, 1 yr**	Effectiv. trapping during culling activities on selected areas & other activities, **160k, 1 yr**					Carcass removal, **< 144k, 1 yr**	
Protocol based on field work (not telemetry)	Short-term field research to address gaps on pop. dyn., **150k, 1 yr**	Farm resources & WB interactions with pigs by CT, **160k, 15m**	WB density estimation & CT analytical tools, **200k** (apps 120k), **1 yr**					Field trials of WB carcass detection with dogs, **200k, 1 yr**		1. Develop WB risk mitigation protocol, **170k, 1 yr** 2. Develop an App, **144k, 1 yr**		
Protocol based on telemetry				Impact of natural resources, crops & artificial feeding on WB social & spatial behaviour,telemetry,**270K, 1 yr**			Efficacy of fencing methods by telemetry & CTs, **170K, 1 yr**					
Protocols based on social science case studies									1. Qualitative case study: short-term ethnography, **150k, 1 yr** 2. Quantitative case study: **150k, 1-1.5 yr**			
Protocols based on international discussion and plan development												European forum & draft a proposal: WB Pan-European manag. plan, **150k, 1 yr**

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Abbreviations

ASF	African swine fever
ASFV	African swine fever virus
CT	Camera trapping
CTs	Camera trapsDistance sampling
DS	European Food Safety Authority
EFSA	Hellenic Statistical Authority
ELSTAT	European Network of Wildlife
ENETWILD	European Parliamentary Research Service
EPRS	European Union
EU	Farm-specific action plan
FsAP	Member states
MS	Professional hunter
PH	Random encounter model
REM	Random encounter rate and staying time
REST	Research objective
RO	Wild boar
WB	

Annex A – Studies on basic aspects of wild boar population dynamics all over Europe

Table S1. Key review papers and reports describing the basic aspects of wild boar population dynamics all over Europe[(a)].

Type of parameter	Parameter	Spatial context	Observations	Ref
Population characteristic	Density (wb/km2)	West and Central Europe	Ranged from 1.2 to 90.9[(b)] based mostly on not reliable data.	Acevedo et al., 2007; Ruiz-Fons et al., 2008
Population characteristic	(Hunting) Growth rate	Europe	Growth rate varied from 0.9 to 1.46, based on hunting bag statistics	Massei et al., 2015
Population characteristic	(Hunting) Growth rate	West Europe (Spain)	Growth rate varied from 2.1 to 40.3, based on hunting bag statistics	Quirós-Fernández et al., 2017
Population characteristic	Growth rate	West and Central Europe, and Asia	Based on projection matrix models, growth rate varied from 0.85 to 1.63.	Bieber and Ruf, 2005
Mortality	By harvest	Central Europe	Based on hunted tracked WB, average mortality rate was 0.53.	Keuling et al., 2013
Mortality	By harvest and disease	West Europe (Spain)	Average mortality rate was 0.53 by harvest; and 0.30 by disease (tuberculosis).	Barasona et al. 2016
Reproductive	Litter size	Europe	Mean ranged from 3.58 to 6.5.	Bieber and Ruf, 2005
Reproductive	Litter size	West and Central Europe	Mean ranged from 2.2 to 4.	Rosell et al., 2001
Reproductive	Litter size	Europe	Mean ranged from 3.6 to 7.6	Fonseca et al., 2011
Reproductive	Litter size	West and Central Europe	Mean ranged from 3.1 to 6.9.	Bywater et al., 2010
Spatial behaviour	-	Global	Research tendencies and gaps, no values provided.	Morelle et al., 2014; Morelle and Lejeune, 2015

(a): Extensive literature is also available for feral pig population dynamics, especially in the USA, but of very low application to our cases.

(b): This value is reached under artificial conditions, such as fenced game estates with artificial feeding.

Table S2. The main drivers identified on publications that could influence significantly on WB population dynamics.

Type of driver	Driver	Observations	Ref
Interspecific interactions	Predation	Lack of top-down control can favour population growth.	Bassi et al., 2020; Jędrzejewski et al., 1992; Segura et al., 2014
	Diseases & parasites	Effects on survival, reproductive or mortality rates.	Barasona et al., 2016; Ruiz-Fons et al., 2008
Landscape	Land use change	Easier food access or the increment of available and favourable habitat could contribute on WB population growth.	Acevedo et al., 2011; Hearn et al., 2014; Kodera et al., 2010
	Urban expansion		
	Rural abandonment		
Climatic	Global warming	Favourable climatic conditions increasing winter survival and food availability throughout the year.	Bieber and Ruf, 2005; Melis et al., 2006; Vetter et al., 2020; Vetter et al., 2015
	Drought episodes	Effect on reproductive performance.	Fernández-Llario and Carranza, 2000
Food availability	Productivity	Related with climatic conditions.	Barbosa et al., 2020; Frauendorf et al., 2016
	Supplementary feeding	Associated with higher recruitment rate and litter size.	Massei et al., 2015
Management	Hunting	Hunting induce mortality and affects WB dynamic. A decrease in the number of hunters, difficult population management.	Cromsigt et al., 2013; Holland et al., 2009; Merli et al., 2017
	Conservation or agroforestry policy	Differential effect on population dynamic among different applied policies.	Vicente et al., 2005

Table S3. Parameters describing the basic aspects of WB population dynamics relevant to understanding disease dynamics and improve science-based ASF management. Colours of "trait" column indicate the priority of each parameter to be determined (orange: high; yellow: medium; green: low).

Population parameters	Trait	Sex by age class	Temporal	Spatial resolution	Units	Why is important?	Ref
Population characteristics	Local density		Optimally pre-harvest season (for standardization)	Management or ecological unit	ind/km^2 or social group/km^2	-Disease transmission is a density-dependent process. Population and individual traits are density dependent. Management is based on numbers (abundance indexes are not sufficient or comparable) -It could further elucidate complex species-habitat-management relationships in spatial distribution models	Kramer-Schadt et al., 2009
	Absolute abundance				Nº individuals		Yu et al., 2020
	Carrying capacity		Lowest over the year	Ecological unit	maximum population size or density (*K*)	-Variable due to habitat perturbations and environmental factors (e.g., resource availability and climate). Theoretically, maximum productivity (i.e., population growth rate) is achieved when the population is approx. 50% of the K (basic logistic growth models). Useful for modelling scenarios of potential population growth and consequences for disease spread, maintenance and control.	Groot Bruinderink et al., 1994
	Sex ratio	juvenile (< 1 y) yearling (1-2 y) adult (> 2 y)	Optimally pre-harvest season (for standardization)	Management or ecological unit	ff:mm	-Essential to rebuild population structure and model population dynamics -Influence on the spatial behaviour and interactions among social units (groups) and modulate the spread of infectious diseases -Each sex by age class has distinct properties in terms of their demographic and infection dynamics -Key parameters to define population control strategy -These parameters are among those presenting larger variation over geographical distribution and management	Hema et al., 2020; Mortensen et al., 2016
	Group size	male	average annual and by month or season		mean number of individuals, assumed 1		Loehle, 1995; Pepin et al., 2020; Podgórski et al., 2018
		maternal groups			mean number of individuals		
	Age structure	By sex	Pre-harvest season		%		Hoy et al., 2020
	Population growth rate		yearly		% or increase rate (r)		Fonseca et al., 2011

	Recruitment rate			coefficient of young/adult		DeCesare et al., 2012
Population characteristics: mortality	Natural: predation/ disease	Sex by age. Especially on piglets (<3 months old)	yearly	% mortality (1/survival)		Bassi et al., 2020; Keuling et al., 2013; Lange et al., 2012; Merli et al., 2017; Tanner et al., 2019b
	By harvest					
	Other: e.g., road kills					
Reproduction (productivity)	Litter size	By age*	yearly	Number of offspring born by female age class		Fernández-Llario & Mateos-Quesada, 1998; Frauendorf et al., 2016
	Pregnant females		yearly and monthly	% of females becoming pregnant by age class		Fernández-Llario & Mateos-Quesada, 2005; Lombardini et al., 2014
Spatial behaviour	Proportion of dispersants	Sex by age	yearly	%	-Related with species geographical and disease dispersion. -Spatial behaviour determines interactions (within and among groups) -Spatial behaviour is relevant to implement effective management strategies. - Influenced by land uses and human activities among other factors, including population control and response to ASF	Casas-Díaz et al., 2013; Truvé & Lemel, 2003; Truvé et al., 2004
	Dispersal period	Sex by age		month/season		
	Dispersal distance			km		
	Home range (50 & 95%K)	Sex by age (males, maternal groups)	seasonal	km^2		Bisi et al., 2018; Keuling et al., 2008

Annex B – Implementation of practical methods to estimate wild boar density

Instructions for the placement of camera traps and calculation of density of WB without individual recognition

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

• The work should be developed during autumn/early winter, with the CTs placed a minimum of 60 days.

• They will be placed (registering the geographical coordinates) following a regular uniform distribution as a grid with a minimum of 45 camera placements. The separation between CTs will be approx. 1.5 km, but there is no problem if it is longer or shorter for a representative sampling design in large territories or to get a relevant number of sampling points in small ones. The exact location can be within a diameter of less than 100m around the points of the grid. If the number of CTs available is not enough to sample the 45 placements at the same time, the CTs should be moved during the experiment to cover the minimum of 45 sampling points. For instance, 15 CTs moved three times (every 3 weeks), which fit a study area of approximately 2500-3000 has. However, in case the study area is bigger, the distances between CTs can be larger than 1.5 km, and if possible, it is recommended placing more camera sites.

• The grid must cover at least one patch beaten during the hunting season, if possible, more; or several grids for several patches.

• Place stakes in 2.5m intervals (Figure B1). Connecting the stakes with signalling tape helps to better visualize distances (Figure B1.C). Finally, ensure that a photograph is taken from the CTs where these stakes are evident. Put natural marks (stones, branches…) before remove the stakes for later identification of the path of the animals photographed (Figure B1.D)

• The CTs will be placed on poles or vegetation 40cm above the ground.

• The CTs are configured with operation of 24 hours per day and to take up to at least three consecutive images (the maximum number possible), with the minimum waiting time (0 sec. if possible) between activations. Use medium sensitivity.

• The flash intensity should be set at medium (if possible) to avoid "overexposed photos".

• Check that the date and time are correctly set, and that they are printed automatically on each image.

• The CTs should be reviewed at least in the half of the study period (ideally once a month) to check its functioning and placement. Normally it will not be necessary to change the batteries and the memory cards, since the CTs are placed at random points and high wildlife activity is not expected.

• Choose a field of vision of the CTs that is cleared of vegetation (it is not necessary to be totally clean, but that allows the detection of any WB that passes within the first 5 m), being better a north orientation.

• A form must be filled in, collecting the information of each CT during its placement (see below). All the information that is subsequently extracted must keep the traceability of the CTs (mark the source camera of each memory card extracted and keep this nomenclature in the folders that are created on the computer to archive the images).

• This protocol is accompanied by basic instructions to place at least one additional CTs per study area in order to calculate more precisely the average group size of the population.

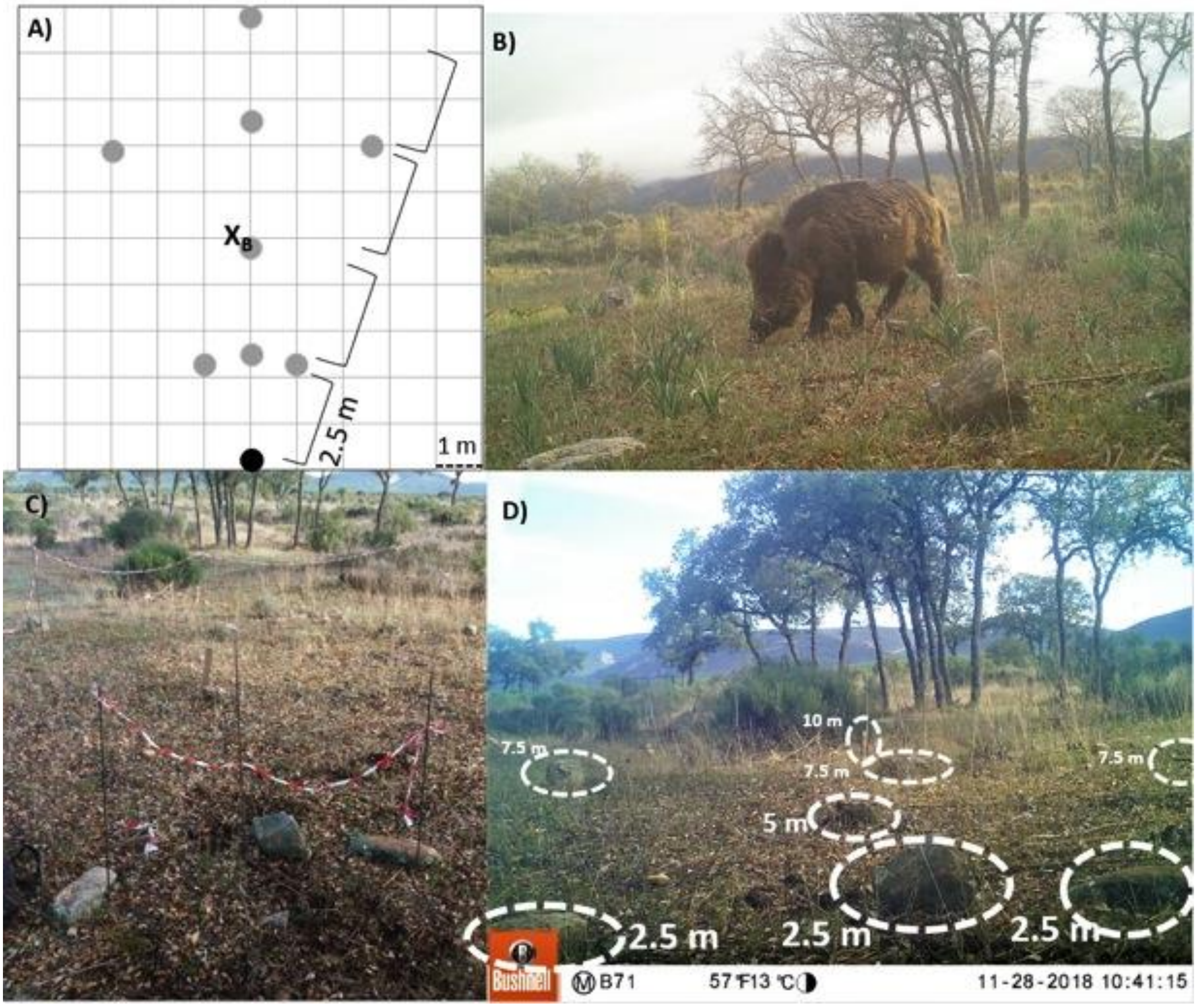

Figure B1. A) Scheme of the stick-structure (grey dots) used to reference the animal captured by the camera-trap (black dot). XB indicates the position of the WB captured in the image B. B) WB photo-captured. C) Photo of the structure installed in one photo-trapping sampling point. The camera should be oriented so that the well-centred stakes are displayed. D) Natural marks (stones) used as references after removing stakes.

Required material

• CTs adequately configured (see above), with proven batteries (alkaline) and compatible memory card. Check that the cards save the photos well, since sometimes they are not compatible with the camera model

• Memory card of 8 GB minimum size, recommended 16 GB if the camera supports it

• 50 cm stakes (or poles) and hammer to place them. 8 of them are required for the initial photograph of each study point. 2 of them will stay (5 and 10 m)

- Signalling tape
- GPS for recording geographical coordinates (WGS 84)
- Single-use camps are very practical for fixing the cameras
- Hoe for vegetation cleaning, only the strictly necessary within the first 5 m

Nº of the study point	Nº CT and memory card	Coordinate X [WGS 84]	Coordinate Y [WGS 84]	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	/								

Use as many forms as necessary

Wild boar group size estimation using camera-traps

This document describes basic instructions to estimate WB group size from camera-trapping.

Group size is a key parameter for WB monitoring and management.

- One camera-trap in the study where density is being calculated should be placed in a tree at as higher as possible in a range of 2-2.5 meters above the ground for 2 months. We recommend moving the location twice or 3 times during the study period.
- The camera-trap should be tilted downwards pointing to a distance between 5-8 meters from the camera.
- Lures or attractants (corn, fruit…) should be placed in the centre of the field of view of the camera. Lure should be placed under big stones to increase the amount of time that animals will spend in front of the camera. It is not recommended to use high amount of lure to avoid that two groups visit the point as the same time. For instance, when using corn, 1-1.5kg will be enough.
- The experiment should be checked once (if possible, twice or three) per week to bait the sampling point, and to check camera-trap memory and battery.
- The cameras will be configured to be operative 24h per day, with low or medium sensitivity, and to record 1-2 minutes videos per activation. The time lapse between activation should be as minimum as possible (e.g., 1 second).
- Camera-trap should be placed in a point with high probability to photo-captured WB.
- Camera-trap placement should be moved to other location every two-three weeks. The location can be any point inside of the sampling area.

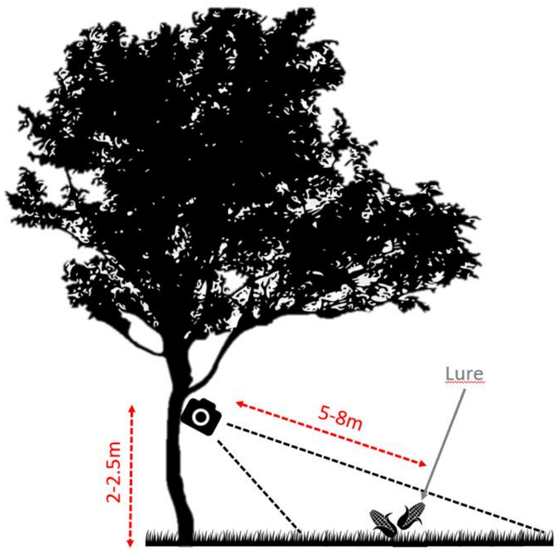

Figure B2. Scheme of the sampling point.

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 C – Assess the effect of natural resources and artificial feeding on wild boar population dynamics and managing

Instructions for the placement of camera traps and calculation of density of WB without individual recognition

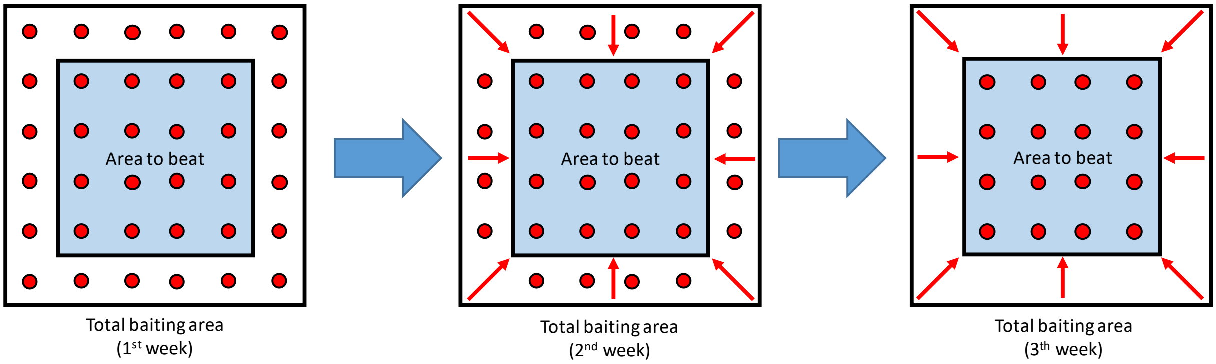

Figure 1. Schematic diagram of surface to bait. Red points represent baiting points regularly distributed in all the study area (baiting area; left picture). During the third week, baiting points are present only in the area to beat (where hunting is going to be developed). The red arrows (second and third weeks) represent artificial trials created with bait and/or attractant to favour WB movements present out of the area to beat towards this one.