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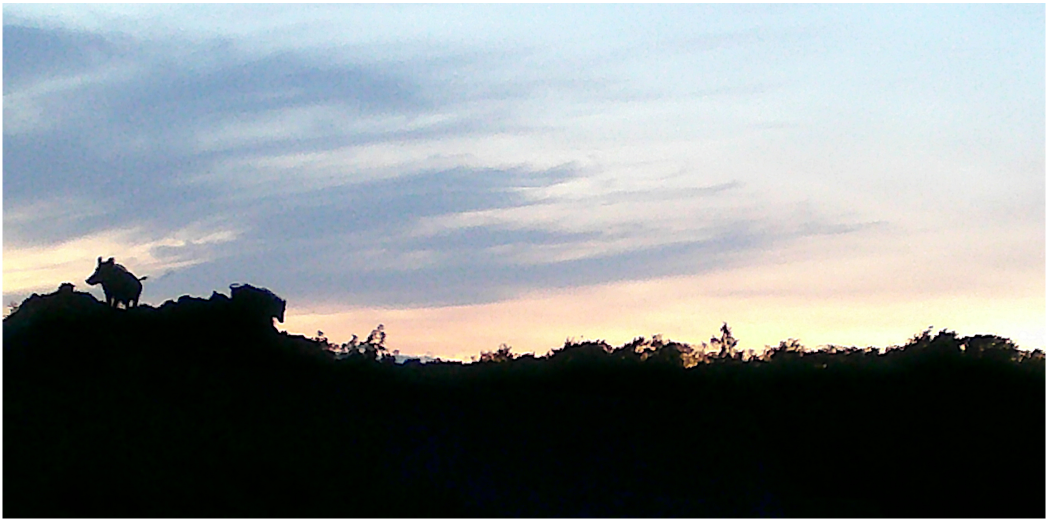
Wild boar at the farm gate

Infectious diseases and epidemiology at the wildlife-livestock interface

Linda Ernholm



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Cover: Wild boars at sunset (Image by camera trap, Linda Ernholm, 2023)

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Abstract

The wildlife-livestock interface is a complex system shaped by various factors including hosts, pathogens and possible transmission routes of infections. The global spread of African swine fever (ASF) and the detection of *Salmonella* Choleraesuis in wild boar highlight the need to understand potential contacts between wild boar and domestic pigs in Sweden. ASF, a viral disease affecting pigs and wild boars, has a case fatality rate of up to 100% and can remain infectious in carcasses for extended periods. *S*. Choleraesuis may cause systemic disease with pneumonia, sepsis and mortality in both pigs and wild boar alike. Although these two diseases are caused by distinctly different pathogens, they share certain epidemiological features which can be used when conducting surveillance.

A survey of Swedish pig producers found that 80% had noted wild boar or wild boar activity near their farms within the past year, with one-third reported more frequent encounters. Almost two-thirds reported crop damage from wild boars. Perimeter fences were rare, and common wild boar deterrents included hunting and strategic baiting. Hunters expressed willingness to participate in ASF surveillance and control, emphasizing the need for practical reporting systems. Baiting was common, with maize and cereals as typical feeds, but the use of imported maize had decreased. National surveillance of *Salmonella* in wild boar was initiated, as *S*. Choleraesuis is seen in dense populations in the eastern and southern parts of Sweden. In summary, the proximity of wild boar to pig farms poses a risk of disease transmission, necessitating surveillance and biosecurity measures. Collaboration with hunters and an understanding of local dynamics contribute to preventing the spread of infections.

Keywords: (wildlife-livestock interface, disease transmission, epidemiology, infectious diseases, wild boar, *Sus scrofa*, pigs, *Sus scrofa domesticus*)

Vildsvin in på gårdsknuten. Smittsamma sjukdomar och epidemiologi i gränslandet mellan vilda och tama djur.

Sammanfattning

Gränslandet mellan vilda och tama djur utgör ett komplext system som formas av olika faktorer, inklusive värddjur, patogener och möjliga smittvägar. Den globala spridningen av afrikansk svinpest (ASF) och upptäckten av *Salmonella* Choleraesuis hos vildsvin belyser behovet av att förstå potentiella kontakter mellan vildsvin och tamgrisar i Sverige. ASF är en virussjukdom som drabbar grisar och vildsvin. Den har en dödlighet på upp till 100 % och kan förbli smittsam i blod och kadaver under längre perioder. *S.* Choleraesuis kan orsaka systemisk sjukdom med lunginflammation, sepsis och dödlighet hos både grisar och vildsvin. Även om dessa två sjukdomar orsakas av olika patogener, delar de vissa epidemiologiska drag som kan användas vid övervakning. En undersökning bland svenska grisproducenter visade att 80 % hade sett vildsvin nära sina gårdar det senaste året, varav en tredjedel uppgav mer frekvent närvaro. Nästan två tredjedelar rapporterade skador i växande gröda från vildsvin. Stängsel som omgärdar grisgårdar var sällsynta, och vanliga metoder för att hålla vildsvin på avstånd inkluderade jakt och strategisk åtling. I fokusgruppsintervjuer uttryckte jägare vilja att delta i ASF-övervakning och kontroll, men betonade behovet av praktiska rapporteringssystem och ersättningsmöjligheter vid omfattande insatser. Åteljakt var vanlig, med majs och spannmål som typiskt bete, men användningen av importerad majs hade minskat. En nationell övervakning av *Salmonella* hos vildsvin inleddes, där förekomst av *S.* Choleraesuis ses i täta populationer i östra och södra Sverige.

Sammanfattningsvis utgör vildsvinens närhet till grisgårdar en risk för sjukdomsspridning, vilket kräver övervakning och biosäkerhetsåtgärder. Samarbete med jägare och förståelse av lokala dynamiker bidrar till att förhindra spridningen av infektioner.

Keywords: (wildlife-livestock interface, disease transmission, epidemiology, infectious diseases, wild boar, *Sus scrofa*, pigs, *Sus scrofa domesticus*)

Preface

The work presented in this thesis was conducted from 2019 to 2024, a period characterized by significant global disease events including the Covid-19 pandemic, highly pathogenic avian influenza in wild birds, and the extensive global spread of African swine fever in wild boar. In Sweden, the detection of *Salmonella* Choleraesuis and the subsequent introduction of African swine fever in wild boar underscored the critical importance of wildlife surveillance for early detection, and the enhanced local wildlife disease knowledge needed to support pig production. Although this project focused on the potential for disease transmission between wild boar and domestic pigs, the wildlife-livestock interface is heavily influenced by human involvement. The wildlife-livestock interface is an integral key component of the One Health concept, which emphasizes the interconnectedness of human, animal, and environmental health. Understanding and managing this interface is essential for mitigating disease risks for both wildlife and livestock populations.

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I. Linda Ernholm, Karl Ståhl, Aleksija Neimanis, Stefan Widgren, Susanna Sternberg-Lewerin (2023). Understanding the interface between European wild boar (*Sus scrofa*) and domestic pigs (*Sus scrofa domesticus*) in Sweden through a questionnaire study. Acta Vet Scand., 65(1):40. Doi: 10.1186/s13028-023-00705-x

II. Erika Chenais, Linda Ernholm, Annie Frisk Brunzell, Karl Mård, Lotta Svensson, Johanna F Lindahl, Susanna Sternberg-Lewerin (2024). Perceptions and practices of Swedish wild boar hunters in relation to African swine fever before the first outbreak in Sweden BMC Veterinary Research, 20(1):320. Doi: 10.1186/s12917-024-04183-9

III. Linda Ernholm, Susanna Sternberg-Lewerin, Erik Ågren, Karl Ståhl, Cecilia Hultén (2022). First detection of *Salmonella enterica* Serovar Choleraesuis in free ranging European wild boar in Sweden. Pathogens, 11(7):723, Doi: 10.3390/pathogens11070723

IV. Linda Ernholm, Karl Ståhl, Aleksija Neimanis, Stefan Widgren, Susanna Sternberg-Lewerin. From dusk till dawn, camera trapping of wild boar at Swedish pig producing holdings. (manuscript)

The contribution of Linda Ernholm to the papers included in this thesis was as follows:

I. Questionnaire design, distribution, data collection and analysis. Initial drafting, writing, creation of figures and reviewing.

II. Co-supervision of focus group interviews, analysis of questionnaire data, creation of related figures and maps. Writing and reviewing.

III. Study design, coordination, initial drafting, writing, creation of figures and reviewing.

IV. Study design, data collection with camera traps, image classification and analysis. Initial draft of manuscript, including figures and maps.

Abbreviations

ASFv	African swine fever virus
EFSA	European Food Safety Authority
EPA	Swedish Environmental Protection Agency
FGDs	Focus group discussions
GDH	Farm and Animal Health (Gård och Djurhälsan)
SBoA	Swedish Board of Agriculture
SJF	Swedish Association for Hunting and Wildlife Management
SVA	Swedish Veterinary Agency

1. Introduction

In recent years, the wildlife-livestock interface has gained increased attention due to concurrent events of disease transmission between wildlife and domestic animals. In a European perspective, highly pathogenic avian influenza virus (HPAIv) in wild birds and African swine fever virus (ASFv) in wild suids have caused significant mortality in affected wildlife species and has led to numerous spillover events, resulting in substantial consequences for livestock health and production (Verhagen et al., 2021, Sauter-Louis et al., 2021). The large losses of livestock that may occur following a disease transmission, due to disease mortality and disease management strategies, further exacerbate the issue.

In a Swedish context, the introduction and detection of *Salmonella enterica* subsp. *enterica*, serovar Choleraesuis (*S.* Choleraesuis) and subsequent focal introduction of African swine fever virus (ASFv) to wild boar significantly altered the picture, as wild boar in Sweden had not previously served as a significant source of notifiable diseases (Ernholm et al., 2022, Chenais et al., 2024). Although the two diseases elicit different disease management responses, these events highlight the importance of systematic wildlife disease surveillance and monitoring. Moreover, they imply the necessity of a deeper understanding of the wildlife-livestock interface to mitigate and prevent disease spillover and spillback between wild and domestic populations. Detailed studies on the wildlife-livestock interface, focused on wild boar and commercial pig production, has not previously been conducted in Sweden. In the face of the new challenges, research in this field is increasingly urgent emphasizing the importance and timeliness of the studies done in this project.

1.1 Wildlife-livestock interface

The growing interaction between wildlife and livestock is raising global concerns and heightened interest in studying the dynamics at the wildlife-livestock interface. (Wiethoelter et al., 2015). Urbanization, habitat encroachment, and intensified farming practices are expanding these interfaces, potentially facilitating the emergence and spread of infectious diseases (Hassell et al., 2017). The increasing populations and geographic range of wild boar, which in Sweden spatially overlap with areas of pig production, will inevitably lead to risks of direct or indirect contact between wild boar and domestic pigs. This has been evidenced by the transmission of pathogens between these two groups (Stenberg et al., 2021, Fjelkner et al., 2023)

To mitigate the risk of spillover events, it is crucial to conduct surveillance to identify the diseases present in both wild and domestic animal populations and to understand the potential for disease transmission between wild boar and domestic pigs. The risk of disease transmission is bi-directional, and avoiding spillover of diseases from pigs or other livestock into wild boar or other wildlife populations is just as important.

In the Swedish context, the presence and introduction of disease agents of high importance for pig production in wild boar represents a new and concerning situation. A thorough understanding of this interface is needed for informed and relevant policy making, creation of biosecurity strategies for contact mitigation and for effective disease prevention and control.

1.2 Wild boar in Sweden

The wild boar population in Sweden originates from individuals that escaped from game enclosures in the 1970s (EPA, 2020). In 1987, a decision was made to officially recognize wild boar as part of the Swedish fauna (1986/87:JoU 15). Like many European countries, Sweden has experienced a substantial increase in wild boar abundance over the last few decades (Massei et al., 2015). However, there has been a marked decrease in the number of wild boar shot in the last two reported years, 2021 and 2022 (Fig. 1), and this, along with reports from hunters, indicates a reduction of wild boar populations. Proposed explanations include a combination of effective hunting, facilitated by the recently allowed use of night-vision equipment (Bergqvist et al., 2024) and cold and wet springs reducing piglet survival

(Svensk Jakt, 2024). Locally, the presence of *S.* Choleraesuis is likely to have affected the population renewal negatively (Perez et al., 1999), but does not explain the national decrease. The numbers of traffic accidents with wild boar were comparably reduced during the period but have shown a slight increase since 2021 (Fig. 1).

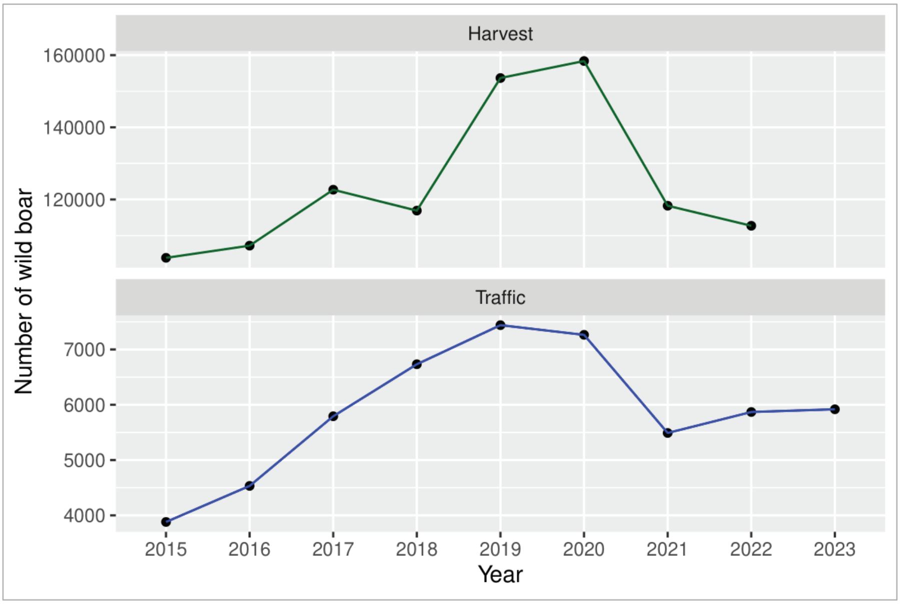

Figure 1. Wild boar shot at harvest 2015-2022, and traffic accidents involving wild boar 2015-2023 (SJF, 2024, Nat. viltolycksrådet, 2024).

In 2020, the Swedish national wild boar population was estimated to at least 300,000 animals, and they are established in all counties in the south of the country, except on the island of Gotland (EPA, 2020). The wild boar abundance is unevenly distributed with higher densities in the east and southeast of the country.

1.2.1 Wildlife surveillance

The national wildlife disease surveillance program in Sweden is primarily conducted through pathology and additional testing at the Swedish Veterinary Authority (SVA). This program is funded through a combination of annual state hunting permit fees and governmental funding. Its primary objective is to monitor and assess the wildlife disease situation in Sweden, facilitating the diagnosis and understanding of both current and emerging diseases affecting the wildlife population (SVA, 2024b). Reports of diseased or dead wildlife submitted by the general public, local authorities and hunters, are paramount to the wildlife surveillance program. Since 2017, a web-based submission form is available at rapporteravilt.sva.se for ease of reporting (SVA, 2024a).

1.3 Swedish pig production

Swedish pig production is predominantly characterized by commercial-scale, indoor operations. Since 2000, there has been a notable trend where the number of pig farms has decreased, but the remaining farms have increased their number of pigs, approximately tripling in scale in this period (Sv. grisföretagare, 2024). This consolidation reflects a shift towards fewer but larger pig farming operations. In 2023, 1,160 pig-producing enterprises were registered with the Swedish Board of Agriculture (SBoA), and the total number of pigs slaughtered in Sweden reached 2.5 million. Outdoor access is mainly provided in organic production, which in 2023 accounted for 1.9% of the pigs slaughtered, marking a decrease from the previous year, when the proportion was 2.6% (Swedish Board of Agriculture, 2024b) The majority of the pig production in Sweden occurs in the south or central parts of the country (Swedish Board of Agriculture, 2024a). The welfare legislation for pigs (SJVFS 2019:20) requires materials such as straw, peat or wood shavings to be provided for enrichment for all pigs. Non-lactating sows are group housed, often on deep straw bedding. These housing setups sometimes include semipermeable walls or sliding wall sections that can be opened to the outside, though the pigs remain behind a barrier inside. Perimeter fences are currently rare on Swedish pig farms (Ernholm et al., 2023). However, if pigs are allowed outdoor access, they must be fenced in.

The system of sow sharing between select piglet producers (so-called sow pools) creates a geographically spread-out, multi-site production network. Although this system is not adopted by all, it presents an interesting entity for biosecurity.

Voluntary animal health programs are delivered by the three animal health organizations 'Gård och Djurhälsan' (Farm and Animal Health), 'Lundens Djurhälsa AB' (Lunden's Animal Healthcare), and

‘Besättningsservice, Gris’ (Herd service, pig) in the district veterinary organization. A vast majority (>90%) of all commercial pig producers are members of either of these organizations.

1.3.1 Biosecurity program

Historically, biosecurity programs have focused on the transmission of infectious agents between and within pig farms, emphasizing livestock trade, quarantines, visitors, and equipment (Alarcon et al., 2021). In Sweden, the voluntary biosecurity program for pigs, ‘Smittsäkrad besättning, gris’ (Infection-secure herd, pigs), was established in 2016 through a collaboration between authorities, animal health organizations, and the Swedish pig producers’ organisation. Initially, this program concentrated on safe animal trade and zoonotic diseases, primarily *Salmonella* (GDH, 2024). However, the situation with ASFv (African Swine Fever virus) in Europe has necessitated strengthened biosecurity protocols. The need to address the potential risk of wild boar as a potential source of the infection led to the creation of an additional, recently launched, ‘ASF module’. This module specifically targets the mitigation of wild boar contacts. Although this initiative was prompted by ASFv, the emergence of *S*. Choleraesuis in wild boar further underscored the importance of including the wildlife-livestock interface in biosecurity measures

The ASF module incorporates measures from the Animal Health Regulation (EU) 2016/429 and its implementing regulation (EU) 2023/594. These measures ensure that affiliated pig producers have an up-to-date, approved biosecurity plan and meet additional requirements. Affiliates must have a perimeter fence, a framework for recurrent biosecurity training for staff, and maintain necessary documentation, such as records of visits. These requirements are prerequisites for obtaining transport permits from the competent authorities. Having these measures in place will help reduce disruptions to production in case of zoning.

Preventing disease spillover from livestock to wildlife is equally important, as it may have devastating consequences for the receiving wildlife population and adds the risk of future spillback.

1.4 Infectious pig diseases

Domestic pigs (*Sus scrofa domesticus*) and European wild boar (*Sus scrofa*) belong to the same species, can interbreed, and share infectious diseases.

Sweden is officially free from infectious diseases of pigs listed within the European Animal Health Law, in accordance with (EU) 2021/620. These diseases include Classical swine fever (CSF), brucellosis (*Brucella abortus, B. melitensis,* B. *suis*), Aujeszky's disease (AD), and animal tuberculosis caused by infection with the *Mycobacterium tuberculosis complex* (MTBc).

Apart from one outbreak of Porcine Reproductive and Respiratory Syndrome (PRRS) in 2007, the disease has been, and is, absent from Sweden (Carlsson et al., 2009, Frossling et al., 2009). African swine fever has never been detected in domestic pigs.

Trade involving live pigs to Sweden is limited, and occurs mainly from Norway or Denmark (SVA, 2024b) and the absence of a shared land border with countries of a differing disease status prevents the free movement of wild boar, thereby reducing the risk of disease introduction. Nevertheless, in 2023, African Swine Fever (ASF) was introduced into Swedish wild boar, most likely via human mediated long-distance virus translocation, resulting in a localized outbreak among wild boar 200 km northwest of Stockholm (Chenais et al., 2024). The 5 pig holdings in the area, comprising a total of 59 pigs, were pre-emptively culled and no spillover to domestic pigs was seen (Chenais et al., 2024).

Historically, Swedish animal disease eradication programmes have focused on controlling and eradicating one disease at a time, by test-and slaughter and strict between-farm and within-farm biosecurity (Cerenius, 2009). Wildlife reservoirs were not a major concern in these eradication efforts.

1.4.1 African swine fever

African swine fever (ASF) is a contagious viral disease causing haemorrhagic fever in pigs and wild boar, typically with high case fatality reaching up to 100% (Dixon et al., 2019). The disease does not infect humans, but anthropological factors are an integral part of the epidemiology of the disease. The current global epidemic of ASF is caused by ASFv of genotype II. The virus was introduced to Georgia in 2007 as catering waste including infected pig meat products originating from Africa reached local pigs in the port town of Poti (Rowlands et al., 2008). With the trade and transport of infected smallholder/backyard pigs, ASF spread quickly throughout the region and to the adjacent countries Armenia, Azerbaijan and the Russian Federation (Beltran-Alcrudo et al., 2018). Due to continued spread, including in wild boar, the first detection of the disease in the EU was made in 2014, in wild boar found dead in Poland and Lithuania (Gallardo et al., 2014).

In northern and central Europe, the ongoing spread of ASF has mainly affected wild boar, with occasional spillover to domestic pigs (Chenais et al., 2019), whereas in the south and south-eastern Europe, the epidemic has mainly affected domestic pigs in backyard settings, with spillover to wild boar (EFSA, 2023).

Although ASF spreads naturally at a rate of 1-3 km per month in wild boar populations (Podgorski and Smietanka, 2018), events of long-distance virus translocations have caused the disease to suddenly appear in previously unaffected countries or areas. Examples include Belgium (Linden et al., 2019), Czech Republic (EFSA, 2018) and Italy (Pavone et al., 2023). This underscores the need for preparedness and knowledge on transmission possibilities at the wildlife-livestock interface, in case of unexpected occurrences. An incursion of ASF into domestic pig populations has severe consequences, not only for pig producers and affected holdings but also for the entire production chain, including significant losses in international trade (Niemi, 2020).

1.4.2 *Salmonella* Choleraesuis

S. Choleraesuis is a host adapted *Salmonella* serovar which causes clinical symptoms including severe systemic disease and mortality in pigs (Uzzau et al., 2000). It used to be the most commonly detected *Salmonella* serovar in pigs worldwide but is now rarely seen in domestic pigs in Europe (EFSA, 2008). However, it has been increasingly detected in European wild boar populations (Gil Molino et al., 2019, Methner et al., 2018).

In 2020, *S.* Choleraesuis was detected in a Swedish pig-producing holding in the yearly surveillance (Fjelkner et al., 2023). This occurrence was later understood to be a spillover event, as this *Salmonella* serovar had not been detected in Swedish pigs for 40 years, but was, following this event, detected in the wild boar population in two regions in Sweden (Ernholm et al., 2022).

The Swedish national control program for *Salmonella* has been in place for almost 70 years and covers the entire chain from feed to food, with regular sampling and control interventions whenever *Salmonella* is detected. The objective of the program is to keep animal-sourced food free from *Salmonella*, and the low prevalence of human cases linked to domestic food sources confirms the success of the program (SVA, 2023).

The detection of *S.* Choleraesuis in wild boar in Sweden presented a novel situation where a disease relevant to pig production has emerged in the wild boar population The presence of a wildlife reservoir for *S.* Cholerasuis in some areas presents a threat to both the health and salmonella-free status of Swedish pig production and highlights the critical need for a more comprehensive understanding of the wild boar-pig interface in Sweden.

1.4.3 Shared epidemiology

Despite being caused by distinctly different pathogens, ASF and salmonellosis caused by *S.* Choleraesuis share certain epidemiological features. Both diseases can be transmitted through direct contact. However, infective materials such as remains of dead wild boar in the case of ASF (Chenais et al., 2018), or faecal matter from wild boar shedding *S.* Choleraesuis can also serve as sources of infection between wild boar groups (Gray and Fedorka-Cray, 2001). Both diseases cause mortality in infected animals, albeit to different extents, and the sampling of wild boar found dead can be used to facilitate early detection and geographical spread. Dense populations of wild boar facilitate the circulation of these pathogens, increasing the environmental load and thereby contributing to the risk of spillover to domestic pigs through indirect pathways.

2. Aims

The overall aim of this project was to enhance the understanding of the wildlife-livestock interface between wild boar and domestic pigs in Sweden. Specific objectives were:

- To increase the knowledge on the extent of wild boar presence in the proximity of commercial pig farms.
- To describe the emergence and surveillance of *S*. Choleraesuis in Swedish wild boar
- To understand the role and motivation of hunters in wildlife disease surveillance, management and possible risk of disease introduction to wild boar.
- To explore the use of camera traps in an on-farm setting to assess wild boar presence at pig farms.

3. Comments on materials and methods

Materials and methods for each study (I-IV) are described in detail in the papers included at the end of this thesis. To cover the complexity of potential disease transmission at the wildlife-livestock interface, both qualitative and quantitative methods were used. Questionnaire surveys were used to interview pig producers about wild boar presence around their farm (study I), and hunters on their practices regarding hunting travels and use of baiting (study II). Hunters were also engaged in focus group discussions (FGDs) to capture hunter attitudes and practices in relation to wild boar surveillance, disease management and perceived risks of introduction of ASF to wild boar (study II). Further, targeted wildlife disease surveillance of *Salmonella* Choleraesuis and other *Salmonella spp*. was done by sampling of wild boar found dead, or at harvest (study III). Finally, the use of camera trapping to investigate wildlife presence at selected pig farms was assessed (study IV).

3.1 Study populations

For study I, the target population was commercial pig producers in Sweden. In study II the target population was hunters in Sweden, with experience of hunting of wild boar. The target population for study III was free-living wild boar in Sweden. The pig farms in study IV constituted a selected non-random sample sourced from two counties, Skåne and Södermanland, where the wild boar population at the time of study was notably high.

3.2 Questionnaires

Questionnaires are seductively simple as an idea, but rather complex in reality. The questionnaire to pig farmers (included in paper I) had 19 questions focused on wild boar activity and farm characteristics such as county, farm size, type of production, and whether the pigs had outdoor access or not. Given that Swedish pig producers are well-surveyed, the questionnaire was deliberately kept short and focused on the topic of wild boar to minimize respondent effort and reduce the likelihood of non-responses due to perceived complexity. The questionnaire was distributed by email through pig health organizations, which at the time of the study encompassed 90-95% of all commercial pig producers in Sweden.

The questionnaire to hunters (included in paper II) had 28 questions, mainly on hunting habits, use of baiting, and hunting travels. The results from the hunter questionnaire were partly analysed in conjunction with those from the FGDs. The link to the online questionnaire was distributed by email through Swedish Association for Hunting and Wildlife Management (SJF). Most Swedish hunters are members of either of the two hunters' organizations, SJF being the largest with >150,000 members and the Hunters' National Association having about 40,000 members. Distribution through a hunter organization can be discussed as a source of bias, but as this organization covers most of the Swedish hunters, it was considered to be representative.

Both questionnaires were anonymous and neither required an answer to questions in order to progress through the form. This was done with the intention of avoiding people abandoning the questionnaire all together, if coming across a question they did not want to, or could not, answer. As leaving questions unanswered was allowed, a 'skip logic' structure, where an answer would direct what the next questions would be, could not be used. This may have caused the respondents having to answer "not applicable" to a few questions, but as both questionnaires were rather short and focused, this was concluded to be an acceptable solution.

The questionnaire used to survey pig producers had a response rate of 21% which is well on par with what can be expected when surveying this group, and all regions in the country were sufficiently represented in relation to their number of pig holdings. The questionnaire for hunters received 3244 answers. Considering that the questionnaire to hunters was distributed to all members of the SJF with an email address, with no possibility of selection for those hunting wild boar, calculating a response rate would be misleading.

3.3 Focus group discussions

As hunters' engagement is paramount, both in surveillance and disease management in wildlife, it is necessary to understand their opinions and motivations (Stonciute et al., 2021, Urner et al., 2020). Focus group discussions (FGDs) are suitable for eliciting experiences and perceptions through informal discussion, and allow participants a voice in planning, implementation and evaluation of interventions (Lewis, 2000). Hunters with experience of wild boar hunting, at least 18 years of age, were recruited to the FGDs by local representatives of the SJF. Due to the Covid-19 pandemic, the FGDs in study II were conducted online. To facilitate a favourable discussion climate in this setting, the group sizes were limited to include a minimum of three and a maximum of five hunters. The group discussion format allowed the discussion to evolve more freely and with use of a topic guide (included in paper II) the facilitator ensured that all intended topics were addressed. Additional FGDs were conducted until data saturation was achieved, meaning that no new information emerged, which was reached after six focus groups. Together with the data collected from the questionnaire, a comprehensive overview of Swedish hunters' perspectives and behaviours related to wild boar disease surveillance and management was obtained.

3.4 Wild boar sampling

Wild boar disease surveillance is important for assessing the risk of disease transmission between wild and domestic suids. Following the detection of *S.* Choleraesuis in a pig farm in 2020 (Fjelkner et al., 2023), a targeted surveillance was initiated to determine the extent of this subtype's presence in Swedish wild boar (study II). Wildlife surveillance will have a non-random sampling element as it relies on reports of dead or diseased wild boar submitted by hunters or the general public. A combination of passive and active surveillance components was used, to survey Swedish wild boar for *S.* Choleraesuis and other *Salmonella* spp. The passive component was sampling of wild boar found dead, reported and submitted to SVA for post-mortem examination, in the general wildlife health and disease surveillance program. In addition, material from wild boar found dead, reported and sampled in the field within the ongoing surveillance for ASF, were cultured for *Salmonella* upon arrival to SVA. Sampling of dead animals inevitably means that the preferred materials may not be available or suitable, due to decomposition. Due to this, muscle, blood bearing organs or bone marrow was sometimes used.

The active surveillance component was hunters that voluntarily collected samples from seemingly healthy wild boar at harvest. Sampling kits with instructions to collect a mesenteric lymph node and a faecal sample, packaging materials, and submission forms were assembled and dispatched from SVA to hunter associations and participating hunters. Geographical distribution of submissions was followed closely and efforts to elicit samples from regions with a lower coverage were made.

As *S.* Choleraesuis, to a greater degree than other *Salmonella* serotypes, causes severe disease and death in wild boar, sampling of animals found dead was an intended strategy to identify areas where this subtype was present. Thanks to the general wildlife surveillance, enhanced by the strengthened passive surveillance in wild boar found dead, this component could be initiated immediately after the outbreak in a pig producing farm was detected. As SVA is the authority responsible for the general wildlife surveillance as well as the intensified passive surveillance, in conjunction with a strong collaboration with hunters nationally, samples from both apparently healthy wild boar and wild boar found dead could be accessed from all regions. All collected samples were analysed for *Salmonella* spp. by bacterial culture at SVA, using a standard protocol. The transport of samples by mail to SVA could possibly affect the probability of detection of salmonellae, should the sample get too hot, or overgrowth of other bacteria occur. However, shipping of samples for *Salmonella* culturing is common practice in routine diagnostics and works well when samples are sent in the beginning of the week to avoid being in transfer over the weekend. Selected isolates were sequenced to verify the subtype as *S.* Choleraesuis, and to determine genetic distances between isolates by single nucleotide polymorphism (SNP-analysis) for epidemiological tracing.

3.5 Camera trapping

Camera traps are commonly used to study wildlife as direct observation is rarely feasible. In study IV, standard wildlife camera traps with passive infra-red sensors (PIR) were used. At the request of the participating farmers, only photographs were captured, and no measures for data transmission or remote access to cameras were used. All information was collected on the equipped SD-memory card during each study period. Placement of cameras, regarding both positioning and location, were done with wild boar and potential direct or indirect pig contacts in mind.

Camera trapping at an operational pig production farm presents several challenges. Desired camera placement must be balanced by available mounting points, avoiding light sources and heat emissions, while considering privacy issues, as well as not interfering with normal workflow. Utilizing camera settings that would limit the active hours to the time from dusk till dawn optimizes the capture of wildlife while lowering the risk of incidental capture. The rapid change of length of daylight during late summer also needed to be accommodated for, as the cameras were not visited during the study periods. Depending on the number of images generated, the manual effort of inspecting them will be time consuming. Although an AI model can be trained and used for image recognition, that technique was not used in this study.

As the eight enrolled farms in this study constitute a small and non-random sample from selected areas, the results cannot be generalized to wildlife presence at pig farms in Sweden. Nevertheless, the information gathered provides valuable insights into wildlife movements on pig farms, and how to monitor such activities. Camera traps can be a useful tool to aid in biosecurity assessments concerning wildlife presence on pig farms. The knowledge gained from this study regarding camera placement and management will be beneficial for future research. Additionally, the results may inform future discussions on critical focal points for other on-farm monitoring and considerations in preventive measures.

3.6 Study size

Depending on the study, obtaining a large enough sample size to be able to generalize the findings is a challenge. Lack of available study subjects, limited access to suitable sample materials, as well as financial, personnel and time constraints are contributing factors. Questionnaires were distributed to relevant recipients in collaboration with animal health services and the hunters' association. These organizations are generally considered trustworthy by their members, and could also emphasize the importance of the studies, thereby leveraging the response rate.

Studies involving wildlife pose challenges as the sample collection is not trivial, compared to livestock, particularly as no registers or pre-determined sample sites are available. For the active sampling of apparently healthy harvested wild boar, contact networks of hunters were used to spread the information and encourage hunters to submit samples. The same interpersonal route was used to elicit increased submissions of samples from harvested wild boar from areas of lower representation. The passive component of the wild boar surveillance gained traction as the ASF situation in Europe requires continuous efforts to increase the reporting of wild boar found dead. By utilising the received samples for additional surveillance efforts, the geographic coverage could be effectively increased. As the surveillance of *S.* Choleraesuis in wild boar has been implemented as a long-term surveillance at national scale, hunters are now aware of the ongoing collection of samples from both passive and active measures, which helps to ensure comprehensive monitoring of this pathogen.

The camera trapping study was constrained by the number of suitable study sites and time available. However, the knowledge gained is still valuable for future studies addressing disease transmission risks at the wild boar-domestic pig interface.

4. Results

To further understand the wildlife-livestock interface, particularly concerning wild boar and domestic pigs, several aspects have been studied, on pig farms, in the wild boar population and among its most important human actors, the hunters. Detailed results are presented in the respective papers, with a summary of the main findings from each paper provided below.

4.1 Wild boar in proximity of pig farms

The questionnaire study on wild boar presence (paper I) was designed to capture the perceived situation regarding wild boar in the proximity of commercial Swedish pig farms.

The absolute majority of Swedish pigs are raised strictly indoors, which was reflected in the responses where 92% of the respondents indicated that their pigs did not have outdoor access. All pigs with outdoor access must be fenced in, but the use of double fencing was still uncommon (25%). The presence of a perimeter fence on farms without outdoor access was very rare (<2%).

Wild boar or signs of their activity (rooting, footprints, droppings) was observed within 1000 meters of their pig holdings by 80% of the respondents, at least once in the previous 12 months. Observations did not significantly vary across seasons. Of the producers growing crops, 63.9% reported wild boar damage, primarily in cereals.

The most prevalent mitigation strategy reported was the hunting of wild boar (61.2% of respondents), followed by strategic baiting (15%). Notably, 33.5% of respondents reported using no mitigation measures at all. Geographical region was significantly associated with wild boar observations. Other factors like farm size, type of production, and level of outdoor access did not show significant associations with wild boar presence.

4.2 Hunters' practices

Swedish hunters with experience of wild boar hunting were surveyed through a questionnaire and focus group discussions (FGDs) on their perspectives on surveillance and control methods, as well as their hunting travel habits and use of bait (paper II).

Both survey methods revealed that the hunters are aware of ASF-surveillance measures and risks of introduction, but to a varying extent between participants.

The FGDs indicated that hunters are willing to engage in ASF prevention and control. For reporting of wild boar found diseased or dead, they emphasize the process need to be simple and practically feasible.

Baiting is a common practice and was considered a prerequisite for effective hunting. However, opinions were voiced that the practice requires further regulation, particularly regarding the amount used. Further, the hunters expressed that baits used should be locally produced, nutritionally appropriate, and of a type that is naturally accessible for the game species. The most used products were maize, peas and grains and the use of animal products was rare.

Of the questionnaire respondents, 6% had been travelling for hunting outside Sweden after 2014. When compared with hunters traveling before 2014, the later travellers showed a statistically significant decrease in bringing back trophies and consumable wild boar products. Hunters travelling after 2014 and receiving biosecurity information were also more likely to clean their gear than their peers who did not receive such information. In both surveys the hunters called for more information and to some degree a higher involvement from authorities, and regulative or legislative measures when it comes to baiting. Their perceived risk of ASF introduction to Swedish wild boar was focused on external groups such as foreign truck drivers and the non-hunting general public.

The study concluded that hunting tourism or baiting did not constitute a major risk for introduction of ASF.

4.3 Surveillance of *Salmonella* Choleraesuis in wild boar

The results presented in paper III provide a comprehensive overview of the geographic distribution, and genetic characteristics of *S*. Choleraesuis, as well as the occurrence of other *Salmonella* serotypes in Swedish wild boar from 2020 to 2022, highlighting differences between active and passive surveillance.

Following the detection of this significant pig pathogen in a gilt-producing herd, a targeted surveillance of *Salmonella* in Swedish wild boar was initiated. The passive component of sampling wild boar found dead, either submitted for post-mortem examination or sampled in the field during strengthened ASF surveillance, enabled a rapid geographic survey using a high-risk category of animals. The active surveillance involved hunters voluntarily sampling seemingly healthy wild boar shot at harvest and submitting the samples to SVA for bacteriological culture.

As *S*. Choleraesuis causes disease and mortality in infected wild boar, passive surveillance of dead or diseased wild boar is particularly useful for detecting this pathogen. This was evidenced by the significantly higher proportion of *S*. Choleraesuis positives in dead wild boar, 27.0%, compared to 1.0% in the seemingly healthy, harvested wild boar. No such difference between the surveillance categories was seen for the other serotypes of *Salmonella*, 4.0% in wild boar found dead or diseased, 3.7% in hunter harvested. While the sampling of wild boar found dead will aid in assessing the geographical spread of *S.* Choleraesuis, the sampling of seemingly healthy wild boar will further clarify the risk posed for humans and livestock in regard to this pathogen.

S. Choleraesuis was detected in two separate clusters originating from Södermanland and Skåne, areas of high wild boar abundance. During the described study period, *S*. Choleraesuis was detected in three additional adjacent counties. Genetically sequenced isolates showed little variation, although genetic separation between the northern and southern region could be seen. In comparison to other European isolates, the strains found in Sweden were most closely related to strains found in central Europe, including Poland, Czech Republic and Germany.

When sampling seemingly healthy wild boar, two materials were collected from each individual a mesenteric lymph node and a faecal sample. Culturing both materials increased the sampling sensitivity as approximately two thirds of the animals were positive in either of these materials while the remainder was positive on both. While the initial intention was to sample the equivalent materials from both categories of animals, at times those materials were not available when sampling wild boar found dead. Regardless, *S.* Choleraesuis was detected from a variety of materials from wild boar found dead, including bone marrow which is the material of choice for ASF sampling when organs are missing.

4.4 Camera trapping of wild boar at pig farms

In study IV (included as manuscript) camera traps were utilised to assess the occurrence and motivation of wild boar visits to pig farms in Sweden. Despite similar conditions and surroundings at the study sites, wild boar visits were recorded at only one of the eight sites. Images recorded wild boar drawn to feed spillage or dust from feed silos. No contact with the live pigs was observed. However, repeated and regular visits in close proximity to pigs and feed storage areas, as well as interacting with discarded bedding used by pigs should be considered a potential risk for the spillover of pathogens between the populations.

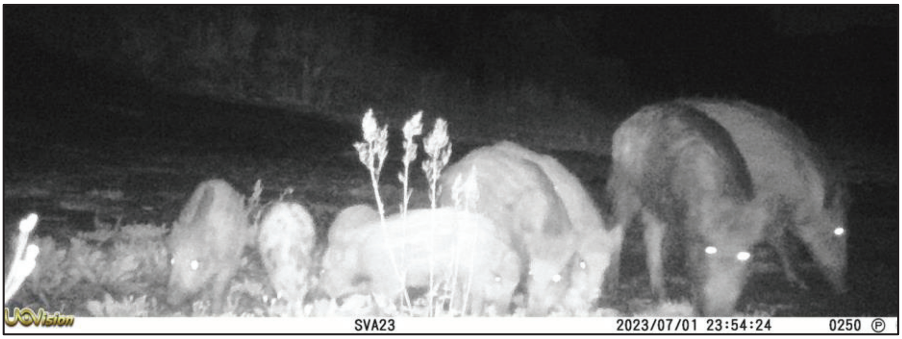

Figure 2. Eight wild boar of varying ages camera trapped while foraging.

With variation in species and extent of presence, wildlife other than wild boar was observed at all participating pig holdings. Foxes, fallow deer, red deer, roe deer and badgers were registered. Although wild boar is currently the primary species of concern for Swedish pig farms, other wildlife may be relevant for other disease-causing agents.

A high presence of foxes and/or domestic cats was recorded at some study sites, which may indicate an excessive rodent population. While cats and foxes contribute to rodent control, their movements between areas such as manure piles, cadaver management locations, and straw storages may interfere with internal biosecurity.

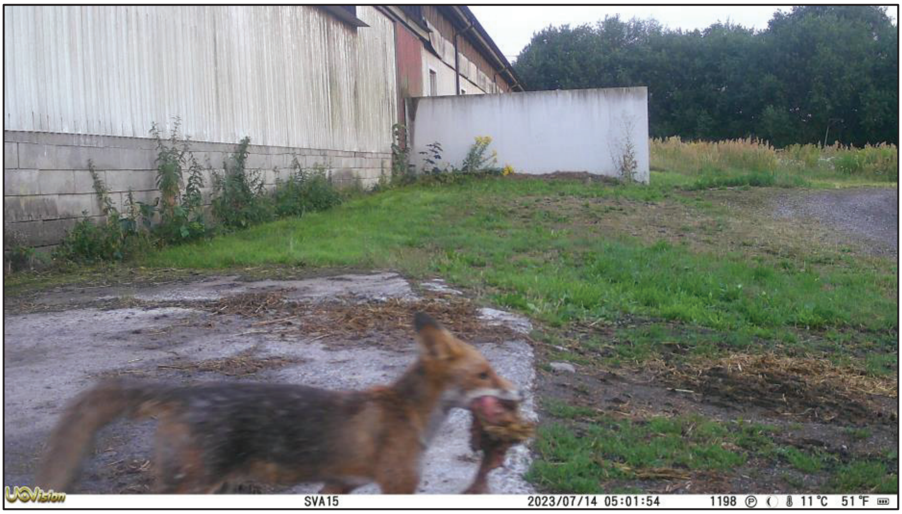

Figure 3. Camera trap photo of a fox carrying biological material (probably a placenta) from a manure pile at a pig farm.

In conclusion, camera traps are a cost-effective tool to investigate wildlife, including wild boar, presence on pig farms. The results can be used to inform and support decisions of mitigation strategies.

5. Discussion

The overall aim of this project was to enhance the understanding of the wildlife-livestock interface between wild boar and domestic pigs in Sweden. The knowledge gained can contribute to future decisions in policymaking and biosecurity considerations and inspire future research. The importance of these studies became apparent when the wild boar population was at its peak, and two pathogens were detected: *Salmonella* Choleraesuis emerged, and African Swine Fever (ASF) was introduced and subsequently controlled (Chenais et al., 2024).

5.1 Study I

Proximity has been considered a risk factor for ASF introduction, if the disease is present in the local wild boar population (Boklund et al., 2020). As wild boar are rarely directly observed, the observations are mostly from the physical signs of rooting activities and occasionally footprints and droppings. Although presence of these signs is indicative of wild boar presence, absence of such signs cannot be taken as evidence of wild boar absence.

Of the pig producers surveyed in study I, 80% had wild boar within 1 kilometre at least at some point during the previous year and 30% reported the frequency to be almost weekly. Very few had a perimeter fence and more than 60% of the pig producers growing crops for pigs had experienced wild boar damage in them.

With passing time new challenges have emerged like the presence of *S.* Choleraesuis in wild boar, while others have been solved outside of the project, like the addition of the ASF-module to the voluntary biosecurity program and the management of the ASF outbreak in wild boar.

The use of straw in pig production in Sweden is common. Swedish oats or straw have previously not been considered a source of *Salmonella* spp. (Elving and Thelander, 2017). With the current situation where *S.* Choleraesuis has caused localized outbreaks in wild boar, studies to investigate the risk of oats and straw from these areas are warranted, and such a study is currently ongoing at SVA.

Sometimes the use of straw for bedding and enrichment has been raised as a biosecurity problem, but regarding ASFv a study from EFSA shows that the risk is most likely negligible as the virus is rapidly inactivated on oats, common bedding and grass (Blome et al., 2024). Oat crops and straw are generally harvested in late summer at higher temperatures and, with recommended storage, materials harvested without inclusion of pieces of carcass from wild boar should be safe. Studies have shown that the resilience of ASF virus outside its host, which is one of its important features for spread, is linked to presence of blood, cadavers or in meat (Fischer et al., 2020). Thus, the risk of indirect transmission in a contaminated environment remains.

5.2 Study II

Hunters play a key role in the Swedish wildlife surveillance, both general and targeted, as well as in disease management involving wildlife. To understand their perceptions, motivations, and the possible risk hunters' travels and practices could pose, a mixed-method survey was conducted using both focus group discussions and a questionnaire. The results from paper II showed that hunting tourism or baiting do not appear to constitute major threats for the introduction of ASF to Swedish wild boar populations.

Nevertheless, baiting was common and considered essential for successful hunting. Furthermore, the responding hunters emphasized the need for appropriate feed ingredients, and some expressed a wish for stricter regulation. The already existing recommendations on baiting by the Environmental Protection Agency (EPA) as well as the Swedish Association for Hunting and Wildlife Management (SJF) align with the hunters' opinions (SJF, 2017, EPA, 2020). The practice is regulated by legislation, but not in a very precisely manner, as the differences between baiting, strategic feeding, and supportive feeding are not clearly defined, which may have contributed to the hunters' expressed opinions. The primary products used for baiting include maize, peas, and cereals, mainly grown in Sweden. Previously, imported maize was used and is believed to have contributed to the introduction of S. Cholerasuis. However, this practice has reportedly ceased or decreased significantly due to widespread concerns about introducing ASFv through feed. The main products used for baiting do not appear to support prolonged survival of ASFv. However, beets or potatoes stored cold showed prolonged virus survival which may be considered as tubers are used for baiting (Blome et al., 2024). The harvest time for these products in Sweden coincides with cooler temperatures and humidity levels that are more beneficial for virus survival.

The participating hunters expressed an interest in taking part in prevention and control activities, given the necessary resources. The study was conducted before the introduction of ASF to Sweden, the outbreak further demonstrated the importance of hunter involvement in surveillance and control.

The hunters in the study asked for more information, especially to groups external to themselves such as tourists and the general public. Such information is already distributed through various communication channels but doesn't necessarily reach all target groups. Personal experience form the *S*. Cholerasuis outbreak demonstrates that published material was not always taken up by hunters, while the ASF outbreak appears to have prompted more attention.

5.3 Study III

Over-abundance, high population densities and a shift towards one host species will affect pathogen circulation (Gortazar et al., 2014), which was illustrated by the regional occurrence of *S*. Choleraesuis from study III.

As maize is a commonly used feed material, and the strains identified in the *S*. Choleraesuis outbreak most closely match strains from north-central Europe, the specific *Salmonella* serovar was possibly introduced through imported maize to managed populations of wild boar through feeding.

Wildlife surveillance is challenging as wildlife populations are not as accessible as livestock. Insights into the population abundance and structure, as well as specific disease aspects are needed to design appropriate surveillance programs. Cost effective sampling usually requires involvement of hunters and the general public. These stakeholder groups have varying knowledge and capability for sample collection, and this must be taken into account. The hunters in study II expressed a need for simple and feasible reporting and sampling procedures. Such aspects were considered when designing the surveillance in study III.

The Swedish general wildlife disease surveillance program, established in 1948, is likely one of the oldest programs of its kind. It relies on post-mortem examinations of wild animals that are found dead or diseased and reported and submitted to the SVA by hunters and the general public. This longstanding tradition of cooperation authorities and hunters has been crucial in detecting both African swine fever (ASF) and *Salmonella Choleraesuis*.

The ASF-outbreak was detected through the enhanced passive surveillance in wild boar. The detection *S*. Choleraesuis has led to a currently ongoing national screening of *Salmonella* spp. in wild boar. The passive component of this screening has been leveraged by the increased observations of wild boar found dead, and the resource allocation for official sampling for ASF.

Many important pig diseases that are currently absent in Sweden can be established and spread in wild boar populations. The emergence of *S*. Choleraesuis served as a reminder and a dress rehearsal for ASF preparedness. The many potential routes of introduction and spread of *S*. Choleraesuis warrant further investigations in order to address other disease threats

5.4 Study IV

The use of camera traps has become an essential tool for monitoring and researching wildlife. However, deploying camera traps in a farm setting presents additional challenges compared to a forest or field habitat due to environmental differences. In study IV the target species was wild boar which has a high probability of triggering camera traps (Palencia et al., 2022). Most likely their fairly large and compact stature, lack of dense coat and gregarious nature, which may have them appear in groups, will increase the possibility of capture by a PIR-triggered camera given they enter the detection range. This makes wild boar a good candidate species for camera trapping, if one has identified their motivation and selected relevant points of interest.

The goal of this study was to determine if wild boar visit Swedish pig farms, assess the frequency of these visits, and understand the motivations behind them. Results from study I indicated that while the presence of wild boar within one kilometre of a pig farm was common, their presence within less than ten meters of buildings holding pigs was rare. Understanding the motivation behind wild boar visits can provide important information to support existing biosecurity measures.

An improvement to this study would be to extend the observation periods to a full year, as the frequency of visits seems to vary, with some periods showing no wild boar activity. Additionally, incorporating local abundance data by deploying cameras in surrounding habitats could add granularity to the context. If the goal is to collect data for modelling purposes, using distance markers for objective measures of proximity to pigs or resources could be beneficial, though challenging to implement in an operational farm environment. Although harmonization of collection and reporting may not be possible due to privacy concerns in farm settings, using standardized protocols for background data collection and camera placements could facilitate future comparisons. For risk assessments regarding disease transmission, frequency and duration of visits, as well as distance to pigs would be useful information for future modelling.

The recurring contacts recorded by wild boar and foxes with discarded bedding material, manure and biologic material from pigs constitutes a risk of spillover from pigs to wildlife, should a disease be present in the pigs. Such spillover may be detrimental for the wildlife, and if the disease is established, the local wildlife population may act as a reservoir for either spillback after the outbreak in the pigs are managed or for transmission to neighbouring farms.

Identifying the motivation for wild boar to visit pig farms is crucial as controlling the presence of and access to such entities may reduce visits, with or without the presence of a fence. In this study, the wild boar appeared drawn to feed dust and spillage, as they were captured foraging in areas immediately adjacent to silos. Of the nine cameras deployed on this farm, the five that captured wild boar were all mounted near the edge of the farmyard, close to neighbouring fields and forested areas, aligning with previous findings (Bacigalupo et al., 2022).

5.5 General aspects

"Managing pathogen spillover at the wildlife–livestock interface is a key step towards improving global animal health, food security and wildlife conservation. However, predicting the effectiveness of management actions across host–pathogen systems with different life histories is an on-going challenge since data on intervention effectiveness are expensive to collect and results are system-specific" (Manlove et al., 2019)

In order to narrow the scope of these studies, the wildlife-livestock interface was specified as the facet between wild boar and domestic pigs. The zoonotic aspect was intentionally not prioritized, to reduce the complexity of the matter. Nevertheless, humans play a crucial role in the wildlife-livestock interface through their management of wildlife populations, adherence to biosecurity protocols, selection and placement of crops, and the impact of global travel and trade, which can introduce pathogens over long distances.

The rapid growth of the wild boar population in Sweden can be attributed to the species being adaptable to habitats, opportunistic feeders and having a high reproductive ability (Stillfried et al., 2017, Malmsten et al., 2017, Bergqvist et al., 2024). Since the peak of the wild boar population, assessed by the national hunting bag as having occurred in 2020, there has been a marked decrease of up to 30% in the number of wild boar shot (Fig 1). However, recent data on traffic accidents reveal that, in the first six months of 2024, close to 3500 incidents involving wild boar have been reported, which is higher than in the responding period of any previous year (Nat. viltolycksrådet, 2024). This suggests a compensatory effect may be occurring in the wild boar population dynamics. The goal of the national wild boar management plan is to reduce the number of traffic accidents involving wild boars to fewer than 3000 per year by 2025 (EPA, 2020), a target that may still require significant effort to achieve.

Although pigs raised for commercial purposes in Sweden are, to a large extent, kept indoors the potential for indirect contact with wild boar exists and must be considered. Variable local situations regarding wild boar abundance may require an adaptive approach, where wild boar management supports implemented biosecurity efforts. Strategies to keep wild boar and pigs separated may need cooperative and communicative efforts, both regarding wild boar population densities and variables that can affect the dispersion of the wild boar. In addition to the farmers' needs, it is also in the hunters' interest that wild boar do not visit pig farms, as the risk of disease transmission is bi-directional.

Biosecurity has traditionally focused on preventing disease spread within and between herds. However, due to anthropogenic drivers, with increasing wildlife populations in closer proximity to livestock, the context within which the farm is situated needs to be included in decisions regarding biosecurity. In a review of biosecurity among cattle farmers Renault et al identified farmers perceived lack of control in preventing contacts with wildlife, as no measure appeared fully effective (Renault et al., 2021) Hence a layered approach where the surroundings are included is warranted. Currently, the use of a perimeter fence around Swedish pig farms is rare, but even when present it is important to identify the motivations of wild boar to visit the farm and restrict access to or remove to such attractive resources.

The interface between livestock and wildlife is a complex field. Changes in disease status, species abundance and habitat use may change rapidly and with knowledge of the local context, adaptations are possible. New diseases may have entered either of the populations, wild boar may have expanded into new areas or changes in the landscape may have affected their proximity to farms. Rapidly changing situations with regards to relevant species of wildlife and occurring pathogens further highlight the need for knowledge and preparedness. Due to the many aspects, a multidisciplinary and multi stakeholder approach is needed to find relevant solutions in the local context. Most pig farms belong to a larger production chain, where pig farms may be interconnected over large distances and various links (trade, supply chains, slaughterhouses). They may even be connected in the local context by sharing the same wildlife neighbours through geographical proximity. Hence, avoiding disease transmissions requires system thinking due to interlinking of farms and interactions between farms and wildlife.

Swedish legislation requires that pigs and wild boar be kept in ways that prevent contact between the species. Although, it may not be possible to fully predict and prevent all indirect pathways, reducing the probability of disease transmission events is still worthwhile. In efforts to mitigate disease transmissions in the wildlife-livestock interface a more holistic, layered, and contextual approach is needed. Single biosecurity measures may fail but if a layered approach is used, small mistakes should not align and result in a breach.

This might be the time to extend to an integrative approach in wildlife and livestock surveillance, and 'systems thinking' in biosecurity in the livestock primary production, and acknowledge the local context to avoid disease transmissions, in either direction.

6. Concluding remarks

The wildlife-livestock interface is a complex system shaped by various factors, including wildlife abundance, potential direct and indirect contact routes between the populations, and differences in host species and pathogens. In a globalized world, it is crucial to maintain preparedness and adaptability for emerging situations and new pathogens.

Continuous disease surveillance in both wild boar and pigs increases the likelihood of detecting changes in pathogen presence. Establishing a clearer connection between surveillance and outbreak investigations in wildlife and livestock can help identify transmission routes, which can then be used to enhance biosecurity measures to prevent disease transmission.

Incorporating knowledge of the local context will help with layering the biosecurity aimed to separating wild boar and pigs and prevent direct and indirect contacts. Since visible signs of wild boar presence such as rooting may not always be present, strategically placed camera traps can help assess the effect of mitigation strategies. Minimizing sources of attraction at the pig farm, such as restricting access to piles of discarded bedding and manure, and remove feed spillage or feed dust may further reduce the motivation of wild boar visits. Communicating and collaborating with local hunters on wild boar management is important. Creating a landscape where population density and management procedures as feeding or baiting aligns with the pig farm efforts to keep the wild boar at a distance from the pigs is in the mutual interest. Keeping the populations separated will reduce the risk of bi-directional disease transmission.

7. Future perspectives

Based on insights gained from the studies presented in this thesis, some specific areas that could be suggested for future research is:

- Utilise camera traps to further explore the motivations behind wild boar visits, assess effectiveness of mitigation strategies aimed at reducing wild boar visits to pig farms, and include studies on pig farms with outdoor access.

- Investigate the emergence of *S*. Choleraesuis in wild boar to gain insights relevant for mitigation of future disease introduction events.

- Explore the possibilities of management interventions to reduce the prevalence of *S*. Choleraesuis in relevant regions.

- Enhance detection and understanding of wildlife health and disease events by including abundance monitoring on a higher resolution.

- Integrate incoming wildlife information, including screening and surveillance results, reports from hunters and the general public, and post-mortem diagnoses, in a structured manner to enhance wildlife epidemiology.

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Popular science summary

The interface between wild and domestic animals has received increased attention over the past decade. Growing wild boar populations, the global spread of African swine fever (ASF), and the recent discovery that the *Salmonella* type *Salmonella* Choleraesuis is present regionally in the wild boar population in Sweden have highlighted the need to prevent the transmission of infections between wild boars and pigs. This has been underscored by the introduction of ASF to wild boars in Fagersta, Sweden in 2023.

ASF is a viral disease that affects domestic pigs and European wild boar. It causes acute haemorrhagic fever with a very high mortality rate, up to 100%, in affected animals. The disease is transmitted through direct contact, but a significant aspect of its spread is that the ASF virus can remain infectious in tissues and blood, such as in carcasses, for a long time. *S.* Choleraesuis is a swine-adapted *Salmonella* bacteria. Unlike many other *Salmonella* types, it can cause severe systemic illness, including pneumonia, sepsis, and death in wild boars and pigs. For both these diseases, although caused by entirely different pathogens, indirect contacts can transmit infections between wild and domestic populations. It is important to consider that this transmission can occur in both directions.

To prevent the transmission of infections between wild boar and domestic pigs, it is necessary to understand the potential contacts that could lead to direct or indirect interaction between wild and domestic populations. A survey was conducted among Swedish pig producers to investigate how common it is for wild boars to be in the vicinity of pig herds, whether they have experienced damage caused by wild boars in cultivated crops, and what strategies they use to reduce the risk of contact between wild boars and pigs. Additionally, hunters' opinions on ASF reporting and control were gathered

through a series of focus group interviews, and a survey was conducted to examine baiting and travel habits concerning international hunting. This study was conducted before the introduction of ASF. In connection with the discovery of *S*. Choleraesuis in a domestic pig herd, a national surveillance of the occurrence of *S*. Choleraesuis in the country's wild boar population was initiated. This involved using both materials collected from wild boars found dead and reported to the SVA and samples collected by hunters from harvested wild boars. Finally, a study with motion activated wildlife cameras set up on pig farms was conducted to investigate whether wild boar visited farm areas, and what might motivate this behaviour.

Almost all commercial pig farming in Sweden is conducted indoors, without outdoor access. Eighty percent of respondents reported having observed wild boars or signs of wild boar activity near their pig farms at least once in the past twelve months. One-third reported that this occurred almost every week. Two-thirds reported wild boar damage in crops grown for pigs in the previous year. At the time of the survey, very few farms had fences surrounding their farms, and the most common measures to keep wild boars away were hunting and the placement of small amounts of feed away from the pigs.

The focus group interviews, and hunter survey, revealed that they were positively inclined to contribute to monitoring and control efforts regarding ASF in wild boar, but it must be feasible to do so. This was demonstrated during the ASF outbreak in Fagersta, where the hunters' reports contributed to early detection and their joint efforts to rapid control. Baiting was reported in the survey to be a prerequisite for effective wild boar hunting, and the general perception was that the feed used should be suitable for the species and preferably locally produced or at least Swedish. Maize is one of the most common feeds, along with cereals, for wild boar baiting, and survey responses indicated that maize was often imported, but with ASF in mind, there has been a shift to Swedish products.

In connection with the detection of *S*. Choleraesuis during routine sampling in a pig herd, a national surveillance was initiated regarding the occurrence of the *Salmonella* type in the Swedish wild boar population. *S*. Choleraesuis had not been diagnosed in Swedish pigs since 1979 when it was discovered in 2020. The infection is primarily seen in dense wild boar populations found in Södermanland and Skåne and is thought to have been introduced through imported maize.

The camera study showed that despite similar conditions on participating farms, only one had wild boar visits on the farm. Strategically placed, motion activated wildlife cameras can help identify wild boar presence, provide insights on what motivates wild boar visits, and evaluate the strategies used to prevent wild boars from approaching pigs. In dry or cold weather, or if they have not rooted while foraging, it can be difficult to detect theirpresence, and strategically placed wildlife cameras can be of great help.

In summary, with wild boars near pig farms, the risk of indirect transmission cannot be ruled out. Monitoring the pathogens that occur or are introduced to both wild and domestic populations is essential, as pathogens may require tailored measures to effectively prevent transmission. Biosecurity on pig production farms was originally designed to protect against the introduction of infections from other herds or between groups of animals within the herd. Today, we face a new situation in Sweden, with the risk of new ASF introductions to the wild boar population and the fact that we now have an established infection of a swine-adapted *Salmonella* type in the wild boar population, which locally poses a risk of indirect transmission. By following the given biosecurity guidelines, significant progress can be made, but as no single measure is foolproof a layered approach will create a more robust system. With knowledge of the local situation, how the wild boar situation is in the area, what wildlife diseases are present, and through communication with local hunters to agree on how to keep wild boars from the immediate vicinity of the farm, a buffer zone can be created to prevent the wild and domestic populations from sharing potential infections.

Populärvetenskaplig sammanfattning

Kontaktytan mellan vilda och tama djur har under det senaste decenniet fått en ökad uppmärksamhet. Ökande vildsvinsstammar, den globala spridningen av afrikansk svinpest (ASF) och upptäckten av att salmonellatypen *Salmonella* Choleraesuis förekommer regionalt i vildsvinsstammen har satt fokus på hur smittspridning mellan vildsvin och grisar kan undvikas. Att detta är ett prioriterat område underströks av att det under 2023 skedde en introduktion av ASF till vildsvin i Fagersta.

ASF är en virussjukdom som drabbar tamgrisar och europeiska vildsvin. Det ger en akut blödarfeber med mycket hög dödlighet, upp till 100%, hos de djur som drabbas. Sjukdomen smittar vid direkt kontakt, men en viktig del i smittspridningen är att ASF-virus kan förbli infektionsdugligt i vävnader och blod, tillexempel i kadaver, över lång tid.

S. Choleraesuis är en grisanpassad salmonellabakterie. Till skillnad från många andra salmonellatyper kan den orsaka svårare systemisk sjukdom med lunginflammation, sepsis och dödsfall hos vildsvin och grisar.

För båda dessa sjukdomar, även om de orsakas av helt olika smittämnen kan indirekta kontakter överföra smitta mellan den vilda och den tama populationen. Att beakta i sammanhanget är att denna smittspridning kan gå åt båda håll. Åtgärder som genomförs för att skydda grisar skall även ha i åtanke att vildsvin inte kan nås av smitta från grisarna heller.

För att undvika att smittoöverföring sker mellan vildsvin och tamgrisar sker behövs kunskap om hur de eventuella kontakter som skulle kunna leda till direkt eller indirekt kontakt mellan de vilda och tama populationerna ser ut.

Via en enkätundersökning till svenska grisproducenter undersöktes hur vanligt förekommande det är att vildsvin uppehåller sig i närheten av besättningar, om de upplevt skador orsakade av vildsvin i odlade grödor samt vilka strategier de använder för att minska risken för kontakter mellan vildsvin och grisar. Vidare efterfrågades jägarnas åsikter kring rapportering och bekämpning av ASF i en serie fokusgruppsintervjuer och med en enkät undersöktes åtlings- och resvanor avseende utlandsjakt. Denna studie genomfördes innan introduktionen av ASF. I samband med att *S*. Choleraesuis upptäcktes i en tamgrisbesättning inleddes en kartläggning av förekomsten av *S*. Choleraesuis hos vildsvin i landet. För det användes både material insamlat från vildsvin som upphittats döda och rapporterats till SVA och prover insamlade av jägare från vildsvin fällda vid jakt. Avslutningsvis genomfördes en studie med viltkameror uppsatta på grisgårdar för att undersöka om vildsvin inte bara uppehöll sig i närheten av grisgårdar, utan även besökte gårdsytor och vad som kunde motivera detta.

Nästan all grisuppfödning i kommersiellt syfte i Sverige sker inomhus, utan tillgång till utevistelse. Åttio procent av de som svarade på enkäten hade observerat vildsvin eller tecken på vildsvinsaktivitet i närheten av sina gårdar vid åtminstone något tillfälle under de senaste tolv månaderna. En tredjedel av dessa uppgav att det skedde nära nog var vecka. Två tredjedelar uppgav att de under det föregående året haft skador i gröda odlad för användning till gris. Det var vid undersökningstillfället mycket få gårdar som hade ett staket kring sin gård och de vanligaste åtgärderna för att hålla vildsvin på avstånd var jakt och utplacering av mindre fodermängder eller spannmålsrens.

Från fokusgruppsintervjuerna och enkäten med jägare framkom att de var välvilligt inställda till att bidra till övervakning och bekämpning, men att det måste vara möjligt att genomföra, till exempel genom tillgängliga rapporteringssystem och ersättningar vid större insatser, vilket bevisades vid utbrottet av ASF i Fagersta där jägarnas rapporter bidrog till den tidiga upptäckten och deras insatser till den snabba kontrollen. Åtling uppgavs via enkäten vara en förutsättning för effektiv jakt på vildsvin och den genomgående uppfattningen var att fodret som användes skulle vara lämpligt för djurslaget och gärna lokalproducerat eller i alla fall svenskt. Majs är en av de vanligaste fodermedlen, tillsammans med spannmål, för åtling av vildsvin och i enkätsvaren beskrevs att majs tidigare ofta varit importerad, men att man med ASF i åtanke övergått till svenska produkter.

I samband med att *S*. Choleraesuis upptäcktes i rutinprovtagning i en grisbesättning inleddes en nationell övervakning avseende förekomsten av salmonellatypen i den svenska vildsvinspopulationen. *S*. Choleraesuis hade inte diagnosticerats hos svenska grisar sedan 1979 när den upptäcktes 2020.

Smittan ses framförallt i de täta vildsvinspopulationerna som finns i Södermanland och Skåne med omnejd och tros ha introducerats med just importerad majs.

Den kamerastudie som genomfördes visade att trots liknande förutsättningar på de deltagande gårdarna var det bara en av dem som hade vildsvinsbesök inne på gården. Strategiskt placerade viltkameror kan bidra till både att identifiera vad som motiverar vildsvinens besök, men även att utvärdera de strategier som används för att undvika att vildsvinen närmar sig grisarna. Vid torrt eller kallt väder, eller om de inte bökat, kan det vara svårt att upptäcka eventuell närvaro och då kan en strategiskt placerad rörelseaktiverad viltkamera vara till god hjälp.

Sammantaget är att med vildsvin nära grisgårdar kan en risk för indirekt smittspridning inte uteslutas. Övervakning av vilka smittämnen som förekommer eller introduceras till både den vilda och den tama populationerna är centrala, då smittämnen kan behöva anpassade åtgärder för effektivt undvikande av smittspridning. Biosäkerhet på gårdar med grisproduktion var ursprungligen för att skydda mot införsel av smitta från andra besättningar, eller mellan grupper av djur inom besättningen. Idag har vi en för Sverige ny situation, dels med risken för nya introduktioner av ASF till vildsvinsstammen, dels för att vi nu har en befäst smitta av en grisanpassad salmonellatyp i vildsvinsstammen som lokalt utgör en riskindirekt smittspridning. Genom att följa givna biosäkerhetsråd kommer man långt, men ingen enskild åtgärd är vattentät. Med kunskap om den lokala situationen, hur ser vildsvinssituationen ut i mitt område, vilka viltsjukdomar finns här och kan man i kommunikation med lokala jägare komma överens om hur man skall få vildsvinen att hålla sig från gårdens absoluta närhet skapar man en buffertzon som förhindrar att den vilda och den tama populationen delar eventuella smittor med varandra.

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Understanding the interface between European wild boar (*Sus scrofa*) and domestic pigs (*Sus scrofa domesticus*) in Sweden through a questionnaire study

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Abstract

Background In recent years, the wildlife/livestock interface has attracted increased attention due to disease transmission between wild and domestic animal populations. The ongoing spread of African swine fever (ASF) in European wild boar (*Sus scrofa*) emphasize the need for further understanding of the wildlife/livestock interface to prevent disease spill-over between the wild and domestic populations. Although wild boar may also act as a potential source for other infectious disease agents, ASF is currently the most severe threat from wild boar to domestic pigs. To gather information on the wild boar situation at commercial pig producing farms in Sweden, a digital questionnaire survey was distributed through the animal health services.

Results Most pigs produced for commercial purposes in Sweden are raised without outdoor access. Of the 211 responding pig producers, 80% saw wild boar or signs of wild boar activity in the vicinity of their farm at least once during the year. Observations were significantly correlated with geographical region, but there was no correlation between farm characteristics (farm size, main type of production, outdoor access) and observed wild boar presence or proximity. However, a reported higher frequency of wild boar observations was positively correlated with the observations being made in closer proximity to the farm.

Hunting and strategic baiting were the most common mitigation strategies used to keep wild boar at bay. Of the 14 farms raising pigs with outdoor access, 12 responded that these pigs could be raised solely indoors if needed.

Pigs with outdoor access are required to be fenced in, but double fencing in these outdoor pig enclosures was not practiced by all. A perimeter fence surrounding any type of pig farm was very rare. More than half of the producers that grew crops with intended use for pigs reported crop damage by wild boar.

Conclusion This study shows that although pigs raised for commercial purposes in Sweden are, to a large extent, kept indoors the potential for indirect contact with wild boar exists and must be considered. Variable local situations regarding wild boar abundance may require an adaptive approach regarding biosecurity efforts.

Keywords African swine fever, Disease transmission, Wildlife-livestock interface

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Background

In recent years, the wildlife/livestock interface has attracted increased attention due to disease transmission between wild and domestic animal populations [1, 2]. Recurrent seasonal epidemics of highly pathogenic avian influenza in wild birds, and the ongoing spread of African swine fever (ASF) in European wild boar (*Sus scrofa*) are two examples of disease events that demonstrate the need for further understanding of the wildlife/livestock interface to prevent disease spill-over between the wild and domestic populations. Wild boar may also act as a potential source for other infectious disease agents such as *Salmonella*, *Mycoplasma hyopneumoniae* and *Toxoplasma gondii* [3]. However, ASF is currently the most severe threat from wild boar to domestic pig populations.

In domestic pigs (*Sus scrofa domesticus*) and European wild boar (*Sus scrofa),* infection with ASF virus (ASFV) typically causes a contagious haemorrhagic fever with high case fatality rate [4]. The virus can be spread through direct contact with infected animals or carcasses or indirectly through contaminated fomites, transports, and materials such as feed or bedding [5–7]. ASFV of genotype II was introduced from the African continent to Georgia in 2007, causing the current epidemic in Europe, Asia, and parts of Oceania. North America was added to the list of affected continents in 2021 following incursion into the Dominican Republic and Haiti [8].

ASFV is not zoonotic. Nevertheless, the disease has devastating effects on animal health and welfare, and far-reaching consequences for farmers, stakeholders, and trade in affected countries. In Europe and most other countries in the global north, ASF outbreaks in domestic pigs will result in whole-herd slaughter and application of movement restrictions for pigs and pig products with potential trade consequences for the whole country [9].

Long distance translocations of ASFV, attributed to human activities, have led to unpredictable introductions of the virus to wild boar populations far from known infected areas [10]. In a globalized world, with ASFV present in more countries and on more continents than ever before, the risk of human activities moving infected meat or contaminated products increases [11]. Sweden is currently free from ASF and does not share a land border with any presently affected country. Therefore, the most plausible scenario for a virus introduction to Sweden is through human activities exposing wild boar to ASFV through contaminated objects or infected pork products. This, and subsequent spread to domestic pigs, is feared by Swedish pig producers.

Similar to many other European countries, Sweden has experienced a substantial increase in wild boar abundance during the last two decades. This is reflected in hunting statistics with reports of less than 400 wild boar shot during hunting in 1990, close to 5000 in the year 2000 and just above 160,000 in 2020 [12]. Likewise, the amount of crops damaged by wildlife doubled from 2014 to 2020, with wild boar causing more than 50% of the reported damage done to cereals and forage [13]. Wild boars are present in the southern half of Sweden and the geographical distribution of the species overlaps with the major pig production areas. A study from 2013 describes presence of wild boar within 10 km in 65% of 60 Swedish farrow-to-finish farms [14]. Even though direct contact between wild boars and domestic pigs can be avoided through use of fencing and housing, routes for indirect pathways and consequences of biosecurity breaches may be associated with having wild boars close to pig farms. Therefore, the presence of infected wild boars around farms is a risk factor for infection of domestic pigs with ASFV [7].

Pigs raised for commercial purposes are generally kept indoors. Even though there is an increasing interest and demand for pork from organic production where pigs have outdoor access, less than 3% of the produced pigs in Sweden are raised under these conditions [15]. Swedish animal welfare legislation requires that all pigs have access to materials to manipulate for enrichment purposes and straw is often the material of choice. Sows are kept in groups during their dry period, often on deep litter straw bedding. Sometimes these groups are housed in a well-ventilated barn with large doors or sliding wall sections that can be opened during suitable weather conditions while the animals remain inside. Even though these pigs are still considered to be kept indoors, these more open barns present an opportunity for direct contact with wild boar, should they approach the building.

No detailed study on the wildlife/livestock interface focused on wild boar and commercial pig production has previously been done in Sweden. Understanding of this interface is needed for informed and relevant policy making, creation of biosecurity strategies for contact mitigation and for effective disease prevention and control. The aim of this study was to investigate the possible direct and indirect contact routes between domestic pigs and wild boars in Sweden.

Methods

A cross-sectional study design was employed. An electronic questionnaire was developed in the tool Netigate (Netigate AB, Stockholm, Sweden). The questionnaire was distributed by email to all pig producers in Sweden affiliated to one of the following pig health organisations: Farm and animal health (FAH), Lundens animal healthcare (LAH), and the district veterinary organisation's pig animal health service (DV). Together these organisations cover 90–95% of the commercial pig producers in Sweden. Pig farms of all common production types and levels of outdoor access are affiliated to the services: farrow-to-finish, specialized fattening, and specialized piglet producers as well as breeding and gilt-producing herds. The invitation to participate and the link to the online questionnaire was sent to 1003 recipients. The link was sent together with information about the study including that participation was voluntary, all answers were anonymous, and that data would only be presented in an aggregated form to avoid identification of individual respondents. The questionnaire was set so that each respondent could only reply once.

To encourage participation, the survey was introduced at a conference for commercial pig producers before distribution. Three weeks after the link to the online questionnaire was made available to the producers, the study was mentioned on two websites, one targeting pig producers and one general agricultural media site, which acted as a reminder to participate. The questionnaire was available from November 15, 2019, to January 31, 2020. Two weeks prior to closing the survey, a reminder was sent out by email to all who had received the original link.

Data collection

The questionnaire had 19 closed questions regarding husbandry, mitigation strategies and wild boar observations. In addition, there were five free text fields for comments. A translated version of the closed questions in the questionnaire is included in Additional file 1.

The questions were related to four areas:

- Farm characteristics (geographical region, farm size, main type of production and housing, including outdoor access)
- Mitigation strategies in use to prevent contacts with wild boar (hunting activities, fences, use of strategic bait feeding, as well as the possibility for closed housing of pigs with outdoor access)
- Risk factors for indirect contact (water source usage, crop damage, and hunting practises)
- Observations of wild boar or their activities (seasonality, distance in relation to pig housings, observations in relation to buildings not housing pigs, and occurrence of hybrid litters.)

The questions on wild boar activities combined direct observations of wild boar and observations of signs of their activity, as direct observations are rare and the focus was on how close the animals came, regardless of how they were observed.

No question or commentary field required an answer for progression through the survey.

The questionnaire was developed in collaboration with pig health veterinarians from the three pig health organisations previously mentioned (FAH, LAH, and DV), a pig health expert at the National Veterinary Institute (SVA) and a representative from the Federation of Swedish Farmers (LRF).

Data management

Data was exported from the survey tool in excel format. Further data handling including cleaning, analysis, and statistical calculations was done in the statistical program R, R Core Team, 2019 [16].

Control of duplicate answers was done by comparing the answers to a select set of questions (postal area, number of pigs, pig housing and mitigation strategies).

When the response option 'other, please specify' was used for clarification purposes of a given option only, and not to provide a different alternative, the answers were recoded into the relevant response options.

Statistical analysis

The geographical representativity of the respondents compared to the target population was assessed by proportional testing. Respondents were asked to provide the first two digits in their postal code which was further aggregated on the European regional level, according to Nomenclature of Territorial Units for Statistics (NUTS 2), of which there are 8 in Sweden. The aggregated responses were then compared to the number of pig enterprises registered in the respective region [15].

To evaluate farm characteristics that may affect the level of wild boar observations done, the variables geographical region, main type of production, farm size, and degree of outdoor contact were selected. Further analysis included whether farm characteristics were associated with the frequency of wild boar observations, or the distance at which these observations were done. Farm location was assessed on NUTS 2 level. Each farm was categorized by size following the size categories used by Pettersson et al., regarding Swedish pig production. For sows, the size categories correspond to the following numbers: 'small' (< 100), 'medium' (100–400) and 'large' (> 400) by number of sows per year. For fattening pigs size categories correspond to the following numbers: 'small' (< 5000), 'medium' (5000–10000) and 'large' (> 10000) fattening pigs produced per year [17]. Integrated farms keeping both categories of animals (sows and fattening pigs) were classified based on whichever category was the largest. Farms were assessed for the level of outdoor access present and classified as 'outdoor access' if pigs were allowed to leave the building to go outside (inside a fenced area) or as 'conventional' if pigs were held inside in closed buildings. 'Open wall sections' stipulates a third category of outdoor contact where the pig housing is very well ventilated through slightly permeable walls or by the use of gates in opened wall segments, keeping the pigs inside the designated building.

Categorical variables were assessed for independence using chi square test or, when there were less than five observations in any group, Fisher's exact test. To compare medians of a numerical variable by levels of a categorical variable, Kruskal–Wallis rank sum test was used.

Graphics

Maps were produced in the software R, R Core Team, 2019 [16], using data of registered pig enterprises per region in 2020, obtained from the Swedish Board of Agriculture's official statistics database [15]. Wild boar abundance was illustrated by the number of wild boars shot per 1000 hectares (10 km^2) for the hunting year 2019/2020 [12].

Results

Of the 1003 invitations sent out to pig producers, 211 (21.0%) submitted a response to the questionnaire. Most of the responses, 83.9% (177/211) were received within the first 10 days. The geographical assessment of response coverage showed that the pig producers in the two most northern regions, as well as the region 'Småland and the islands' in the south-east, were slightly less represented in comparison with other regions (Fig. 1). However, with regards to wild boar abundance, all regions were deemed to be sufficiently represented for the purpose of the study (Fig. 1).

The main types of production and farm size among respondents are summarized in Table 1. Ten respondents used the 'other, please specify' option for main production type. Based on their specified comment, two respondents belonged to one of the available options and were recoded accordingly. Of the eight remaining in the 'other' category, five specified being a sow pool central unit, and the other three were small producers (less than five sows) with outdoor access.

Housing and outdoor access

Of the 211 respondents, 201 provided information about the type of housing. Of these 201 respondents, 194 (96.5%) chose 'conventional pens or group pens indoors', 33 (16.4%) 'pens or group pens in well-ventilated barn with open doors or sliding wall sections', and 16 (8.0%) 'outdoor access behind fence/electrical fence'. Four respondents chose 'other, please specify', but their comments allowed them to be placed in one or a combination

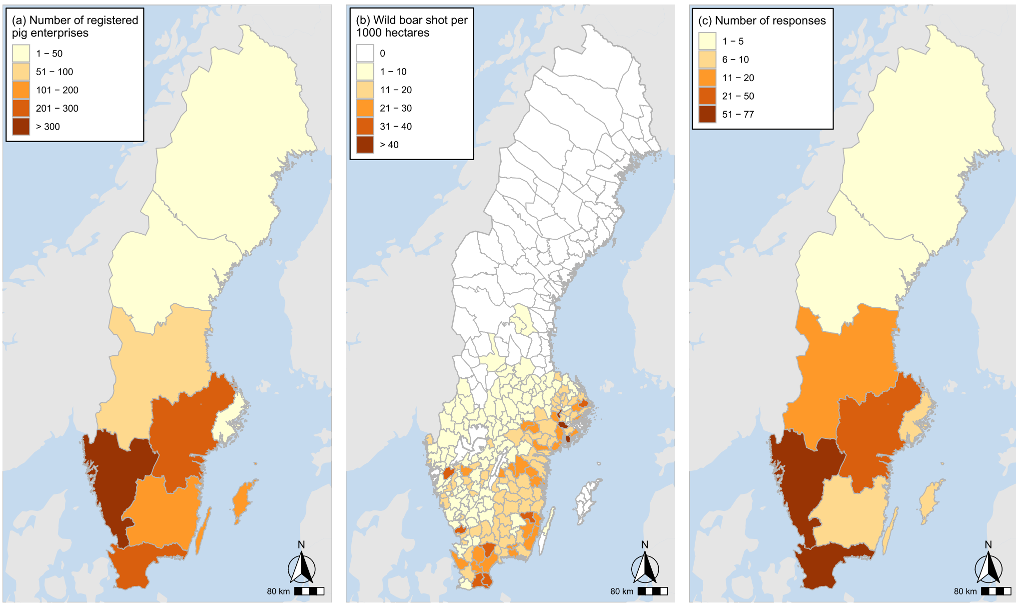

Fig. 1 Location of questionnaire respondents in relation to the population of domestic pigs and wild boars. **a** Geographical distribution of pig enterprises on European regional level, NUTS2. **b** Wild boars shot per 1000 hectares (10 km^2) on the level of regional hunting divisions. **c** The number of questionnaire respondents on European regional level, NUTS2

Table 1 Main type of production of 206 Swedish pig producers responding to a questionnaire on wild boar presence

Main type of production	Number of respondents	Category of pigs	Number of animals		
			Min	Max	Median (IQR[a])
Farrow-to-finish	76	year sows[b]	10	950	250 (120–330)
		finishers per year	200	25000	5600 (2800–8000)
Specialized piglet	54	year sows[b]	9	3000	300 (129–500)
		finishers per year[c]	10	6500	135 (80, 425)
Specialized fattening	64	finishers per year	600	47500	3500 (2500–6000)
Breeding/gilt	4	year sows[b]	110	400	–[d]
		finishers per year[c]	2500	6500	–[d]
'Other'	8	year sows[b]	2	3160	–[d]
		finishers per year	2	300	–[d]

[a] Inter-quartile range (25–75% percentiles)

[b] Sows in production, per year

[c] 20 of the 54 specialized piglet producers, and 3 of the 4 breeding/gilt producing herds also produced finishers

[d] Includes diverse categories or few responses making it unsuitable for a median value

of the given options. As the question allowed for more than one alternative, the percentages add up to more than 100.

Water source

The two questions regarding source of drinking water for the pigs or for cleaning purposes in pig houses were answered by 197 and 192 respondents, respectively. Water from a well was by far the most common with 158 (80.2%) respondents using this source for drinking water and 156 (81.3%) for cleaning purposes. A single respondent replied using a naturally occurring open water source (such as stream or lake) for drinking water and three respondents indicated the use of such open water source for cleaning purposes. The remaining respondents used municipal water, 38 (19.3%) for drinking and 33 (17.2%) for cleaning.

Wild boar observations

The question asked for observations of wild boar or their activities during each of the four seasons. Of the 211 respondents, 207 replied to this question and of these 204 answered for all four seasons while three answered for two or three seasons (Fig. 2). Of the 207 responses, 167 (80%) answered that they had seen wild boars or signs of wild boar activity in the vicinity of their pig holding at least once during the year.

As the frequency of wild boar observations did not differ significantly between seasons ($P=0.26$), an average observation level per farm was calculated and further classified into three categories, 'daily to weekly' (n = 79), 'monthly to rarely' (n = 85), or 'never' (n = 40), which were used for subsequent analyses of association with farm characteristics.

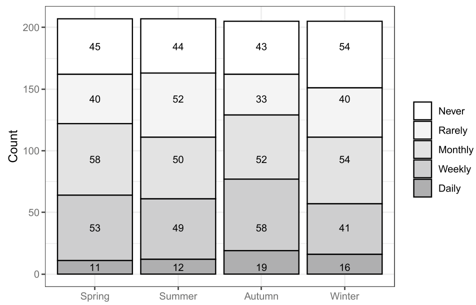

Fig. 2 Seasonal wild boar activity in the vicinity of Swedish pig holdings. Frequency of seasonal observations of wild boars or wild boar activity in the vicinity of pig holdings as stated by Swedish pig producers (n = 207)

Wild boar observations, distance

Respondents who reported wild boar observations were asked to provide information on proximity of observations to their premises. Of the respondents, 114 answered to the question on the shortest distance from different pig holding buildings where they had observed wild boar or wild boar activity. One respondent had contradictory responses regarding distance and observations and was therefore excluded from these results. The responses are summarized in Table 2.

There was no significant difference in the median observed distance between the types of pig housings ($P=0.84$), hence only the closest distance reported by each respondent was used in subsequent analyses.

Of the 211 respondents, 192 replied to the question regarding wild boar in the vicinity of other buildings than pig housings on their premises. All but one respondent

Table 2 Distance of wild boar observations to types of pig housing, reported by Swedish pig producers (n = 113)

Type of building	Number of respondents:	Distance of wild boar observations, in meters		
		Min	Max	Median (IQR), meters
Outdoor climate barn/sliding wall sections	29	1	1000	50 (20, 150)
Conventional pig houses	102	1	1000	55 (20, 200)
Pigs with outdoor access, fenced	10	0	200	100 (20, 100)

As more than one type of pig housing may be present on a pig farm, the total number of responses exceed the number of respondents replying to this question

chose a single answer only, even if the question allowed for multiple answers. Twenty-five of the 192 respondents reported no wild boar presence in the area, 140 stated that wild boars were present in the surroundings, but did not get close to any buildings not housing pigs. Ten respondents indicated that wild boars got close to feed storages and 18 selected ‘other’. One respondent chose both ’other ‘ and ’feed storage’.

Crop damage

All 211 respondents replied to the question of crop damage by wild boar, 20 stated that they did not grow crops for pigs. Of the 191 farmers that were growing crops, 69 (36.1%) answered that they had not experienced wild boar damage during the growth season of 2019. The remaining 122 (63.9%) reported wild boar damage in grain crops and 19 of them had experienced wild boar damage in other crops as well, mainly protein crops such as peas or field beans, and/or grass and forage crops.

Hybrid litters

None of the 208 respondents to the question about hybrid litters indicated that there had been a suspected hybrid litter between wild boar and domestic pig in the last 12 months.

Mitigation strategies and protective measures used to prevent wild boar contact

The responses to the question on mitigation measures are shown in Table 3. Five respondents did not answer this question.

Multiple choices were allowed, hence the total numbers in Table 3 add up to more than 206 or 100%. The option of ‘other’ regarding mitigation strategies was, when specified, either an explanation of why there were no mitigation strategies in place, including being located in a northern region where wild boars are not present, pigs kept in an indoor setting only or the producer did not possess the hunting rights for the land in question. The alternative ‘other’ was also used to make clarifying comments regarding already selected options.

A question about whether all pigs on the farm could be raised indoors only, in case of restrictions imposed during a disease outbreak, was answered by 14 of the 16 respondents who had pigs with outdoor access. Twelve responded that they could raise the pigs exclusively indoors, and two answered that they could not, due to limited space or lack of suitable housing.

Table 3 Mitigation strategies used by responding pig producers to avoid contact with wild boar

Measure	N
Hunting of wild boar in the area	126 (61.2%)
‘Strategic feeding’, baiting off-site	31 (15.0%)
‘Other’	11 (5.3%)
Double fence around pigs with outdoor access[a, b]	4 (1.9%)
Perimeter fence around production site[a]	4 (1.9%)
Nothing	69 (33.5%)

Measures used to avoid wild boar presence at pig production holdings in Sweden as stated by the producers (n = 206)

[a)] One respondent had both types of fences, the remaining three in each fence category had either perimeter fence or double fence around the outdoor pig enclosure

[b)] Sixteen producers of pigs with outdoor access replied to the question, hence 25% of relevant producers replied having a double fence

Regarding the respondent’s own hunting activities, 176 replied to this question of which 116 (65.9%) said they did not hunt wild boar. The remaining 60 (34.1%) did hunt wild boar in Sweden, and six replied also travelling abroad for wild boar hunting. Regarding the hunting activities of any employees in contact with the pigs there were 175 responses of which 133 (76.0%), replied they had no employee in contact with the pigs who was engaged in hunting of wild boar, 38 (21.7%) replied that employees did hunt in Sweden of which one respondent indicated that employee(s) were also engaged in hunting activities abroad. Four respondents (2.3%) stated that they did not know their employees’ hunting habits.

In the univariable analysis of the farm characteristics geographical region ($P < 0.01$), main type of production ($P = 0.96$), farm size ($P = 0.33$), and level of outdoor contact ($P = 0.25$), in relation to wild boar observations, only geographical region showed a significant association. When the same parameters were investigated for association between geographical region ($P = 0.65$), main type of production (P = 0.58), farm size (P = 0.97) or level of outdoor contact (P = 0.88), to the closest distance where wild boar were observed, no significant associations were found.

The two outcome variables, wild boar observations and shortest distance to the observation of wild boars or their activities, showed a significant association (P < 0.01) when assessed.

The explanatory variable main type of production was significantly associated with the level of outdoor contact (P < 0.01), and farm size (P < 0.01). Likewise, in univariate analysis the explanatory variables farm size and level of outdoor contact was associated (P < 0.01), as was main type of production and geographical region (P < 0.1).

Discussion

For the last decades, the wild boar population has been on the rise in Sweden and the rest of Europe [18]. Disease presence among wild boar populations represents a risk for disease introduction to domestic pigs. For ASF, the greatest risk for disease transmission from wild boars to domestic pigs is likely through indirect contact with the external environment [6, 7, 19] and the potential of indirect contact at Swedish pig farms is supported by this study. The fact that respondents to a large degree observed wild boar or their activities implies that, if these animals carry an infection, contamination of the immediate farm environment could occur with subsequent risk of disease transmission.

This study could not correlate the frequency of wild boar observations to any of the recorded farm characteristics, farm size, main type of production or level of outdoor access. However, the recorded presence of wild boar is associated with geographical region. Wild boars are, to a large extent, present close to Swedish commercial pig farms with 80% of the responding pig producers stating that they observed wild boar or wild boar activities in the vicinity of their farm at least once during the year. Although wild boars are shy and rarely observed directly, their presence is readily detected as rooting, sometimes with an addition of tracks or droppings. Farmers in the regions where wild boar are present are experienced in observing the signs of these animals and the risk of false positive responses to these questions may be regarded as low.

Overall, the distribution of production types and farm sizes represented in the responses reflect Swedish pig production. The recruitment for this survey, involving pig health advisory organisations, made it possible to reach the vast majority of Swedish pig producers and we believe that the results sufficiently reflect commercial pig farms in areas where wild boars are present.

Pigs raised commercially in Sweden are mostly kept indoors. Outdoor access is mainly seen on organic farms, which represented 2.6% of the slaughtered pigs in 2020 [20]. Some of the respondents with outdoor access for their pigs stated they had few pigs, indicating that they were not typical commercial holdings. While perimeter fencing around Swedish pig farms is rare, all pigs with outdoor access are required by law to be fenced in. Although fencing reduces the risk of direct contact with wild boar, this risk is not completely eliminated as wild boars may still break through or reach domestic pigs across fences. Double fences further reduce the risk of direct contact or fence breakthrough, but this study shows that double fencing is not used by all farmers. Four of the respondents stated use of naturally occurring open water sources for cleaning of pig houses, with only one also letting the pigs drink such water. Contamination of open water sources by infected wild boar might result in disease transmission if the concentration of the infectious agent is high enough in the water used in the pig house [21].

The majority of the questionnaire respondents who grew crops for pigs had observed wild boar damages in their fields. Hence, at least theoretically, indirect transmission of infectious agents from wild boars to domestic pigs via contaminated straw harvested from these fields is possible since straw is extensively used for bedding and enrichment in Swedish pig production.

Our results indicate that hunting and strategic baiting are the most prevalent mitigation strategies in use to avoid wild boar presence around pig farms, but responses stating doing nothing to control the wild boar population were also common. The response of not applying any strategies may reflect that not all producers are hunters or possess the hunting rights in the areas surrounding their farm, and also that some responding producers' farms are located in areas where the wild boar is less common. Hunting abroad in areas where ASF is present in the wild boar population has been proposed as a risk of introducing the disease to Sweden. A few of the respondents indicated that they or their staff engaged in hunting abroad, which merits further investigation. Potential mitigation strategies included measures to draw wild boars away from the farm (strategic baiting), fencing to prevent them entering as well as reducing the population and hence the risk of unwanted visits. A combination of these strategies seems warranted but require collaboration between different actors (farmers, land owners, hunting rights owners, and hunters) in the same region.

Almost all farms with outdoor access responded that it would be possible to raise their pigs indoors in a disease outbreak situation where restrictions on outdoor access would be imposed. As the results of this study confirm the potential for indirect contact between wild boar and domestic pigs, this remains an important consideration for disease preparedness in Swedish pig production.

Not all participants answered all questions. The questions were grouped in sections on separate pages in the questionnaire, and missing answers were mainly seen in the end of sections, whereas the questions displayed at the top of each page were more often answered by all respondents. This can be partly explained by the layout, where questions located at the end of the section might not have been noticed before progressing. Still, most questions were answered by a majority of the respondents and the number of responses were sufficient for the analyses. The strong association between different farm characteristics is not surprising but prevented assessment of any single risk factor for wild boar presence in the farm vicinity. Nevertheless, it seems that most pig farms located in areas where wild boars are present will be at risk for indirect contact between wild boars and the domestic pigs. It is also important to keep in mind that the wild boar situation in Sweden is not static. Even though a farm currently may not experience wild boar contacts, the local wild boar abundance may rapidly change and require adaptation or deployment of mitigation strategies. Hunting activities in regions in which ASF is present among wild boars are also important for the risk of introduction of ASF to the wild boar population in Sweden. Other studies are currently investigating these aspects.

Conclusions

The results of this study confirm that wild boars are present in close vicinity of commercial pig farms in Sweden, providing opportunities for contamination of the immediate farm environment should an infectious disease like ASF be present. Apart from geographical region, no other investigated potential risk factor was found to be associated with wild boar observations. Wild boar presence around pig farms calls for measures to mitigate direct and indirect contact between wild boar and domestic pigs and a need for deeper understanding of the wildlife/livestock interface to adjust measures accordingly.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13028-023-00705-x.

Additional file 1: Web questionnaire questions as PDF, translated to English from Swedish by authors.

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Author contributions

LE, SW, KST, AN and SSL did the study design and questionnaire development. LE and SW conducted the data analysis, and LE made the initial draft of the article. All authors reviewed the manuscript, and all authors have read and approved the final version of the manuscript.

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Availability of data and materials

To ensure anonymity, the categorized version of the dataset regarding geographic location and farm size is available from the author on reasonable request.

Declarations

Ethics approval and consent to participate

This study did not require official or institutional ethical approval. The questionnaire recipients were informed of the purpose of the questionnaire, that the study is anonymous, and that participation is voluntary.

Consent for publication

Not applicable.

Prior publication

Data has not been published previously.

Competing interests

The authors declare no conflicting interests.

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Publisher's Note

Questions from an online questionnaire survey directed at commercial pig holders in Sweden regarding wild boar observations in the vicinity of their pig holding. The study was conducted in November 2019 to January 2020

First two digits in your farms postal code: ____
Main pig production of farm: □ Farrow-to-finish production; □ Piglet production; □ Finisher pig production; □ Live animals (Breeding/Gilts); □ Other, please specify: ____
Animal trade category: □ Conventional, indoor; □ Outdoor access; □ Specific Pathogen free (SPF); □ Other, please specify: ___________
Approximate number of year-sows in production (SIP), per year: □ I do not keep sows; □ Number of sows (SIP): ____
Approximate number of finisher pigs produced yearly: □ I do not keep finisher pigs; □ Number of finisher pigs: _____
What pig housing alternatives are present at your farm: (Check all that apply) □ Conventional pen/group pen indoors; □ Pen/group pen in outdoor climate barn; □ Outdoor access with fence/electric fence; □ Other, please specify: ________________
Water source for pigs (drinking): □ Municipality water; □ Well; □ Open water source (lake/creek); □ Other, please specify: _________
Water source for cleaning of pig housing: □ Municipality water; □ Well; □ Open water source (lake/creek); □ Other, please specify: _________
In the last 12 months, have you had a suspected hybrid litter between wild boar and domestic pig: □ Yes; □ No
In the last 12 months, have you observed wild boar, or signs of wild boar activity (rooting/footprints/droppings) close to pigs with outdoor access? □ Not relevant, no pigs with outdoor access; □ No, no wild boar close to pigs with outdoor access; □ Yes. Please specify the distance (m): _____
In the last 12 months, have you observed wild boar, or signs of wild boar activity (rooting/footprints/droppings) close to pigs in outdoor climate barns? □ Not relevant, no pigs in outdoor climate barns; □ No, no wild boar close to pigs in outdoor climate barns; □ Yes. Please specify the distance (m): ___
In the last 12 months, have you observed wild boar, or signs of wild boar activity (rooting/footprints/droppings) close to conventional indoor pig houses? □ Not relevant, no pigs in

conventional pig houses, indoor; □ No, no wild boar close to pigs in outdoor climate barns; □ Yes. Please specify the distance (m): __
Have you, this year (2019) had damage caused by wild boar in crops grown for use in pigs: (Multiple choices possible): □ I do not grow crops for use in pigs; □ No, no wild boar damage in my crops; □ Yes, in grain; □ Yes, in other types of crops. Please specify what crop: ____
In the last 12 months, have you observed wild boar, or signs of wild boar activity (rooting/foot prints/droppings) close to other buildings, not housing pigs, at your farm (Multiple choices possible) □ No, there is no wild boar in my area; □ No, wild boar is present in the area but they do not come close; □ Yes, by feed- or litter storage; □ Yes, by other buildings. Please specify: ____
Approximately how frequently do you observe wild boar or signs of wild boar activity (rooting, footprints, droppings) during each of the four seasons (spring, summer, autumn, winter). Question asked for each season, separately: □ Never; □ Very rarely, once during the season; □ Rarely, once monthly during the season; □ Often, every week during the season; □ Very often, daily, or close to daily, during the season.
What mitigation strategies do you use at your farm to avoid contacts between the wild boar and domestic pigs: (check all that apply): □ Perimeter fence surrounding the farm; □ Double fencing in pig pens; □ Hunting; □ Strategic use of feeding/baiting in other location; □ Nothing; □ Other, please specify; _____
In case of restrictions imposed by animal disease outbreak, could you for a period of a few months, keep all your pigs solely indoors? (Please disregard any certifications that require outdoor access): □ Not relevant, no pigs with outdoor access, my pigs are already kept indoors; □ Yes, pigs that are kept outdoors or have outdoor access can temporarily be housed solely indoors; □ No, please specify what prevents you from housing the pigs indoors (e.g. lack of building, lack of feeding/watering facilities): __
Do you hunt for wild boar: □ Yes, in Sweden only; □ Yes, in Sweden and abroad; □ Yes, only abroad; □ No
Does any of your staff in contact with the pigs hunt for wild boar: □ Yes, in Sweden only; □ Yes, in Sweden and abroad; □ Yes, only abroad; □ No; □ I do not know

II

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RESEARCH

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Perceptions and practices of Swedish wild boar hunters in relation to African swine fever before the first outbreak in Sweden

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Abstract

Background The first outbreak of African Swine Fever (ASF) in Sweden was detected in 2023 in wild boar. This study was conducted before the first ASF outbreak with the objective of investigating Swedish hunters' perceptions and practices pertaining to ASF ahead of any potential future outbreak.

A mixed-methods interview study with Swedish wild boar hunters, consisting of focus group discussions and a questionnaire, was undertaken between October 2020 and December 2021. Six focus groups were conducted online, and an online questionnaire with questions related to practices and habits concerning hunting, the use of bait and hunting trips was sent to all members of the Swedish Hunting and Wildlife Association. A total of 3244 responses were received.

Results Three general themes were identified in a thematic analysis of the data from the focus groups: hunters are willing to engage in ASF prevention and control, simplicity and feasibility are crucial for the implementation of reporting, sampling and control measures, and more information and the greater involvement of the authorities are required in ASF prevention and control. Results from the questionnaire showed that the use of bait was common. Products of animal origin were rarely used for baiting; the most common product used was maize. Hunting trips abroad, especially outside of the Nordic countries, were uncommon.

Conclusions Hunting tourism and the use of bait do not seem to constitute a major risk for the introduction of ASF to wild boar populations in Sweden. The accessibility of relevant information for each concerned stakeholder and the ease of reporting and sampling are crucial to maintain the positive engagement of hunters.

Keywords Focus group discussions, Questionnaire, Disease control, Hunting tourism

Background

The incursion of African swine fever (ASF) into Georgia in 2007 [1] was the starting point of the current epidemic of ASF in Europe. Since then, the epidemic has developed in unprecedented global dimensions [2]. The disease is currently present in large parts of Europe (to date: Azerbaijan, Bosnia and Herzegovina, Belarus, Belgium (declared free in 2020), Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Moldova, North Macedonia, Poland,

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Romania, Russia, Serbia, Slovakia, Sweden and Ukraine), and the continuous spread, emergence and re-emergence of ASF present a constant threat to domestic pigs and wild boar [3, 4]. Controlling ASF in wild boar populations has proved difficult [5]. In the current epidemic in Europe, only Belgium and the Czech Republic have so far managed to eradicate the disease after its introduction into a wild boar population (the Czech Republic was re-infected in 2022) [6, 7]. Hunters have been identified as extremely important stakeholders in ASF control [8, 9] and several studies have investigated European hunters' perspectives in relation to the disease [10–12]. However, as hunting realities and practices, land ownership and wild boar population dynamics vary between countries, it is important to understand their perspectives in a local context [13]. For the same reason, data related to the risks of introducing ASF into new areas and the further spread of the disease in these areas need to be collected locally [14].

Hunting tourism and certain hunting practices have been identified as risk factors for introducing or spreading ASF [15]. To hunt in a foreign country the individual hunter needs follow the country's rules for weapons and for hunting, and if bringing a hunting weapon, have a weapon's license and a permit for travelling with the weapon (weapon passport). To hunt in Sweden a valid hunting licence and hunting card (issued from the Swedish Environmental Protection Agency) is needed. Access to hunting grounds must be given by the landowner. Most Swedish hunters belong to local hunting groups and are members of either of the two hunters' organisation, the Swedish Association for Hunting and Wildlife Management (SJF) being the largest with > 150,000 members or the Hunters' National Association with about 40,000 members.

The first outbreak of ASF in Sweden occurred in September 2023 in wild boar in an area at the northern limit of the bioregion for wild boar [16], where there is a relatively low wild boar density and few domestic pig holdings [17]. The exact source of the outbreak has not been identified, but disease introduction through natural wild boar movements was ruled out as most areas containing wild boar populations in Sweden are surrounded by water, preventing direct contact between Swedish wild boar and ASFV-infected populations in neighbouring countries. The only area that has a wild boar population and a land border is the western part of Sweden, which borders Norway. Norway has a very limited wild boar population, which is free of ASF. It was assumed that the virus reached the wild boar population via virus-contaminated food waste from domestic pigs or wild boar in an affected country [17]. Swedish pig farmers' perceptions of this outbreak have been described [18], and the perceptions and experiences of the hunters who participated in outbreak control actions are currently being investigated. However, general information about Swedish hunters' knowledge, attitudes and practices in relation to ASF prior to the outbreak, has not yet been compiled. This study was conducted before the first ASF outbreak in Sweden with the objective of investigating the perceptions and practices of Swedish hunters ahead of any potential future outbreak in order to be able to make use of the lessons learned should ASF come to Sweden.

Methods

This interview study with Swedish wild boar hunters was implemented between October 2020 and December 2021 and consisted of focus group discussions (FGD) and a questionnaire. The methods for these two parts are described separately below.

Focus group discussions

FGDs were conducted online using video conference software (Zoom Video Communications, Inc., San Jose, California, United States) in October and November 2020.

Study area and participant selection

Based on an evaluation of the geographical distribution of the wild boar population in Sweden, the decision was taken to limit the study area for the FGDs to southern/central Sweden (Fig. 1). Interviewees were recruited with the help of local representatives of SJF in the study area, with the inclusion criteria being people who hunted wild boar in Sweden and were aged 18 and over. Membership in SJF was not an inclusion criterion and not asked for or recorded. Discussions were arranged in hunting districts where at least three hunters would be willing to participate in an online FGD. To facilitate an inclusive and participative discussion, and especially as the FGDs took place online, it was decided to include maximum five participants per group. Once at least three people had agreed to participate, an invitation was sent by email. Additional groups were included until data saturation was achieved, meaning that no new information emerged from the discussions.

Data collection

The FGDs were conducted in Swedish and led by a facilitator (AFB or LS), and followed a topic guide (see Additional file 1). Before the first FGD, the topic guide was tested in a pilot FGD and adapted accordingly. Each FGD started with the facilitator introducing the study and the research team and informing participants about data handling and confidentiality. With the consent of all participants, the discussions were recorded via the

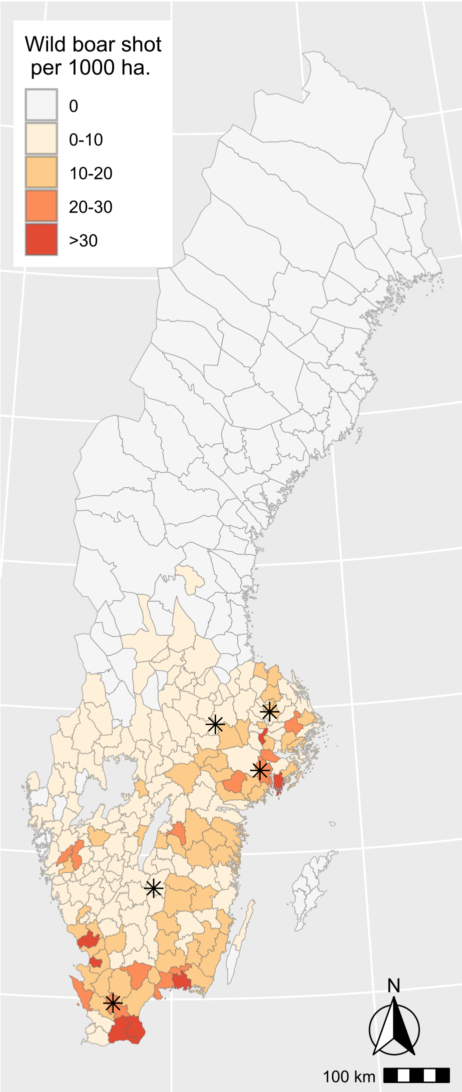

Fig. 1 Map showing numbers of wild boar shot per 1000 ha in Sweden 2018–2019. The distribution of the hunting bag is considered to reflect the distribution of the wild boar population. Asterisks represent the approximate locations of the hunting districts of participants in the focus group discussions. The map was created in the statistical software 'R' (R core team, Vienna 2024), using the package 'ggspatial'. Data source: "The Swedish Association for Hunting and Wildlife Management, game monitoring. Available online: www.viltdata.se"

built-in recording feature in the video conference tool, with detailed notes taken as backup. Recordings were transcribed *ad verbatim.* Following the introduction, a short presentation was given by one of the researchers (EC or LE) about the current situation regarding ASF in Europe and in Sweden, before the group discussion took place. The FGDs were flexible, allowing the discussion to evolve according to the participants' interests and priorities, while the facilitators ensured that the topics in the topic guide were covered. When the discussion concluded, the second part of the presentation was given, focusing on the prevention and control of ASF. At this point in the meetings, participants could ask any questions arising out of the discussion. Each FGD lasted approximately two hours.

Data analysis

Transcripts were imported into a qualitative data analysis software (NVivo, QSR International Pty Ltd. Version 12, 2018) and coded. At all steps of the analysis, codes and themes were allowed to emerge inductively through repeated reading of the data, with the aim of capturing the participants' perspectives. Based on primary codes representing similar expressions and reasoning, emerging themes and general overarching topics were developed. The analysis was performed in Swedish and, once established, the codes, themes and topics were translated into English. Where participants are quoted, their answers have been translated into English.

Online questionnaire

The online questionnaire was created in the software survey tool Netigate (Netigate AB, Stockholm, Sweden) and was available to respondents during the month of November 2021.

Data collection

The online questionnaire was written in Swedish and had 28 single response or multiple-choice, closed or semi-closed questions focusing on wild boar hunting, and related to hunting practices, hunting travels and the use of bait. An English version of the final questionnaire, translated for the purposes of this article, is included in Additional file 2. The replies were anonymous and no personal information, such as age, gender or home location, was collected.

A pilot version of the questionnaire was tested on a group of people that were active hunters or that had former hunting experience and adapted accordingly. Subsequently, a first version was distributed through the authors' personal contacts, hunting groups on social media, and via the website of the Swedish Veterinary Agency (SVA). Based on feedback from the respondents of the first version, a second, slightly adapted and improved version was distributed to all members of the SJF who had a registered e-mail address. There was no selection based on region or whether the receiver had an active hunting permit. This second version of the questionnaire was distributed in early November 2021 and remained open during that month. To avoid duplicate answers, only responses from the second version were included in this study.

Data analysis

Questionnaire data were exported from the Netigate tool in Excel format. Further handling and analysis were performed in the open-source statistical program R (R Core team, 2022). Graphs were made with 'ggplot' from the 'tidyverse' package, and the map in Fig. 2 was created using the 'ggspatial' package.

The words 'baiting' and 'supportive feeding' were used either in conjunction or interchangeably throughout the questionnaire. For the purpose of this analysis, the two concepts were considered as the same practice of 'baiting', i.e. placement of feed in order to attract wild animals. When relevant, categorical answers were aggregated to accommodate the analyses. Free-text answers, given if the respondent was asked to specify a selected answer further, were read and analysed for content and used to improve and deepen understanding of the quantitative data.

Whenever appropriate, descriptive statistics were produced and associations between categorical variables were assessed by Pearson's chi-squared test or odds ratio calculations. $P < 0.05$ was considered significant.

Data from the final question, which was a free-text field with room for general comments or any other additional information, were analysed by one of the researchers (LE) in several steps. First, the whole text was read through for the purpose of becoming familiarised with the data. Second, inductive coding was applied. After the inductive coding was completed, it became apparent that the codes that emerged were very similar to the emerging themes from the thematic analysis of the FGDs. In a third step, deductive coding using the emerging themes from the analysis of the FGD was applied to the data.

Results

Focus group discussions

In total, six FGDs were conducted, comprising a total of 25 hunters (minimum three, maximum five participants per FGD) from five different hunting districts (located in the counties of Jönköping, Skåne, Södermanland, Uppsala and Västmanland) (Fig. 1). A few of the participants hunted in other districts outside the study area (namely in the counties of Dalarna, Hälsingland, Jämtland, Västerbotten and Västernorrland). Of the 25 hunters, three were women and 22 were men. This skewed gender balance roughly represents the gender composition of Sweden's licensed hunters (8.1% female in 2022) [19]. The median age was 47 years (minimum

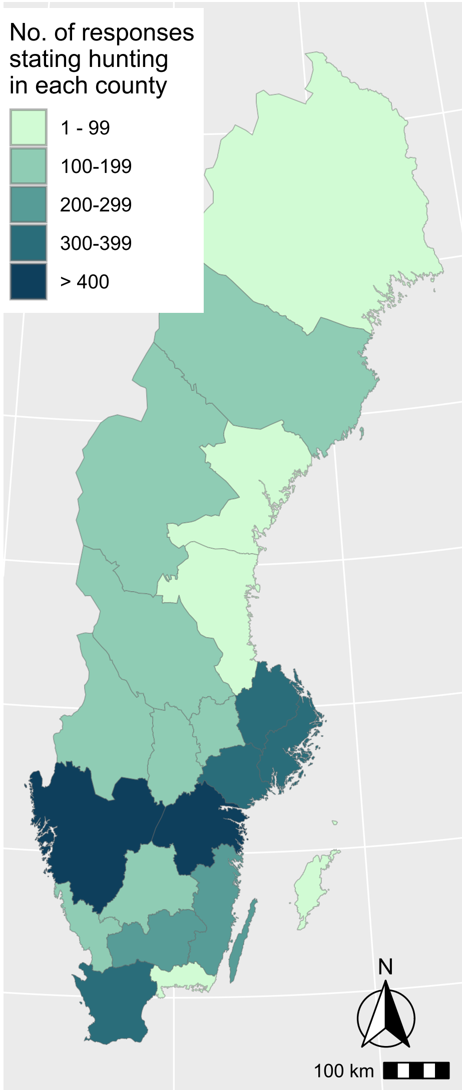

Fig. 2 Map visualising the county/counties in which the respondents hunt. As this was a multiple-choice question, respondents may have selected more than one county as the numbers exceed the total number of questionnaire responses

20, maximum 72 years). The majority of the participants reported that they hunted several times a week.

In the thematic analysis, 46 primary codes emerged (Table 1). Some of these codes were related to each other and could be grouped into eight emerging themes. From the emerging themes, three general topics could be derived. The emerging and general topics are developed and described in the subsequent section.

Emerging themes

ASF introduction The participants expressed a general concern that if the ASF epidemic continued to develop in Eastern/Central Europe, the disease would eventually reach Sweden at some point. This scenario was described as almost inevitable: *"In the long run, I think it's incredibly hard not to get it. Whether it will be in 3 years, 5 years, 10*

Table 1 Primary codes, emerging themes and general topics from the six focus group discussions with hunters conducted in 2020

General topics
- Hunters are willing to engage in ASF prevention and control
- Feasibility is crucial for the implementation of reporting, sampling and control measures
- More information and the greater involvement of the authorities are required in ASF prevention and control

Primary code	Emerging theme
Concern about ASF introduction (general) Concern about ASF introduction with imported feeds Concern about ASF introduction with tourists and lorries Hunters are not the major risk of introduction Increased border control for pig/pork/wild boar products Will change practices if ASF arrives	ASF introduction
Carcass detection Carcass finder's fee – positive and negative perceptions Concerns about ASF spread with carcass handling Finding wild boar carcasses is difficult Hunters are already spending the maximum possible time in forests	Carcass handling
Control measures – generally positive perceptions Control measures need to be easy Culling is not hunting Fencing – difficult and negative perceptions Financial compensation per shot wild boar – positive perceptions Forest access restriction – positive and negative perceptions Incentives to increase hunting Selective hunting – positive and negative perceptions Population density control – positive and negative perceptions	Control measures
Cleaning and disinfection of hunting equipment Promotion of wild boar hunting in Sweden Trophies are important Use of hunting weapon exit passport to enable risk-based information campaigns	Hunting tourism
Hunters' knowledge gaps concerning ASF Information campaigns to the public Information requirement for hunters Use hunters as ASF ambassadors to inform people about the disease	Knowledge
ASF task force within hunting organisations Contact with authorities Hunters' local knowledge important Hunters' work needs to be remunerated (Top-down) coordination and governance	Outbreak management
Relationships with farmers Relationships with other hunters Relationships with landowners	Relationships and cooperation
Better feedback after reports Early detection Form a task force within hunting organisations for ASF reporting Integration with hunting applications Knowledge gaps concerning reporting and sampling Not relying on hunters volunteering for reporting and sampling Online reporting – not aware Positive perceptions of reporting Reporting and sampling need to be easy and simple Use local hunting leaders for reporting	Reporting

years or 20 years I can't say, but I believe that sooner or later we'll have it in the country." (FGD 3).

The participants expressed concern and worry about the negative impact that the introduction of ASF would have on their own leisure hunting and on the hunting industry. In this regard, several risks of introduction were repeatedly mentioned: hunting tourism including the risk of bringing back equipment, dogs and trophies; workers, truck and ferry traffic from ASF-infected countries in Europe and the associated danger of people bringing and discarding infected pork/wild boar products within reach of Swedish wild boar; and the import of animal feed from affected countries.

Carcass detection Participants said that despite spending a lot of time in the forest (hunting, preparing for hunts, walking dogs, picking berries and mushrooms), they rarely see wild boar carcasses. They mentioned that wild boar carcasses are hard to find as the animals tend to hide in inaccessible terrain. Participants explained that it was literally impossible to spend more time in the forests without compromising work or family duties, especially if there is no compensation for it: *"...every weekend there is a hunt. So we're out examining our own land thoroughly, basically all the time at weekends"* (FGD1). A more immediate or closer threat of ASF or a specific mission to search an exact area might be an incentive for active carcass searches. The issue of compensation for detected/reported carcasses was discussed and was not really considered to be an incentive (as the participants already spend the maximum possible time in the forest), but it would be seen as a positive gesture, at least compensating for direct costs such as fuel. Several participants said that they were not sure if handling carcasses constituted a risk of spreading ASF, and therefore were unwilling to do so. It was suggested that information about what to do with found carcasses should be included in information materials handed out in connection with larger hunts.

Control measures The participants expressed a generally positive attitude towards contributing to ASF control. This was based on a desire to reduce the negative impact of ASF on the wild boar population, which was regarded as a valuable resource, on hunting as a hobby and a lifestyle, and on other stakeholders involved in forests and farming: "*As wildlife management is more or less our main task, it's good if diseases are not being spread among animals. It's not just among pigs, it's all of them"* (FGD5). In this regard participants seemed to trust that the authorities would know what the most effective control approach would be and expressed their readiness to be involved and assist. However, they emphasised that control efforts cannot rely solely on hunters volunteering to help: *"I think it's quite considerable, there's a considerable interest from hunters to help out, so I think that if there were information and training, and even some financial compensation, there wouldn't be any problems"* (FGD 1) and *"No, but we should be clear that to carry out something like this, it's not for entertainment, it's very hard work and takes many hours. We're counting on people doing this voluntarily. Nobody has the resources to do it on voluntary basis"* (FGD 6).

Some of the specific control measures used in the ASF epidemic in Europe were discussed: culling, fencing, reducing the wild boar population, restricting access to forests, and selective hunting. General restrictions in forest access were considered to be counterproductive as this would mean that wild boar hunting would cease, and population sizes thus increase. They also discussed that if access to forests were restricted in some areas where there is a high density of other wildlife populations that damage crops (e.g. fallow deer), the reduced hunting pressure could potentially result in substantial damage to forests and farming. The abundance of forests and the significance of forests for the general population's recreation in Sweden were also underlined. Locally applied access restrictions were still considered to have a negative impact on the participants' daily lives, but would be acceptable for the common good of ASF control and for short time periods: *"But absolutely, if it was swine fever, to not spread that, we would of course do it, but it's not something that people want to do"* and" *No, then we have to deal with the problem and solve that problem so that we can get out into the woods and the lands"* (both FGD 5).

Fencing was discussed as being difficult to implement. Factors mentioned were the ability of wild boar to penetrate fences, the difficulties of fencing off areas where people live and farm, administrative challenges with multiple landowners and also the length of the fence if the fenced areas needed to include the entire home range of affected populations. Some participants were aware of the positive experience with fencing from the ASF outbreak in the Czech Republic, and seemed to have a more positive attitude towards the use of fencing for controlling ASF.

As for other control measures and reporting (see below), participants were positive about assisting in reducing the wild boar population, but requested clear information both regarding the purpose of the measure and instructions for the procedures for doing so. Many participants had experienced challenges with reducing the wild boar population by hunting (increased hunting pressure leading to dispersal of populations, increasing populations despite intensive hunting, and the time and manpower required). Incentives for increasing wild boar hunting were proposed: reducing the rent for state hunting grounds, reducing the cost for *Trichinella spiralis* and caesium testing, and facilitating and legalising the sale of wild boar meat by hunters. It was discussed that if the goal was to reduce drastically or even eradicate a local wild boar population, methods not currently permitted for regular hunting (e.g. hunting from cars, use of night vision) and increased cooperation between hunting grounds would be needed. In this regard, participants made a clear distinction between culling (as in shooting large proportions of the populations with the help of baits or traps without using the meat, and disregarding the usual hunting ethics) and hunting. The use of poison was discussed, mainly in negative terms both regarding its efficacy and the ethics of it. A specific method to reduce the wild boar population, selective hunting of females, was discussed in both negative and positive terms: *"So in that particular situation it's not necessarily so wrong to shoot a sow"* and*"No, not if you know that you have the disease in the area"* (FGD 6). The negative perception of this measure dominated the discussion, with many participants referring to hunting ethics: "*If they become ill in an area where there is confirmed swine fever, then you'll have to remove everything, so it doesn't matter what it is. But to go out and shoot a sow with piglets today, no, that's not done"* (FGD 5).

Hunting tourism Awareness of biosecurity measures while hunting in different hunting grounds in Sweden, on hunting trips abroad and among foreign hunters coming to Sweden for commercial hunting was generally considered to be low: *"I think hunters in general maybe don't really understand, if you haven't worked with agriculture, that you don't go from one cow barn to another cow barn in the same clothes, but you wash clothes and shoes because of the disease transmission risk… […] So that knowledge also has to be mentioned and talked about. Because I don't know anyone who walks from one cow barn to another cow barn without washing properly and changing shoes* etc., *but I've never seen a hunter go and wash or change shoes or clothes when going from a hunt in one area to another area. I've never experienced that"* (FGD2). It was discussed that this could be associated with a lack of awareness and knowledge, and also that there is a tradition that hunting clothes should not be clean (to conceal the smell of washing powder, for example). In general, it was not considered problematic to clean dogs, clothes, boots or weapons, but clear information and instructions were requested. One group discussed hunting trophies, stating that it was an important part of hunting to be able to bring back trophies. It was suggested that the application process for taking weapons abroad (weapon passport) could be used as a way to distribute risk-based and targeted information to concerned hunters.

Knowledge The participants' knowledge about ASF varied, from hunters who had attended courses or lectures and were very knowledgeable about the disease and its prevention and control, how to handle suspicions of outbreaks, and the current status of the epidemic in Europe, to those who had little or fragmented prior knowledge. In general, those who were less knowledgeable about ASF were also more unsure how to handle, report and sample carcasses, for example. Specific knowledge gaps were identified and discussed: how ASF is spread, especially how indirect spread can be avoided, and how biosecurity measures during hunting, such as the cleaning of weapons, equipment and dogs, can prevent the spread of disease. As described previously, the participants were positive about participating in reporting, sampling, prevention and control, but demanded more and clearer information about their role and how to act: "*Everything depends on how the responsible organisations and authorities actually reach ordinary hunters and, yes, in fact the general public, explaining how we should handle the issue of African swine fever. That's where it begins"* (FGD2).

It was repeatedly mentioned that hunters are better informed about ASF than the general public, and that information campaigns should be directed at other actors who use forests, both for recreation and professionally, including in several languages, in different forms and at specific places such as ferry terminals and country borders: *"Because I think we hunters, we're updated and have the information, but the general public don't really know about this. And then there's a lot more information needed.* Via *all channels really, I think"* (FGD2). Mention was made that hunters and hunting organisations have an important role to play communicating within their organisations, but also with the general public. Reaching out to all members within the organisations was mentioned as challenging because not all hunters use e-mail or social media, for example. Hunters have unique knowledge that could be better utilised, but all the actors concerned need to join forces: *"And when we can do that, then we can be well informed, but we need help to be able to be ambassadors for this issue with swine fever, and again, maybe not put all the responsibility on the hunters, but enlist help from the outdoor recreation organisation or other who can also be ambassadors in relation to swine fever"* (FGD 3).

Outbreak management The need to urgently prepare and plan for an outbreak, and the changes that this might require in organisations at several different levels compared with the current set-up, was discussed. In this regard, the establishment of special "African swine fever task forces" within hunting organisations and hunting districts that would be more informed about the disease, take part in preparing action plans and be ready to react to reports of found carcasses was highlighted. It was emphasised that if hunters were asked to participate in hunting (or culling) outside their own hunting grounds in outbreak situations, this would need to be meticulously organised: to make sure that hunting does not contribute to disease spread, and for security in relation to the use of weapons and different hunting traditions in different hunting districts. In this regard, the importance of utilising hunters' local knowledge of the wild boar population and hunting grounds was emphasised, as was the opposite: that hunters mobilised to participate in eradication operations in other hunting grounds, for example, would not have this local knowledge. The participants again repeated that ASF outbreak management cannot rely on hunters volunteering for intensive and time-consuming tasks such as eradicating wild boar populations from an infected area. There were calls for firm instructions and top-down organisation from the authorities: *"There has to be some authority that deals with it and maybe does not force us out, but engages our help to prevent the spread of the disease where it emerges. Because it has to be local, the disease has to come somewhere first. There has to be some authority, or SVA, well someone who drives the whole thing" (FGD 4)* and *"How are we going to get people? Yes, we're a hunting team, but not everyone is part of the same hunting team. [...] as there is always someone who opposes things and then that's it. So someone has to come here and put their foot down so that it will be possible to carry it out on the day" (FGD 2).* These two citations reflect a generally expressed perception of trust towards the authorities, but one group (FGD 3) held the opposite view, highlighting a distrust, especially among older hunters.

Relationships and cooperation It was acknowledged that different stakeholders have different interests and priorities, i.e. some landowners and farmers struggle with the presence of wild boar and are eager to reduce their density, while hunters generally see them as a valuable resource that they would like to keep and develop. Owing to this, better cooperation and coordination were called for, for example with the selection of crops to optimise hunting and permission to shoot wild boar even if they cross over to another hunting ground during a hunt. Many of the participating hunters were also well rooted in their respective communities, and expressed concern about the negative impact on the farming and forest sectors: *"It overturns everyday life for so many people. For farming and, well, it's all businesses in the area that will be affected. Something that I think we all have in common, and all organisations no matter what, it's that we fight for a prosperous rural environment, and it would be absolutely devastating if we had a hot-spot area in Jönköpings län. [...] It's almost like Covid, but times 200 for the wild boar"* (FGD 2). It was further discussed that if an ASF outbreak were to occur, hunters from different hunting grounds would have to cooperate more closely than before, and clear governance from the authorities would be needed to facilitate cooperation and optimise effective hunting in that scenario.

Reporting A generally very strong interest was expressed among hunters about participating in reporting and establishing the cause of death in wild animals found dead: *"I think that generally among hunters there's a keen interest if you find a dead animal in sending it to SVA for investigation, because we all want healthy wildlife and to map if there is any kind of disease on our land or in our hunting area. So I think that there is already a strong willingness to help if we were to find a dead animal and send it in"* (FGD1). One group presented a conflicting opinion: that the most immediate action would be to shoot any unhealthy-looking animals and get rid of the carcasses by burying or burning them without any extra tasks attached to this, such as reporting, sampling or carrying a carcass to an accessible place: *"If you see a sick animal or an animal acting strangely, then you shoot it and burn it or bury it. That's how it works"* (FGD 3). Some participants were aware of what to do if they found a dead wild boar and were frequent users of the current reporting system in Sweden ("Rapportera vilt"). Others were unsure about what to do, did not know how to make a report, or what would happen or be requested of them as submitters of a report following a report being made. In this regard, several participants stated that in such situations they would call a local hunting leader who they were sure would know what to do. It was repeatedly expressed that reporting (as well as the ensuing procedures such as sampling, storage and sending in samples) must be as easy as possible if hunters are to participate: *"But what I'd like to see is that it's easy and smooth and it should go fast because then you'll do it. If it takes time and is bothersome then you don't want to spend energy on it"* (FGD 2). It was suggested that sampling material should be stored in central places in the regions for easy access, and reporting of carcasses incorporated into existing mobile applications used during hunting. When suggesting how reporting could be made easier, some participants described functions that are actually included in the current reporting system: *"It would be easier if there were an app where you can report quickly, that takes your coordinates where you are"* (FGD3) and *"As long as it's easy to send in animals, if there's good management around it, that you know exactly how to do it, the transport is paid for, then I don't think there are any doubts that people will send in what they find"* (FGD4). It was mentioned as important for hunters' willingness to participate in reporting that the objective of the reporting be explained, and that the person making the report received feedback of the results from all submitted reports and samples. Building up a local/regional organisation for reporting and sampling based in the county administrative boards or in hunting grounds (similar to other hunting and wildlife administrations) was also suggested. It was suggested that there could be a dedicated person (in the hunting district or the county administrative board) with expertise and equipment for reporting and sampling, and for the county administrative board to reduce the voluntary work expected of hunters and hunting districts, with this work being undertaken by paid staff instead.

General topics The emerging themes could be synthesised into three general, overarching topics: hunters are willing to engage in ASF prevention and control, feasibility is crucial for the implementation of reporting, sampling and control measures, and more information and the greater involvement of the authorities are required in ASF prevention and control. Throughout all the emerging themes, it was evident that the participants generally had positive views towards the authorities involved in ASF, and were *willing to engage in ASF prevention and control*. Participants considered it their duty to protect and preserve the wild boar population and to be involved for the common good, although of course with some variability in attitudes and their ability to commit. It was concurrently noticed that participants in most cases already invested a great deal, or virtually all, of their free time in hunting and were negative about putting more (formal or informal) responsibility for ASF prevention and control onto hunters, especially without compensation. This issue was associated with a general theme highlighting the importance of the *feasibility of the implementation of reporting, sampling and control measures*, especially with hunters participating as volunteers. Feasibility in this regard includes all measures being easy and quick to perform and information about what to do and any materials required being easily accessible for all hunters at all times. The need for more information and communication around ASF created a separate general theme calling *for more information and greater cooperation in ASF prevention and control*. In this regard, voices promoting firmness and strictness in the authorities' contingency planning and outbreak management were balanced by a simultaneous call to bring ASF prevention and control closer to the hunters (using hunters as ambassadors, making better use of hunters' local knowledge, creating ASF taskforces in the local hunting organisations) and for enforcing feedback loops, for example in reporting. This last point would require the authorities not only to issue instructions, but also to involve hunters in the planning of surveillance, prevention and control, share the science and knowledge behind the suggested measures, and use local knowledge to adapt measures to each local setting. The need for more information on ASF featured in all emerging themes, including both practical and technical information on reporting and sampling procedures for example, knowledge about ASF including its spread, prevention and control, and the general purpose of reporting, sampling or control measure.

Online questionnaire

In total, 3244 responses were received for the second version of the questionnaire. As questions in the questionnaire could be skipped, not all respondents replied to all questions. Results from questions that turned out to give ambiguous answers, indicating that they were easily misunderstood, or that were answered by too few respondents to draw any conclusions were not included in the analysis (the latter concerned only one follow up-questions which recieved less than 15 responses).

Hunting habits Questions to describe hunting habits included the counties in which the respondents hunted, and if and how often they engage in the hunting of wild boar in Sweden (Table 2).

Most respondents selected just a single county, but hunting in up to eight counties was reported. All 21 counties in Sweden were mentioned, including the more

Table 2 Hunting practices, as stated by Swedish hunters responding to an online questionnaire. *No.* number, *WB* wild boar

No. of counties hunted in	**1**	**2–3**	**4–8**
Total answers: $n=3233$	2517 (77.9%)	630 (19.5%)	86 (2.7%)
WB hunting	**Yes**	**No**	
Total answers: $n=3210$	2747 (85.6%)	463 (14.4%)	
Extent of WB hunting/year	**Single days**	**7–14 days**	**> 14 days**
Total answers: $n=2752$	655 (23.8%)	871 (31.6%)	1226 (44.5%)

northerly ones where wild boar are not present, indicating that respondents also participated in the hunting of other species.

Baiting More than a third of the questions were related to the concept of baiting. Some of these answers did not concern baiting intended for wild boar, but if the activity took place in an area where wild boar are present it is still relevant for the purposes of this study. Of the respondents ($n = 3191$), the majority had participated in baiting ($n = 2222$, 69.9%). The ensuing questions regarded the extent to which baiting was implemented in the course of a year, how many people were engaged in maintaining the baiting station, and how much feed was used (Table 3). As the question did not specify this as relating to one specific baiting station or location, the answers may reflect the amount used at more than one baiting station.

A multiple-choice question asking for the leading cause or causes influencing the choice of bait feed was answered by 2166 respondents. More than one cause could be selected. The results are displayed in Table 4.

The order of the top four choices remained unchanged when the responses were stratified based on the amount of feed used. For the group stating that they used the least amount of feed, the fourth factor 'cost' was followed by 'tradition' and then 'feed security/biosecurity', whereas the respondents stating the use of larger volumes of feed had a reversed order in the number of selections of those last two choices. The choice of 'other' came with a possibility for further specification. While some free-text specifications were repeats of the choices previously made regarding attractiveness, availability and simplicity of use, other common comments were *"selecting healthy and natural feed for the wild animals"*, *"using products to which the animals have access in the wild"* or *"using products that would otherwise have gone to waste"* (fallen apples, by-products from grain harvest), as well as selecting locally produced cereals and peas. Other comments related to the ease of access or to requirements from the landowner with regard to what feed can be used.

A free-text question asking for the main contents of the feed used for baiting was answered by 2157 respondents. The most commonly mentioned ingredient was maize ($n = 1501$, 69.6%), followed by peas ($n = 614$, 28.5%), cereals and pelleted feed ($n = 520$, 24.1%), root crops and tubers ($n = 147$, 6.8%), fruits and vegetables ($n = 118$, 5.5%) and bread ($n = 55$, 2.5%). Thirteen respondents (less than 1%) mentioned using by-products from slaughter. Seven of them specified that the by-products were from hunting, and four mentioned that it was used with the intention of baiting fox. Two respondents mentioned using fish. Maize, peas and cereals where often used in

Table 3 Wildlife baiting practices, as stated by Swedish hunters responding to an online questionnaire. *No.* number, *kg* kilograms

Baiting deployed	**On a single occasion**	**During one or a few weeks**	**During one or a few months**	**Continuously**	**Do not know**
Total: $n = 2203$[a]	161 (7.3%)	219 (9.9%)	596 (27.1%)	1173 (53.2%)	54 (2.5%)
No. of persons maintaining it	**1**	**2–3**	**4–6**	**> 6**	**Do not know**
Total: $n = 2194$[a]	361 (16.5%)	1109 (50.5%)	387 (17.6%)	298 (13.6%)	39 (1.8%)
Average kg feed used/year	**< 100 kg**	**100–300 kg**	**300–500 kg**	**> 500–1000 kg**	**Do not know**
Total: $n = 2177$[a]	459 (21.1%)	643 (29.5%)	365 (16.8%)	492 (22.6%)	218 (10.0%)

[a] Respondents who stated participation at baiting and answered the follow-up questions

Table 4 Reasons for choice of feed for baiting, as stated by Swedish hunters responding to an online questionnaire. *No.* number

Factors influencing the choice of bait feed	**No. of answers**	**% of respondents**
Attractiveness for the animals	1248	57.6%
Availability	1148	53.0%
Simplicity of storage and handling	1015	46.9%
Cost	646	29.8%
Feed safety/biosecurity	169	7.8%
Tradition	154	7.1%
Other	108	5.0%
Total number of respondents ($n = 2166$)	5388	

combination. One respondent who stated that they used slaughter by-products from hunting also mentioned using meat from 'private consumption', but did not specify if the meat was from their own harvest of game or included other meat products. A similar multiple-choice question on ingredients placed as bait followed. It showed comparable results, and these are included as Additional file 3.

The ensuing question regarded whether any of the baiting feed used originated from outside Sweden. This was answered by 2219 respondents with'yes' ($n=88$, 4.0%),'no' ($n=1779$, 80.2%) and'do not know' ($n=352$, 15.9%). A follow-up free-text question on what type of feed and what country it originated from was answered by 59 of the respondents who previously stated they had used such feed. The most commonly mentioned imported product was 'maize' ($n=26$), followed by 'fruits and vegetables' ($n=6$), while one mentioned 'cereals or peas' and one 'Norwegian salmon'. The countries mentioned were Poland ($n=25$), Denmark ($n=10$), Europe or EU ($n=3$), USA ($n=2$) and the Baltic countries ($n=2$). Two respondents cited maize from Hungary and Ukraine, respectively.

One question addressed the use of animal products or food prepared for human consumption for baiting. This question was answered by 2184 respondents, with the absolute majority ($n=1924$, 88.1%) stating that they had not used such products. Of the 260 respondents who answered that they had used such products, 240 (92.3%) estimated that they constituted less than 25%, while 20 (7.7%) estimated that they constituted more than 25%.

Hunting travel The first question regarding hunting travel asked if the respondent had ever hunted for wild boar outside of the Nordic countries. This was answered by 3074 respondents, with 418 (13.6%) replying that they had done so. These respondents were also among those who hunted in more than one county (Table 2).

A follow-up question on when and where they had been travelling resulted in 413 free-text replies. Of these, 321 respondents left a year or a comment that allowed their travel to be dated as before 2014 ($n=123$, 38.3%) or in 2014 or later ($n=198$, 61.7%). In the case of a respondent travelling both before 2014 and after, the latest travel date was used in the analysis. For countries or regions, 411 respondents made 529 country mentions. The countries or regions mentioned by 20 or more respondents were Germany ($n=147$), Poland ($n=140$), the three Baltic countries of Estonia, Latvia and Lithuania ($n=47$), Africa ($n=38$), Hungary ($n=38$) and the Czech Republic ($n=20$). There were six mentions of Norway, Denmark or Finland, all in conjunction with other countries outside of the Nordic countries.

A single-choice question regarding if wild boar products were brought back to Sweden was answered by 420 respondents with the options 'yes, trophy parts only' ($n=111$, 25.9%), 'yes, products intended for human consumption' ($n=12$, 2.9%), 'no' ($n=291$, 69.3%), 'do not know' ($n=6$, 1.4%). Of the 111 respondents who stated that they brought back trophy parts, 110 answered the follow-up question of whether the trophy parts were processed in any way before they were brought back to Sweden: 103 reported 'yes' (93.6%) and seven 'no' (6.4%). There was a significant association between respondents travelling for hunting before or after 2014 and bringing back trophies or products for human consumption ($p=0.013$). Of those who travelled before 2014 and who replied to the question of whether they brought back anything ($n=120$), 39.2% said they brought back products, while of those travelling in 2014 or later ($n=194$), 25.3% brought back products.

In all, 418 participants responded to a question of whether they had received any information regarding infectious animal diseases, relevant to hunting travel. Table 5 illustrates the responses by category of organiser and includes the 416 respondents who answered both questions. Focusing on those who had travelled in 2014 or later, 85/168 had received biosecurity information.

Table 5 Data on hunting travel, as provided by Swedish hunters in response to an online questionnaire

Organiser	Yes, received bio-security information	No, did not receive bio-security information	Unsure if such information was given	Total
Individual person	54	113	9	176
Professional hunting travel organiser	68	101	28	197
Other	12	23	8	43
Total	134	237	45	416

On the question about whether and how clothes and equipment used abroad were cleaned, 68 respondents answered 'no' (16.3%), 231 answered 'yes, basic cleaning, rinsing of boots and visibly contaminated clothing' (55.5%) and 117 answered 'yes, thorough cleaning/disinfection, e.g. clothes washed at 60 °C' (28.1%). Focusing on respondents travelling in 2014 or later, a comparison of whether any cleaning of equipment had been done with biosecurity information provided showed that the odds ratio of cleaning equipment after receiving biosecurity information was 6.22 (CI 1.95- 28.81, $p=0.001$) compared with those not receiving such information. One question concerned whether the respondent or anyone else participating in the same hunting trip brought a hunting dog from Sweden. In total, 413 replied to this question, with 23 (5.6%) selecting 'yes', and 390 (94.4%) 'no'.

In the next question the respondents were asked whether they had ever invited hunters from abroad to hunt in Sweden, and if so from where and whether biosecurity was discussed or not. This question was answered by 3058 respondents with the alternatives 'yes' ($n=269$, 8.8%), 'yes, but not to an area where wild boar was present' ($n=93$, 3.0%) and 'no' ($n=2696$, 88.2%). Of the respondents who had invited hunters, 271 provided further information regarding country/countries and 33 of these stated that they had provided information about or discussed biosecurity. The countries mentioned by more than ten respondents who had invited hunters were Denmark ($n=100$), Germany ($n=97$), Norway ($n=36$), Finland ($n=22$) and the USA ($n=11$).

In the questionnaire's final comments field, some respondents reflected on answers previously given, while others offered more elaborate answers. In the deductive coding, four out of the eight emerging themes from the FGD analysis were present: "ASF introduction", "control measures", "knowledge" and "relationships and cooperation". Many responses revealed a fear of ASF being introduced, with comments that called for stricter regulations on baiting volumes, and the type and origin of baiting feed used. At the same time, frequent mention was made of hunting at baiting stations being an effective form of hunting, although the amounts used may need to be regulated in order to avoid increasing wild boar populations. There were also mentions of the risk of ASF introduction through wild boar access to rubbish at waste collection centres. Many comments also mentioned tourism, truck drivers and foreign forestry workers as a risk of bringing ASF contaminated meat products that may end up within reach of wild boar in the forest, especially close to service areas or ferry ports. The themes "relationships and cooperation" and "knowledge" were present in responses that emphasised the importance of continuous, reliable information disseminated to relevant stakeholders. Furthermore, many comments included concerns about the current hunting rights system as an obstacle to effective population control. It may contribute to local issues with wild boar density as there are conflicting interests where cooperation between landowners and hunters is needed to prevent agricultural damage.

Discussion

The results reveal that three years before the outbreak of ASF in Sweden, Swedish hunters were concerned about the disease, seeing it as a threat to the wild boar population, their hunting activities and lifestyle, and most importantly to the local communities of which they are part. One of the major risk factors for ASF introduction that was mentioned in both the FGDs and the free-text responses to the questionnaire was food waste reaching wild boar by means of the careless handling of waste by individuals or at waste collection centres. This is a recognised risk for the introduction of ASF to wild boar populations in ASF-free countries [5], and for Sweden this assumption appears to have been correct as it has been reported that the most probable route of introduction for the outbreak in Sweden was via food waste [17]. In the FGDs it was also evident that the participants' risk attribution was focused on external groups such as foreign truck drivers and the general public who do not hunt, rather than towards local groups (hunting and farming communities) who were seen as better informed and less likely to introduce ASF through careless handling of food waste [20].

Wild boar hunting tourism to infected countries has been mentioned as a risk activity for introducing ASF to ASF-free countries [15]. The focus group participants expressed worry about hunting tourism as a risk of ASF introduction into Sweden, and the survey confirmed that some Swedish hunters hunt abroad as well as in several different Swedish counties. However, most of the respondents did not hunt outside of the Nordic countries. It appeared that those who did hunt abroad also tended to hunt in more counties within Sweden than their non-travelling peers. About half of the hunters who had hunted outside Sweden since 2014 had received some biosecurity information, and most of them stated that they cleaned their equipment before returning. This, in combination with the results indicating that very few products were brought back from these hunting trips, means that hunting tourism probably does not represent an important threat of exposing Swedish wild boar to ASF. The observed effect on the cleaning of equipment following provision of information on biosecurity in conjunction with travel is positive and shows that providing such information can be useful, despite the generally complex and indirect relationship between increased knowledge and changed behaviour [21, 22]. In addition, it appears that very few people take their dogs on hunting trips outside the Nordic countries.

Baiting/supplementary feeding was not mentioned as a primary risk by the focus group participants, and the survey results confirmed that feed used at baiting stations is rarely of animal origin and that slaughter by-products used for the baiting of foxes mainly originated from hunted game. However, feeding maize was very common and some respondents stated that this must be imported as it is not produced in Sweden. Although this assumption is erroneous, previous imports of maize from Poland were mentioned by a few respondents. Most respondents stated that they only use feed of Swedish origin, including maize. While baiting might constitute a low risk for the introduction of ASF [23], there has been speculation that it might have contributed to the introduction of *Salmonella cholerasuis* into the Swedish wild boar population [24]. Import of pig feed ingredients has been mentioned as a risk for introducing ASF in risk assessments for other countries [25, 26]. Moreover, excessive baiting can maintain wild boar population numbers and influence the animals' spatial behaviour, making them gather around the baiting station, and is therefore considered a risk factor for disease spread among wild boar [27]. In addition, it is not just baiting meant for wild boar that might present a risk, as wild boar may visit baiting sites intended for other animal species and foxes, for example, may move material from baiting stations to places visited by wild boar.

Early detection is crucial to the management of ASF outbreaks in wild boar, and passive surveillance with testing of all detected wild boar carcasses has been deemed the most effective surveillance component in this regard [5, 28]. Hunters spend a lot of their time in wild boar habitats, and are considered essential stakeholders for early detection and increasing the sensitivity of passive surveillance for ASF [8, 29]. The focus group participants called for more information on how to report dead wild boar and why this is important, and also what is required afterwards of the person making the report. Since the completion of the study, given the development of the ASF epidemic in Europe, a great deal of communication has been provided about the importance of reporting findings of wild boar carcasses and about the online reporting system in use in Sweden ("Rapportera vilt") aimed at the general public and the hunting community. It would appear that these efforts have been worthwhile; the number of reported wild boar carcasses increased from 36 in 2019 to 76 in 2022. Furthermore, the first detected cases in the current ASF outbreak in Sweden were in carcasses found by local hunters and reported using "Rapportera vilt".

Once an outbreak has been detected, an active search for wild boar carcasses is needed to map the outbreak and remove the carcasses in order to reduce the environmental contamination [30, 31]. The cooperation of local hunters is essential in this activity [9], as has been seen in the outbreak in Sweden. Although the focus group participants had a positive attitude towards participation in ASF surveillance and control, they also expressed a wish for financial compensation for their efforts or at least for fuel costs. This does not appear unreasonable in light of current legislation regulating compensation for actors participating in eradication efforts in disease outbreaks among domestic animals (Swedish law of epizootic diseases (1999:657) and (1999:659)). Despite hunters' willingness to contribute to disease control, financial compensation has been identified as an important incentive, and further essential momentum may be lost if there is no compensation framework in place at the start of an outbreak [32]. In the outbreak in Sweden, hunters were compensated for their time devoted to carcass search, although with a slight delay in the system for compensation becoming operational. In this study, a main driver of the willingness to contribute to ASF control appeared to be the feeling that an outbreak and its consequences would have serious negative effects on the participants themselves as well as on their respective local communities. The importance of community cohesion and positive peer pressure in disease control has been recognised for other diseases in other contexts, and shown to be effective for improving the implementation of control or biosecurity measures [33–35]. The significance of access to local forests by the public and landowners described by the participants in the study was confirmed in the ASF outbreak in Sweden, where restrictions severely affected the livelihoods of the local community (unpublished data).

The general awareness of biosecurity around hunting appeared low in both study populations, although the respondents to the questionnaire mentioned cleaning routines. Hunters are the stakeholder group expected to have the greatest knowledge of wildlife management, but this does not necessarily imply knowledge of infectious wildlife diseases or hunters having the same awareness of infectious disease risks and the need for disease prevention that is part of farmers' everyday life. As hunting is an outdoor event, it can be compared to more extensive livestock keeping, while the toughest biosecurity is generally applied to indoor intensive livestock production [36]. As the hunting community in Sweden and the participants in this study were diverse in age, occupation and education level (although less so in gender), the knowledge about ASF and biosecurity also varied among the participants. Some FGD participants were very well informed and had actively searched for information about ASF prior to the study, whereas others had never heard of it. In the FGDs, the participants said that if they were in doubt about what to do if they found a dead wild boar, for example, they would ask for advice from someone they trusted to be knowledgeable, often the local hunting leader or local SJF representative, underlining the importance of the local community and local knowledge in disease control [37]. Furthermore, the local community with its formal and informal networks provides opportunities for the communication and dissemination of information to individual hunters. This was noted in the ASF outbreak in Sweden where the regional SJF representative and the database held at SJF (viltdata.se) were pivotal for baseline data on hunting grounds and for reaching out to local hunters. The diversity among hunters presents a challenge for communication as the preferred communication channels vary (i.e. some parts of the hunting community do not use e-mail or hunting apps, while others are very comfortable with these channels of communication).

The focus group participants called for stricter governance as well as clear instructions and directions. This can be compared with previous findings about hunters requesting increased participation in wild boar management during outbreaks [10–12, 38], and other contemporary research demonstrating that participation and ownership are pillars of sustainable disease prevention and control [8, 13, 33, 39]. Rather than calling for a "top-down approach", as in not wanting to be engaged or involved stakeholders in ASF prevention and control, this could however be seen as the hunting community wanting clear instructions for technical issues such as sampling techniques and biosecurity, and requesting more engagement from the authorities in an issue that is very important for them and in which, at the time of the study, they saw a lack of presence of public authorities. For example, participants expressed a fear of ending up without support or an appropriate mandate in situations requiring several landowners and hunting groups to cooperate regarding fencing or local eradication of wild boar populations. In this regard, requests were also made for ASF prevention and control to be brought closer to the hunters, i.e. to increase participation, making better use of hunters' local knowledge concerning wild boar populations, habitats and hunting.

In this study the combination of focus group discussions and a larger online survey allowed for in-depth insights as well as capturing data from a large number of respondents. Nevertheless, a potential selection bias due to participating hunters being those with a keen interest in the issue and comfortable with online group discussions/online questionnaires cannot be disregarded. In addition, the questionnaire was only distributed to SJF members who have an e-mail registered in their membership profile, meaning that the sample population was biased towards members of SJF and who use e-mail. The focus group discussions included only participants from regions with a wild boar presence, while some respondents to the online survey hunted in regions north of the current extent of the Swedish wild boar population. In the questionnaire, several questions offered an opportunity to provide free-text specification if none of the options were suitable for the respondent (given as "other, please specify"). This field was often selected and used to comment on, or repeat, selected options or leave more general comments on the question. This suggests a general willingness among the respondents to supply detailed information. This study was conducted before the first ASF outbreak in Sweden and thus now provides a unique snapshot of a "before-the-crisis situation" that cannot be re-created.

Conclusions

Hunting tourism and baiting do not appear to constitute major threats for the introduction of ASF to Swedish wild boar populations. The study participants were generally positive towards the authorities involved in ASF management and were willing to engage in ASF prevention and control. The hunting community is a very important resource for ASF control, and their goodwill may not last if it is not nurtured. In this regard, compensation to hunters should be considered not only during outbreaks, but for other surveillance and prevention services as well. Ensuring that information is accessible for all and that reporting and sampling procedures, for example, are simple and feasible seem to be other important issues for maintaining the positive engagement of hunters in ASF surveillance and control.

Supplementary Information

The online version contains supplementary material available https://doi.org/10.1186/s12917-024-04183-9.

Additional file 1. Topic guide used in focus group discussions.

Additional file 2. Translated version of the online questionnaire.

Additional file 3. Questionnaire question not presented in main text due to redundancy.

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Authors' contributions
EC, JL and SSL designed the study. AFB and LS collected the data from the FGDs and KM from the questionnaire. EC analysed the FGD data and LE the questionnaire data. EC, LE and SSL drafted the manuscript. All authors participated in the compilation of the final draft manuscript, and read and approved the final manuscript.

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Availability of data and materials
All data and materials are available by email to the first author upon reasonable request.

Declarations

Ethics approval and consent to participate
According to Swedish legislation, ethical permit can only be sought for human studies on people, human tissue or sensitive personal data. This study did not concern any sensitive or personal questions and no personal data were handled during the study. The legal department at the Swedish University of Agricultural Sciences deemed the current study to fall outside the scope for requirements for ethical review of the Act concerning the Ethical Review of Research Involving Humans. All participants were informed that participation was voluntary and about how the data would be handled, and that they could refuse to answer any questions. Participants in the FGDs gave oral consent to participate and answering the questionnaire was regarded as consent to participate.

Consent for publications
All participants have consented to the data being used in a publication. All authors have read the final version of this manuscript and consent to its publication.

Competing interests
The authors declare no competing interests.

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Publisher's Note

Additional file 1. Focus group discussion topic guide

Translated from Swedish to English for the purpose of this article.

Place:
Date:
Number of participants: Women: Men:
Start time: Finish time:
Facilitator:
Note taker:

Instructions: Introduce yourselves, your roles during the discussion and the discussion rules; explain the purpose of the discussion; ask for permission to take notes, photos and record audio and video; and inform about anonymity and voluntariness.

Background information about participants:

1. Name
2. Age
3. Gender
4. Land owner yes/no
5. Hunting experience (years)
6. Main hunting area

Discussion:

Describe your everyday hunting life in relation to wild boar and wild boar hunting?

We talked about African swine fever before, what are your thoughts about that disease?

What advantages do you see in preventing African swine fever from coming to Sweden?

Have you found any dead or sick wild boar, and what do you do if you do?

What advantages or disadvantages do you see in reporting to SVA if you find a dead wild boar?

What would motivate you to report more/submit more?

What would motivate you to go out into the forest more to actively look for wild boar carcasses?

What can you as hunters do to prevent African swine fever from coming to Sweden?

If not addressed, mention the following:

1. do not bring meat products from an infected country

2. do not leave food waste in reach of wild boar

3. if traveling to an affected country, thoroughly clean the equipment before going home

4. avoid handling wild boar feed or visiting a baiting place on return

What do you see as disadvantages with these measures?

What advantages do you see with these measures?

What do you think about the feasibility of these measures?

How effective do you think each measure is?

1	**In what county/counties are you hunting?**	□ Blekinge, □ Dalarna, □ Gotland, □ Gävleborg, □ Halland, □ Jämtland, □ Jönköping, □ Kalmar, □ Kronoberg, □ Norrbotten, □ Skåne, □ Stockholm, □ Södermanland, □ Uppsala, □ Värmland, □ Västerbotten, □ Västra Götaland, □ Östergötland, □ Västernorrland, □ Västmanland, □ Örebro
2	**Are you hunting wild boar in Sweden**	□ Yes, □ No
3	**Approximately, how many days per year are you hunting wild boar?**	□ Single days, □ 7–14 days, □ More than 14 days
4	**Have you participated in baiting or supplemental feeding of wildlife, in areas where wild boar are present? (even if the baiting/supplemental feeding was not intended for wild boar)**	□ Yes, □ No, □ No, but baiting stations are kept by others on my land.
5	**To what extent is the baiting/supportive feeding used?**	□ Single occasion per year, □ During one or a few weeks per year, □ During one or a few months per year, □ Continuously, □ Do not know
6	**How many people use or maintain the baiting station/stations?**	□ 1, □ 2–3, □ 4–6, □ More than 6, □ Do not know
7	**What amount of baiting- or supplemental feed is used at the station/stations during a year?**	□ Less than 100 kgs, □ 100–300kgs, □ 300–500kgs, □ 500–1000kgs, □ More than 1000kgs, □ Do not know
8	**What composes the main part of the feed used for baiting?**	*Free text*
9	**From the list below, please select all alternatives that has been used at the baiting station/stations at any occation (regardless of amount). If "Other", please specify.**	□ Cereals, □ Fruits, root crops or other vegetables, □ Food intended for human consumption (eg. leftovers from households, restaurants, or food industry) □ Meat/meat products or slaughter by products from wild boar or domestic pigs, □ Commercially produced baiting feed, □ Meat/meat products from other wildlife or livestock, □ Do not know, □ Other:_____
10	**Does any of the feed used for baiting originate from a country other than Sweden?**	□ Yes, □ No, □ Do not know
11	**Which of the used feed originated from outside Sweden, and do you know which country it came from?**	*Free text*
12	**If used, what proportion of the feed used for baiting consisted of meat, other animal products or food intended for human consumption?**	□ Not used, □ Very little, □ Less than 25%, □ 25–50%, □ 50–75%, □ More than 75%
13	**What are the leading cause/causes behind the choice of feed used for baiting? If "Other", please specify.**	□ Cost, □ Availability, □ Attractivity for the animals, □ Feed safety/biosecurity □ Simplicity of storage/handling, □ Tradition, □ Other:________
14	**If you at any point used material of animal origin for baiting, was it heat treated or prepared in a similar way before it was used? If so, please specify**	□ Not used, □ No treatment, □ Yes:_______

15	**Have you previously been hunting or are you planning to go hunting wild boar outside the Nordic countries?**	□ Yes, □ No, □ No, but I plan to, □ Do not know
16	**Where, outside the Nordic countries have you been hunting? Which year and month?**	*Free text*
17	**Where, outside the Nordic countries are you planning to go hunting?**	*Free text*
18	**Who arranged the abroad hunting? If "Other", please specify.**	□ Private individual, □ Professional hunting travel organizer, □ Other:_______
19	**Do you remember the name of the organizer, if so, please write it in the free text field**	□ No, □ Yes, ________
20	**Was any part of shot wild boar brought back to Sweden?**	□ Yes, but only trophy parts, □ Yes, products intended for human consumption, □ No, □ Do not know
21	**Was the trophy processed (e.g heat treated) in any way before bringing it back to Sweden?**	□ Yes, □ No
22	**Did the organizer of the travel hunt give participating hunters any information on infectious diseases?**	□ Yes, □ No, □ Not sure
23	**Was any gear (clothes, boots etc.) that could have been contaminated with blood or faecal matter from wild boar brought back to Sweden?**	□ Yes □ No
24	**Was gear used at hunting abroad cleaned at the return to Sweden?**	□ No, □ Yes, basic cleaning, rinsing of boots and visibly contaminated clothing. □ Yes, thorough cleaning/disinfection, f. ex. clothes washed at 60°C
25	**Did you, or anyone else participating in the travel hunt bring a hunting dog from Sweden?**	□ Yes □ No
26	**Was the dog bathed at the return to Sweden?**	□ Yes, □ No
27	**Have you ever invited foreign hunters to hunt in Sweden?**	□ Yes, □ Yes, but not to areas where wild boar was present, □ No
28	**Which country were the invited hunters from? If relevant, did you consider and address appropriate biosecurity measures (Clean gear/clothing/dogs, no leaving of food in the forest etc.)**	*Free text*
	Additional comments:	*Free text*

Additional file 3

Responses to a multiple choice question on what products they had ever used for baiting or supportive feeding, answered by 2186 hunters.

Product used	No. of answers (%)
‘Cereals’	1716 (78.5 %)
‘Fruits, root crops or other vegetables’	896 (41.1 %)
‘Commercially produced baiting feed’	310 (14.2 %)
‘Other’	225 (10.3 %)
‘Food intended for human consumption (e.g. leftovers from households, restaurants or food industry)’	122 (5.6 %)
‘Meat/meat products from other wildlife or livestock’	64 (3.0 %)
‘Meat/meat products or slaughter by-products from wild boar or pigs’	45 (2.1%)
‘Do not know’	52 (2.4 %)
Total number of respondants: n = 2186	3430

Of the 225 respondents selecting ‘Other’ as food that had even been used for bait, 224 left a free text response containing ‘maize’ (n=115, 51.3%), ‘peas’ (n=47, 21.0%), ‘silage’ (n=28, 12.5%), ‘bread’ (n=27, 12.1%), ‘cereals or pelleted feed’ (n=8, 3.6%), ‘fruit and vegetables’ (n=7, 3.1%), ‘root vegetables’ (n=6, 2.7%), ‘fish’ (n=3, 1.3%) and less than one percent mentioned the use of by-products from slaughter or game killed by traffic (n=2). Some respondents mentioned more than one product, hence the total number of mentions exceed the total number of responses.

III

pathogens

Article

First Detection of *Salmonella enterica* Serovar Choleraesuis in Free Ranging European Wild Boar in Sweden

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Abstract: Following the first detection of *Salmonella enterica* subsp. *enterica*, serovar Choleraesuis (*S.* Choleraesuis) in a Swedish pig herd for more than 40 years and subsequent detection of the same serotype in an enclosure with kept wild boar, a national surveillance for *S.* Choleraesuis in free living wild boar was launched. A total of 633 wild boar sampled within the active and the enhanced passive surveillance were examined for *Salmonella enterica* serovars by culture. Of these, 80 animals were culture positive for *S.* Choleraesuis var. Kunzendorf. All positive animals, including those in the original outbreaks, originated from counties located in the southern and eastern parts of Sweden. Fifty-eight isolates were selected for sequence typing, revealing a relatively homogenous population of *S.* Choleraesuis with two distinct genetic clusters containing isolates from the southern counties in one and the counties further northeast in the other. Sequenced isolates from domestic pig farms all clustered with wild boar in the same region. *S.* Choleraesuis appears highly contagious in dense wild boar populations, making it a relevant model for other infectious diseases that may be transmitted to pigs. The many potential routes of introduction and spread of *S.* Choleraesuis warrant further investigations in order to prepare for other disease threats.

Keywords: wildlife/livestock interface; surveillance; *Salmonella* Choleraesuis; wild boar; *Sus scrofa*

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1. Introduction

Many contagious diseases such as African swine fever (ASF), classical swine fever (CSF), Aujeszky's disease (AD), and porcine reproductive and respiratory syndrome (PPRS) are absent in the Swedish pig population [1]. The last outbreak of CSF was in 1944, and AD was eradicated in 1996. PRRS was detected for the first time in 2007 but eradicated shortly thereafter [2]. ASF has never been detected in the country, but the spread within Europe and the role of European wild boar (*Sus scrofa*) is a continuous worry for Swedish pig producers. Despite biosecurity programs in pig holdings (including all-in-all-out indoor production, with hygiene locks at building entrances), the risk of disease transmission between wild boar and domestic pigs has increased due to growth of the wild boar population, and the transmission of other viruses between domestic pigs and wild boar in Sweden has been demonstrated [3].

The importance of longitudinal surveillance of diseases in wildlife has been highlighted in many studies as reviewed by Barroso et al. (2022) [4]. The Swedish general wildlife disease surveillance program, based on passive surveillance of animals found dead, has been in place since the 1940s [5]. This program has contributed to baseline knowledge of diseases present in the wildlife population and provided a large sample collection, which has allowed for retrospective investigations of certain diseases. Within the surveillance program, all wildlife species are tested for *Salmonella* upon suspicion. Moreover, an enhanced passive surveillance of ASF in wild boar has been implemented since 2013 [1].

In the 18th century, the free-living wild boar population was eradicated in Sweden. In the 1970s, a few wild boar escaped their fences in hunting estates in the Southern part of the country and became part of the wild fauna. In 1981, a decision was taken to reduce the population to below 100 animals, but this was later revoked, and since the late 1980s, the population has grown steadily [6]. The national hunting bag has been around 120,000 animals/year during the past five years [7], and the total population was estimated to be at least 300,000 in 2020 [6]. Wild boar are present in all counties in the southern parts of Sweden, where, in some areas, a high population density coincides with the location of pig holdings (Figure 1a,b), emphasizing the need for disease surveillance in the wild boar population.

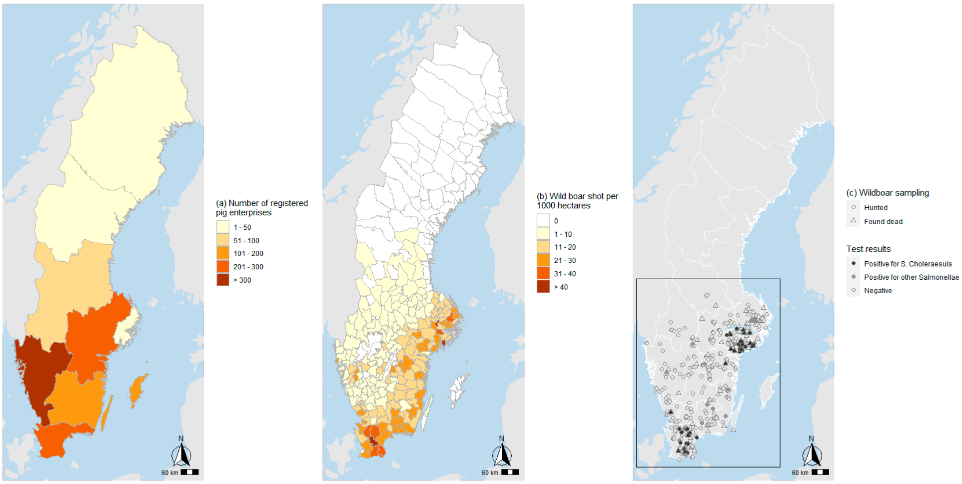

Figure 1. (**a**–**c**) Geographic distribution of Swedish pig holdings (**a**); wild boar population, based on hunting bags (**b**) and sampled wild boar in this study (**c**). The square indicates the area shown in higher resolution in Figure 2.

A national *Salmonella* control program was initiated in the 1950s and 1960s and was gradually developed to its current form, covering the entire chain from feed to food. This program was the basis for the additional guarantees regarding *Salmonella* when Sweden joined the European Union in 1995. These guarantees allow national requirements for *Salmonella* sampling of fresh meat from cattle, pigs and poultry, table eggs, and raw feed materials brought into Sweden. The program focuses on food-producing animals with the objective of *Salmonella*-free products originating from domestic livestock.

In 2020–2021, *Salmonella enterica subsp. enterica*, serovar Choleraesuis (*S*. Choleraesuis) was detected in five domestic pig herds and one estate with a small group of fenced wild boar. These were the first findings of this serovar in more than 40 years [1]. Similar to human infections with *S*. Typhi and Paratyphi, *S*. Choleraesuis is a pig-adapted serovar that can cause a clinical picture resembling swine fever, and a high mortality may be seen in domestic pig herds [8], particularly in the presence of other infections [9]. Historically, it was the most common serotype in pigs worldwide but is now rarely seen in domestic pigs in Europe [10]. A study on 102 isolates from Europe and the United States used molecular epidemiology to reveal geographical clustering of isolates and a possible association with poorly disinfected vehicles in outbreaks in Danish pig holdings [10]. Detailed study of isolates from the Danish outbreaks also indicated several introductions and a possible link to corn transported from Eastern Europe [9]. The bacteria can survive for long periods in the environment and have been shown to persist in dry feces from infected pigs for up to 13 months [11].

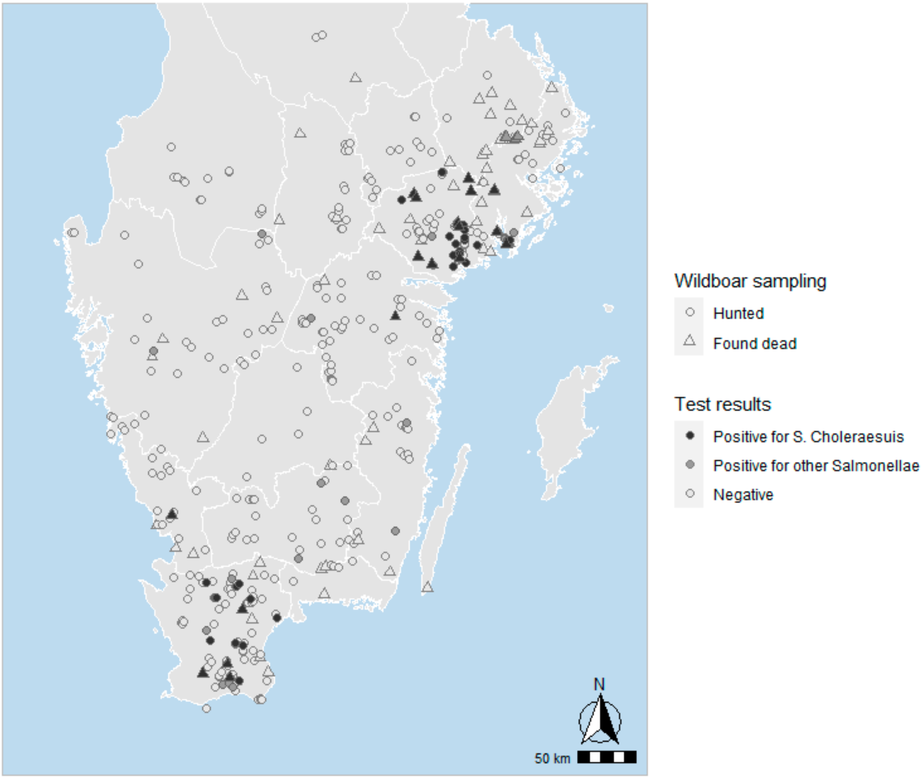

Figure 2. Geographic location of sampled wild boar and results of sample analyses in the surveillance of Swedish wild boar for *Salmonella* enterica serovars in 2020–2022.

Human infections are rare but may be severe, due to the systemic nature of the infection presenting as septicemia, mostly in young or debilitated individuals [8,12].

In wild boar, the clinical signs of infection with *S.* Choleraesuis appear similar to those in domestic pigs [13]. Molecular typing of isolates from an outbreak in Italian wild boar could not detect a link to isolates from domestic pigs [14], while a German study revealed different genetical clusters of wild boar isolates, of which one also included isolates from domestic pigs [15]. Indications of an increased prevalence of *S.* Choleraesuis among wild boar have been noted in Germany, possibly associated with a heightened awareness of the ASF risk, leading to more post-mortem examinations of wild boar [16]. Although transmission patterns differ slightly, the similarities between infection with *S.* Choleraesuis and ASF infer that close study of *S.* Choleraesuis outbreaks in wild boar may provide useful knowledge for the surveillance and control of ASF.

After the detection of *S.* Choleraesuis in domestic pigs in Sweden, surveillance targeting this agent in free-ranging wild boar was initiated, to complement the wildlife disease surveillance program. The design and results from the surveillance of wild boar since the first detection of *S.* Choleraesuis are described in this report.

2. Results

A total of 633 wild boar sampled within the active and the enhanced passive surveillance were examined for *Salmonella enterica* serovars by culture. Of these, 80 animals were culture positive for *S.* Choleraesuis var. Kunzendorf (Figure 1c, Table 1) in at least one of the materials collected from each animal (Table 2). All positive animals, including those in the original outbreaks, originated from counties located in the southern (Skåne and Halland) and eastern (Södermanland, Stockholm, and Östergötland) parts of the country (Figures 1c and 2).

Table 1. Results from testing wild boar for *S.* Choleraesuis.

Surveillance Category	Positive for *S.* Choleraesuis	Negative for *S.* Choleraesuis
Active, hunted	53	480
Passive, found dead	27	73

Table 2. Results from sample materials cultured individually from Swedish wild boar found dead during 2020–2022.

Material (*n*)	*S.* Choleraesuis	Other Salmonellae
Mesenteric lymph node (52)	34.6%	3.8%
Intestine (37)	43.2%	2.7%
Feces (24)	20.8%	4.2%
Bone marrow (22)	18.2%	0
Tonsil (10)	10.0%	20.0%
Spleen (11)	54.5%	0
Liver (1)	0	0
Muscle (2)	50.0%	0
Stomach (1)	100%	0
Kidney (1)	0	0
Joint (1)	100% *	100% *

* The joint sample from one animal yielded both *S.* Choleraesuis and *S.* Newport.

A total of seven *Salmonella* serotypes other than *S.* Choleraesuis were detected including *S.*Diarizonae (nine); *S.* Typhimurium (four); *S.* Newport (two); and one of each of *S.* Hessarek, *S.* Duesseldorf, *S.* Enteriditis, and *S.* Coeln. In addition, one isolate was identified of antigen type 'O4′ and four of antigen type 'O6,8′, with no further serotyping available.

The detection of *S.* Choleraesuis was significantly ($p < 0.01$) more frequent from the carcasses of wild boar found dead than from wild boar sampled at hunting. This association between category and detection was not seen for other *Salmonella* serotypes in this study.

2.1. Wild Boar Found Dead

In this category, a total of 100 wild boar were sampled with one to four materials each, depending on availability and suitability. For 14 of these animals, the collected sample materials ($n = 2-3$) were analyzed as individual pools (i.e., one from each animal), all with negative results. The results from each type of individually cultured sample material are shown in Table 2. Of the 100 animals, 27 were culture positive for *S.* Choleraesuis, and, with two exceptions, all sample materials from these animals were positive. One of the 27 was, in addition to *S*. Choleraesuis, also positive for another *Salmonella*, while three animals of the 100 were positive for *Salmonella* of other serotypes only.

The sex of the wild boar was recorded for 77 of the animals (Table 3). Although *S*. Choleraesuis was isolated from more female than male animals, the association was not significant (p = 0.10). There was no obvious association between the detection of *S*. Choleraesuis and the age category of the animal among the wild boar found dead.

Table 3. Recorded sex of wild boar found dead and their status for *S*. Choleraesuis.

Sex	Neg. for *S*. Choleraesuis	Pos. for *S*. Choleraesuis
Male	31	5
Female	27	14

2.2. Samples from Hunted Wild Boar

A total of 533 wild boar were sampled by hunters, at normal hunting. For 448 of these, information about the sex of the animal was provided, and 46% were male and 54% female. While both requested materials, a mesenteric lymph node (MLN) and a fecal sample, were submitted from 509 animals, only the fecal sample was available from 20 animals, and from four animals, just the MLN was available. Both materials were available from 51 out of 53 wild boar from this category that were positive for *S*. Choleraesuis. Out of these, 12 (23.5%) were positive in both MLN and feces, 17 (33.3%) only in the mesenteric lymph node, and 22 (43.1%) in feces alone. All *S*. Choleraesuis positive wild boar among the hunter collected samples were shot in the before-mentioned counties of Skåne, Södermanland, and Stockholm, and the proportion of positives did not differ between the sexes. However, the proportion of young animals with positive culture results was significantly higher than for adult animals ($p < 0.01$).

2.3. Sequencing

When the surveillance was initiated, isolates previously detected in the wildlife disease surveillance but not fully typed were re-examined and sequenced. Two isolates from the most southern area, one from 2018 and one from June 2020, were identified as *S*. Choleraesuis and included in the sequence typing, together with a selected number of isolates from the current surveillance.

All selected isolates were confirmed by whole-genome sequencing to be multi-locus sequence type (ST) 145, consistent with *S*. Choleraesuis var. Kunzendorf [17].

Whole-genome sequencing revealed a relatively homogenous population of *S*. Choleraesuis; among 58 sequenced isolates from 2020–2022, there were only a total of 96 SNPs, most of which were unique for individual isolates or small groups (Figure 3). Isolates clustered by hunting district, however, not consistently so. A genetic separation between isolates from the southern (Skåne and Halland) counties and the counties further northeast was evident, although based on very few SNPs. Sequenced isolates from three pig farms in Skåne county all clustered with wild boar in the same region. A comparison of the Swedish 2020–2022 sequence cluster to publicly available sequences in EnteroBase revealed a high degree of similarity to wild boar isolates from central Europe, including Poland, Germany, and the Czech Republic (HierCC HC50 79087).

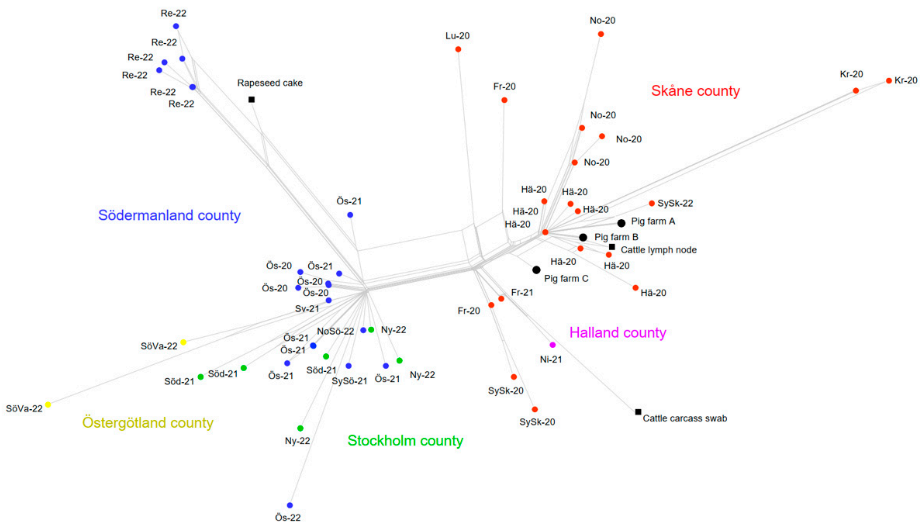

Figure 3. NeighBor net visualization of whole-genome SNP variation among all sequenced isolates of *S*. Choleraesuis in 2020–2022. Isolates are labelled by hunting district and year and colored according to the county of the hunting district.

The isolate from 2018 did not show genetic similarity with the isolates in the current outbreak, while the isolate from June 2020 is seen centrally in the "Skåne county" cluster in Figure 3.

3. Discussion

The long-standing wildlife disease surveillance and *Salmonella* control programs in Sweden have provided a historical context supporting the assumption of a recent introduction of *S*. Choleraesuis. An established collaboration with the hunters' organizations allowed for rapid enrolment in the voluntary sampling effort.

When relying on samples from hunter-harvested animals from the ordinary hunting bag, similar to most active surveillance, the collection will have an element of convenience sampling and inherently consist of apparently healthy animals. By complementing the samples from wild boar found dead with sourcing samples from apparently healthy, hunted wild boar in varying locations, our sampling strategy provided as far a representative picture as possible of *S*. Choleraesuis in the wild boar population. As the aim in this study was disease detection rather than national prevalence estimation, the samples from wild boar found dead were useful as a risk-based sampling. In order to strengthen the assessment of the future probability of introduction to domestic pig herds, more detailed prevalence figures in combination with data on potential transmission routes between wild boar and domestic pigs would be needed. Nevertheless, our data indicate that transmission between wild boar and domestic pigs may be a significant factor in the spread of *S*. Cholerasuis in the Swedish context and that this route of introduction to domestic pigs might be relevant for a number of infectious diseases. In this context, studies on *S*. Choleraesuis in affected areas may serve as a proxy for ASF and contribute to preparedness for ASF outbreaks in new regions. In addition, surveillance samples that are negative for ASF should be examined for *S*. Choleraesuis, in regions where this infectious agent has not previously been detected.

In the latest European Union One Health 2020 Zoonoses Report (p. 75) [18], only four countries reported *Salmonella* in wild boar. Some studies have reported the finding of *Salmonella* antibodies or PCR reactions in wild boar in Scandinavia [19,20], while *S*. Choleraesuis in wild boar has previously been reported from Italy [14,21], Germany [16], Austria, France, Estonia and Hungary [10], and Spain [13,22]. The risk of human infection via pork products is acknowledged but, based on reported numbers of human cases, appears to be less common than other serotypes [18]. We have not been able to obtain information about the presence of human cases in the 1970s, when *S*. Choleraesuis was present in domestic pigs in Sweden. As the wild boar population at that time was almost extinct, the current situation is new. Since the prevalence of *S*. Choleraesuis in wild boar may be high in densely populated areas, as reflected in our study, it could present a public health risk via consumption of meat products from infected wild boar. During the outbreak, the Swedish Food Administration presented a scientific opinion on *S*. Choleraesuis from wild boar and disseminated advice on relevant food hygiene aspects to hunters and the public.

To assess the probability of foodborne disease, sampling of apparently healthy animals is needed, as these reflect the population of interest. However, these animals would not be expected to have an established systemic infection, and hence, selecting the optimal sample material is a challenge. In this study, samples consisting of lymph node and feces were collected. Roughly one-third of the *Salmonella*-positive wild boar were positive in both materials, one-third in just the lymph node, and one-third only in feces. Hence, when testing apparently healthy wild boar, it is advisable to sample at least two materials to increase the probability of detection.

The sometimes-extended period between death of the animal and sample analysis may lead to bacterial overgrowth and impair the detection of *S*. Choleraesuis. This aspect would be most relevant for the sampling of wild boar found dead, but as these animals are expected to have died from septicemia, the bacteria will be present in high numbers in many organs, and hence, detection may still be possible. The fact that *S*. Choleraesuis causes systemic disease and death among wild boar makes sampling of wild boar found dead a logical approach for disease detection in new areas.

The origins of outbreaks of wildlife disease are difficult to investigate. In the light of previous reports from Denmark [9], indicating a possible introduction via corn from Eastern Europe, this route of introduction to Sweden is not entirely unlikely. We know from other studies (unpublished data) that feeding of wild boar with imported corn from Eastern Europe is not uncommon in Sweden; however, no such feed has been available for sampling. The affected areas are characterized by dense populations of wild boar and the presence of hunting estates with both regular feeding activities and regular visits from international hunters. Despite genetic clustering according to geographic origin within Sweden, the isolates are not so different as to indicate numerous different introductions, at least not from different regions. The sequencing results demonstrate similarities with strains from Poland, Germany, and Czech Republic, indicating a possible connection with these countries. In addition, the low variation between the Swedish isolates indicates a rather recent introduction. The outbreaks in domestic pig herds were most likely caused by spillover from the wild boar population.

As many important pig diseases that are currently absent in Sweden can be established and spread in wild boar populations, this outbreak may serve as a warning and an opportunity to investigate how a very low probability of introduction for individual events may still, eventually, result in an established disease outbreak. The many potential routes of introduction and spread of *S*. Choleraesuis warrant further investigations in order to address other disease threats.

4. Materials and Methods

The surveillance activity was designed by applying a combination of enhanced passive and active surveillance. Data on GIS-coordinates and the sex and estimated age of the wild boar were collected via the submission form. When possible, all wild boar were sampled by a mesenteric lymph node (MLN) and a fecal sample.

4.1. Wild Boar Found Dead

Wild boar found dead and submitted for necropsy within the wildlife disease surveillance program, as well as material from wild boar found dead and sampled in the field within the ongoing surveillance for African swine fever, were cultured for salmonellae. Due to cadaverous changes or missing organs, materials other than the above-mentioned were sometimes used, including muscle, blood-bearing organs or bone marrow.

4.2. Samples from Hunted Wild Boar

Appearingly healthy wild boar were sampled during hunting in the period beginning October 2020 to the end of February 2022. Sampling kits were assembled and dispatched from the National Veterinary Institute to hunter organizations and hunters that volunteered to assist in sampling in areas of geographic interest. Initially, these were areas around the detected cases but later expanded to all counties with a known wild boar population. From hunter-harvested wild boar, a mesenteric lymph node and a fecal sample was collected.

4.3. Bacterial Culture

Sample materials submitted were individually cultured for *Salmonella enterica* serovars in accordance with EN-ISO 6579-1:2017. Briefly, this included pre-enrichment in buffered peptone water followed by culture on MSRV (Modified Semi-solid Rappaport Vassiliadis) agar plates at 41.5 °C for 24–48 h and subsequent culture of suspect colonies on XLD (xylose-lysine-deoxycholate) and BG (Brilliant Green) agar at 37 °C for 24 h. All suspect isolates were tested for O- and H-antigen, and positive isolates were further classified using the White–Kaufmann–Le Minor scheme. Strains with O6,7:c:1,5 or O6,7:-:1,5 were further biochemically tested using H2S and Dulcitol., with all isolates being H2S+ and Dulcitol–, which is compatible with var. Kunzendorf.

4.4. Sequencing

DNA was extracted from cultures of selected isolates using the IndiMag Pathogen kit (Indical Bioscience GmbH, Leipzig, Germany) on a TANBead Maelstrom-9600 automated system and quantified using the Qubit BR dsDNA kit (Thermo Fisher, Waltham, MA, USA). Library preparation was carried out using Nextera chemistry, and sequencing was performed using either an Illumina NovaSeq instrument at SciLifeLab Clinical Genomics, Solna, Sweden, or an in-house Illumina MiSeq instrument. All isolates were sequenced to a minimum of 40× coverage. Sequence data and relevant metadata are available at the European Nucleotide Archive [23] under project accession PRJEB52916. Genetic distances between isolates were determined by single-nucleotide polymorphism (SNP) analysis as previously described [24] and visualized with the NeighborNet algorithm in the open software SplitsTree 4.14.4. A comparison with publicly available genome sequences of S. Choleraesuis isolates from other countries was done by core-genome multilocus sequence typing (cgMLST) including HierCC hierarchical clustering in EnteroBase (https://enterobase.warwick.ac.uk/, accessed on 28 May 2022).

Geographical maps were produced in the statistical open-source software 'R' (R Core Team, 2021, Vienna, Austria) based on data on shot wild boar from the Swedish Hunters' association and the Swedish board of Agriculture regarding the pig enterprises.

Statistical analyses were done in the statistical open-source software 'R' (R Core Team, 2021, Vienna, Austria), with the addition of the package 'tidyverse' [25]. Associations between two variables were assessed by Pearson's chi-squared test or Fisher's exact test.

Results from individual wild boar were communicated to the submitter, and aggregated results were visualized in an interactive map on the website of the National Veterinary Institute. Any personal data were handled according to GDPR within the laboratory information system of the National Veterinary Institute.

5. Conclusions

S. Choleraesuis appears highly contagious in dense wild boar populations, making it a relevant model for other infectious diseases that may be transmitted to pigs.

Wild boar found dead constitute a useful source of sampling material, but sampling hunted animals can also be applied in surveillance. In the latter case, both the mesenteric lymph node and feces are recommended to increase the probability of detection.

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Institutional Review Board Statement: Ethical review and approval were waived for this study due to all samples collected from dead wild boar, either found dead or from normal harvest by hunting. No animals were killed for the purpose of sampling for this study.

Informed Consent Statement: Not applicable.

Data Availability Statement: Upon reasonable request, anonymized data from the surveillance are available from the corresponding author. Raw data for the sequenced strains were uploaded to European Nucleotide Archive (https://www.ebi.ac.uk/ena, accessed on 28 May 2022) under project accession PRJEB52916.

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Conflicts of Interest: The authors declare no conflict of interest.

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The wildlife-livestock interface is a complex system shaped by various factors, including wildlife abundance, host species, pathogen and potential contact routes between populations. The studies in this thesis focus on understanding contacts between wild boar and pigs that may result in disease transmission, with African swine fever and *Salmonella* Choleraesuis as examples. With more knowledge and a multidisciplinary, multiactor approach, effective strategies can be developed to address these challenges and safeguard the health of both wild and domestic animal populations.

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