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African swine fever in wild boar Ecology and biosecurity

Second edition

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African swine fever in wild boar: ecology and biosecurity

Second edition

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Abbreviations and acronyms

ASF	African swine fever
ASFV	African swine fever virus
CCS	Critical community size
CSF	Classical swine fever
EFSA	European Food Safety Authority
FAO	Food and Agriculture Organization of the United Nations
GF-TADS	Global Framework for the Progressive Control of Transboundary Animal Diseases
ISPRA	Istituto Superiore per la Protezione e la Ricerca Ambientale [Italian National Institute for Environmental Protection and Research]
Nt	Host threshold density
PCR	Polymerase chain reaction
SOCO	Single Overarching Communication Outcome
WOAH	World Organisation for Animal Health

Introduction

In 2007, African swine fever (ASF) was discovered in the Caucasus, and has now spread to several countries in eastern and northern Europe. By 2018, the ASF crisis had expanded to Asia, where the virus continues to spread. The large-scale epidemic travelled thousands of kilometres from its point of detection in Georgia and, in addition to its endemic establishment in domestic pigs, the disease eventually invaded populations of wild boar. In Europe, from 2014 to 2015, the circulation of this virus in natural ecosystems developed into a self-sustained epidemiological cycle. Currently, the disease is endemic in wild boar populations in several countries and continues to expand its range in Europe, a cause for very serious concern. The situation in parts of Asia is likely to follow the European trajectory, not only with the involvement of wild or feral pigs belonging to the species *Sus scrofa*, but also with other wild suids. Controlling this sylvatic epidemic is a challenging task for veterinary authorities, given the complexity of the disease epidemiology, a lack of previous experience, the unprecedented geographical scope of the problem, and its transboundary and multisectoral nature.

This document was prepared following the recommendations of the Standing Group of Experts on African Swine Fever in the Baltic and Eastern Europe subregion. The group was set up under the umbrella of the Global Framework for the Progressive Control of Transboundary Animal Diseases (GF-TADs) to build closer cooperation between countries affected by ASF, fostering a more collaborative and harmonized approach to the disease across the Baltic and Eastern Europe subregion. At the eighth meeting of the Standing Group of Experts on African Swine Fever in Chisinau, Moldova, on 20 and 21 September 2017, the World Organisation for Animal Health (WOAH), the Food and Agriculture Organization of the United Nations (FAO) and the European Union decided to cooperate in the preparation of a technical, but also practically useful, document containing a compendium of essential information about hunting management, biosecurity and wild boar carcass disposal. More recently, reflecting the continuing threat posed by ASF, the evolution of the crisis, and scientists' and authorities' understandings of how to manage it, it was felt that a new edition would make an important contribution to the situation.

This document provides an evidence-based overview of ASF ecology in the northern and eastern European populations of wild boar. It briefly describes a range of practical management and biosecurity measures or interventions, which can help stakeholders in the countries experiencing large-scale epidemics of this disease to address the problem in a more coherent, collaborative and comprehensive way. The publication should not be viewed as an authoritative manual providing ready-made solutions on how to eradicate ASF from wild boar. The facts, observations and approaches described in the document are presented with the intention of broadly informing veterinary authorities, wildlife conservation bodies, hunting communities, farmers and the general public about the complexity of this novel disease, and the need to plan wisely and carefully coordinate any efforts aimed at its prevention and control.

In order to reduce risks and prevent the negative implications of the now widespread presence of ASF in the ecosystems of northern and eastern Europe, close and continuous cross-sectoral collaboration is essential. Veterinary authorities, forestry and wildlife management agencies and nature conservation and hunting bodies, organizations, communities and clubs should be mutually informed of different aspects of the problem, which sometimes go well beyond their immediate competencies and conventional responsibilities. Therefore, the focal target audience of the publication includes a broad range of potential readers, whose decisions or actions on national or local scales can contribute to controlling ASF in wild boar and mitigating the negative implications of this devastating disease for agriculture, as well as for the forestry and game management and nature conservation sectors.

The geographical scope and most of the information or examples provided in this document are intentionally limited to the countries of northern and eastern Europe. These countries share similar environments, agroecological and wildlife management systems, and have experienced the same sylvatic transmission cycle of ASF, which emerged a few years ago. As the epidemiological situation in Europe remains dynamic, and the knowledge on ASF epidemiology in wild boar is far from complete, the document will require future revision and updates in order to reflect new findings, experiences and lessons to learn. This is particularly relevant regarding the ongoing evolution of the global situation and spread of the disease into tropical countries, where its epidemiological profile in new environments may significantly differ from what has so far been seen in European contexts.

The publication consists of seven chapters. Chapter 1 describes the epidemiological cycle of ASF in wild boar as it is currently perceived by expert and research communities. It details the main risk factors related to the circulation of the virus in the ecosystems of northern and eastern Europe. Chapters 2 and 3 briefly reflect on questions and issues (some of which are controversial) that are typically raised and debated in relation to wild boar biology and population management in the context of ASF control. Chapters 4 and 5 provide a detailed description of the key elements of biosecurity strategy recommended at the level of hunting grounds, and its practical implementation, based on the experiences of countries in northern and eastern Europe affected by the ongoing sylvatic epidemic of ASF. Chapter 7 concerns data collection, stressing the need for continuous systematic efforts to better document field observations in order to improve our understanding of disease epidemiology as it evolves and expands its geographic range. Finally, the document addresses risk communication strategies and approaches, which are crucial for effective cross-sectoral collaboration among stakeholders dealing with such a complex problem as the spread of ASF in wild boar. Each chapter opens with a short paragraph briefly introducing its contents and concludes with a summary of the key messages.

Chapter 1

Epidemiology of African swine fever in wild boar populations

Vittorio Guberti and Sergei Khomenko

This chapter describes the epidemiology of ASF in the wild boar populations living in northern and eastern Europe. It focuses on the most successful determinants of the virus – wild boar ecological systems. The chapter briefly describes the evolution of the transmission cycles of the disease in its journey from Africa to northern Europe.

EPIDEMIOLOGICAL CYCLES AND GEOGRAPHICAL DISTRIBUTION OF AFRICAN SWINE FEVER IN EUROPE

ASF is a disease of pigs, which was originally associated with the ecological niche of the ticks of the genus *Ornithodoros* and the common warthog (*Phacochoerus africanus*) in sub-Saharan Africa. Warthogs and ticks, which naturally co-inhabit burrows, can sustain the transmission cycle of this virus for an unlimited time. It is a well-established natural host–vector–pathogen system, the sylvatic transmission cycle of ASF (Penrith and Vosloo, 2009), with a distribution restricted to parts of the African continent. Warthogs are naturally

FIGURE 1
From warthogs to wild boar: adaptive modification of African swine fever virus transmission cycles, from Africa to Europe

Notes: **Cycle 1:** the natural African sylvatic cycle; **cycle 2**: the anthropogenic cycle involving ticks (Africa and Iberian Peninsula); **cycle 3:** the pure anthropogenic cycle (western Africa, eastern Europe and Sardinia); **cycle 4:** wild boar–habitat cycle (northern and eastern Europe, 2014 to present).

Source: Author's own elaboration based on **Chenais, E., Ståhl, K., Guberti, V. & Depner, K.** 2018. Identification of wild boar–habitat epidemiologic cycle in African swine fever epizootic. *Emerging Infectious Diseases,* 24(4): 810–812. https://dx.doi.org/10.3201/eid2404.172127.

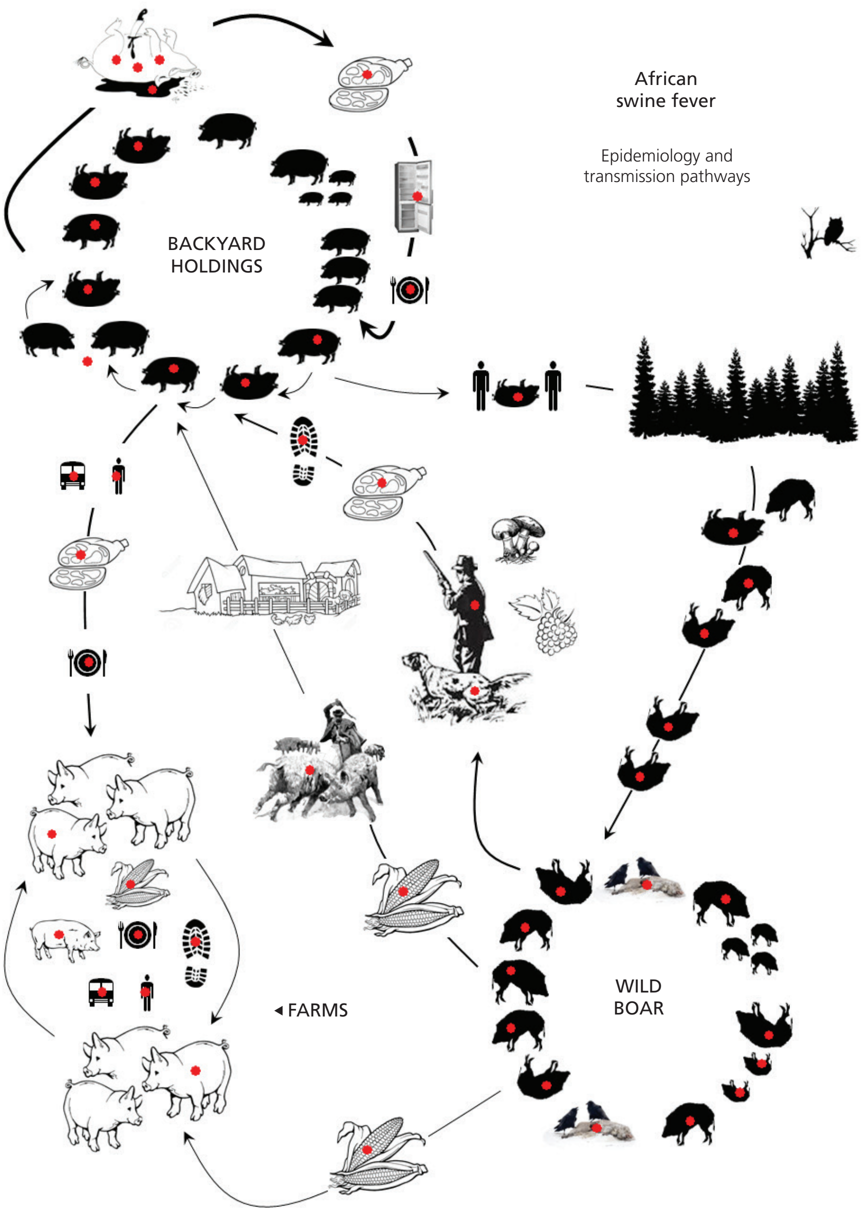
resistant to the effects of the African swine fever virus (ASFV) and do not usually develop clinical disease. Infection takes place within burrows, where a strong symbiotic relation exists between the warthogs and ticks . Young warthogs are born uninfected, and first become infected when bitten by *O. moubata*. They then develop viraemia which lasts for two or three weeks, which is sufficient to infect new ticks in turn (Thomson *et al.*, 1980).

In Africa, the virus has shown a trend to shift towards a more anthropogenic cycle (Figure 1, cycle 2) in which domestic pigs instead of warthogs assumed the role of an epidemiological reservoir, with the occasional involvement of *Ornithodoros* ticks. This kind of transmission cycle was also reported from the Iberian Peninsula during the 1960s and 1970s (Sánchez-Vizcaíno, Mur and Martínez-López, 2012). Again, in Africa, driven by the growing human population and increasing numbers of domestic pigs, ASF spread to areas where it had never occurred naturally before. In these new areas, its transmission cycle no longer involves ticks or warthogs (Figure 1, cycle 3). The spread of the virus in domestic pigs is facilitated by human activity. Movements of animals due to trade, the sale of infected meat and free-range pig farming are the main risk factors in this system. A similar, purely domestic, pig cycle, has also evolved in the Caucasus since 2007 (European Food Safety Authority [EFSA], 2010a, 2015), when the genotype II virus was first introduced in Georgia. Thereafter, it has spread northwards, primarily in the domestic pig population, moving from the Caucasian countries to the Russian Federation, Belarus and Ukraine, and then to other European countries (Gogin *et al.*, 2013; Figure 2 and Figure 3).

Finally, the most recent step in the evolution of the biological cycle of ASFV and its geographical spread is related to the formation of the wild boar–habitat cycle (Figure 1, cycle 4) which has developed in northern and eastern Europe. This novel host–pathogen–environment system has steadily expanded the range of ASF in Europe (EFSA, 2017), facilitated by the exceptional stability and resilience of ASFV in the environment and infected carcasses of animals. Since 2014, spread has occurred in the Baltic states, Poland and Czechia (Khomenko *et al.*, 2013; EFSA, 2017), followed by Hungary, Romania and Belgium, and later Slovakia, Greece and Germany, with Italy and North Macedonia being the most recent (January 2022) European countries to be affected.

Photo 1
Free-ranging domestic pigs in Georgia feeding next to a waste bin, illustrating one of the main mechanisms of disease spread in domestic pigs.

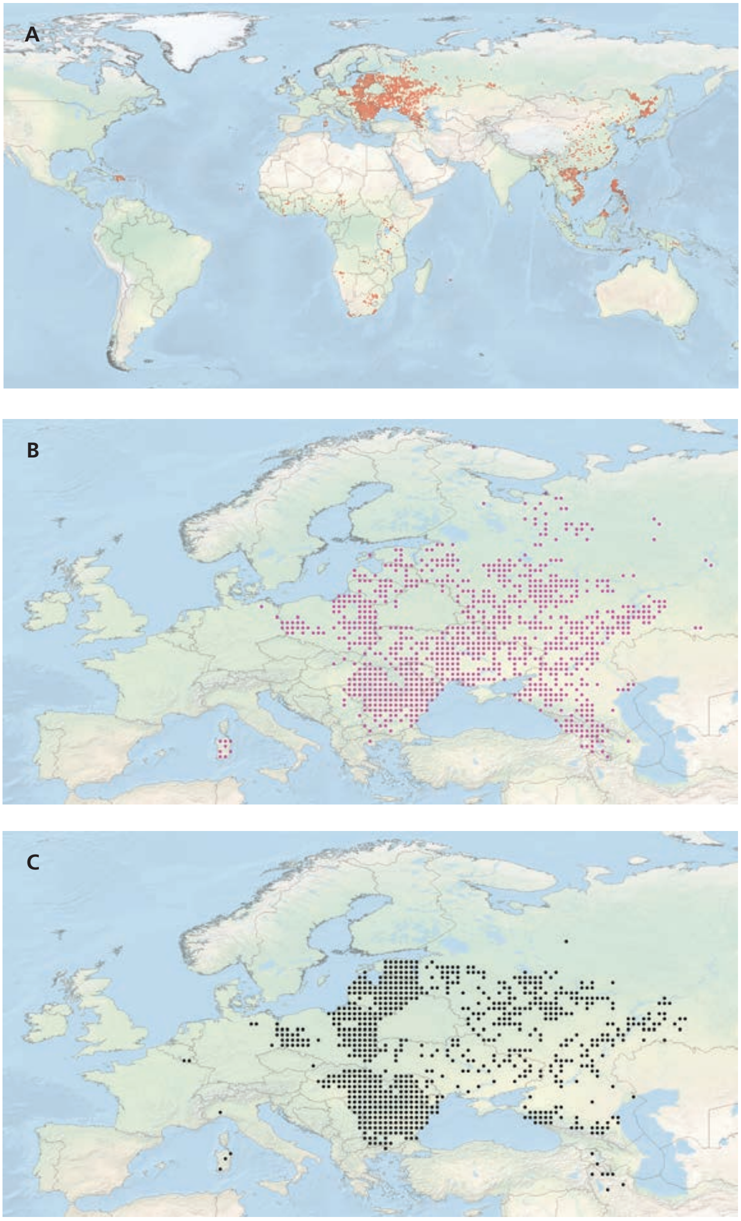
FIGURE 2
Complex of epidemiological factors and transmission pathways involved in sustaining endemicity and facilitating geographical expansion of African swine fever virus in eastern Europe (cycles 3 and 4, Figure 1)



Source: **Guberti, V., Khomenko, S., Masiulis, M. & Kerba S.** 2019. *African swine fever in wild boar ecology and biosecurity.* FAO Animal Production and Health Manual No. 22. Rome, FAO, WOAH and EC. https://doi.org/10.4060/CA5987EN.

FIGURE 3

Geographical occurrence of African swine fever in 2007–2022 represented as centroids of 30 arcmin grid cells with at least one detection of the disease: either in domestic or wild suids globally (A); in Europe in domestic pigs (B); in Europe in wild boar (C)



Notes: Only ASFV genotype II is implicated in disease expansion everywhere outside of the African continent, except for the island of Sardinia (Italy).

Source: Authors'own elaboration based on ASF official notifications to WOAH, 2007–2022 (as of 31 January 2022).

This cycle is characterized by the continuous presence of the virus in the affected wild boar populations, which represents a serious challenge for the pig production sector and wildlife management authorities, as well as hunters. In the last four years, ASF has become endemic in wild boar over remarkably large areas (Figure 3), and the scale of the problem poses a major threat to the European pig production sector (Figure 2). From 2018 onwards, genotype II ASFV spread eastwards into Asia, affecting China, Hong Kong, the Democratic People's Republic of Korea, the Republic of Korea, the Lao People's Democratic Republic, Viet Nam, Myanmar, Cambodia, Indonesia, Philippines, Timor-Leste, Papua New Guinea and India (Penrith, 2020), crossing the Atlantic to be detected in the Dominican Republic and Haiti in 2021 WOAH, 2021); in some Asian countries, wild boar populations seem to be taking the same role which has been observed in Europe. This chapter is mainly based on knowledge accumulated in the last decade on the epidemiology of ASF genotype II in the wild boar in central and eastern Europe, although reference is occasionally made to specific epidemiological situations outside this area.

The ongoing progressive spread of ASF around the world opens possibilities for formation of new, as yet undescribed, epidemiological cycles of ASF. These might involve domestic, feral or wild suids, with or without involvement of competent or mechanical vectors of the virus. Naturally or artificially attenuated strains of ASF have a potential to change the epidemiology of ASF, resulting in host–pathogen–environment constellations that are difficult to predict. Given the exceptionally wide distribution of susceptible host species of the genus *Sus*, the ASF clearly has panzootic potential, and if not promptly controlled, might become endemic on any continent (except Antarctica) shortly upon incursion.

CHARACTERISTICS OF THE AFRICAN SWINE FEVER VIRUS CIRCULATING IN EUROPE AND ASIA

ASF is caused by a DNA virus belonging to the *Asfarviridae* family. It affects species belonging to the *Suidae* family only; in Europe, the sole susceptible species are domestic pigs and wild boar (*Sus scrofa*). They show similar clinical signs and have similar case fatality rates. Although a total of 24 genotypes of the virus are known to circulate in Africa, only two currently occur in Europe, both in wild boar and domestic pigs (Gabriel *et al.*, 2011). Genotype II spread extensively in eastern Europe from 2007, while genotype I had been reported as endemic in Sardinia only, where it remains confined and is under systematic observation and control (Franzoni *et al.*, 2020).

The genotype II virus now circulating in Europe and Asia has a very high case fatality rate of over 90 percent, irrespective of whether the infected animals are wild or domestic. Being a DNA virus, the genetic structure of ASFV is rather stable, and thus the use of molecular epidemiology for tracing back the origin of the virus is of limited use, though a few mutated and attenuated Georgian genotype II viruses have been isolated in Europe (Zani *et al.*, 2018; Gallardo *et al.*, 2019). However, recent findings from Poland and Germany demonstrate the existence of new variants facilitating molecular epidemiological tracing (Mazur-Panasiuk, Woźniakowski and Niemczuk, 2019).

The attenuated strains of the Caucasian genotype II seem to show milder clinical symptoms and a reduced lethality. Under the field conditions, the attenuated strains should – at least in theory – cause higher seroprevalence, and have a higher probability of locally persisting as an endemic infection. The spread of the attenuated strains would pose a change in the early detection strategy (see chapter 4), which would then not be solely based on passive surveillance. So far these attenuated strains have failed to replace the original highly lethal strain. For instance, the Estonian strain has already disappeared, while the Latvian strain can be still isolated, but its prevalence is extremely low. With carcasses being the most important source of virus contamination of the environment and, in this way, for infecting susceptible wild boar, in most European countries the virulent ASFV strains of genotype II do not so far seem to be losing their adaptive advantage by retaining their lethality. Counterintuitively, if the host mortality contributes to the spreading of the virus, which is apparently the case with ASF in wild boar, the highly virulent strains are naturally selected for continued transmission. The behaviour of an attenuated strain when spreading into a wild boar population is hard to predict, but currently it seems to be the virus lethality that helps it to propagate itself in the wild boar–habitat cycle. For low-virulence strains to become established, their transmission rate would have to increase, which has not been observed so far.

ENVIRONMENTAL RESISTANCE

The extreme environmental resistance of the virus is the key to understanding the epidemiology of ASF and developing adequate measures and interventions for its control, both in the pig production sector, and under natural conditions when it circulates in wild boar populations. Currently available information on the potential of different matrices to facilitate spread of the virus is provided in Box 1, and fully listed by Fischer *et al.* (2020).

Two points deserve special consideration. First, most of the literature describing the tenacity of the ASFV is based on virus detection with a polymerase chain reaction (PCR) test. However, the detection of its genome does not necessarily mean that a live, infectious virus is present in the animal. The virus genome can be detected even when the virus itself is not viable, and thus no longer infectious. Only virus isolation proves the viability of the virus, and is a more sensitive diagnostic method than PCR testing; however, virus isolation is difficult to routinely perform, and is therefore much less frequently used for diagnostic purposes at present (Fischer *et al.*, 2020).

Second, any environment (such as the central European continental platform) is composed of a number of ecosystems (i.e. forests) that contain a number of habitats (i.e. broad-leaved deciduous trees), each subdivided into a number of microhabitats. While abiotic factors (such as sunlight, radiation, temperature, humidity and air composition) are largely shared in the environment, each of the habitats and microhabitats is characterized by specific characteristics such as pH, retained humidity and solar exposition. The thousands of square kilometres of forests in central and northern Europe consist of a wide range of different microhabitats in which the virus can persist for a variety of periods, while infected wild boar (as live animals) continue to spread the virus or contaminate the environment (as carcasses). Both environmental complexity and diversity guarantee – together with these infectious wild boar and contaminated carcasses – the continuous presence of the viable virus, and the consequent risk of repeated reinfection, determining the wild boar–habitat cycle.

In any ASF-infected wild boar population, there are seven categories of animals, each with a different epidemiological role in spreading the disease. These categories are:

Susceptible: Any healthy individual that has never been infected by ASFV and is thus susceptible to it. Such animals normally comprise the largest part of the population. The number of susceptible animals changes seasonally due to reproduction and mortality, with the latter largely due to hunting, though predation, limits on food resources and disease may also contribute.

Incubating: Any individual that is infected but does not yet show visible clinical signs of the disease. Incubating animals could spread the virus for a number of days (usually one) before showing evident signs of the disease. The number of incubating animals is usually very small (usually less than 2 percent) and is dependent on the phase of virus invasion, the season and other factors. The only way to determine if a hunted wild boar is in the incubation phase is to collect samples and conduct laboratory testing; positive animals should be safely destroyed. However, during the incubation period, especially during the first days, no virus can be detected. Usually the virus is detectable between the end of the incubation period and the beginning of the clinical phase, in the very early stage of which signs can still go unnoticed.

Diseased: A wild boar showing clinical signs of ASF, or appearing healthy but, when tested, shown to be virus positive. In experimental conditions, wild boar show clinical signs for 4–9 days before death (Nurmoja *et al.*, 2017a); 90–95 percent of diseased animals die (Pietschmann *et al.*, 2015; Nurmoja *et al.*, 2017a). Clinical signs are not pathognomonic, instead being represented by many possible abnormal behaviours (such as lack of escaping, trembling of hind legs and prostration) that simply indicate that the wild boar is sick. Sick animals could be more prone to predation. In the hunting bag, the average virus prevalence ranges from 0.5 percent to 2.5 percent; however, according to local sampling strategies or specific epidemiological situations it could be higher, for example 13.7 percent in southern Estonia (Nurmoja *et al.*, 2017b). The true proportion of virus-positive animals in the population can be under-represented in the hunting bag as sick animals deviate from their predictable behaviour, changing their daily routines, losing appetite and shifting to inaccessible parts of their territory, all of which prevent them from being easily hunted. Only laboratory tests can verify if a wild boar is infected with ASF, and if positive, it must be destroyed. Any wild boar killed in a road accident in ASF-affected or at-risk areas should also be tested.

A wild boar infected with the Caucasian strain of genotype II has a limited probability of survival; however, seropositive animals do occur in low numbers where ASF is present in wild boar populations. For the animals that survive the infection, the scientific literature describes three distinct occasions when serological tests may turn positive, of which only the two latter are observed with genotype II:

Chronically sick (Sánchez-Vizcaíno *et al.*, 2015; defined as Category 1 by Ståhl *et al.*, 2019): Animals with a reduced lifespan that host the virus for the rest of their life. These animals shed the virus when showing clinical signs and/or ASF lesions. The animals show as positive according to both PCR and antibody tests. There is no evidence that the ASF Caucasian genotype II induces the chronic form of the disease.

Convalescent (defined as Category 2 by Ståhl *et al.*, 2019): Animals that completely recover from the infection and will not show any clinical signs or lesions. ASFV remains attached to the external membrane of the erythrocytes, the lifespan of which determines the presence of the virus in the blood. There is no evidence that these animals became long-term spreaders of the virus. They become virus negative at around 96 days after infection (Nurmoja *et al.*, 2017a; Petrov *et al.*, 2018). Often, convalescent animals are wrongly regarded as "carriers" (similarly to foot-and-mouth disease carrier individuals), but they are not capable of playing this specific epidemiological role (Figure 4).

BOX 1

Role of different matrices for the secondary spread of ASF

Oral-nasal excretions/secretions

The virus is present in both the nasal and the oral secretions of infected animals, and can be detected even before its appearance in blood and clinical signs. These oral and nasal fluids are likely to be involved in the direct contact spread of the infection. The quantity of shed virus is relatively low, though sufficient to trigger new infections. In the oral and nasal fluids, the virus is shed for a number of days (2–4), while its half-life is not known. The more the clinical phase progresses, the more virus is excreted, especially towards the end of the animal's life when mortality is brought on by the infection.

Blood

The virus can be detected at very high titre in the blood of infected wild boar at 2–5 days (on average, 3 days) after infection; its detection is concomitant with the onset of clinical signs, and can survive for up to 100 days in convalescent animals. The virus in the blood can survive for 15 days at room temperature, months at 4 °C and indefinitely when frozen. The blood contamination of soil, hunting premises and tools, including knives, clothes and cars used for transport of infected hunted animals, are important sources for the local persistence and further spread of the virus.

Raw meat

The virus is also present in the meat from infected animals, which represents an important source for both the local maintenance and long-distance spread of the virus. Since the virus is resistant to putrefaction, it can survive for more than 3 months in meat and offal. It remains infectious for almost one year in dry meat and fat, and it survives indefinitely in frozen meat. The frozen meat of infected wild boar can ensure the survival of the virus for years, and thus represents a possible source for new epidemics.

Carcasses and offal

The ASFV outlives its host. As in meat, the virus can survive in entire carcasses or offal for a very long time, depending on ambient temperatures, organs or tissues. A frozen carcass can maintain infectious virus for months, which means that the pathogen can overwinter even in the temporary absence of any live host and initiate a new transmission cycle when the defrosted carcasses are approached the following spring by susceptible wild boar. In the ecology of ASF in wild boar, the virus's survival in carcasses plays a crucial role. Once an infected wild boar dies, the virus remains infectious in the carcass for an extended period of time. Safe removal of carcasses from the environment and their disposal is thus among the most important disease control measures, without which ASF eradication from wild boar populations is not possible. Similarly, if infected animals are hunted and dressed in the field, the offal (including viscera, skin, head and other parts of the body) also becomes an important potential source of the virus. Particularly in winter, when most hunting activities take place, offal that has not been properly disposed has the potential to increase the risk of secondary infections and the further spread of the disease. The genome of the virus can also be detected in buried carcasses, but the virus is no longer infectious. The soil on which an infected wild boar dies and its carcass then lies, is also likely to be contaminated, and thus has to be considered as a source of live virus for at least two weeks following the removal of the carcass (Carlson *et al.*, 2020).

Faeces and urine

Both faeces and urine are infectious, and the half-life of the virus is determined by the environmental temperature. ASFV survives longer in urine than in faeces. Its half-life in urine ranges from 15 days at 4 °C to 3 days at 21 °C. In faeces, virus half-life ranges from 8 days at 4 °C to 5 days at 21 °C, and the virus DNA is still detectable from two to four years (de Carvalho Ferreira *et al.*, 2014). Davies *et al*. (2017) have demonstrated that the virus is still infectious in urine and faeces after five days. It is important to underline that the half-life of the virus is strongly affected by enzymes (proteases and lipases) produced by the bacteria which colonize faeces and urine; thus, the exact survival time in a forest where ASF is actively circulating is not fully comparable to the estimates obtained under laboratory conditions. However, in areas highly contaminated by infected faeces and urine, the risk of secondary spread of the virus will be more likely, through vectors such as contaminated boots, tyres or hunting tools. At feeding stations visited by many animals, contamination by infected faeces or urine could increase the rate of secondary infections.

Soil

As already mentioned, viral DNA has been detected in the soil after the removal of the body of an infected wild boar or when the soil is contaminated by infected blood or other excretes-secretes. Laboratory experiments show that the pH of the soil (which reflects the amount of organic material), the temperature, initial virus titration, amount of virus contamination and the source matrix that contaminated the soil all affect the lifespan of the virus, and thus its infectious period (Carlson *et al.*, 2020).

Scavenging insects

It has been hypothesized that ASFV can potentially survive in insects (adult and larval stages) scavenging on infectious carcasses. However, while maggots of the green bottle fly (*Lucilla sericata*) and blue bottle fly (*Calliphora vicina*) have been detected as contaminated with ASF DNA, the presence of viable ASFV could not be proven (EFSA, 2010a; Forth *et al.*, 2018). It is not known if the virus maintains its infectivity in other scavenging invertebrates. In any case, scavenging insects are attractive food for wild boar, thus increasing the contact rates between infectious carcasses and susceptible wild boar.

Hematophagous arthropods

The stable fly (*Stomoxys calcitrans)* is considered a potential mechanical vector of the virus, which it is capable of carrying for 48 hours (Mellor, Kitching and Wilkinson, 1987), but their role in the transmission cycle in Europe has not yet been fully investigated. The role played by other blood-feeding arthropods is unclear too, especially in the wild. *Ornithodoros* ticks, strongly involved in the natural ASF transmission cycle in Africa, do not occur in the parts of the European continent currently affected by ASF. In a heavily infected area with high virus prevalence in wild boar and in the absence of infected pigs, all the tested ticks (genus *Ixodes*), midges (genus *Culicoides*) and horseflies or tabanids were ASFV negative despite the PCR tests proving they fed on suids (Herm *et al.*, 2021).

Fomites

The high environmental resistance of the virus implies that its transmission is possible via any fomite, (non-living objects capable of carrying infectious organisms when contaminated), such as shoes, clothing, parts of vehicles, knives and other kinds of equipment.

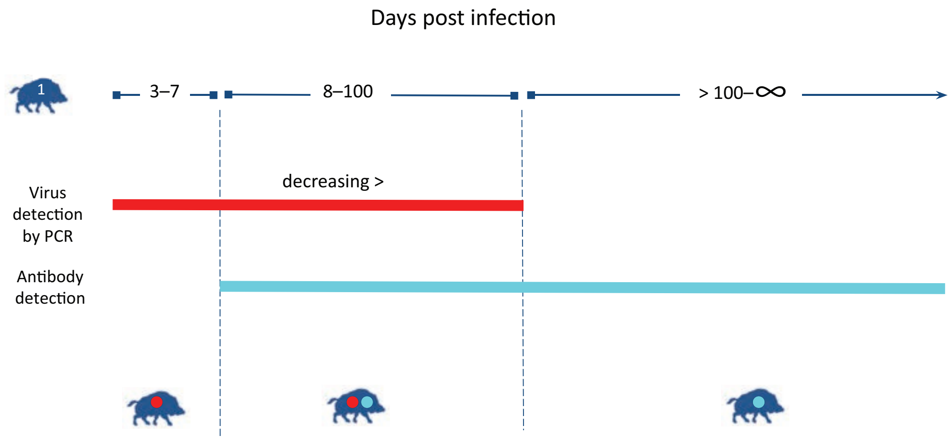
Food/kitchen waste

The high resistance of the virus means that thermally untreated food originating from infected animals (both domestic pigs and wild boar), such as sausages, salami or ham, as well as food leftovers accidentally released into a wild boar habitat, can initiate an ASF epidemic. It is well known that food waste is considered the main source of the virus in the long-distance spread of ASF.

Grass and other growing crops

Infected wild boar could contaminate grass and other growing crops, such as corn plants, intended for use as feed by other animals when harvested. Therefore, feeding grass or unprocessed vegetables to domestic pigs should be forbidden everywhere that ASF is present in wild boar populations.

FIGURE 4
Timeline of infection and outcomes of testing for ASFV by PCR and for antibodies in relation to the day of its onset in infected, convalescent and survived wild boar



Source: Authors'own elaboration.

Seropositive: Animals that have survived the disease and, when tested, appear to be antibody-positive only. They are resistant to reinfection, at least from the same strain of the virus, against which antibodies were developed. In infected areas, the proportion of seropositive wild boar in the hunting bag ranges from 0.5 to 2 percent; however, the number of seropositive animals is correlated with the duration of ASFV persistence in the area. Thus, increased seroprevalence reveals an endemic stability rather than an attenuation of the virus virulence. While seropositive animals no longer shed the virus, the viable virus could be still detected in their lymph nodes (Wilkinson, 1984; EFSA, 2010a); hence, they must be considered as potentially infective and thus whenever hunted and testing as seropositive for ASFV, should be safely destroyed in the same way as virus-positive animals.

Dead: The majority of wild boar infected with ASFV die (ASF has a case fatality of 90–95 percent) and remain in the environment for some time, providing a significant source of infection for other wild boar. The simplest and most frequent way of identifying the potential presence of ASF in an area is through hunters or other people visiting wild boar habitats finding carcasses, which can then be tested. Any dead wild boar should be removed from the forest and safely destroyed, as well as tested for the presence of ASFV or other pathogens. Although in any wild boar population there is always a proportion of animals that die naturally without any infection from ASFV (Keuling *et al.*, 2013), as an ASF epidemic unfolds the number of carcasses increases substantially, thus signalling the incursion of the virus or, more often, an ongoing epidemic. In Europe, the detection of ASF-infected carcasses increases from winter through spring and summer, peaking in July and August. These observations reflect certain patterns of the disease transmission cycle and population dynamics, as well as the cumulative effect of climatic and seasonal factors on carcass decomposition and the probability of their detection by people.

In a wild boar population, the virus is shed by:

1. **Incubating animals,** during a very short period before the appearance of clinical signs. As this phase is rather short, it is of minor importance in the whole chain of ASF infection.
2. **Sick animals,** towards the end of the clinical phase. Shortly before the animal dies, virus shedding reaches its peak.
3. **Convalescent animals,** which have survived the acute/subacute stage of infection. These can spread the virus for some time; the virus is attached mainly to the erythrocytes (95 percent), and to a lesser extent, white blood cells (1 percent). During this period, the virus is shed only through blood, for example from wounds resulting from fights among wild boar.

INFECTION ROUTES AND MECHANISMS

Direct horizontal transmission: The usual physical contact among wild boar in the same group, and sometimes, with individuals from other groups, is sufficient to transmit the virus, as happens with many other infectious diseases. Direct horizontal transmission plays a very important role in habitats with relatively high wild boar density, as happens when the virus is newly introduced into a disease-free population.

Local indirect transmission through contaminated environment: The habitats where the infected wild boar population lives can be heavily contaminated through the excretions and secretions of infected individuals and their remnants after death (that is, whole carcasses or parts disseminated by scavengers), and from infected materials originating from the hunting of ASF-positive animals (blood, meat and offal) that spill into or are disposed of directly into the habitats. The effectivity of environmental transmission is impacted by the time of year, the weather and other factors.

Infected carcasses: The indirect transmission via infected carcasses of wild boar (or domestic pigs) is considered to play a pivotal role in the epidemiology of ASF (see Box 2 for the results of the first study into the topic). Infectious carcasses have the capacity to maintain live virus in the habitat for a much longer period of time (months) compared to its persistence in excretions, especially during winter, thus making wild boar population density and contact rates less relevant for long-term maintenance of the ASF transmission cycle. Particularly in summer, after they pass through the first stages of decomposition, these carcasses provide good conditions for the development of communities of invertebrate insects that can further attract susceptible, healthy wild boar.

Remnants of infected animals: Offal abandoned by hunters when dressing infected animals in the field may also play a relevant role by increasing virus loads in the environment. A susceptible wild boar living in a habitat contaminated in this way has a high probability of becoming infected with the virus.

Excretions: The virus excreted with urine and faeces contaminates wild boar habitats and, during periods when temperatures are low (especially winter) which are favourable to the survival of the virus, can be transmitted to susceptible animals. In proximity to wild boar feeding points, environmental contamination may be of high importance. In winter, provided

BOX 2

Role of wild boar carcasses in ASF epidemiology

ASF-infected wild boar usually die from the infection, and their carcasses are exposed to scavengers including ASF-susceptible wild boar. The decomposition process may vary substantially depending on a variety of factors, including the weight of the dead animal, the season and the weather conditions. Especially in winter, it may take several months before the carcass is fully decomposed and skeletonized. ASFV is extremely stable in the environment and is transmitted via the blood and meat of infected animals. The persistence of the virus in carcasses depends mainly on temperature, viral load, matrices including the characteristics of the underlying soil and – in wild boar which have been hunted – carcass management. Tissue and organs from decomposing carcasses that persist in the environment can be a source of infection for several months, especially at low temperatures between -20 °C and +4 °C (Fischer *et al.*, 2020).

At present, two studies by Probst *et al.* (2017) and Cukor *et al.* (2020a), conducted respectively in Germany and Czechia, quantified the contacts between live wild boar and conspecific carcasses. In Czechia, the first contact with a carcass was observed at day 5 post-mortem (average 30 days; 95 percent confidence interval (CI) 12–49 days), while in Germany at day 1 post-mortem (average 15 days; 95 percent CI 1–32 days). Most of the visits resulted in direct contact between live and dead animals. This contact could consist of sniffing and poking the carcass, chewing on bones and rooting in the soft soil that had formed after the decomposition of several carcasses on the same spot. Often, younger wild boar (piglets) were particularly interested in carcasses and displayed obvious signs of excitement (such as bristling neck hairs), while other age groups were interested in the soil surrounding and underneath the carcasses.

(Cont.)

with regular supplementary feeding, some wild boar tend to reduce the extent of their home range to within just 200–300 m of the feeding point, while other individuals regularly visit all the feeding points, acting as a connector among feeding sites. This tendency, along with the increased probability of encountering other individuals that can spread infection through direct horizontal transmission, also increases probability of infection. Excretions may also contaminate crops and grass, which can subsequently end up as fresh feed in domestic pig stables.

RISK OF INTRODUCTION

ASF is introduced to new wild boar populations through two main mechanisms summarized below and in Table 1. The first is human-mediated or anthropogenic introduction, in which people carry the virus from infected into free areas over long, medium or short distances. Such unintended translocations of the disease may involve anybody who has been in contact with the infection or carries contaminated products of pig origin, including groups such as hunters, mushroom collectors, tourists, the military, loggers and farmers. People can transport the virus over long distances through contaminated meat and other products such as skins, skulls, tusks and other hunting trophies. Irrespective of whether the virus originates from domestic pigs or wild boar, and even if unintended or accidental, this

In Czechia, the wild boar showed cannibalistic behaviour in about 10 percent of the contacts, when carcasses were an average age of 70 days post-mortem (95 percent CI 30–109 days).

In general, it is assumed that all previously mentioned types of contact represent a reasonably high risk of ASFV transmission. The high resistance of ASFV, and the relatively long time which remnants of dead wild boar may persist in the environment until complete decomposition, are likely to contribute to the contamination of the habitat and to the continuous presence of infectious ASFV even in the absence of the live host. In an infected area, this situation can last for months. Hence, the spread of ASFV through carcasses gains particular importance, even when the wild boar density is relatively low and the frequency of direct contact between animals fails to sustain a horizontal transmission cycle (Pepin et al., 2020).

All authors underlined that the rapid detection and removal of carcasses (along with safe destruction and decontamination of the immediate area) are effective control measures capable of reducing ASFV transmission rate in the wild boar population. Even if a carcass is detected and removed several days post-mortem, such a delayed removal still proves to be an effective control measure. Therefore, safe methods of carcass removal and decontamination of the environment must be developed in order to manage the situation. Hunters should be appropriately trained and involved in ASF contingency measures, with clear understanding of the purpose and rationale behind their actions.

Scavenger species (both avian and mammalian) accelerate the decomposition and eventual disappearance of carcasses. When ingesting infected material, they inactivate the ASFV through their low stomach pH (Probst *et al.*, 2019); their faeces, therefore, should not pose any risk of disease spread. Finally, Zani *et al*. (2020) could not detect any viable ASFV in wild boar carcasses buried from 18 to 440 days, suggesting that deep burial is a safe way to dispose of infectious carcasses in forests.

TABLE 1
The two main mechanisms of the introduction of ASF

Anthropogenic introduction	Introduction from natural progression of epidemic wave
Human activities bring the virus from infected areas to infection-free areas where wild boar are newly infected The risk is unpredictable and prevention of introductions is almost impossible	Natural enlargement of the geographical range of the virus Easy to predict but difficult to prevent because of the large areas involved
Punctual introduction An initially limited area involved	Recurrent reintroductions Often large areas involved

mechanism provides the means of spreading the disease over distances greatly exceeding those involved with the transmission mechanisms already described.

Release of the virus by humans through contaminated materials is particularly dangerous because the disease may flare up in unexpected locations far from known outbreaks in domestic pigs or cases in wild boar. On multiple occasions, including in Europe, indirect long-distance spread of the virus has initiated new clusters of infection in wild boar (and in domestic pigs), some of which have now developed into long-lasting epidemics, as mapped in Figure 3. The most recent examples are the localized epidemics of ASF in Czechia (Zlin District), Poland (Warsaw and western Poland), Hungary (Heves County) and Belgium (Étalle). According to EFSA (2018), anthropogenic introduction has played a pivotal role in the epidemiology of ASF in the wild boar populations of northern and eastern Europe; the anthropogenic introduction and spread of ASFV among wild boar populations is a continual risk which is difficult to minimize.

The second main mechanism of introduction is through an unfolding epidemic, which expands the virus circulation due to the geographical continuity of the infected wild boar population. It is the most common way in which the virus progressively spreads across the landscape, affecting adjacent host populations in new areas because of their spatial and ecological continuity with already infected areas. Unless inappropriate control measures are applied on the geographical edges of the epidemic (such as, for example, driven hunts which strongly enhance disease progression through increasing the mobility of animals), this type of ASF spread is a purely natural process and does not involve any human action. It is characteristic for a naturally progressing epidemic to initially produce multiple introductions in new areas, as was the case with the ASF epidemic crossing the border between Poland and Germany. This type of introduction is highly predictable, although almost unavoidable without efficient barriers. It becomes a real challenge to ensure effective surveillance and control in the newly infected areas when the virus arrives in a frontal fashion.

TRANSMISSION CHAIN IN WILD BOAR POPULATIONS

Once the virus is introduced into an area, an epidemic is likely to occur and evolve in a fairly predictable manner. The epidemiological cycle of ASF in wild boar is characterized by a combination of a simultaneous steady geographic spread (epidemic wave) to neighbouring disease-free areas, and local endemic persistence. These elements are now explored in greater detail:

Epidemic wave: Initially, the virus spreads as a wave, leaving multiple ASF-positive carcasses in its wake. The speed (velocity) of the wave depends on the density of the wild boar population: the higher the density, the faster the velocity at which the epidemic moves. The velocity can range from approximately 1 km/month to 1 km/week, according to wild boar density and human activities such as hunting. In Belgium, the speed was higher due to the higher wild boar density. Calculations show that natural geographical spread of ASF in areas of typical density of wild boar populations for northern and eastern Europe occurs at the speed of several kilometres per month, resulting in continuous expansion of the epidemic wave, followed by local endemic persistence (EFSA, 2017; Belgium data). Differences in the speed of the infection may also be impacted by the timing of incursions, the continuity of suitable wild boar habitat and the types of interventions and management activities put in place.

Wild boar are generally a sedentary species (Podgórski *et al.*, 2013), with stable group home ranges rarely exceeding 50 km^2. However, episodes of long-distance spread of the virus significantly beyond the normal movement range of wild boar have occasionally been observed. There have been incidences of some significantly long-distance movements, for example approximately 100 km in six months (Jerina *et al.*, 2014). Possible longer-range movements during which an infectious (i.e. in incubating and disease phases) animal might spread the virus (e.g. young males during dispersion period or adult males in pursuit of females in heat) last for a limited time, roughly 5–7 days. In the course of a week, wild boar (particularly when undisturbed and sick) are highly unlikely to cross large distances. Hence, long-range incursions of ASF are most likely caused by human activities, although their unintended or illegal nature (often accompanied by a lack of awareness of the sources of the virus and its transmission mechanisms) make this difficult to prove with sufficient epidemiological evidence.

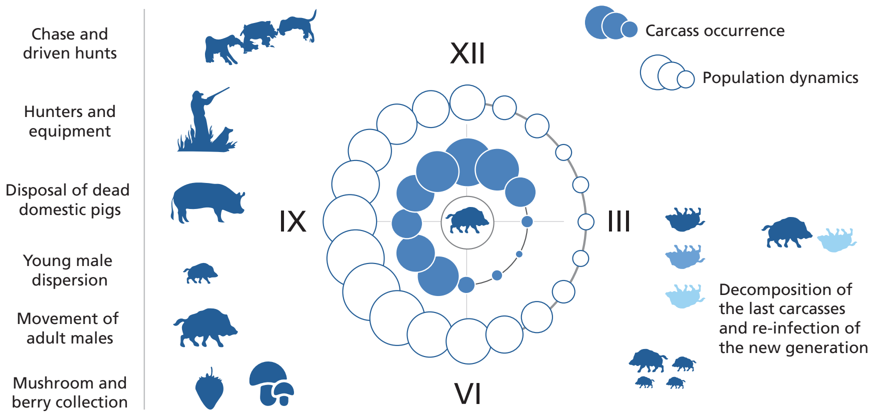
The direction of the wave is determined by the suitability of wild boar habitats. Large coterminous forested areas and/or wetlands will facilitate the spread of the virus. The speed of the virus wave is lower in fragmented habitats and where natural or artificial barriers disrupt habitat continuity. Artificial or natural barriers rarely halt the epidemic wave, but they do slow its speed, making it possible for the authorities to plan and implement specific disease control interventions. In the absence of entirely effective barriers, it is only a matter of time before the virus can spread indefinitely, reaching any wild boar (meta)population in geographical continuity with the infected one(s).

Direct animal-to-animal transmission of the virus is prevalent at the onset of the infection, during the epidemic phase. Intensification of direct transmission may also occur following the reproductive season, when the host population size almost doubles and newborn individuals (from 2 to 6 months of age) explore their habitat. This behaviour increases intraspecific contact, as does the regrouping or aggregation of herds when it occurs in cereal fields or protected reserves. At the peak of the unfolding epidemic, human interventions can neither prevent nor substantially enhance the demographic crash of the ASF-infected population; mortality rates produced by the disease significantly exceed human capacity to react to this crisis (Morelle *et al.*, 2020).

Endemic persistence: The more effective the spread of the virus, the sooner it will lead to a relatively rapid decline of the wild boar population. Ultimately, as a result of decreasing populations, intraspecific contact also declines and the epidemic moves into an endemic phase. Following the initial epidemic wave, the virus remains endemic in all those areas crossed by the wave. With the decline of wild boar abundance, the indirect mode of transmission through infectious carcasses and/or contaminated habitat becomes more important, favouring the local maintenance of endemic infection. Robust relationships between low density and indirect transmission of the virus have been highlighted in the endemic areas of Poland and are further shown in modelling (Pepin *et al.*, 2020; Gervasi and Guberti, 2021).

The endemicity of ASF in wild boar can be sustained naturally; however, the natural disease dynamics are often intermingled with human actions propagating the virus. Some counteractive hunting practices, including human attendance at feeding locations, disposal of contaminated offal and the involvement of fomites are among the most frequent faults contributing to disease endemicity. Finally, the presence of infected domestic pigs, and the illegal disposal of their carcasses in the environment where wild boar may come in contact with them, will further increase the probability of virus persistence. In such an epidemiological landscape, the interference consisting of short-, medium- or long-distance anthropogenic introductions of the virus make the complete eradication of ASFV extremely unlikely.

FIGURE 5
Endemic transmission cycle of African swine fever in a large continuous wild boar populations



Notes: Roman numerals denote months of the year, with XII representing December.

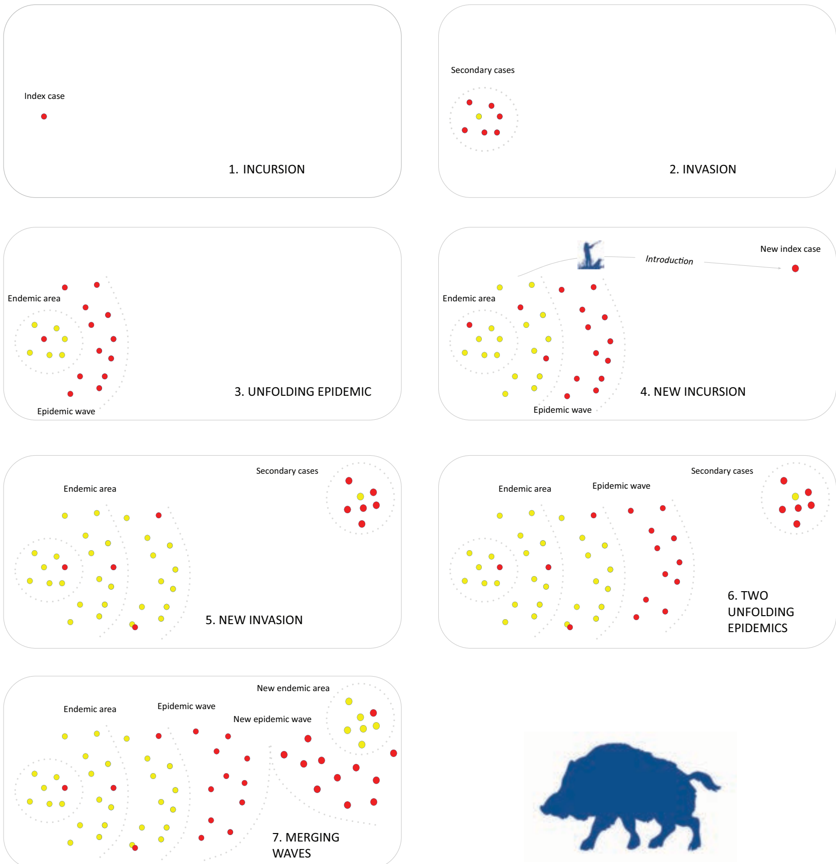
Source: **Guberti, V., Khomenko, S., Masiulis, M. & Kerba S.** 2019. *African swine fever in wild boar ecology and biosecurity.* FAO Animal Production and Health Manual No. 22. Rome, FAO, WOAH and EC. https://doi.org/10.4060/CA5987EN.

The complexity of the spatial dynamic: The typical chain of events associated with the introduction of ASF to a new area is illustrated in Figure 6. The index case (incursion), which is almost always missed by scientists and the authorities who monitor the status of ASF in their national or regional territories, creates a successful invasion that, on most occasions, also remains a "silent" epidemiological event which fails to trigger any control interventions. The invasion then turns into an apparent epidemic wave; only now is opportunistic passive surveillance likely to detect the worrisome signals. In the areas impacted by the epidemic, the infection remains endemic for extended periods of time. As the size of this endemic zone grows, the probability of further anthropogenic translocations of the virus and introductions into virus-free areas increases. The new introductions lead to new successful invasions, evolving into another epidemic wave. Expanding waves tend to merge, resulting in enlarged areas where the virus persists endemically; without specific control interventions, the cycle is repeated again and again. Such a pattern of disease activity is also fuelled by the re-establishment of the wild boar population following the initial demographic collapse, and recolonization of the territories where animals were killed by the disease.

AFRICAN SWINE FEVER DYNAMICS AND WILD BOAR POPULATION DENSITY

Understanding the relationship between the spread of ASFV and the wild boar population density is of paramount importance, since major efforts in controlling the infection are based on population density and size reduction. The natural history of infectious diseases (Burnet and White, 1972) highlights the quantitative relationship between a transmissible

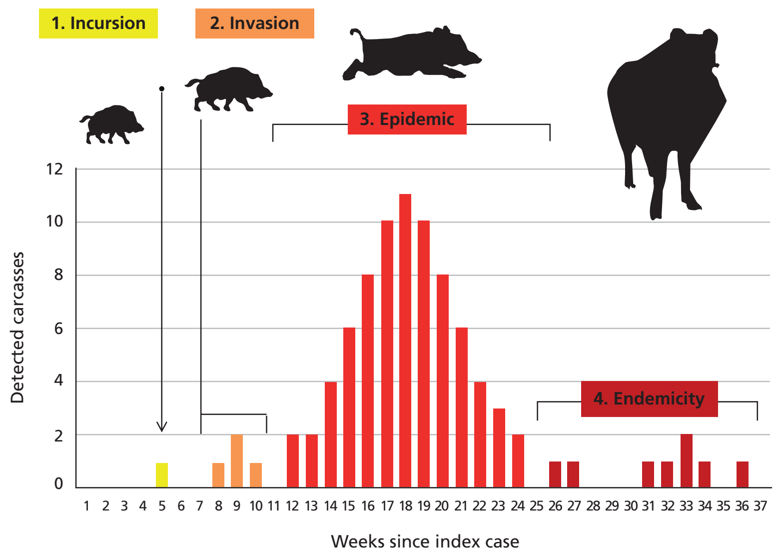
FIGURE 6
Generalized patterns of African swine fever epidemic in wild boar, showing the interplay of the two main mechanisms of introduction, natural progression of the epidemic wave and anthropogenic spread



Source: Author's own elaboration. FAO Animal Production and Health Manual No. 22. Rome, FAO, WOAH and EC. https://doi.org/10.4060/CA5987EN.

disease agent and the host population. Four main phases of the infection dynamics at the population level are recognized: introduction (or incursion), invasion, epidemic and endemic persistence (Figure 7).

FIGURE 7
Hypothetical example of the four phases of the infection dynamic in a population of wild boar, measured through the number of carcasses detected weekly



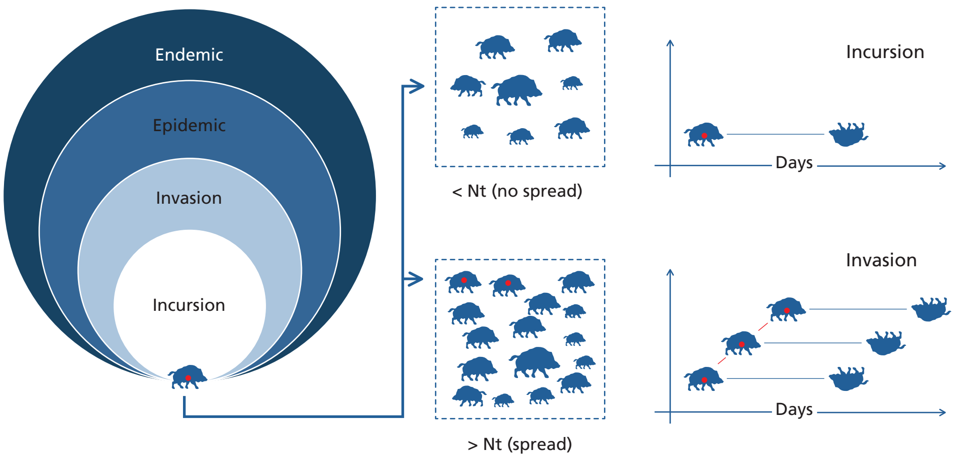
Source: **Guberti, V., Khomenko, S., Masiulis, M. & Kerba S.** 2019. *African swine fever in wild boar ecology and biosecurity.* FAO Animal Production and Health Manual No. 22. Rome, FAO, WOAH and EC. https://doi.org/10.4060/CA5987EN.

Incursion phase: This is the initial introduction of the virus into a disease-free, susceptible wild boar population. The incursion can happen through virus spread from a neighbouring infected wild boar population, or through accidental release of the virus in contaminated materials, often mediated by humans. The probability of the occurrence of an incursion is independent of the size and density of the local wild boar population.

Invasion phase: This is the initial successful spread of the virus in a susceptible wild boar population following an incursion. The probability that an infected wild boar will spread the virus depends on the availability of susceptible hosts. Any virus will spread when a large number of susceptible hosts are available. Conversely, in the absence of any susceptible hosts, the virus will become extinct, so the numbers and the density of available hosts will determine the outcome of the invasion (Figure 8).

For infections with a density-dependent dynamic, it is possible to estimate the minimum number of susceptible animals per unit of area needed to trigger a successful invasion. This number is called host threshold density, referred to as Nt. Nt-1 is the density at which an infectious host fails to encounter any susceptible individual within the time frame for transmission of the infection (Anderson and May, 1991; Lloyd-Smith *et al.*, 2005). It is important to underline that the Nt value is mainly determined by the virus characteristics. Its practical use is restricted to the initial spread of an infection (that is, the invasion phase) and not to epidemic or endemic situations (Deredec and Courchamp, 2003; Lloyd-Smith *et al.*, 2005).

FIGURE 8
Four possible phases of African swine fever infection and two different outcomes of an incursion in the population



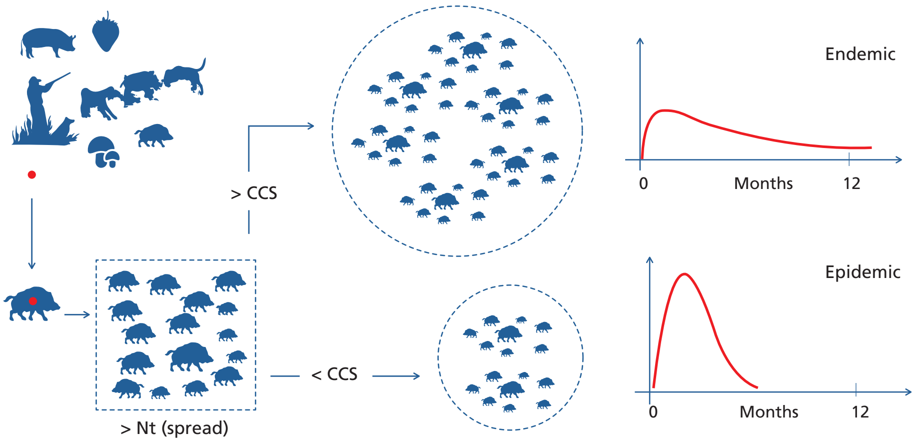
Notes: Density > Nt (spread) and density < Nt (no spread).

Source: **Guberti, V., Khomenko, S., Masiulis, M. & Kerba S.** 2019. *African swine fever in wild boar ecology and biosecurity.* FAO Animal Production and Health Manual No. 22. Rome, FAO, WOAH and EC. https://doi.org/10.4060/CA5987EN.

Among other methods used to control a disease, one might try to reduce the host population density to a level where the disease incursion would not be able to develop into an invasion and eventual epidemic. The Nt can be reached through depopulation or the direct elimination of all the animal categories, including those animals which are susceptible, infected and immune. Vaccination and immunization are also means of reducing the number of susceptible individuals though, unlike depopulation, the host population's size and density will remain unaffected. In the case of ASF, no vaccine is currently available, so the only option is reduction of the population size and density.

The demographic parameters needed to estimate Nt are almost unknown, due to the lack of reliable estimates of wild boar population sizes for affected populations; appropriate data are available only for a few, ad hoc investigated populations, most of which are outside the range of ASF occurrence. In general, wild boar population size data are very poor, obtained using unstandardized methodologies with unknown error variability, and as such are mainly useful for describing trends rather than real population densities or sizes. As for the epidemiological data, they are collected in infected wild boar populations in which two different mixed transmission mechanisms, such as direct contact plus carcass-mediated infection, co-occur. It is a matter of fact that any mathematical estimation of Nt is simply impossible, most likely because a constant Nt does not exist for ASF in wild boar.

FIGURE 9
Incursion of African swine fever into wild boar populations



Notes: This depicts ASF spread in densities above Nt and the implications of critical community size for the evolution of epidemiological situation.

Source: **Guberti, V., Khomenko, S., Masiulis, M. & Kerba S.** 2019. *African swine fever in wild boar ecology and biosecurity.* FAO Animal Production and Health Manual No. 22. Rome, FAO, WOAH and EC. https://doi.org/10.4060/CA5987EN.

In any case, the practical application of the density threshold approach is justified in wild boar populations at risk of ASF as a preventive measure (i.e. in surrounding virus-free areas; see chapter 4). The logic behind using the Nt-oriented population management approach is that even if the virus incursion cannot be prevented, its further successful spread in the population with density below Nt will be unlikely because of insufficient numbers of susceptible wild boar.

Epidemic phase: This phase follows a successful invasion. The host population density is above Nt and thus the virus can spread and progressively invade the local wild boar population. The epidemic phase is described by a typical epidemic curve, the gradient and width of which depends on the quantitative relationship between the virus and the host populations. At high host density the epidemic curve is steep and narrow, while at the lower host density it is flat and wider. The number of contacts between infectious and susceptible animals drives the shape of the epidemic curve (Figure 9, graphs on right).

During the epidemic period, disease-independent mortality plays an important role in disease progression and can be used to modulate its outcome. Since the most common source of disease-independent mortality in wild boar is hunting, it is theoretically possible to modify the natural course of the infection by simply reducing the numbers and eventually the contact rate between susceptible and infectious wild boar by hunting them. The main effect of hunting is to accelerate the evolution of an epidemic into an endemic situation, which would naturally take longer to achieve (Swinton *et al.*, 2002; Choisy and Rohani, 2006). However, in shaping a longer-lasting epidemic, the recruitment rate of new susceptible individuals through reproduction or immigration also plays a crucial role and should be accounted for. Failure to keep numbers below Nt may, again, result in a recurrent epidemic.

Managing ASF during the epidemic phase is a prohibitive task. At the onset of the epidemic, the number of infected individuals is higher than in any other phase, and any depopulation effort hardly matches the rate at which the virus spreads. The probability (p) of having a successful chain of ASF cases is determined by the number of infectious individuals (I) that are present in that specific time (t) according to p=1-(1/R_0)^{It} (Lloyd-Smith *et al.*, 2005) where R_0 is the number of secondary infections determined by each infected wild boar (Anderson and May, 1991; Marcon *et al.*, 2019). During the epidemic phase, the probability of eradicating the infection is almost 0, due to the large number of infectious individuals. Moreover, since depopulation activities are not selective towards infectious animals (that is, not all infected animals are shot and removed from the hunting ground), they will die of the disease and, as infected carcasses, further contribute to the maintenance of the virus in the area. Both theoretical modelling and field evidence show that any intervention during the epidemic phase is likely to enhance those host population resilience mechanisms that facilitate infection persistence (Swinton *et al.*, 2002; Choisy and Rohani, 2006).

Moreover, only a small percentage of carcasses (< 10 percent) are found and safely destroyed in most kinds of wild boar habitats (EFSA, 2015); thus, the virus is usually detected rather late, and usually during the epidemic period following a successful invasion. In practice, what is perceived as the invasion phase (e.g. the very first detection of an infected carcass) is, in reality, the onset, or sometimes even the peak, of a previously "silent" epidemic, with a large number of infected carcasses already present in the area. However, in the infected area, the number and timing of detected carcasses is the sole available tool for following the entire spread process, including identification of the different phases of the evolution of the infection.

Endemic phase: After the epidemic peak is passed, any disease either becomes endemic or fades out. Endemic evolution does not depend merely on host density (as described above concerning Nt), but also on the availability of a host critical community size (CCS). The CCS is defined as the minimum population size, rather than density, with which a pathogen has 50 percent probability of fading out spontaneously (Bailey, 1975; Nåsell, 2005).

The value of the CCS is variable for different pathogens and host species. In the case of ASF, it is mainly determined by wild boar biology and, in particular, by the main demographic characteristics of the population. A smaller CCS would sustain epidemics when the host population has a high turnover, short lifespan and high reproductive rates, which is the case for wild boar. The size of the CCS cannot be estimated using mathematical formulas, but can be obtained only through ad hoc computer simulations (McCallum, Barlow and Hone, 2001).

During the endemic phase, the ASFV spread and the wild boar population reach an equilibrium. Breaking this equilibrium through management interventions could be a way to make such populations unsuitable for sustained virus transmission, thereby eradicating ASF. However, multiple factors contribute to the endemic persistence of the infection, such as the real size of the wild boar population, the continuity of its distribution, population turnover and fertility, and thus the recruitment rate. The relative contribution of each factor to the endemic transmission cycle of ASF has not yet been properly evaluated. The strong contribution of the infected carcasses to the local maintenance of the disease cycle additionally complicates understanding of the whole dynamic of this novel host–pathogen–environment system. Intuitively, with the possible overwintering of the virus in infected carcasses, a simple depopulation approach aimed at reducing population density of animals is highly likely to fail to eradicate the disease. At a sufficiently low wild boar density (which is usually the aim of the depopulation efforts carried out during the epidemic phase), the infected carcasses assume the role of the main epidemiological reservoir of ASFV; in this circumstance, wild boar density becomes of ancillary importance in the cycle. ASF is eradicated when the last infectious wild boar and the last infectious carcass are removed from the infected area.

KEY MESSAGES

1. ASFV survives in the wild boar population inhabiting northern and eastern Europe without any help from domestic pigs or ticks.
2. ASFV is highly resistant in any matrix, and low temperatures increase its survival time.
3. The infection spreads through both direct and indirect contact. The carcasses of infected wild boar maintain the live virus for a long time, especially during winter, allowing for indirect transmission when in contact with susceptible wild boar.
4. Due to the epidemiological role played by carcasses, the simple mechanistic reduction of the wild boar population size has an ancillary value if carcasses are not removed and safely disposed; infected carcass presence allows for the persistence of the virus, even if the infected wild boar population is managed at extremely low density.
5. The imprecise estimates of the wild boar population size and density, together with a lack of knowledge of the main epidemiological parameters of the transmission cycle, prevent any estimate of a possible density threshold for infection fade-out, and the critical size of the wild boar community required to modulate disease dynamics.
6. Any depopulation approach should consider that:
   - The introduction phase can be avoided only by interventions and preventive measures implemented in the source population, never in the receiving population.
   - A successful invasion can be prevented or minimized by managing a wild boar population at the lowest possible density, but only before introduction has taken place.
   - During the epidemic phase, chances of eradicating the disease are low (if any), simply due to the high number of infectious wild boar present, whereas the risk to promote further geographical spread of the virus is high.
   - During the endemic phase, there is a certain probability of eradicating the infection through the reduction of the host community as much as possible, together with carcass removal under strict biosecurity measures.
   - Continuous passive surveillance is the main tool for understanding the evolution of the disease (phase identification, geographical spread etc.).

Chapter 2
Some aspects of wild boar biology and demography relevant to the control of African swine fever

Sergei Khomenko and Vittorio Guberti

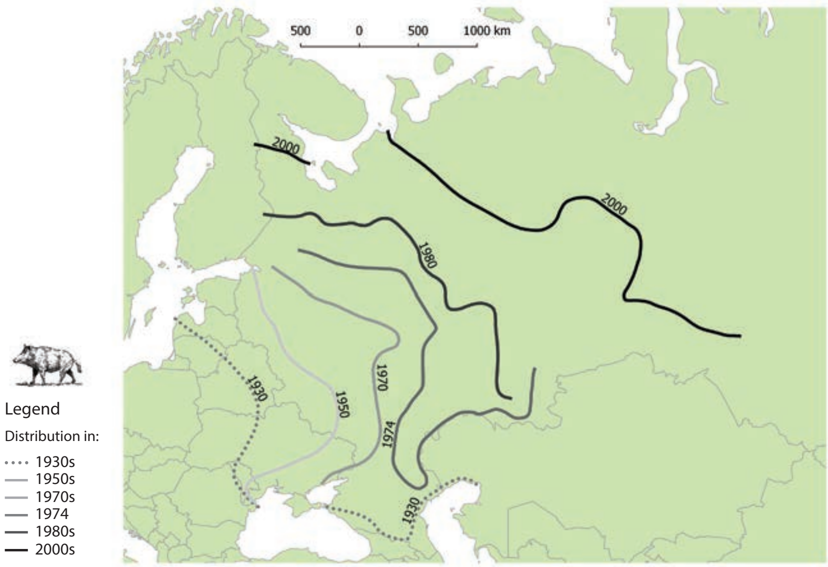
Wild boar are a native ungulate of Eurasia, which in recent decades have recovered much of their historic occurrence range in eastern Europe and increased in number throughout the European continent. Although trends in their population dynamics are not well monitored, there is substantial evidence to implicate climate change, human activities and game management practices in this significant increase. Along with other associated problems, wild boar are increasingly involved in the transmission of livestock diseases, of which ASF is probably the most concerning. This chapter briefly reviews selected aspects of biology and demography of this species relevant to the control of ASF, and explains how and why some common game management approaches (particularly supplementary feeding) affect wild boar population dynamics and contribute to the population growth and epidemiological significance of this species.

CHANGES IN WILD BOAR DISTRIBUTION

Wild boar are a native species to the majority of natural zones in the European continent. The occurrence range of this species has historically fluctuated in size under the influence of climate (Sludskiy, 1956; Fadeev, 1982), but in the last centuries it is human influence that has affected it most significantly. Wild boar were exterminated in recent centuries from parts of northern and eastern Europe mainly due to heavy hunting, competition with livestock and domestication. In eastern Europe, the most recent contraction of wild boar range occurred in the 1930s (Danilkin, 2002). In the following decades, however, the species has recovered its former historical distribution, and in some areas of the Russian Federation it has expanded even beyond known fossil records (Figure 10).

Several factors have cumulatively contributed to the successful comeback of wild boar. Massive development of industrial agriculture and favourable landscape changes have provided additional feeding resources and shelter to this omnivorous species, in both northern and southern Europe. This has coincided with large-scale reintroduction efforts (including with stock originating from other geographical populations), facilitated by protection measures, predator control and supplementary winter feeding (Danilkin, 2002). In many countries, the status of wild boar switched from that of pest to that of game species, meaning many legal constraints have been applied to wild boar hunting, whereas previously farmers could cull the animals. Widespread vaccination of domestic pigs and wild boar against classical swine fever (CSF), decreases in poaching and moderated hunting pressure, as well as the general decline of rural human populations in the later decades of the last millennium, also contributed to the growing number of wild boar. Further geographical expansion and

FIGURE 10
Changes in wild boar distribution range in eastern Europe and the Russian Federation/former Soviet Union



Source: Adapted from **Daniklin, A.A.** 2017. Is there an alternative to wild boar in the hunting grounds, or, how to empty hunting grounds and drain governmental money. [in Russian] *Vestnik Ohotovedenia*, 14(1) 61–73 http://www.rgazu.ru/db/vestohotoved/14_01_17.pdf.

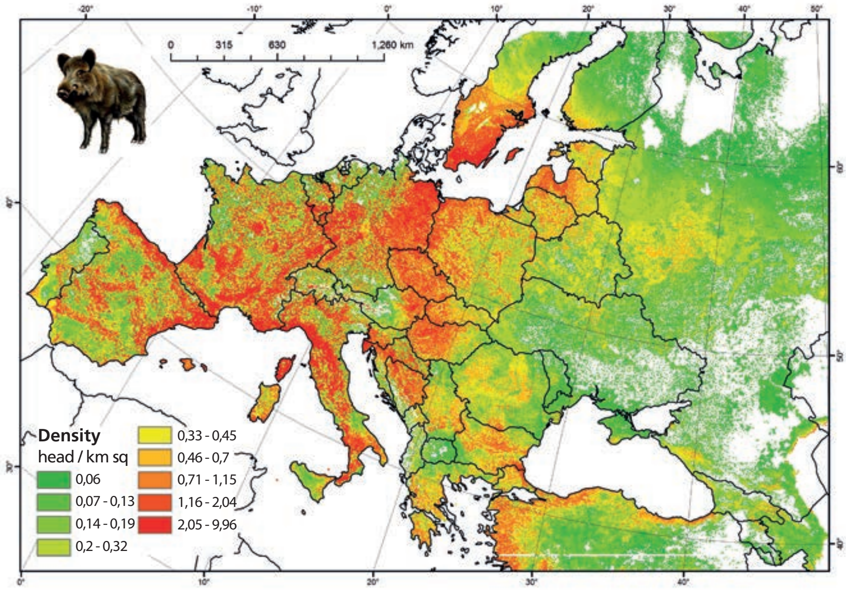
the increase of wild boar populations throughout Europe were additionally facilitated by milder winters, prompting their better survival and reproduction.

While the relative contribution of each of these factors might have varied in timing, as well as from place to place, the cumulative effect is that now wild boar have successfully re-established themselves across northern and eastern Europe. Their numbers continue to increase (Massei *et al.*, 2015), and in some areas are already regarded as excessive (Figure 11).

MEASURING WILD BOAR NUMBERS

One difficulty with the sustainable management of wild boar lies in assessing population sizes. Even if official statistical hunting data are available for most countries, their reliability is often questionable. Scientists and practitioners have developed many different methods of measuring the relative abundance of wild boar in particular natural zones or habitats, but there is no standardized reproducible approach that could give comparable results on larger spatial scales, fit all situations and be logistically feasible and cost-efficient (Engeman *et al.*, 2013). Existing population estimates differ by methods, timing, accuracy and reliability from country to country, and even within the same country. For example, in countries with stable snow cover, approaches such as track counts with correction indexes and closed transect surveys repeated two to three times are often used. These approaches can be supplemented with, for example, counts at the feeding

FIGURE 11
Modelled wild boar population density map, based on official hunting statistics and population estimates for 2000–2010

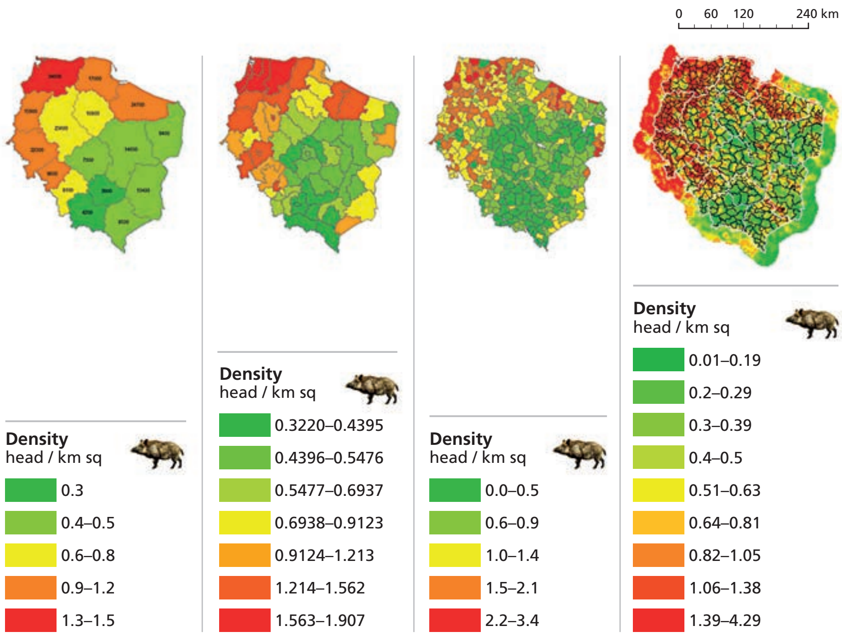


Source: **Pittiglio, C., Khomenko, S. & Beltran-Alcrudo, D.** 2018. Wild boar mapping using population-density statistics: From polygons to high resolution raster maps. *PLOS ONE,* 13(5): e0193295.

locations, driven counts (especially in snow-free areas) and camera traps. In other countries, only hunting bag statistics are available for analysis as a relative measure of wild boar abundance. Census data from hunting grounds are usually self-reported by hunters and gamekeepers, who are not always adequately coordinated and trained to carry out such surveys using standardized methods.

Furthermore, population data obtained with a mixture of unreliable methods are routinely summarized for administration purposes to give a generalized picture for a country or region at some level of aggregation, as shown in Figure 12. Interpretation of such aggregated statistics can be very misleading, as it shows averaged (normalized or levelled) wild boar population density estimates; these can be acceptable metrics of relative abundance for comparison with other areas, but are not very helpful for informing decisions or management interventions on the local scale. For this reason, whichever census methods are used, wild boar population data should be collected and analysed at the highest spatial resolution possible, preferably at the level of individual hunting grounds as the smallest census and management units. Sufficient granularity of population data is a particularly important prerequisite for developing realistic interventions for wild boar populations in ASF-affected areas. Hunting communities should be encouraged to collaborate with wildlife biologists and experts in wildlife disease epidemiology in order to improve their monitoring methods and obtain more objective, reliable and comparable population estimates.

FIGURE 12
Different visualizations of the population density of wild boar in Poland



Notes: Such maps might appear misleading if an inappropriate scale and resolution of data are chosen to inform population control interventions.

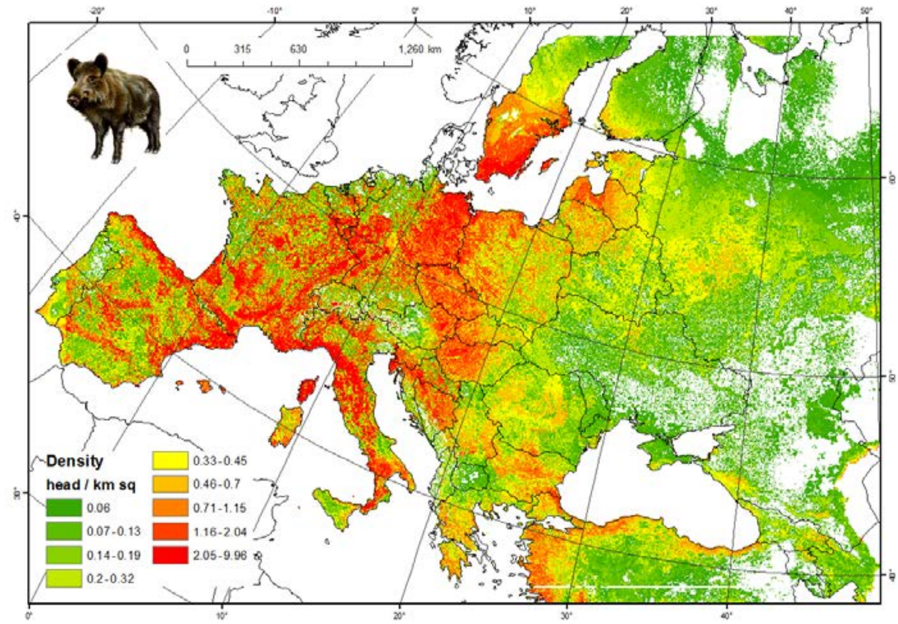
Source: **EFSA.** 2017. Scientific report on the epidemiological analyses of African swine fever in the Baltic States and Poland. *EFSA Journal,* 15(11): 5068; **Pittiglio, C., Khomenko, S. & Beltran-Alcrudo, D.** 2018. Wild boar mapping using population-density statistics: From polygons to high resolution raster maps. *PLOS ONE,* 13(5): e0193295.

WILD BOAR: HOW MANY ARE "TOO MANY"?

The ecological capacity of habitats varies widely across Europe and is dependent on environmental conditions. The situation is also complicated by a high level of habitat transformation, the seasonal availability of crops, climate and weather change patterns, and hunting management practices. Studies suggest that the main factor naturally limiting wild boar abundance is winter temperature (Melis *et al.*, 2006). The warmer the winter conditions, the higher and more stable the population of wild boar (Figure 11 and Figure 13). Water availability is another factor limiting wild boar abundance in more arid climates (Danilkin, 2002). However, long-term climatic and land cover characteristics can only explain approximately 50 percent of the variation in wild boar population abundance (Figure 13), while the rest is mainly related to in situ factors such as population management, food availability and seasonal variability of climatic conditions (Pittiglio, Khomenko and Beltran-Alcrudo, 2018).

Due to the extensive distribution and high ecological plasticity of wild boar, there is no standard or average density that can be universally recommended as "optimal" across Europe. Wild boar have evolved as a species adapted to seasonally (and sometimes for longer periods) varying feeding resource availability, such as changes in beech and oak productivity (Groot Bruinderink, Hazebroek and Van Der Voot, 1994; Selva, Berezowska-Cnota

FIGURE 13
Predicted map of wild boar abundance in Europe, modelled with statistical analysis of the most important long-term climatic and land cover characteristics



Notes: Wild boar abundance, long-term average before reproduction season. The white area indicates the absence or very low predicted density of wild boar or areas outside the prediction extent (to the east and south of Europe).

Source: **Pittiglio, C., Khomenko, S. & Beltran-Alcrudo, D.** 2018. Wild boar mapping using population-density statistics: From polygons to high resolution raster maps. *PLOS ONE,* 13(5): e0193295

and Elguero-Claramunt, 2014). Local variations within a range of some 60 percent of their average pre-reproduction numbers are a common occurrence, dependent on such factorsas weather conditions, habitat productivity, hunting pressure, predation and disease (Bieber and Ruf, 2005). For example, under the conditions of predictable climate and without artificial feeding, an average long-term population density of 1.0 head/km^2 would fluctuate within the range of some 0.7–1.3 head/km^2. Sharp year-on-year variations in animal density are particularly characteristic for northern populations, which are strongly impacted by climatic factors. However, in the last few decades, over most of Europe, wild boar demonstrate positive long-term population trends (Massei *et al.*, 2015).

WILD BOAR POPULATION INCREASE IN EUROPE

Wild boar have a very high natural reproduction potential. Litter size in this species has a wide range of variation, on average 3–7 and sometimes as high as 11–15, and is the largest among all European ungulates. Litter size largely depends on age (generally smaller in younger females and larger in mature females) and the physical condition of the female. Average litter sizes vary across northern and eastern Europe, and are generally larger in warmer climates. Litter sizes also vary between years, increasing in years following warmer winters and mast (years with abundant production of seeds such as acorns, chestnuts and others which wild boar eat). In addition, animals can extend the duration of their reproduction season well beyond the spring months. Under particularly favourable conditions, they can potentially breed all year round. In some parts of Europe, some females can deliver two litters a year. The participation of a considerable number of first-year females in reproduction is also increasingly common in many European countries, since fertility is related to body mass rather than age; as a result, a larger proportion of females contributes to reproduction.

Although mortality levels in juvenile wild boar are also high, these apparently do not fully compensate for the increased productivity. Wild boar have no natural predators over most of western Europe, while some eastern European populations do experience some level of predation by wolf (Canis lupus). Unless affected by disease such as CSF or tuberculosis (EFSA, 2017), the fertility and survival of wild boar do not seem to be density dependent, and dispersion rates decrease rather than increase with growing numbers (Truvé, Lemel and Söderberg, 2014). Therefore, at the population density levels generally encountered in Europe their population growth does not seem to be self-limiting and is barely controlled by current levels of recreational hunting (Massei *et al.*, 2015).

A number of recent studies suggest that the increase in wild boar populations in Europe is strongly driven by climate change (Vetter *et al.*, 2015), and that this trend appears to be irresponsive to the existing levels of hunting pressure (Massei *et al.,* 2015). Although population growth is reportedly associated with increasingly warmer winter conditions everywhere (Figure 14), its rate was highest in the colder climates (Vetter *et al.,* 2015). Eastern European populations of wild boar were more responsive to favourable changes in winter weather and reached maturity more quickly. Whether this result is due to better adaptation of "northern" wild boar to the cold, or is related to the widespread practice of providing supplementary feed, remains to be investigated. But it is very likely that the winter feeding of animals in colder climates has made a significant contribution to the better survival and reproduction rates of wild boar and should be considered in the analysis of population growth.

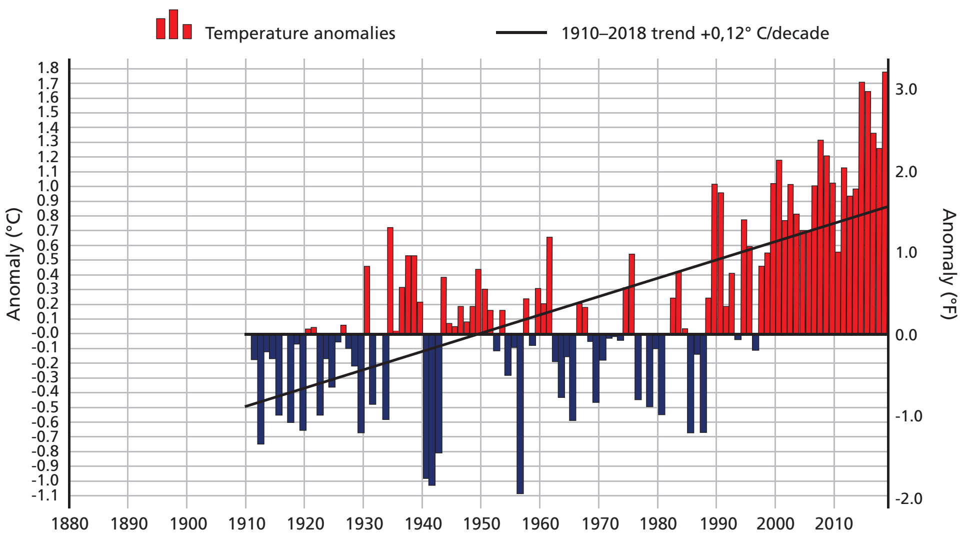
THE IMPACT OF SUPPLEMENTARY FEEDING ON WILD BOAR POPULATIONS

In general, supplementary feeding means that additional food is provided for wild animals in their natural habitat. For wild boar, supplementary feeding is done for a number of reasons, including to keep animals away from crops, to attract them to particular locations for hunting, or just to fully support their nutritional needs on a year-round or seasonal basis. Supplementary feeding is commonplace across northern and eastern Europe, but it is not well documented, and until recently was not properly regulated. Research has shown that supplementary feeding on the scale it currently occurs in many European countries is excessive, particularly in view of the sustained decrease in the severity of winters, and significantly contributes to the increase of wild boar populations.

The impact is strongest in eastern Europe, where provision of winter food has long been promoted as a key aspect of game management. Long-term observations such as, for example, those conducted in Belovezhskaya Pushcha in Belarus from 1890 to 1980 (i.e. before recent climate warming could have had a significant positive effect on population dynamics), illustrate that the provision of food in winter was capable of doubling average population density (Figure 15).

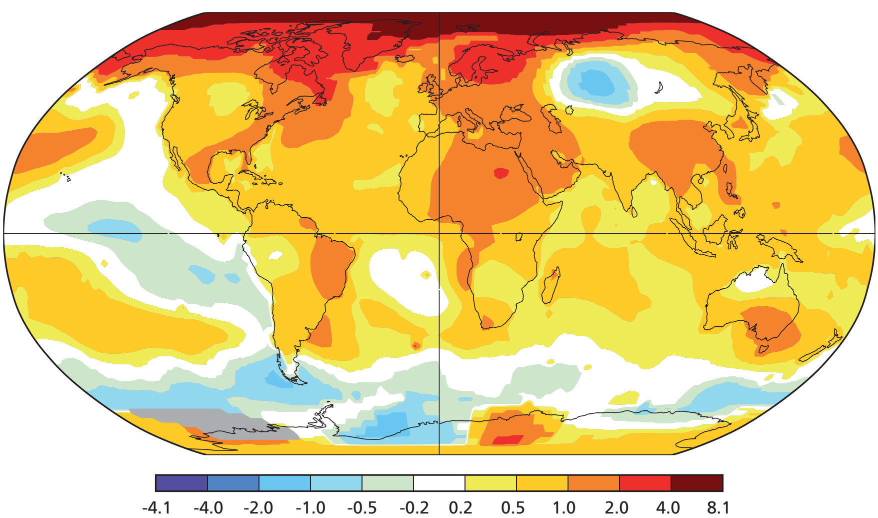
FIGURE 14
Winter temperature anomalies in Europe, 1910–2017 (top) and map of global average winter temperature change (bottom)

Europe (January–December)



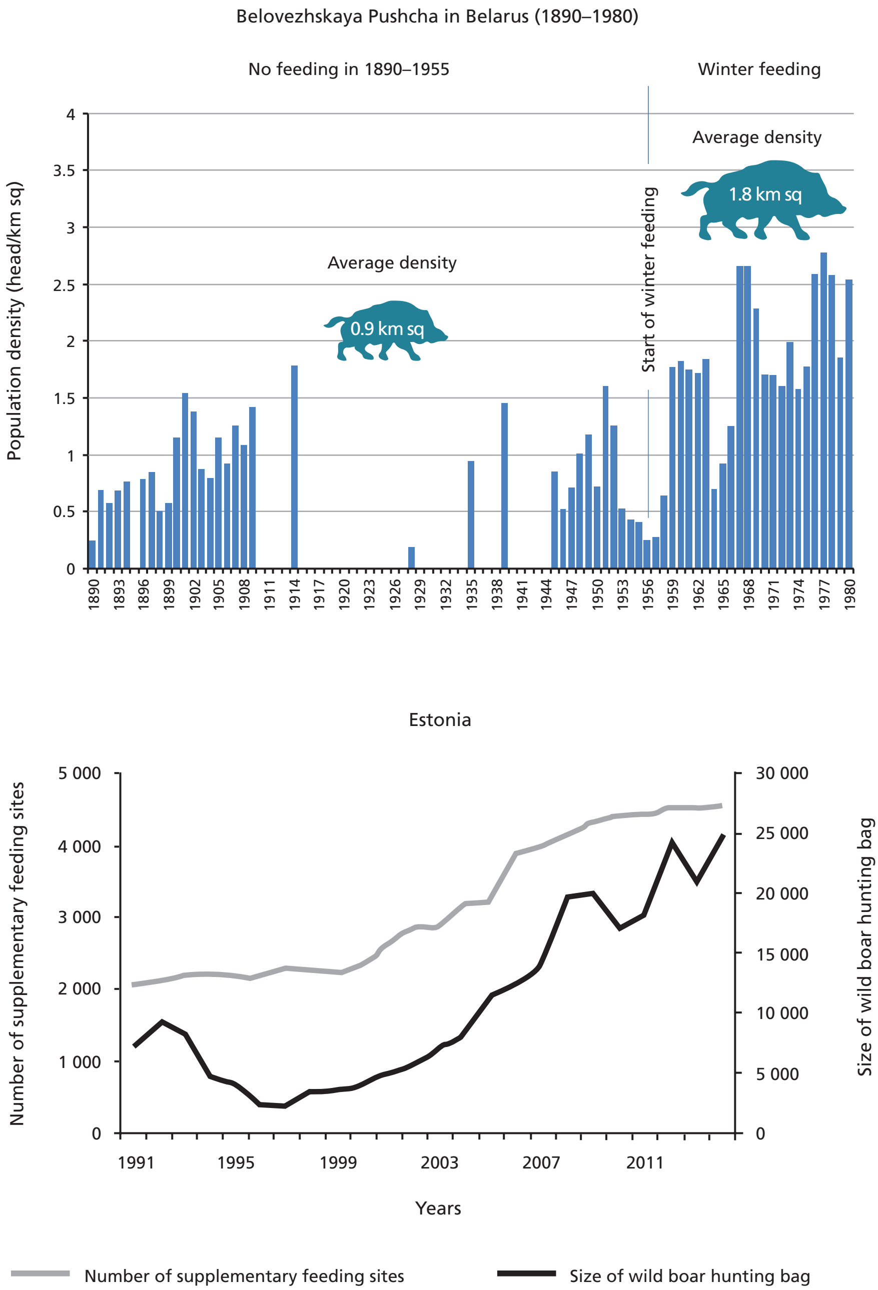
Global map of average winter temperature change

Dec–Jan–Feb Land-Ocean Temperature Index (°C) change 1980–2018 0.63



Source: National Oceanic and Atmospheric Administration (generated using www.climate.gov).

FIGURE 15
Long-term population density (top) and the correlation between wild boar hunting bags and the number of supplementary feeding sites (bottom)



Source: Top adapted from **Danilkin, A.A.** 2002. Pigs (Suidae). *Mammals of Russia and the Adjacent Areas.* [in Russian] Moscow, GEOS; bottom adapted from **Oja, R., Kaasik, A. & Valdmann,** H. 2014. Winter severity or supplementary feeding – which matters more for wild boar? *Acta Theriologica,* 59(4): 553–559 and **Oja, R., Zilmer, K. & Valdmann, H.** 2015. Spatiotemporal effects of supplementary feeding of wild boar (Sus scrofa) on artificial ground nest depredation. *PLOS ONE,* 10(8): e0135254.

Supplementary feeding has been shown to seriously interfere with conservation of other species and habitats, including protected nature reserves and national parks. In many countries, regular provision of food to wild boar develops into commercial game farming aimed at increasing revenues, utilizing the unlimited population growth potential of this species. Supplementary feeding can be provided on a year-round basis (Photo 2 and Photo 3), and can consist not only of cereals or root vegetables, but also of expired or unsold foodstuffs from shops. Some hunting grounds grow crops such as potato or maize especially to feed wild boar, and keep them from raiding commercial fields and residential gardens.

SUPPLEMENTARY FEEDING AND CONTROL OF AFRICAN SWINE FEVER

The chain of negative implications for population management of wild boar due to unbalanced or excessive supplementary feeding can be generically summarized as follows.

© Vittorio Guberti

Photo 2
A winter feeding location for wild boars in Romania.

© Vittorio Guberti

Photo 3
A feeding point designed to provide supplementary food to piglets in summer.

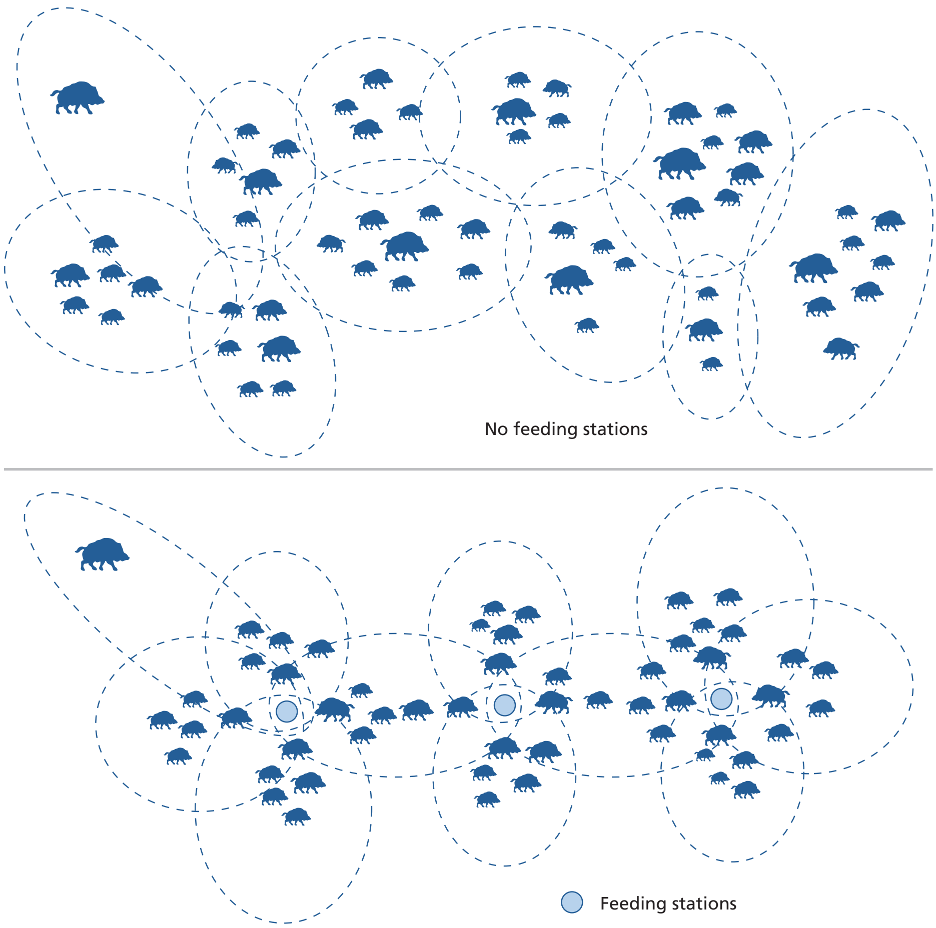
Wild boar habitat use is modified because of feeding, and hunting grounds attract more animals. Feeding increases winter survival chances, thus reducing natural selection, and will maintain females in required threshold of body mass necessary to reproduce, around 27–33 kg live weight (Servanty *et al.*, 2009).

As a result of supplementary feeding, the general fertility rate may double, and the average proportion of young animals significantly increases at the population level. Such an elevated population surplus due to favourable environmental conditions would be likely only once in 3–4 years naturally, but in the populations receiving regular supplementary feeding, animals enjoy "good years" every year (Groot Bruinderink, Hazebroek and Van Der Voot, 1994). Artificial feeding reduces or completely negates the natural regulatory effect of limited food availability in winter, which is when most wild boar mortality should naturally occur. An extended maintenance of this practice over years leads to an increase of population density beyond the carrying capacity of the natural environment and drives emigration of animals to neighbouring areas, which is often counterbalanced by provision of even more supplementary food.

Wild boar take advantage of seasonally abundant natural feed, such as cereals, acorns, beechnuts or other valuable foods. Therefore, another very important implication of supplementary feeding is that it significantly changes the behaviour, territorial structure and patterns of social interaction in the population. This effect is particularly common in the colder climates during cold spells and snowy weather. Feeding sites become regularly attended by several family groups of animals, and some animals or groups visit more than one, even in a single day. Both direct and indirect contact occurs, whether among groups feeding at the same time, or between groups attending the same feeding site (Figure 16). Such space-use patterns particularly intensify during winter when more food is given to animals both to support their diet and to prepare them to be used for hunting. Rates of interaction are much higher than they would normally be in the population without supplementary feeding, increasing the risk of the transmission of infections, including ASF.

Studies have shown that the practice of supplementary feeding results in increased risk of contamination of feeding sites with endogenous parasites (Oja, Kaasik and Valdmann, 2014; Oja, Zilmer and Valdmann, 2015). Historically, in eastern Europe, most devastating outbreaks of CSF in wild boar were associated with local overabundance of animals and increased interaction rates, both of which often resulted from supplementary feeding or under natural conditions during mast years (Danilkin, 2002). Current understanding of the epidemiology of ASF suggests that inflated and clustered populations of wild boar maintained under regular supplementary feeding are more susceptible to invasion of the virus which finds higher Nt density (see chapter 1) and, therefore, can spread more easily (Sorensen, van Beest and Brook, 2014). Moreover, once introduced, the disease has better chances of developing into a persistent problem in the areas where networks of feeding sites exist. This is driven not only by the more frequent interactions and indirect contacts between live animals, but also by heavy contamination of the environment with the virus and accumulation of carcasses of dead animals which remain infective for long periods of time.

FIGURE 16
Schematic representation of changes in the territorial behaviour of wild boar related to attendance at supplementary feeding stations



Source: **Guberti, V., Khomenko, S., Masiulis, M. & Kerba S.** 2019. *African swine fever in wild boar ecology and biosecurity.* FAO Animal Production and Health Manual No. 22. Rome, FAO, WOAH and EC. https://doi.org/10.4060/CA5987EN.

WHY HUNTERS NEED TO REVISE WILD BOAR POPULATION MANAGEMENT SYSTEMS

The risk of ASF and its devastating effects on wild boar and the swine industry are not the only reasons for improving the way the hunting community manages wild boar in regions overpopulated by them. Growing numbers of wild boar are increasingly regarded as a problem for agriculture, forestry and wildlife conservation (Massei, Roy and Bunting, 2011). They cause many transport collisions, particularly in western and central Europe, but also in some eastern European countries. At the same time, wild boar are an important economic resource for many landowners and hunting organizers and are important game for many hunters.

The emergence and spread of ASF from 2007 to 2017 has provided an extra justification to consider wiser and more sustainable management solutions for the wild boar problem. Their considerable involvement in the transmission cycle of ASF in parts of Europe (see chapter 1) is a new and escalating challenge for the veterinary services of the affected countries. Although it is not clear if and how much population control can help, there are expectations that lowering wild populations through changing hunting management approaches could slow down its geographical spread and help reduce the risk of introduction of the virus into the pig production sector and will reduce the cost of managing ASF in the field. There is little doubt that the spread of ASF in Europe will remain a threat to the pig production sector and will complicate hunting-sector operations for quite some time. These problems do not have a simple and quick solution, and likely require long-term changes to the wildlife management paradigm and practice.

Countries affected by the disease have already adopted some decisions aimed at reducing or stabilizing wild boar numbers, which have several implications for hunters and hunting or wildlife management authorities. It is important that the aims, purpose and rationale behind suggested management solutions are well understood and accepted by hunters. It also needs to be recognized that the problem of ASF negatively affects hunters, as well as local companies that produce different products from the wild boar shot in local areas. Therefore, it is reasonable to have a broad perspective when addressing issues related to ASF, including an exploration of the various ways hunters might be compensated for losses.

KEY MESSAGES

1. Recent expansion of wild boar and reoccupation of their historical range in Europe is a result of multiple factors acting synergistically (climate, agriculture, management, protection).
2. Efforts are needed to standardize and improve monitoring of wild boar populations across Europe as a baseline prerequisite for more sustainable management of this species and effective control of diseases such as ASF.
3. Large between-year variations in numbers of wild boar are a normal feature of their demography as a species adapted to fluctuating resources and harsh climates.
4. Some parts of Europe have better climatic and environmental conditions for wild boar (which generally have winter temperatures) and can sustain large population densities of this species.
5. Climate change and excessive supplementary feeding are two major factors that are likely to account for local overabundance of wild boar.
6. The practice of supplementary feeding under climatic conditions that are becoming increasingly more favourable for the survival and reproduction of wild boar should be reconsidered and abandoned where the wild boar population has increased too much.
7. Wiser game management and better population control can contribute to reducing risks related to the spread of ASF by wild boar, for which an understanding of the aims, objectives and principles of proposed disease control interventions by hunters and game managers are of paramount importance.

Chapter 3
Approaches to wild boar population management in the areas affected by African swine fever

Sergei Khomenko and Vittorio Guberti

The problem of controlling wild boar numbers should not be mixed with the complex set of issues surrounding circulation of ASFV and control of its spread in this species in Europe. Reduction of wild boar populations is just a part of a wider set of measures needed to minimize the implications of disease presence and spread. This chapter reviews different approaches to wild boar population management in the areas already affected by the disease. Some of them have been applied and tested in the infected countries, while others are currently considered and hotly debated by stakeholders. Non-lethal methods aimed at restricting animal movements (fencing, distraction with odours), impacting on wild boar demography and survival, as well as lethal approaches aimed at more or less intensive removal of animals from the population are briefly described, specifically in the context of ASF presence in the populations, with indications of their pros, cons and limitations.

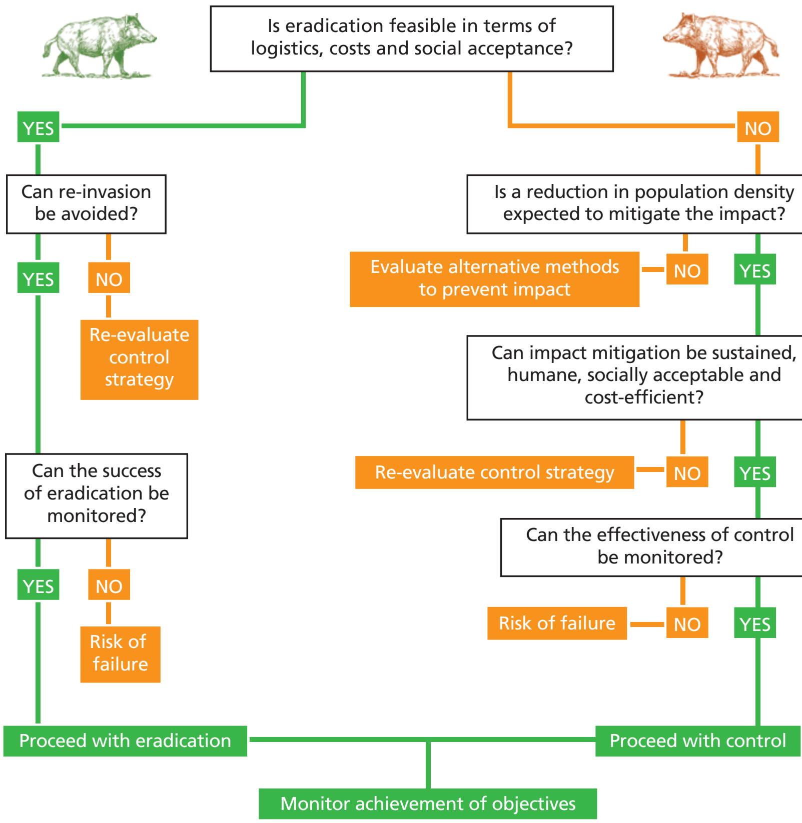
CAN ERADICATION OF WILD BOAR BE A SOLUTION?

In light of the expanding epidemic of ASF in Europe, voices have been raised in favour of extermination of wild boar as a pest or an invasive species (as in Australia, the United States of America and other areas outside of its native range in Eurasia). In some of the affected European countries this question has already provoked considerable debate in the media among game management professionals, hunters and veterinarians. This is not surprising considering that in northern and eastern Europe wild boar are a highly valued game species, whose extermination is quite reasonably opposed by the hunting community. That community is perceived to be responsible for the management of game species, and veterinary authorities often make formal requests that they carry out depopulation or extermination campaigns.

Experience shows that extermination of wild boar was feasible only on islands and as a well-organized, systematic and long-term effort (Massei, Roy and Bunting, 2011). The main lessons to learn from attempts to eradicate this species are that they can succeed only when: i) social acceptance; and ii) logistical and economic prerequisites for such a campaign are in place; and when iii) reinvasion of this species can be effectively avoided; and iv) monitoring of eradication success can be ensured (Figure 17). In northern and eastern Europe, fulfilment of these four basic requirements cannot be achieved, with even less likelihood of achievement in western Europe.

In the biological sense, wild boar are not an invasive, or non-native, species in the northern and eastern European ecosystems (Heptner, Nasimovich and Bannikov, 1961); therefore, their eradication inevitably conflicts with national nature and wildlife conservation legislation.

FIGURE 17
Decision tree to evaluate control options to decrease the impact of overabundant populations of feral hogs or wild boar on human interests



Source: Adapted from **Massei, G., Roy, S. & Bunting, R.** 2011. Too many hogs? A review of methods to mitigate impact by wild boar and feral hogs. *Human–Wildlife Interactions*, 5(1): 10

It is difficult to reach a consensus on these issues among the respective authorities, academia and non-governmental organizations (Danilkin, 2017). Although local extinction of wild boar can be achieved, reinvasions from other areas will occur, quickly decimating all eradication efforts. Existing population monitoring methods are not sensitive to low densities of animals and cannot verify the success of eradication with the required level of confidence.

In some eastern European countries, ASF is endemic in pig populations (EFSA, 2010a, 2010b, 2014, 2015, 2017; Khomenko *et al.*, 2013); thus, even when wild boar are absent, the infection can remain a threat for long periods of time in domestic pigs and contaminated by-products.

Therefore, based on ecological, epidemiological, practical and ethical considerations, extermination of wild boar as a species anywhere in northern and eastern Europe should not be viewed as a principal or a key solution for ASF. Rather than making decisions that create a complex collision of interests among stakeholders, it is more appropriate to try to change hunting management practices, to reduce the size of the wild boar population for a period of time to manage the situation with ASF, and to take precautionary measures to avoid spreading the disease (see later sections of this chapter and chapters 4 and 5).

WHY CONVENTIONAL HUNTING FAILS TO CONTROL WILD BOAR POPULATION GROWTH

The exact demographic mechanisms behind positive population balance of wild boar may differ between parts of Europe (Gamelon *et al.*, 2011; Servanty *et al.*, 2011). However, in general, it is evident that contemporary hunting pressure, the main source of mortality in wild boar, cannot stop the population growth of this species. Although in some countries hunting wild boar is permitted without restrictions and occurs all year round, the feasibility of a significant increase in hunting seems to be low (Massei *et al.*, 2015). Apart from the demographic aspects, the natural resilience of wild boar to hunting pressure is facilitated by complex behavioural responses such as individuals learning to avoid risk, changing activity patterns, home range sizes and habitat preferences. Wild boar often take advantage of the network of protected areas and concentrate around urban or buffer zones along State borders where hunting is prohibited, restricted or otherwise problematic. Large crop fields, particularly those of ripening maize, are another type of shelter where animals can avoid hunters and stay out of reach for extended periods of time.

In the temperate forests of northern and eastern Europe, hunting wild boar is recreational and occurs mainly during autumn and winter months, when it is more practical and efficient. The most effective hunting occurs in a relatively narrow window of 3–4 months. Even if hunting takes place all the year round, the bulk of the hunting yield is nonetheless amassed during the traditional winter gaming season. For the majority, hunting is a recreational activity and a supplementary business activity for gamekeepers and hunting organizations. For the latter, wild boar are an important economic resource that is purposely managed, protected and exploited, often with remarkable investments of money, time and labour.

In this particular system, non-professional hunters expect easy and predictable encounters with wild boar with little investment of time dedicated to searching for animals. Therefore, game managers typically aim at increasing the density and survival of wild boar populations and in this way ensure stable services, attractiveness and the economic sustainability of their seasonal hunting business. The most widespread management approach to achieve these results with the free-living populations is provision of supplementary feeding and shooting restrictions on adult females to ensure ethical hunting practices are employed.

IS POPULATION CONTROL OF WILD BOAR A PANACEA FOR AFRICAN SWINE FEVER ERADICATION?

So far, there is no empirical evidence that eradication of ASF from wild boar populations can be achieved **on a large spatial scale** through a significant reduction of their numbers. The experience from Czechia and Belgium summarized in chapter 4 serve as examples of eradication of ASF from wild boar following focal introduction and localized spread.

It requires extraordinary effort, resources and an unprecedented level of coordination. However, population management and hunting practices in Europe need to account for the presence of this important pig disease within ecosystems to minimize the negative impact of risky activities.

The most challenging aspect of ASF epidemiology is the capacity of the virus to survive for a long time in the environment, particularly in or in association with carcasses of wild boar that have died of the infection. Because of this complication, the disease transmission cycle only partially depends on the density and interaction patterns of live animals. Apparently, both long-term survival of the virus and involvement of the carcass-to-animal transmission mechanism make it possible for the disease to circulate even at low wild boar population densities.

Research and statistical simulations based on current understanding of ASF epidemiology in wild boar showed that population management measures potentially available to limit the spread of ASF should be exceptionally drastic (EFSA, 2017). Under the conditions found in the disease-affected countries in Europe, to prevent the spread of the virus in still-free areas – with an average abundance of one to two animals per square kilometre – a preventive reduction by 80 percent of the **actual, real number** of wild boar in the area over four months within a 50-km zone adjacent to the infected area would be required to prevent the propagation of the virus. **In the areas where ASF is already endemic, the same de-population level cannot guarantee the eradication of the disease due to the presence of infected carcasses.**

Alternatively, targeted hunting of reproductive females and a ban on supplementary feeding could be applied for a minimum of three years in a buffer zone of 100–200 km surrounding ASF-infected areas to halt the geographical spread of the infection to the free areas. However, it must be stressed that there is limited experimental evidence regarding the success of either of these approaches in the control of ASF in wild boar. Furthermore, no minimum population density threshold to stop transmission of ASF has been reliably identified to date (see chapter 1).

The general lesson from the computer simulations is that a combination of several measures most suitable or feasible for a particular context should be applied at the same time (EFSA, 2017) as a potential solution for lowering wild boar numbers where this is considered beneficial for reducing the risk of infection.

Population reduction and control are the measures that can help to decrease disease burden and the risk of its spread but only in combination with a variety of other interventions, including strict biosecurity during hunting, fencing, removal and safe disposal of infected carcasses, effective surveillance and overall good cooperation and coordination of efforts among wildlife authorities, game managers, hunters and veterinary professionals.

REVIEW OF APPROACHES TO WILD BOAR POPULATION MANAGEMENT IN AN INFECTED AREA

Coordinated and efficient reduction of wild boar numbers on considerably large spatial scales (e.g. thousands of square kilometres) is extremely difficult to achieve and to be maintained over the years, as might be required given the persistent nature of the disease. It is a very complex and challenging task in the areas where wild boar populations demonstrate strong population growth. Systematic collection of demographic and population data for wild boar at high geographical resolution is a very important baseline component of a sustainable, coherent management strategy.

Various population management and control approaches (Massei, Roy and Bunting, 2011) and ways of mitigating the role of hunting in the spread of ASF should be considered based on local knowledge, the context and disease-spread risk assessments, rather than the adoption of a simple solution for the whole country or region. Different parts of the country, and even different hunting grounds, may require different methods and/or combinations thereof that might be more efficient for limiting the implications of ASF in the long term or at particular times of the year. Some of the available options, including some radical or potential solutions such as poisoning and immunological contraceptives (not currently allowed by legislation, but which are being discussed in some countries), are briefly reviewed below in light of their applicability to managing the risks of ASF related to virus circulation in wild boar populations.

NON-LETHAL METHODS INVOLVING MOVEMENT RESTRICTION

Permanent boar-proof fencing. Construction of reliable long-lasting boar-proof fencing requires resources, time and effort. Such fences are usually made of woven wire mesh and need to be a minimum 1.5–1.8 m high and fixed to the ground in order to provide effective movement restriction for wild boar. The fences can be fitted with strands of barbed wire on the top and sides of the mesh net. Electrification of fences increases their effectiveness. The fence design also depends on whether the task is to keep animals in or out of the fenced area. Several specifications have been identified (see Wild Boar, no date) for building wild boar-proof fencing and those need to be carefully considered before making any decisions.

As a measure aiming at physical prevention of any movements of animals between infected and disease-free areas, the fence design should also account for irregular factors such as the presence of oestrus females or a desirable food source/hunger as well as a requirement for cover for farrowing or the population's desire to escape from threats such as hunting or other means of persecution. Where terrain is rough, stony or otherwise difficult to navigate, such as wetlands or densely forested areas, fence building is problematic, and its prompt erection in response to ASF wild boar cases would be challenging or unfeasible.

Fences will not prevent the long-distance spread of the virus since biological materials and contaminated fomites would still have enormous potential to introduce disease well behind the fence (Photo 4). Effective prevention of the spread of ASF and the long-term ecological implications of the large-scale permanent fencing need to be carefully evaluated, particularly given that such measures are not aligned with nature and wildlife conservation concepts (Trouwborst, Fleurke and Dubrulle, 2016; Linnell *et al.*, 2016). Temporary fencing can provide certain assistance when there is a focal introduction and localized spread of the virus as was the case in Belgium and Czechia (see chapter 4). They help to reduce the contact rate among individuals and groups of wild boar by creating a habitat fragmentation effect and thus potentially slowing down the speed of the geographical spread of the virus and increasing the window of opportunity for local disease eradication through other appropriate depopulation measures.


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Photo 4
An example of a fence aimed – unsuccessfully – at halting ASF spread in the wild boar population.

Electric fencing. Different electric fencing designs are available on the market for wild boar distraction. Both permanent and portable solutions exist including solar-powered autonomous systems. Most electric fences are developed for use in populated areas to seasonally protect relatively small parcels of land with crops, gardens and property from damage due to invasions of wild boar. Although electric fencing is often reported to be effective in preventing crop damage, it cannot provide long-term protection of larger and more uninhabited areas (Reidy, Campbell and Hewitt, 2008). Electric fencing requires construction, a system for regular power supply, dedicated daily supervision and maintenance. Their year-round use is problematic in the climatic conditions of the temperate north and east European forests due to the snow and the freezing temperatures. The functionality of the fencing can also be severely compromised by larger species of wild ungulates, such as deer or elk. Electric fences do not withstand high pressure and do not completely block the movements of animals. They may reduce the overall number of movements, but will not stop animals motivated by hunger, persecution and sexual interest.

Other deterrents. Deterrents can be chemical, visual, acoustic or a combination thereof. Studies and practical experience in several affected countries generally find use of deterrents to be rather inefficient means of distracting wild boar and reducing crop damage (Schlageter and Haag-Wackernagel, 2012). Closer investigations demonstrated that commercial products of this kind produced effects that were negligible or statistically insignificant (Schlageter, 2015). Deterrents are unlikely to have significant impacts on the long-term prevention of wild boar movements and the potential spread of infection. Even if some effect can be initially achieved, wild boar quickly adapt to them. These deterrents can be used as temporary solutions to contain focal incursions of the virus in new areas (see chapter 4) but are useless as a long-term strategy for broader-scale disease eradication.

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Photo 5
A solar-powered electric fence in Italy aimed at protecting vineyards from wild boar damage.

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Photo 6
An electric fence in the region of Zlin in Czechia, set up in response to an African swine fever inclusion event in 2017.

NON-LETHAL METHODS WITH IMPACTS ON POPULATION DEMOGRAPHY

Regulation of supplementary feeding. Supplementary feeding is a widespread and very popular population management practice known to contribute significantly to the growth of wild boar populations (Selva, Berezowska-Cnota and Elguero-Claramunt, 2014; see also chapter 2). Whenever the strategic management goal is to reduce wild boar numbers significantly, strict regulation of supplementary feeding should be considered the primary and the most feasible intervention. To facilitate hunting from towers, provision of food as bait (and not for subsistence) might be needed, but its amounts should be reduced dramatically. For example, in the European Union, guidelines set a limit of ten kilograms per square kilometre per month which can be used as an indicative amount in most parts of northern and eastern Europe (European Commission, 2018). Commercially available automatic feeders are particularly useful as they can help to reduce the amount of food provided at any one time and can decrease human attendance at feeding sites. These feeders help manage and organize hunting activities, and they minimize the disturbance of animals, as well as the risk of humans spreading infections from site to site. Baiting of hunting sites with salt licks, which can often effectively attract wild boar, can be used instead of massive provision of food or other smelly attractants such as diesel, creosote or commercially available products (Lavelle *et al.*, 2017). Another solution to attract and retain animals in one location while reducing their food uptake is to use devices that complicate access to food, such as hog pipes. Banning supplementary feeding is the least destructive population management approach, and it should be part of standard wild boar management. It will encourage the local wild boar population to adopt a more natural relationship with the environment, but by the same token, could include winter mortality and the decreasing fitness and fertility

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Photo 7
An odour repellent fence set up in the region of Zlin in Czechia – the odour-producing agent is the foam contained in the plastic cup placed on the ground at about four-metre intervals, with an electric fence in front.

of reproductive females. Natural regulation might prove to be a more efficient means of population control than hunting. Other areas of concern are a possible increase of damage to winter crops and the extended home ranges of animals. The effects of a feeding ban will depend on winter weather conditions and are likely to be most prominent in the colder climates and during less favourable years or in habitats with low natural food resources, such as coniferous forests.

Contraception. Contraception is a promising non-lethal method that can be used to reduce the reproductivity of animals and potentially help with many human–wildlife conflicts, including the wild boar population. The general public, who often criticize lethal population control methods (Massei and Cowan, 2014), find contraception more humane and ethical. However, a fully operational method of contraception for wildlife species should fulfil a number of criteria, without which the method is unlikely to be accepted and adopted in practice. The contraception should:

- be effective when orally administered;
- be strictly species specific;
- have high efficacy (70–80 percent);
- prevent reproduction in both sexes;
- be environmentally safe;
- remain stable and effective within a wide range of environmental conditions (temperature, sunlight, precipitation);
- have no negative impact on the behaviour and welfare of the treated species.

At present, a contraception method that fulfils these criteria remains the subject of ongoing research and is neither commercially available nor officially allowed in wildlife population control programmes in any of the affected northern and eastern European countries (or anywhere else in Europe).

Three classes of contraceptives have been developed for application in different wild species: hormonal, chemical and immunizing. To date, only immunological contraceptives have been successfully tested in wild boar (Massei *et al.*, 2008). Immunological contraceptives are vaccines that induce animals' immune responses, which in turn suppresses their reproductivity. They work by stimulating the production of antibodies against proteins or sex hormones essential for reproduction, which makes ovulation and spermatogenesis impossible (Massei *et al.*, 2008). Fertility control methods for wild boar and feral pigs in particular face several major difficulties and complications in terms of the practical implementation of immunological contraceptives in free-living populations of these species.

Currently, commercially registered immunological contraceptives are only available as an injectable formulation and require capturing and manually injecting the vaccine into wild boar, which greatly limits its applicability. The availability of an oral immunological contraceptive could make this approach an easier and more effective way to attain desirable population levels. However, delivery methods are not the only (nor the most important) limitation to the application of immunological contraceptive vaccines in wild boar population control.

In Europe, ensuring that immunological contraceptives achieve species specificity (i.e. that they only affect wild boar) is strongly desirable, but wild boar-specific oral formulations are not yet available for use beyond experimental conditions. Without species specificity, the potential risk of negatively affecting the fertility of various non-target species with immunological contraceptives is too high. Unfortunately, the range of potentially susceptible animals includes all mammals. The conservation implications of the extensive systematic application of immunological contraceptives, along with their impact on populations of endangered or endemic species, are therefore of strong and well-justified concern.

Another way to deal with this issue is to develop species-specific immunological contraceptive delivery systems, which would limit non-target species' access to vaccine-treated bait. Research and experiments with boar-operated system feeders show that this can be achieved in principle (Ferretti *et al.*, 2018), but the approach relies on having a network of feeding locations established. In addition, applying this approach on large spatial scales is much more labour intensive than any aerial or unrestricted manual bait distribution scheme. It is also not quite clear whether boar-operated system feeders can ensure the required individual dosage and population coverage, considering territoriality, strong hierarchical relationships and competition for food both between and within family groups of wild boar. As with any other bait-based vaccine delivery system for wildlife, various factors will likely have an impact on the success of the approach, which must be evaluated through experiments to account for any possible variations due to geographical, climatic and ecological conditions encountered throughout Europe's wild boar populations.

The lack of oral immunological contraceptive formulations, their currently perceived ecological risk and a number of uncertainties concerning dosage effectiveness, immunity duration and required population coverage, mean that years of research and experimental work will be needed before immunological contraceptives can be adopted and officially approved for use in Europe.

MANAGEMENT APPROACH THROUGH A BAN ON HUNTING AND FEEDING WILD BOAR

Banning wild boar hunting in or around an infected area is a reasonable solution for disease management where compliance with hunting biosecurity is problematic (e.g. when the preservation of carcasses until the exclusion or confirmation of infection, or the safe destruction of infection, are impossible). This measure can help reduce the probability of spreading disease beyond the infected area in two ways: i) by avoiding the disturbance and movement of animals; and ii) through the total exclusion of risks related to the dressing and transportation of killed animals. This approach should be supplemented with the search for and removal and safe destruction of wild boar carcasses to reduce the environmental load of infection. While hunting bans are a management approach that can be implemented quickly, the hunting community may not easily accept them. Possible side effects, such as an increase in agricultural damage, a medium-term increase in populations, a long-term increase in populations of other game species and a lack of diagnostic material from hunted animals are always mitigated because of the high mortality attributed to ASF. Under certain circumstances, particularly in low-resource settings, stopping both the feeding and hunting of animals is a relatively safe and inexpensive management solution for an ASF-affected hunting ground compared with other approaches involving active population reduction and requiring costly biosecurity measures.

LETHAL METHODS INVOLVING POPULATION REDUCTION

Driven hunts. If hunting in an infected area continues, careful consideration should be given to the hunting methods used (Thurfjell, Spong and Ericsson, 2013). Recent experience and knowledge of the behavioural response of wild boar to driven hunts suggest that the heavy persecution of animals in areas with an active circulation of ASFV are likely to cause further spread of the infection. Intensive driven hunts, particularly with dogs, may lead to the large-scale dispersion of animals and an increase in their home ranges, which can be counterproductive for disease control (Keuling *et al.*, 2008; Ohashi *et al.*, 2013). A ban on driven hunts is therefore generally recommended when ASF is present in wild boar populations.

Targeted hunting of reproductive females. Conventional hunting bags usually consist of about 50–60 percent of first-year animals (piglets), about 20–30 percent of subadult animals (yearlings or second year) and about 10–20 percent of adult animals (3 years and over). This age distribution of animals in the hunting bag roughly reflects the proportion of each category in an over-age population. However, hunting from towers, which usually comprises three-quarters of the total kill in northern and eastern European countries, provides more opportunities for hunters to have an impact on the demography of local populations and purposely decreases their reproduction potential (Bieber and Ruf, 2005). The selective removal of **second-year females** (subadults) beyond a normal proportion can help reduce wild boar numbers, but only if such an approach is maintained over five or more years. In countries where the early recruitment of female wild boar into the reproduction cycle occurs normally, it might be worthwhile to also target first-year females, although, in practice, identifying different ages and sexes in the field is difficult. For this reason, the targeted hunting of all females is generally carried out.

To ensure that targeted hunting can be implemented successfully requires having knowledge of the demographic structure of local populations (Bieber and Ruf, 2005). Furthermore, the approach is more time-consuming than non-targeted harvesting methods (e.g. driven methods), requiring up to 30 hours per individual on average (Schlageter, 2015). Targeted hunting is most relevant and feasible at hunting grounds where wild boar numbers are above the regional average density and where animals regularly attend baiting sites and are more accessible.

The drawback of targeted hunting is that the social structure of family groups disintegrates, particularly after the removal of leading sows, with the remaining animals possibly regrouping or redistributing. It is therefore advisable to avoid killing dominant (oldest) sows, especially at the start of the hunting season, as this tends to compromise successful targeted hunting efforts (Massei, Roy and Bunting, 2011). In the longer term, the systematic overharvesting of female boar may lead to the earlier adaptive recruitment of younger females and stimulate larger litters among older animals. At present, empirical data on the population response of wild boar to targeted hunting are very limited, but are likely to differ depending on the cumulative roles of other factors, such as climate, predation and supplementary feeding.

Trapping with euthanasia. In terms of disease control, trapping is the least destructive way to remove animals from a population. The approach requires large investments in trap construction, baiting, daily maintenance and operation. A positive aspect of catching, rather than shooting animals, is that large corral traps could allow entire family groups of wild boar to be captured. However, traps could also increase animals' capture-related stress and mortality (Fenati *et al.,* 2008). Trapping animals in groups helps avoid such social distress, which may lead to increased disease transmission and encourage long-distance movements. From a practical perspective, the trapping of wild boar is a very costly and time-consuming population management approach. However, when managed appropriately, it can be a highly effective method and help drastically reduce infected wild boar populations.

Wildlife conservation laws and hunting legislation regulate the use of trapping. Regulations on trapping wild boar vary between northern and eastern European countries. In some countries, such hunting is not allowed at all, while in others, only certain trapping methods are illegal. Some trapping methods, such as snaring, that are inhumane and cause suffering are entirely prohibited. Changes in regulations might be required if hunting with traps is to be pursued as a population control method, as these must fully comply with welfare, ethical and biosafety requirements.

In northern and eastern Europe, wild boar trapping is most successful during winter and early spring months, which is when the hunting season usually takes place. However trapping can be successful during spring and summer months, without directly interfering with hunting (Licoppe *et al.*, 2020).

USE OF BOAR TRAPPING IN THE CONTEXT OF AFRICAN SWINE FEVER MANAGEMENT: PRACTICAL ASPECTS, PRELIMINARY RESULTS AND RECOMMENDATIONS

Operations in ASF-affected areas require the same biosecurity measures as during normal hunting, but could be easier to ensure due to the limited surfaces of contaminated areas and involved personnel. Logistical arrangements should account for the fact that a proportion (up to 7 percent, or possibly more for an infected family group) of captured animals could have a subclinical infection. Precautionary biosecurity measures must therefore be developed and strictly adhered to during trapping campaigns to avoid the spread of ASF between trapping locations and its introduction to domestic pigs. Practical ways to euthanize, transport, keep and, when needed, destroy carcasses that are ASF-positive must be considered.

Catching wild boar with mobile traps or cages can help in residential areas and public parks where no other population control option is available. The successful application of wild boar trapping as part of a disease management strategy was demonstrated in small CSF-affected populations in Bulgaria (Alexandrov *et al.,* 2011) and Belgium where trapping contributed up to 24 percent of the depopulation approaches (Licoppe *et al.*, 2020). Finally, fencing in (or close to) affected areas reduces escape movements of wild boar, which are one of the main challenges faced when implementing driven hunts.

Increase in overall hunting pressure. A general increase in hunting rates is recommended and/or officially prescribed to hunting associations as a primary wild boar population control approach. Though wild boar hunting bags have been growing throughout Europe, these cannot compensate for the population increases (Massei *et al.,* 2015; Vetter *et al.,* 2015). Despite bigger hunting bags, there have been indications in recent decades that the number of hunters in many European countries is steadily declining, along with the overall interest in wild boar hunting. Furthermore, research suggests that under these conditions in central Europe, the removal of up to **80 percent of wild boar piglets** will be needed to keep populations stable (Bieber and Ruf, 2005). This figure could be slightly lower for more continental wild boar populations, such as those in eastern Europe, but this result can be rarely achieved in practice.

Where feasible, a general increase in hunting bags can be a strategy to control populations, though it is usually difficult to significantly increase hunting pressure without deploying more effective or destructive hunting methods, such as driven hunts, killing from helicopters or use of mounted night vision equipment to facilitate the location of game. Intensifying driven hunts is only possible to a certain extent, after which the dispersion and redistribution of animals are inevitable. In some areas, driven hunts can be organized in a way that reduces the risk of dispersion, provided that the hunt is performed over a very large area with many different hunters, hunting clubs and landowners involved, though this approach increases the cost and time required to achieve success. As population densities decline, encountering and hunting animals also becomes more difficult and time-consuming for hunters, regardless of the approach used.

Aerial hunting within temperate forest and forest steppe areas that have a moderate-to-high human population is problematic due to the dense foliage and danger it poses to humans. Hunting with night vision equipment is regulated in many European countries. Under environmental conditions of temperate European forests, the extension of the hunting season beyond colder months does not always lead to increased hunting bags. In spring months, wild boar become difficult to track due to farrowing, with green foliage during this season strongly complicating their location.

In some countries, the army or other armed corps have been involved in hunting. Aside from legal constraints, it is clear that intense actions limited by time and space are less effective than continuous coordinated efforts carried out across large geographical areas when the abundance of wild boar is decreasing. Experience from Czechia has shown that even if professional snipers are involved in a hunt, their knowledge of the area and wild boar habits are critically important for hunting success. In Belgium, trained local forest officers combined their knowledge of the area and used night vision equipment and baiting sites with Global System for Mobile Communications (GSM) camera traps to successfully cull the last surviving wild boar in the infected area.

In general, the increase in hunting pressure using conventional recreational hunting methods can only succeed as a population control approach for stable or slowly-increasing populations. Unconventional hunting involving armed forces and special troops is not likely to help with extensive long-term population control programmes, as these require sustained systematic efforts and a mix of locally applicable measures.

Wild boar poisoning. The application of poisonous substances as a means of radically increasing the mortality of wild boar has been proposed in several ASF-affected countries as a potential, and seemingly very attractive, population control solution. These considerations are fuelled by attempts in other countries to apply biocides as a way to manage overabundant populations, such as feral pigs in Australia or wild boar as an invasive species in the United States of America. At present, poisoning is legally prohibited in all northern and eastern European countries.

In European Union countries, for example, the use of biocides is strictly regulated (Regulation (EU) No. 528/2012). The regulation places several restrictions on the use of any biocide outside of its authorized purposes and means of distribution. Though derogations to the law can be obtained (art. 55), it is very difficult to minimize all the risks posed by the intensive, large-scale use of biocides in natural conditions.

Aside from the ethical aspect of the approach, a specific plan should be designed outlining motivation, feasibility, probability of success and risk factors linked to the operations. Any possible risk should be clearly considered and minimized. A lack of data and experience would make any attempt to poison wild boar a hazard, as the risks are currently very difficult to evaluate and manage. **Currently, it is not possible to promptly design and implement an effective and safe large-scale wild boar poisoning programme in any of the European countries.**

Any biocide aimed at poisoning wild boar in the natural environment should fulfil a number of criteria to become legalized, officially accepted and practically applied in population control programmes. The substance used should be species specific to ensure that only the targeted species is killed, without any secondary or accidental poisoning of non-target species, such as brown bears, wolves or birds. It should also be highly attractive to wild boar and easily accepted by them. An effective antidote should be available both for humans and domestic animals in case of its large-scale application. The biocide must cause minimal pain and suffering to the animals after consumption and must be sufficiently safe for people involved in the field operations. Its complete and safe degradation in the environment, including soil, ground and surface water, and invertebrate biocenosis, should also be guaranteed. The poison itself, as well as its distribution and delivery systems to the target species, should all be reasonably priced so that they can be used repeatedly on large spatial scales to achieve a sufficient long-term reduction of target species populations.

Practical experience with the application of several biocides for the control of wildlife populations is available from the Americas and Oceania (Cowled *et al.*, 2008). In those areas, warfarin, phosphorus, sodium fluoroacetate (1080) and sodium nitrite were the most used. Both warfarin and phosphorus failed to meet welfare requirements and were abandoned. The environmental risk linked with 1080, particularly in terms of secondary poisoning of non-target species, was also unacceptable. Nitrites were shown to be the least dangerous of the options and were capable of fulfilling some of the requirements.

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Photo 8

A large coral trap for catching wild boar baited with maize (left) and the immobilization of a leading sow (upper right) and capture with several litters (lower right) in Strandzha, Bulgaria.

In addition to the choice of an effective and safe poison, the implementation of large-scale wild boar control programmes using biocides in northern and eastern European countries will likely face many known and unknown challenges.

Any type of poison will need to be incorporated into baits ingestible by wild boar. Baits will always attract a large number of non-target species, particularly birds and mammals, which will vary depending on the type of environment, habitat and season. To prevent poisoning non-target species, baits should be delivered exclusively to wild boar using species-specific systems (see the section on contraception). Bait delivery devices have never been tested in areas inhibited by brown bears, bison, wolves or jackals, nor have they been used across a wider range of European environments and animal communities.

At least one bait delivery device should be used per every 300 hectares. At present, the area of ASF occurrence in wild boar populations is more than 300 000 km^2, which implies the manual installation of a significant number of bait delivery devices (more than 70 000). This dramatically increases the probability of non-target species poisoning (including species with high conservation status), unpredictable involuntary accidents and environmental contamination. Due to the highly hierarchical social structure of wild boar family groups and the different mobility patterns of animals, depending on sex, age and season, it could be difficult to ensure that animals have an individual dose of poison, which is also the case for oral contraceptives. Other issues that should be considered include the persistence of poison in the food web chain and its accumulation in certain substrates.

WILDLIFE MANAGEMENT AND CONSERVATION CHALLENGES DUE TO THE SPREAD OF AFRICAN SWINE FEVER

While most governments in Eurasia view ASF control as an important goal, the reality is that the disease is firmly establishing itself in the continental area's ecosystems and gradually becoming part of ecological dynamics. Given then extent of the current ASF distribution in Eurasia, it is highly unlikely that the disease will fade out naturally in European ecosystems or be quickly and successfully eradicated from both domestic and wild pigs. This means that management of the species and ecosystem conservation should account for either a permanent or occasional presence of the pathogen and its potential role as a key mortality factor for wild boar.

While it is difficult to estimate overall ASF-related losses of the Eurasian wild boar population for 2008–2021, it is clear that wild boar numbers declined significantly in all areas where the disease was present. Multiple observations at managed hunting grounds in the Southern Federal District in the Russian Federation in 2007–2012 documented rapid local declines of wild boar populations shortly after the virus was found in the area (FAO, 2014). Mortality estimates ranged from 85–90 percent, which closely corresponded to observations made in Poland in 2012–2017 (Morelle *et al.*, 2020). Whenever the disease finds sufficiently abundant wild boar it is likely to develop into a severe epidemic that results in population crashes and may be followed by an extended period of "tail" endemicity (see chapter 1).

At present, the nature conservation implications of the ASF expansion and the massive mortalities it produces among wild boar populations could be overshadowed by worries related to economic losses within the pork industry and threats to food security. Wild boar is a very important autochthonic species found in a wide range of habitats across the continent (Heptner, Nasimovich and Bannikov 1961; Danilkin, 2020). Its extermination should not be viewed as a major way to eradicate ASF (as highlighted in chapter 3), with game biologists and conservation scientists questioning the relevance and effectiveness of the species' depopulation measures.

Nonetheless, in some countries, massive "depopulation" campaigns or official orders have already been implemented or issued to reduce wild boar numbers significantly (Danilkin, 2017, 2020). In some cases, plans or attempts were made to "replace" wild boar with exotic species of ungulates, such as white-tailed deer (*Odocoileus virginianus*; Danilkin, 2020). Such a replacement is itself an impossible task, since the ecological niche that wild boar occupy is rather specific and not suitable for any other ungulate species. Both the extermination of wild boar and introduction of exotic species are actions that clearly conflict national and international nature conservation legislation and can create a cascade of ecological implications, some of which are briefly described in this section. Problems stemming from such actions will depend on the local situation and context, but outcomes can be grouped around several main issues outlined below.

IMMEDIATE IMPLICATIONS OF THE EXTINCTION AND/OR EXTERMINATION OF WILD SUIDS

The elimination of wild boar from Eurasian ecosystems, particularly in the boreal zone where the species has an important ecological role, will further reduce biological diversity and impact ecological dynamics and forest health. From a nature conservation perspective, the extinction of wild boar, even local extinction, should not be viewed as positive or desirable, regardless of whether it is the result of increased ASF-related mortality, depopulation efforts or both. In parts of Southeast Asia, similar effects are expected among endemic suid species that also play an important role in ecosystems and shape plant communities (Luskin *et al.*, 2020).

Hunting pressure on other ungulates, including illegal hunting (poaching), will increase as a result of wild boar extinction. This will further decimate biological diversity and threaten ungulate populations in locations where they are not very abundant. This is particularly relevant in eastern European countries, where ungulate numbers are critically low and will not survive the additional hunting pressure that shifts from wild boar (Danilkin, 2020). Game management experts do not see how wild boar, a core species for recreational hunting, can be substituted by other game species (Danilkin, 2020). In Southeast Asia, local communities face losing wild pigs, such as *Sus barbatus* in Borneo (Kurtz *et al.*, 2020), a key animal protein source, due to the spread of ASF.

RISK OF SPECIES EXTINCTION FOR RARE ENDEMIC ASIAN SUIDS

The spread of ASF to Asian ecosystems is already impacting wildlife and is anticipated to have severe implications for endemic Asian suids. A recent review by Luskin *et al.* (2020) indicates that Southeast Asia is a pig diversity hotspot, with 75 percent of global suid species found in this region. Three suid genera occur in Asia: *Sus* (nine species or subspecies); *Babyrusa* (three species); and *Porcula* (one species in Assam, India). The unfolding ASF epidemic in the region raises the need to establish sufficiently large captive populations of some of these species, without which their survival may not be possible (Luskin *et al.*, 2020).

The risk of population crash or extinction due to the spread of ASF is likely to be strongest for the *Sus* genus (Luskin *et al.*, 2020; listed in order of increasing International Union for Conservation of Nature (IUCN) conservation status and risk evaluation score): Visayan warty pig (*Sus cebifrons*) critically endangered (CR) risk: very high; Javan warty pig (*Sus verrucosus*) endangered (EN) risk: high; Sunda bearded pig (*Sus barbatus oi*) vulnerable (VU) risk: very high; Mindoro warty pig (*Sus oliveri*) VU risk: very high; Philippine warty pig (*Sus philippensis*) VU risk: very high; Sunda bearded pig (*Sus barbatus barbatus*) VU risk: high; Sulawesi warty pig (*Sus celebensis*) near threatened (NT) risk: very high; Palawan bearded pig (*Sus ahoenobarbus*) NT risk: high. If ASF were to be introduced, Asian *Sus* species will likely be strongly impacted, with Malaysia having already reported its first mass mortality due to the disease in Sunda bearded pigs in Borneo.

The situation is also worrying for the Indian endemic Pygmy hog (*Porcula salvania*; CR risk: high), which had only survived until now due to captive breeding programmes in Assam, India. Unfortunately, ASF was already introduced to this part of India in 2020, meaning this critically endangered species is likely now most at risk.

Although *Babyrousa* suids all have unfavourable conservation status, overall they seem to be at a lower risk of ASF infection (Togian babirusa (*Babyrousa togeanensis*) EN risk: Medium; Sulawesi babirusa (*Babyrousa celebensis*) VU risk: High; Hairy babirusa (*Babyrousa babyrussa*) VU risk: Low). However, the ecology and epidemiological cycle of ASF in Southeast Asia, and in tropical forests in particular, likely differ from what is observed in temperate latitudes with wild boar, as the habitats and environment of Asian wild suids, their ecology and demographics are different from their Eurasian counterparts. The situation is also complicated by sympatric co-occurrence of different species, their widespread hybridization and the potential involvement of biological or mechanical ASFV vectors.

CASCADING EFFECTS ON RARE CARNIVORES

In some areas, and for some species of carnivore, wild boar, particularly juvenile animals, are an important component of their diet. This is the case for the *Canis lupus* wolf in Italy, for which wild boar comprises 49 percent of the species' diet (Mori *et al.*, 2016), although the importance of wild boar in wolf diets across Europe may vary (Nores *et al.*, 2008; Sin *et al.*, 2019). The extinction of wild boar in areas where it is an important wolf prey species has the potential to increase the depredation of livestock and other game species and provoke human-wildlife conflict (Mori *et al.*, 2016).

Large felids whose occurrence ranges are now very fragmented may strongly depend on wild boar as a major prey species. For example, the spread of ASF to the far eastern part of the Russian Federation (Primorsky Krai and Amur Oblast) threatens two subspecies of large felids: the Siberian tiger (*Panthera tigris tigris*; EN) and the Amur leopard (*Panthera pardus orientalis*; CR). Concerns are being raised that an expected population crash of wild boar due to ASF-related mortality and depopulation efforts could negatively affect these rare felids. Wild pigs also play an important role in the diet of the endemic and critically endangered Sumatran tiger (*Panthera tigris sumatrae*) and Javan leopard (*Panthera pardus melas*) in Indonesia (Luskin *et al.*, 2020). The decline of these felids' main prey species may increase human-wildlife conflicts, thus creating an additional risk factor for their populations (Lubis *et al.*, 2020).

KEY MESSAGES

1. The large-scale extermination of wild boar as a species to eradicate ASF is an unrealistic, unacceptable and unfeasible task due to ecological, epidemiological, practical and ethical considerations.
2. The failure of conventional recreational hunting to level the population growth of wild boar largely relates to the widespread practice of providing supplementary feeding as well as to the highly adaptive behaviour of wild boar, favourable changes in climate and agriculture.
3. The restriction of wild boar movements using various types of fencing or odour repellents is not a reliable approach to prevent the spread of ASF, even if the fence is boar-proof. While such methods might be useful in an isolated virus incursion, the restriction of wild boar movements on a large spatial scale and over an extended period of time is problematic and expensive, with low effectiveness in terms of disease control.
4. A set of lethal approaches aimed at actively reducing wild boar numbers includes: trapping with euthanasia, which is probably is the easiest way to guarantee biosecurity; the selective shooting of reproductive females; and driven hunts, which should be avoided as they are likely to increase animal and virus dispersion.
5. Contraception and poisoning are, respectively, non-lethal and lethal population management methods, both of which are the subject of ongoing

research, testing and evaluation. At present, they are not ready for use in temperate European forests and years of efforts are needed to develop them into fully operational, environmentally-safe and ethically-accepted alternatives to currently available solutions.

6. The reduction of the population density of wild boar is part of a complex series of measures that could break the transmission cycle of ASF and thus serve as a reliable tool to eradicate the disease. Due to the environmental persistence of ASFV in infected carcasses, virus transmission can continue within very low wild boar population densities.
7. Computer simulations show that to prevent the spread of ASF to ASF-free areas, 80 percent of the actual number of wild boar in a 50 km wide strip of habitats would need to be killed or otherwise removed from the population within just 4 months. For a number of reasons, this is almost impossible to attain and the method has never been practically tested.
8. Theoretically, prevention can be achieved through a slower population reduction method based on the targeted hunting of reproductive females and a ban on supplementary feeding, but this would require targeted hunting efforts over a minimum of three years and in a much wider (100–200 km) area. Given the current occurrence range of the disease in wild boar, this approach would also be extremely difficult to test empirically.
9. It is more realistic to consider the application of different strategic and area-specific population management approaches based on local knowledge and epidemiological information. Efforts should be made to mitigate risks through the application of a complex series of approaches that include hunting, biosecurity measures, the safe disposal of infected carcasses and awareness campaigns.

Chapter 4
African swine fever surveillance and disease management in wild boar

Vittorio Guberti

This chapter describes how the early detection of ASF can be achieved, with the sensitivity of active and passive surveillance compared at both the onset and final phases of infection. The chapter also addresses possible approaches to zoning according to different epidemiological contexts and the practicalities of the eradication process.

Surveillance of ASF in wild boar addresses some aspects that deserve an appropriate strategy to achieve feasibility and sustainability:

- early detection;
- identification of the area of virus circulation and an infected area established;
- estimation of the spread of the virus into the infected wild boar population;
- regaining of an ASF-free status.

EARLY DETECTION

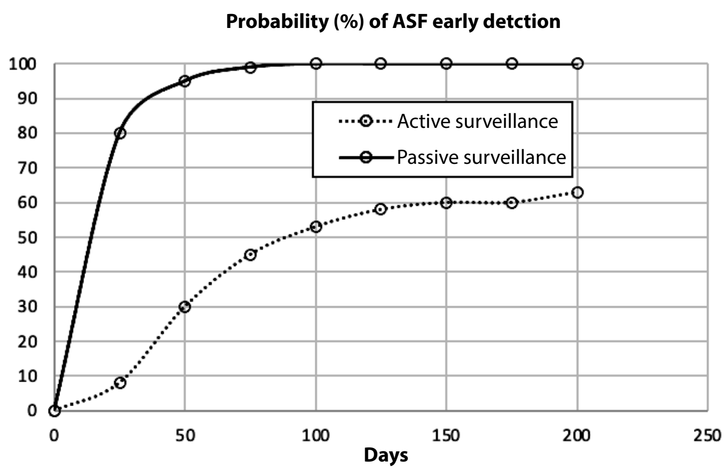
Early detection of ASF in wild boar populations is fundamentally important for its control. Prompt detection of the virus following its introduction in an ASF-free area increases the chances that its spread will be localized, negative economic consequences reduced and the situation possibly reversed back to normal. To build an early detection system that is sensitive enough to achieve these tasks, several epidemiological factors and limitations specific to this complex disease must be considered. These include the relationships between the host recovery rate and virus lethality, the ecology of wild boar, hunting limitations (as the means of accessing animals for testing) and available diagnostic techniques.

According to the definition of *per capita rate* (Anderson and May, 1991; Scott and Smith, 1994), the daily probability that an ASF-infected wild boar will die is 0.9/5 (90 percent probability the animal will die in five days), while a wild boar living in a hunting ground has a 40 percent chance of being hunted during the autumn-winter period (0.4/100 days). The per capita lethality rate of an infected animal is therefore 45 times higher than the per capita rate at which a wild boar is hunted, at $0.18^{\text{day-1}}$ (0.90/5) and $0.04^{\text{day-1}}$ (0.04/100), respectively. This indicates that the speed at which the virus kills infected wild boar is 45 times faster than the capacity of hunters to bag animals (0.18/0.004 hunting rate). Due to this high lethality rate (i.e. the daily rate at which the genotype II ASFV kills infected animals), only passive surveillance offers the possibility of detecting it promptly, simply because the virus works faster than hunters (Figure 18). The early detection of the disease has a very strong impact on the effectiveness of the entire ASF crisis management system. Delays in discovering the virus prompt rapid and often poorly predictable increases in the infected area. The exponential spatial progression of the infected area means that the situation will be more difficult to manage (number of carcasses, tests for hunted animals), resulting in a greater likelihood of the virus escaping from the area. Without the effective early detection of the virus, any future efforts to eradicate the disease will be strongly compromised.

HOW CAN THE EFFICIENCY OF EARLY DETECTION BE MAXIMIZED?

Diseases are detected based on the simple relationship between detection efforts and the actual number of cases. As is the case with any activity, the amount of effort put into achieving a task greatly impacts its success. If no searches are being carried out for carcasses, it is likely that the pathogen will never be detected. The number of dead wild boar in the forest and the effort put into finding carcasses should be reasonably correlated and sustained both during peaceful periods and periods of escalation. In inaccessible forests, not a single dead wild boar will be reported even if the disease has killed hundreds of them. In contrast, areas that are generally frequented by the general public, hunters and loggers, will likely have more prompt reports, which will help better reveal the scale of an unfolding epidemic. The mix of actions involved in the early detection of the virus therefore translates into what is known in epidemiological terms as the sensitivity of the system. A 100 percent

FIGURE 18
Probabilities of detecting African swine fever virus through passive and active surveillance during the initial spread of the virus



Source: Adapted **Gervasi, V., Marcon, A., Bellini, S., Guberti, V.,** 2019. Evaluation of the efficiency of active and passive surveillance in the detection of African swine fever in wild boar. *Veterinary Sciences,* 7(1): 5.

sensitive early detection system should be able to detect the very first case of ASF in an area considered disease-free.

Provided that passive surveillance based on finding dead animals is the selected approach for the early detection of ASFV, its sensitivity can be evaluated in a very simple way by asking wildlife management authorities in the area how many dead wild boar they normally detect in the absence of ASF. The answers "never" or "none", which are often provided as evidence of good management and health conditions of the population, indicate that there is a problem. As with any other species, wild boar have a certain level of natural mortality, with reports of "no dead animals" suggesting that the passive surveillance in place is not effective or sensitive enough to detect baseline mortality levels. The level of natural mortality among the species is not easy to determine and estimates differ across locations. However, in ASF-free areas across the European Union, passive surveillance should certainly detect at least some dead animals. A rough conservative proportion to consider is that the number of wild boar found dead for any reason approximates 1 percent of the current wild boar population estimate. The logic behind this is that the natural wild boar mortality is estimated at about 10 percent per year, with at least 10 percent of wild boar carcasses likely to be reported (and hopefully tested), which results in 1 percent overall wild boar population estimate at any given period.

If such a baseline level of passive surveillance is normally practised and sustained in areas unaffected by the disease, the task of early detection of the virus is more achievable, though could still be delayed due to several limitations as shown in Table 2.

Table 2 shows that it is almost impossible to have a 100 percent efficient early detection (e.g. to immediately detect the very first wild boar that died from ASF). The virus is more likely to be detected when the epidemic has already produced a number of carcasses, which were missed or not reported. However, the calculations show that the best early detection strategy is to look for carcasses rather than trying to bag and test animals. The two weakest

TABLE 2
Sensitivity of the early detection system

Passive surveillance (found dead animals)		**Active surveillance (hunted animals)**	
Probability that an infected wild boar dies	0.9	Probability of hunting a wild boar	0.4
Probability that a dead wild boar is discovered	0.1	Probability that the hunted wild boar is infected	0.02
Probability that a dead wild boar is reported to the competent authority	0.5	Probability that the hunter will take a sample	0.9
Probability that the competent authority takes a sample from the dead wild boar	1	Probability that the sample is properly dispatched to the laboratory	1
Probability that the sample is tested	1	Probability that the sample is tested	1
Probability that the sample's test results are positive	1	Probability that the sample's test results are positive	1
Sensitivity of early detection system (SedS)	**0.045** **4.5%**		**0.0072** **0.72%**
Number of infected wild boar needed to obtain a 95% probability to detect the virus			
$0.95 = 1-(1-SedS)^{cases}$	**66**		**430**

steps in passive surveillance (discovering and reporting) can be improved through active, well-planned and organized carcass searches coordinated by competent authorities, which can also ensure that maximum sampling and testing rates are achieved. Enhancing carcass searches and reporting is not an easy task. The terrain and weather, availability of personnel, awareness of the local population and logistical issues (such as transportation) limit active carcass searches. In high-risk areas, awareness campaigns should address the importance of reporting any dead animals to the competent authorities. Financial incentives, the use of specially trained dogs, the application of drones and thermal imaging and any other methods that increase the chances of discovering and testing carcasses with ASF improve the sensitivity of passive surveillance.

HOW MANY WILD BOAR ARE ALREADY DEAD?

Since the sensitivity of the early detection system based on carcass detection is imperfect, it is likely that the first infected wild boar (considered an "index case") is just one individual among others that did not survive the infection. For this reason, efforts should be made to promptly investigate the possibility of a much wider spatial distribution of the virus and to establish the size of the virus circulation area. The basic reproduction rate of ASF in wild boar during an active epidemic is currently estimated at two. This means that during the initial epidemic phase, any infected wild boar will on average infect two other wild boar. Since ASF has a serial interval of approximately seven days (incubation plus sickness), the number of dead wild boar likely to be found (i.e. expected to have died) will be twice the number of carcasses found the previous week. Targeting the search of carcasses in an area and defining realistic tasks will motivate the involved personnel and enable more robust epidemiological data to be obtained that will inform further interventions.

PLANNING A CARCASS SEARCH: AREA AND PERSONNEL

Active searching for carcasses is a very time-consuming but critically important activity to reveal the situation so that appropriate decisions can be made to help stop the spread of the virus. There are no strict rules on where to look for carcasses to increase detection rates. Sick wild boar tend to prefer colder, moist forest habitats, possibly owing to their high fever (Morelle *et al.*, 2019). Infected carcasses are more likely to be found in young broad-lived forests or in meadows with significant vegetation (Cukor *et al.*, 2020b). Since wild boar apparently do not come in contact with infected carcasses before 12–15 days post-mortem (Probst *et al.*, 2017; Cukor *et al.*, 2020a), carcasses should ideally be removed every two weeks. However, it is not always possible to implement this "golden rule" standard, especially when human resources are limited. In a best case scenario, a group of five people can actively search an area of 1–1.5 km^2 per day, making the standard increasingly difficult to carry out when the infected area is already quite large. For relatively small infected areas, and when the disease is still in an invasion or early epidemic phase, the standard is more realistic to use. When there are not enough people to carry out a thorough search, forest habitats can be quickly scanned, even if accuracy and coverage need to be sacrificed. Observations show that more than 80 percent of wild boar die in forests, suggesting that sick animals perceive this habitat as a safer and more comfortable environment (Cukor *et al.*, 2020b). Farmers, fishers and the general public tend to frequent less-forested areas, where they are more likely to come across carcasses incidentally, a fact that also requires consideration. The use of new search techniques (e.g. drones, dogs) can be a helpful addition to the strategy, but the role of people should not be replaced by their means. It is important to involve professionals (e.g. forestry corp, professional hunters and gamekeepers, rangers of protected areas) to avoid placing too much of a demand on excessive effort from amateur hunters.

VIRUS PREVALENCE ESTIMATES

The prevalence of ASFV in wild boar can only be estimated by testing samples obtained during hunting activities carried out as part of active surveillance during the endemic phase. In such epidemiological settings a proper sampling intensity can be ensured that will achieve a desired level of confidence, though it must be highlighted that hunting always provides opportunistic samples. For low wild boar densities, and when prevalence declines below a threshold value (about 1 percent), prevalence estimates progressively lose their precision until they reach a point at which the virus can no longer be detected. Positive results instead come from serological tests, suggesting a detectable "accumulation" of disease survivors in the population, which is an aftermath of the epidemic phase that further develops into an endemic equilibrium.

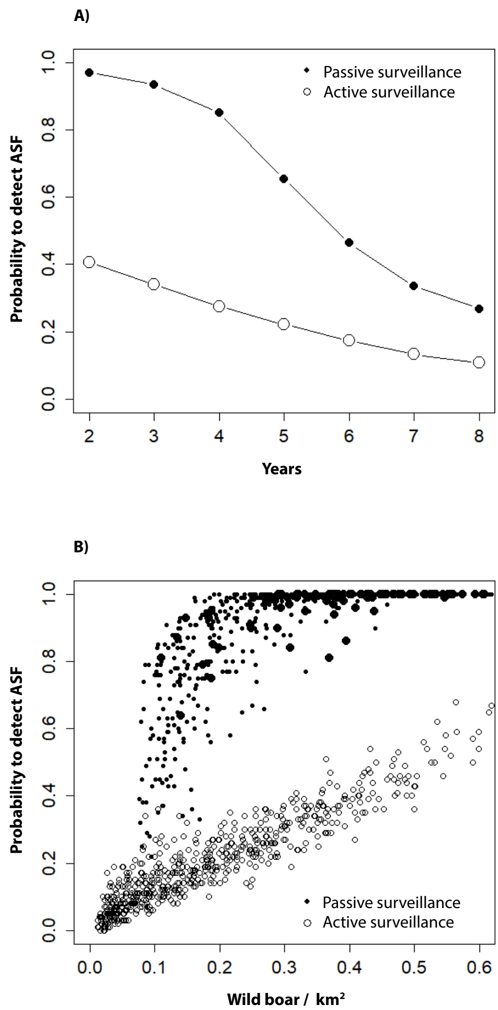
When prevalence drops below 1 percent and the population density of wild boar is very low (around 0.1–0.3 wild boar per km^2), the usual sampling rates obtained through recreational hunting (about 40 percent of the post-reproductive wild boar population) cannot ensure sufficient statistical power to detect the virus. During this phase, active virological surveillance through hunting could provide the false impression that the disease has vanished spontaneously. However, evidence obtained in such epidemiological settings cannot prove there is no ASF, which should be demonstrated through a special strategy for the situation.

REGAINING AN AFRICAN SWINE FEVER-FREE STATUS

By now only two affected countries (Belgium and Czechia) could regain an ASF-free status after months of extensive efforts. According to WOAH regulations, this status can be self-declared after one year of monitoring that proves an absence of the virus. Such monitoring requires a specific surveillance plan that can demonstrate a defined level of confidence that the virus has disappeared from the population and can no longer be detected. As previously mentioned, at the end of the epidemic phase, the epidemiological situation often becomes difficult: the virus may still be present, but for statistical reasons, may not be proved by virological surveillance. A decline in seropositive animals may be reported, again invoking the false impression of an improving situation.

As the number of reported dead animals decreases due to declining wild boar density (both as a result of ASFV-induced mortality and population control measures), the epidemiological situation evolves into an endemic phase. This phase is characterized by an extremely low prevalence of the virus among the population, with rare sporadic detections and intervals in detection that are sometimes several months (up to 2–3 years according to Lange, Reichold and Thulke, 2021). When the wild boar population is naturally restored in this epidemiological scenario, ASF will re-emerge in the area and numbers of dead and virus-posi-

FIGURE 19
Relationships between virus detection and wild boar density



Notes: At a low wild boar density, the likelihood of detecting the virus is extremely low.

Source: **Gervasi, V., Marcon, A., Bellini, S., Guberti, V.,** 2019. Evaluation of the efficiency of active and passive surveillance in the detection of African swine fever in wild boar. *Veterinary Sciences,* 7(1): 5.

tive animals will again reach the detection threshold. To declare a country ASF-free, the EFSA (2021) suggested the use of an ASF exit strategy that ensures a high level of confidence, while reducing the time needed to carry out the procedure. The strategy involves two different but interconnected periods. The fist is known as the "screening phase", which involves usual (standard) active surveillance (sampling and testing of all hunted animals) combined with opportunistic passive surveillance (i.e. incidental detection in the absence of active carcass searches). The second phase is known as the "confirmation phase", which exclusively involves enhanced passive surveillance, the duration of which is inversely correlated to the length of time of the screening phase. The number of carcasses to be detected during the confirmation phase is determined according to the estimated size of the infected wild boar population. It should be noted that at the end of the endemic phase, the population density of wild boar is always low, as is the number of wild boar carcasses expected to be detected (at least two per 1 000 km^2).

Provided that the country passed the defined period of the confirmatory phase without the detection of virus-positive animals or carcasses, the country (or an area of a country) can claim an ASF-free status with a desired level of confidence.

African swine fever management

The presence of ASFV in any wild boar population is a serious animal health threat for the sympatric domestic pig population. In the European Union, almost all domestic pig outbreaks occurred in areas where ASF was present among wild boar. In the absence of an effective and safe vaccine and due to strict international trade limitations imposed on an infected area or country, the presence of the virus in wild boar populations has very serious negative economic implications for the pork industry. While the complete eradication of the virus is the desirable outcome of management interventions, experience shows that it is neither a quick nor easy solution to the problem. ASF eradication in wild boar has proven to be a serious challenge everywhere and failures to achieve this strongly outnumber successful eradication campaigns. In most cases, virus eradication is simply not possible for various reasons, such as the lack of resources to manage very large infected areas inhabited by thousands of wild boar, or the nature of the wild boar's habitats, where the active search and removal of carcasses is complicated and cannot be sustained (e.g. wetlands, mountain areas, border areas, minefields).

Three main ASF strategies have been used (Table 3) in attempts to reduce prevalence, limit the spread or eradicate the disease in wild boar. Eradication was only successful in relatively small infected areas (< 1 000 km^2) where fencing was possible, which somewhat contributed to the other measures being carried out.

Aim of African swine fever management

For ASF management to be successful, it should aim to:

1. **Halt the geographical spread of the epidemic wave.** If the epidemic wave is not halted, the process of virus eradication will inevitably fail and the size of the infected area will grow indefinitely.
2. **Eradicate the virus** in the area the epidemic wave has passed through and where the virus is reaching an endemic status.

Immediate actions following first case detection

Following the detection of the index case, almost all usual forest, agricultural and leisure activities should be banned and the size of the area under restriction defined by landscape characteristics and the geographical distribution and abundance of the wild boar. Active searches for carcasses should provide key epidemiological information on the local evo-

TABLE 3
Main strategies for African swine fever

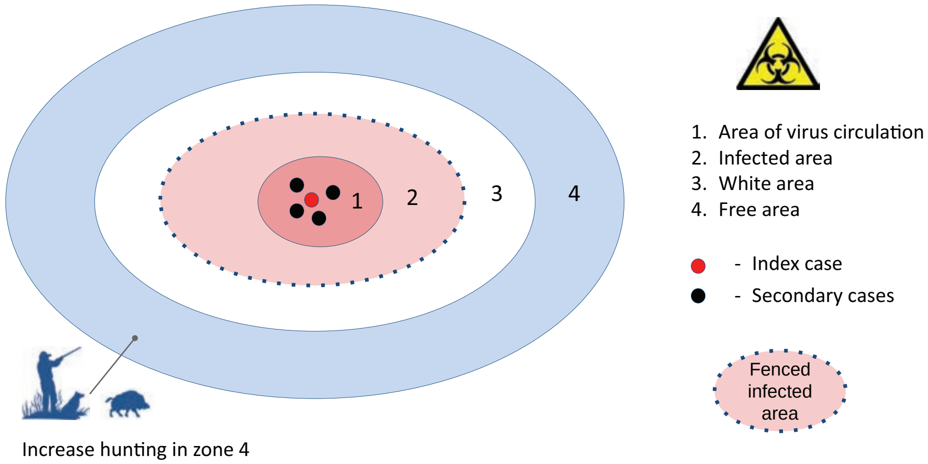
Strategy	Implementation in infected area	Implementation in surrounding area	Likelihood result
Depopulation The eradication of the virus is attempted through the extinction of the host population.	Between 80 and 90 percent of the post-reproductive wild boar population is killed in a short period. The spatial distribution of the involved host population is vaguely defined, as well its size and the hunting bag achieved.	Not considered foreseen or 80–90 percent of the post-reproductive wild boar population is killed in a short period.	Fast spread of the virus.
Soft hunting The eradication of the virus is attempted through a progressive reduction of new cases (incidence) by reducing both host population density and size.	Around 60 percent of the post-reproductive wild boar population is hunted. Adult and subadult females are targeted. Carcasses are safely disposed and hunting is allowed following the implementation of specific biosecurity measures.	Between 60 and 100 percent of the post-reproductive wild boar population is hunted Adult and subadult females are targeted.	Slow but steady spread of the virus.
Fencing and hunting ban The eradication of the virus is achieved through the extinction of the infected host population after it has been spatially defined and fenced.	The infected area/area of virus circulation is fenced. A ban of almost all economical (e.g. logging) and leisure activities, including the hunting and culling of wild boar, is implemented following the epidemic phase.	Hunting and culling are increased to approximately double the usual hunting bag. The quasi-extinction of the local wild boar population is reached.	Eradication.

lution of the ASF epidemic. In practice, active searches for carcasses, sampling and their safe disposal should be the only activities permitted and must be carried out by trained personnel. To avoid disturbance, prevent long-distance movements of wild boar and limit virus contamination of hunting tools, vehicles and dressing rooms, **all hunting activities should be banned in infected areas** (zones 0 and 1, Figure 20). **Feeding should be strictly prohibited** throughout all zones to minimize contact rates between animals attending feeding sites and to **eradicate any positive demographic effects** on the wild boar population related to supplementary feeding. Logistics and biosecurity measures should be identified and implemented to ensure the **safe removal of carcasses** from the infected area (zones 0 and 1, Figure 20) until an ASF-free status is regained, which could require years of effort.

Defining areas

The primary objective of zoning is to define the spatial distribution of the virus and thus improve actions according to the risk posed by the presence of the virus, including the protection of the domestic pig population, as well as the eradication strategy of the competent authorities.

FIGURE 20
Area zoning



Source: Authors' own elaboration.

Area of virus circulation

Once the first infected animal is detected (index case), the priority should be to further delimit the area of virus circulation. This area is the convex polygon defined by the most external ASF-positive carcasses. The active search for wild boar carcasses (passive rather than active surveillance with hunting) should be immediately organized to better understand the spatial pattern of the infection around the index case. The logic behind this search is that the first detection of ASFV likely represents a much larger situation (Figure 20). To accomplish this epidemiological recognition phase usually takes around 3–4 weeks. All positive carcasses must be fine-scale mapped and the convex polygon must be drawn with a surrounding buffer area. The role of this buffer area is to account for the likely extent of the spreading wave of the virus given the apparent duration of the epidemic. The size of the buffer area can be identified based on: i) the size of an average annual home range of a wild boar; or ii) the expected speed of the epidemic wave (in Europe this is estimated to vary between 1 km per week and 1 km per month) (zones 0 and 1, Figure 20). The applied constant for this exercise was 6 km wide, which corresponded to the maximum annual home range of an adult male wild boar (6 x 6 x 3.14 = 10 000 ha) or a few months of an epidemic wave progression. The procedure should be repeated whenever new positive detections are reported outside the infected area (zones 0 and 1), with the zoning areas updated accordingly.

Infected area

Once the real extent of virus circulation is revealed, the "infected area" must be defined. This area is created based on the likelihood that the virus will geographically progress during the implementation of the containment or eradication campaigns. All ASF containment or eradication measures, including restrictions to domestic pigs, should be applied to the entire infected area. The size of the infected area should account for the size of the area of virus circulation. The infected area should be largest in size. The exact ratio between the sizes of these two areas is lacking, but experience shows that the size of the infected area should be at least twice the size of the area of virus circulation. It is highly recommended that the border of the infected area be shaped according to the presence of natural or artificial barriers and taking into account various other epidemiological considerations (season, population density, duration of the epidemic, availability of resources, anticipated duration of the management efforts, among others). As experience shows, artificial or natural barriers will not definitely halt the epidemic wave of the virus, but may contribute to the success of disease management interventions. The primary role of such barriers is to slow the spread of the virus, allowing for more time to implement appropriate management interventions aimed at adjacent areas (surrounding areas inhabited by ASF-free wild boar populations). In any case, ASF eradication is only achievable if the epidemic wave of the virus spread is successfully interrupted.

White area

The aim of creating and including a white area in the ASF management processes is to obtain a "wild boar vacuum" so that the infected population can be isolated, thus breaking the chain of the infection responsible for the epidemic wave. To halt the epidemic wave, the size of the white area should be planned to obtain the quasi-extinction of the local wild boar population. Too large an area means the wild boar population size is too big to manage, too small an area means there is potential for wild boar to escape the infected area and also for the local redistribution of animals, which could hinder management efforts. A quasi-extinction means that the wild boar population is no longer viable, despite some individuals still being alive. In epidemiology, the wild boar quasi-extinction density level does not enable virus transmission.

White area borders are defined through four main approaches:

- implementing administrative borders or weak geographical barriers (in this case the virus always bypasses the area);
- fencing off the area of virus circulation encircled within an infected area and very large white area (e.g. in Czechia);
- fencing off the whole infected area and building several small extra fences in the white area, which depends on the spatial evolution of the epidemic (e.g. in Belgium);
- fencing off a strip of forest (a few kilometres) to separate the infected wild boar population from the healthy population, while culling the boar inside the fenced forest.

African swine fever-free surrounding area

An ASF-free area is set out at the external border of the white area. In ASF-free areas, hunters are required to increase hunting efforts (i.e. double the previous year's kill). While competent authorities supervise all activities carried out in infected and white areas, activities in ASF-free areas are carried out as part of usual hunting activities (with the sole exception of an increased effort). The size of ASF-free areas varies and issues addressed in such areas mainly concern wild boar management rather than disease control.

Once the zoning has been completed, competent authorities must decide if they plan:

- To contain the infection and possibly regain ASF-free status through medium-term wild boar population management. The strategy implies a certain period of endemic presence of the virus, which means that it could only reduce the speed of the epidemic wave, rather than halt it. As a result, the infected area tends to progressively enlarge, though not as quickly as when left unmanaged.
- To eradicate the virus through a short-term wild boar management strategy and regain ASF-free status through the local quasi-extinction of the infected population. The strategy is based on spatially isolating the chain of infection (hence stopping the epidemic wave) using boar-proof fences and reducing transmission inside the fence ($R_0 < 1$).

The choice between the two different management strategies requires an assessment that should consider – among other circumstances – the size of the infected areas, economic implications and the impact on the pig industry, the numbers and geographical distribution of domestic pigs, the number of hunters and the wild boar density and available financial and labour resources. Actions should be carried out for at least one year following the detection of the index case, meaning volunteers should not be the sole labour force for carrying out disease control interventions.

Containment followed by eradication

The aim of this strategy is to contain the virus inside the infected area, while strongly reducing wild boar density in the white (if defined) or ASF-free surrounding areas. The gradual reduction of the wild boar population (both inside and outside the infected area) through the targeted hunting of adult and subadult females, the safe disposal of carcasses and the application of biosecurity measures during hunting should drive ASFV to extinction. Unfortunately, according to European experience, this strategy tends to maintain an endemic equilibrium for years, which increases the risk of the virus escaping outside of the infected area. Table 4 shows the main measures that are implemented.

Eradication achieved through the extinction of local wild boar populations

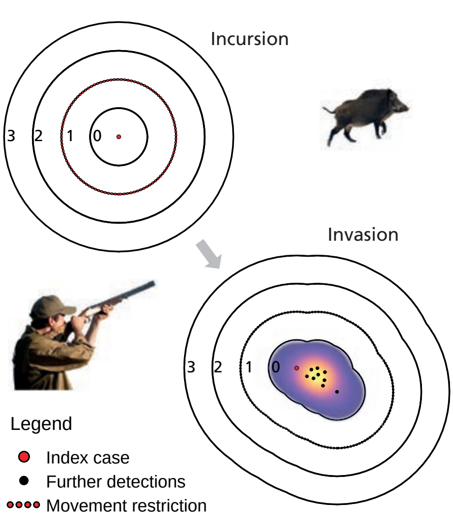
This strategy uses fences to achieve eradication. Boar-proof fences are erected to delimit areas where all wild boar should be culled by specially designated teams, tested and then disposed of regardless of the test results. Usually, public employees (e.g. foresters, gamekeepers, snipers) cull the wild boar in the area. This depopulation effort is a special measure that requires extremely high biosecurity standards of conduct. Provided that the extinction of the local wild boar population is successful or at least achieves a significant reduction in numbers, passive surveillance should be established. This surveillance should aim to exclude the possibility that the virus escaped from its known circulation zone to the white area. In white areas, the wild boar population is rapidly reduced by any legal means, but never through driven hunts. The quasi-extinction of the infected wild boar population requires spatial isolation (quarantine). The combination of management actions coupled with the lethality of the virus should result in virus eradication.

Area adjacent to the infected area

A very strong reduction of the wild boar population is desirable in areas that are adjacent to the infected area. Whenever possible, recreational hunting pressure should be increased. Further economic incentives may stimulate the active participation and involvement of hunters and subsidies can help maintain local venison markets. The reduction of wild boar populations can only be considered effective when hunting bags grow by a factor of at least 1.8 compared with the previous year. To avoid excessive testing of hunted wild boar, areas adjacent to the infected area should be carefully monitored for any wild boar carcasses (see the section on surveillance). However, if hunted animals are to enter the market chain, every wild boar should undergo PCR testing and receive a negative ASF result.

The proposed containment and eradication of ASF are largely based on the epidemiological considerations and principles described in previous chapters. The approach should be implemented and fine-tuned according to the local epidemiological landscape and adjusted following the evolution of the disease.

FIGURE 21
Delineation of zones in case of a focal introduction of African swine fever to wild boar populations



DISEASE CONTROL

ZONE	PASSIVE SURVEILLANCE	ACTIVE SURVEILLANCE	CARCASS REMOVAL
0	***	-	***
1	***	-	***
2	***	***	**
3	***	**	*

PRIORITY: * low | ** intermediate | *** high

POPULATION MANAGEMENT

ZONE	INTERVENTIONS
0	No hunting, no feeding
1	No hunting, no feeding
2	Targeted hunting + biosecurity
3	Intensive hunting, no biosecurity

This image is a hypothetical example to illustrate disease control principles. The exact configuration and size of the zones will be specific to countries and epidemiological situations. Zone 0 encompasses all funding of ASF-positive carcasses (e.g. 100 percent kernel density contour); zone 1 is a buffer zone set up to anticipate further epidemic progression of the infection (based on an epidemiological evaluation and local landscape) and can be fenced off to restrict movements (optional measure); zone 2 is an area adjacent to the infected area where the population is reduced as quickly as possible to achieve density below Nt (involves strong biosecurity measures); zone 3 is recognized as infection-free ("business as usual" or as prescribed by the country's control measures and regulations for ASF-free areas).

Source: **Guberti, V., Khomenko, S., Masiulis, M. & Kerba S.** 2019. *African swine fever in wild boar ecology and biosecurity.* FAO Animal Production and Health Manual No. 22. Rome, FAO, WOAH and EC. https://doi.org/10.4060/CA5987EN.

TABLE 4
Summary of recommended control measures and associated activities where African swine fever is endemic and its occurrence range is extensive

Activity	Surrounding free areas (zone 3)	Buffer/white area (zone 2)	Infected area (zones 1 and 0)
Supplementary feeding	Banned	Banned	Banned
Baiting	Allowed	Attractive only	Attractive only
Hunting (activity carried out by hunters; wild boar meat might be consumed)	Increased hunting bag, possibly targeting female adults and subadults	Increased hunting bag (150–180 percent of the previous year's hunting bag)	Initially banned, then allowed under biosecurity measures; meat from tested animals with a negative result allowed for consumption
Culling (activity carried out by/ under the supervision of the competent authority; culled wild boar are always disposed)		When hunting bag is insufficient	When hunting bag is insufficient
Biosecurity	Encouraged by the competent authority	Hunters are encouraged to properly implement biosecurity measures	Unavoidably applied when hunting is allowed
Public access restriction	None	Competent authority's decision	Allowed with biosecurity measures
Trapping	None	When hunting bag is insufficient	When hunting bag is insufficient
Disposal of wild boar carcasses	Competent authority to define the procedure	Safe disposal of all found carcasses	Safe disposal of all found carcasses
Surveillance	Promote passive surveillance All dead wild boar to be sampled and tested	Opportunistic passive surveillance Programmed active search for carcasses Active surveillance	Opportunistic passive surveillance Programmed active search for carcasses Active surveillance
Testing	Antigen detection	Antigen detection	Antigen detection

Notes: ASF eradication is attempted through the progressive reduction of new cases (incidence).

TABLE 5
African swine fever eradication through the quasi-extinction of the local infected wild boar population

Activity	Free areas (zone 3)	White area (zone 2)	Infected area (zones 1 and 0)
Supplementary feeding	Banned	Banned	Banned
Baiting	Only if trapping is foreseen	Only for trapping and culling	Only for trapping and culling
Hunting (activity carried out by hunters; wild boar meat might be consumed)	Increased hunting bag, targeting female adults and subadults (qualitative effort) Meat consumed	Targeted hunting bag Passive surveillance in place All animals tested and safely disposed	Banned
Culling (activity carried out by/under the supervision of competent authority; culled wild boar are always disposed)		When the foreseen hunting bag has not been achieved All animals tested and safely disposed	Local extinction of the wild boar population when the endemic phase has been reached (after the epidemic phase)
Biosecurity	Encouraged	To be applied	To be applied
Public access restriction	None	Competent authority's decision	Area is restricted No leisure activities Farmland activities under derogation
Trapping		When the foreseen hunting bag has not been achieved	To reach local wild boar extinction
Fencing		Depending on the epidemiological situation and landscape characteristics	Areas defined by passive surveillance Built before any other wild boar management measures are initiated
Disposal of wild boar carcasses	Competent authority to define the procedure	Tested and safely disposed	Tested and safely disposed
Surveillance	Promote passive surveillance All dead wild boar to be sampled and tested	Opportunistic passive surveillance in place Programmed active search for carcasses; all dead wild boar to be tested Hunted or culled animals to be tested	Opportunistic passive surveillance in place Programmed active search for carcasses; all dead wild boar to be tested Hunted or culled animals to be tested
Testing	Antigen detection	Antigen detection	Antigen detection

KEY MESSAGES

1. ASFV can only be detected early through passive surveillance.
2. At the end of the epidemic, passive surveillance is the only strategy that can demonstrate the elimination of the virus.
3. Passive surveillance is also key to determining the different zones through which the infection in wild boar populations can be managed.
4. ASF eradication is possible if two concomitant goals are achieved: halting the geographical spread of the virus; and drastically reducing the number of infected wild boar in the endemic area through which the epidemic wave was passing.
5. ASF eradication is possible through the progressive reduction of virus incidence or through the quasi-extinction of the local infected wild boar population.
6. The progressive reduction of virus incidence is possible through carrying out targeted hunting of adult and subadult females, the strict application of biosecurity measures during hunting in the infected area and an increased hunting effort in ASF-free surrounding areas.
7. The eradication of the virus through the quasi-extinction of the local infected wild boar population is possible through fencing and rapidly culling the wild boar population surrounding the infected area.
8. Eradication is only possible when a complete set of measures is applied to both the infected and surrounding areas.

Chapter 5
Biosecurity in affected forests

Vittorio Guberti and Marius Masiulis

In forests, the presence of infected wild boar carcasses increases the environmental viral load, enhancing local long-term persistence of the virus. This chapter outlines the different methods to dispose of infected wild boar and how to minimize the risk of mechanical transportation of the virus outside infected forests through human activities.

AFRICAN SWINE FEVER DETECTION IN FREE AREAS

Usually, ASF in wild boar in free areas is first detected in dead animals. Initially, a practical carcass management plan is rarely available, so the veterinary services should immediately lead the field operations. After the first detection, the infected area should be defined through an active search for carcasses. This search will help identify the geographic extent of ASF and allow for the designation of the infected area. The border of the infected area should follow the borders of the hunting ground involved as they will represent the main wild boar management units.

A general disposal strategy must be developed and should consider the availability of paved and unpaved roads to facilitate transport, soil characteristics (including texture, permeability, surface fragments, depth to the water table, depth to bedrock and hydrological properties) and proximity to water bodies, wells public areas, dwellings and residences. At the local level, the landscape of each hunting ground should also be considered to implement the strategy.

The personnel responsible for carcass disposal or transport must be trained on ASF and biosecurity. They must also be appropriately equipped with disposable clothes and overshoes or clothes and shoes that are easy to clean and disinfect. Involved personnel must not have any direct contact with healthy pigs for 48 hours.

DETECTION OF WILD BOAR CARCASSES

In the control and eradication of any animal diseases, the effective and safe disposal of infectious carcasses plays a crucial role. Safe disposal of carcasses is even more relevant for ASF due to their role in the epidemiology of the disease. Since early 2015, the role of carcasses has been highlighted and their detection and safe disposal is included on the list of the measures to control ASF in wild boar populations in the European Union (European Commission, 2018). The first step in detecting carcasses is to raise awareness among hunters and other stakeholders, particularly foresters and forest workers, and to include the general public. The awareness campaign should clearly address the procedure to be applied when finding a wild boar carcass.

Awareness campaigns should be carried out using all possible information modalities (e.g. face-to-face meetings, mass media, posters, leaflets, radio and TV shows). Different actors should be informed, including hunters and hunting associations, the general public

BOX 3

African swine fever DNA in soil samples collected from the sites of discovery of wild boar carcasses in Estonia

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In Estonia, soil samples were collected from beneath 2–3 ASF-infected wild boar carcasses at various levels of decomposition, following their removal from the sites. The samples were collected from ten sites of discovery in seven different locations in all four seasons, including three samples per site at an interval of 1–3 weeks. Samples were tested for the presence of ASF viral DNA by the rt-PCR test. The rt-PCR signal of ASFV was considered positive at a cycle threshold value below 40.

In the samples collected in July 2016 from three sites of discovery of wild boar carcasses, ASF viral DNA was detected in two sites up to one and two weeks after the discovery and removal of the carcasses.

At one site of discovery of the carcasses found in October 2016 (n=5), the viral DNA persisted up to six weeks.

At one of the two sites discovered on 8 February 2017 (n=2), the viral DNA persisted almost four months, until the end of May 2017.

The persistence of the viral DNA was dependent on the level of the decomposition of the carcasses and was longer at sites where the fresher carcasses were discovered.

through municipalities and non-governmental organizations, veterinary practitioners, forest workers and forest management bodies, to increase the reporting of dead wild boar findings. Any individual who could potentially find a dead wild boar should know the basic rules on how to behave around the carcass:

- Do not touch the carcass.
- Ensure that the spot where the carcass has been found is visible or communicate exact coordinates of its location (any smartphone can be used).
- Inform the authority in change of carcass management, without delay.

Competent authorities must facilitate communication and never view reports of wild boar carcasses as a nuisance. In fact, those who report carcasses should be rewarded. The rapid detection and removal of contaminated carcasses is regarded as one of the pillars for the eradication of ASF in wild boar (EFSA, 2017).

It is well known that nothing is easier than ignoring a rotten, smelly wild boar carcass in a forest.

The availability of a free 24-hour phone line (green line) simplifies the collection of information, even when received from different areas of the country. Financial motivations for carcass reporting are one way to increase such reporting and a specific procedure should be developed in a country before ASF is detected. Several countries used to only reward hunters for reports, who would be paid through their official hunting associations.

Local hunters play a pivotal role in carcass detection as they are some of the main experts of the infected area. Following an ASF diagnosis in a wild boar population, hunters and foresters should actively search and regularly patrol the area, especially near wild boar resting and feeding areas, and natural or artificial water bodies (rivers, ponds, lakes). Sick wild boar usually hide in swamps or densely covered areas, where they can avoid disturbance.

Under normal conditions, even for hunted populations, natural mortality in wild boar is 10 percent of the population (Toïgo *et al.*, 2008; Keuling *et al.*, 2013). The reliability of the carcass reporting system, and therefore ASF detection, is measured through the number of dead wild boar reported in the absence of ASF. **A desirable goal is to report 10 percent of carcasses that account for approximately 1 percent of the whole estimated wild boar population** (i.e. ten reported dead wild boar out of 1 000 estimated wild boar indicates efficient passive surveillance).

PRECAUTIONARY MEASURES

Once an ASF-positive carcass is reported, there are several methods to dispose of it and thereby inactivate the virus. Countries are responsible for choosing which carcass disposal method to apply, and base their choice on factors such as local facilities, the environmental situation, constraints and costs.

Local burning or burying of carcasses must be authorized by competent authorities to prevent a negative impact on the environment. At the onset of the epidemic, the legal competence of each involved entity was often not clearly defined. Countries at high risk of ASF infections should therefore organize authorization protocols before the first case of ASF detection. The disposal of large numbers of wild boar carcasses poses both logistical and environmental problems, especially when carried out in mountains or wetland areas, and should be planned well in advance, particularly where the density of wild boar is high.

Countries at risk of ASF infection should define which service or agency is responsible for carcass collection and disposal. Veterinary, forestry or environmental services, municipalities or even local hunters and their associations could be made responsible. However, veterinary services should always be responsible for supervising carcass disposals and taking samples.

In each country, it is advisable to involve the forestry services and local hunters, including hunting clubs or associations, as fundamental partners in providing information and support during the collection and disposal of carcasses in the field.

CARCASS DISPOSAL

Due to the epidemiological evolution of ASF in Eurasia, each wild boar carcass, even if detected hundreds of kilometres away from the nearest infected area, should be considered as a suspected ASF case unless the presence of the virus is ruled out through laboratory testing. All precautionary measures aimed at limiting the possible further spread of the virus should be taken at the site where carcasses are found and while waiting for laboratory test results. Following ASFV detection, all biosecurity measures should be promptly implemented for each detected carcass. The main aim of carcass disposal is to reduce the probability of the virus remaining locally.

BOX 4

Latvia's experience of managing African swine fever in wild boar and ensuring biosecurity during hunting

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The first ASF biosecurity requirements that were implemented for hunters in Latvia were:

- storage of the carcass of a hunted wild boar until laboratory results became available;
- prohibition to leave offal in the forest.

These requirements were implemented a few days after ASF had been confirmed in wild boar in June 2014 (Olševskis *et al.*, 2016). The requirements were established by order of the Chief Veterinary Officer on hunting in ASF-affected territories.

From October 2014 to October 2015, driven hunts were prohibited in areas within a 20-km radius of each ASF case in wild boar. From November 2015, driven hunts were prohibited at a distance of 10 km on both sides of the line separating ASF-affected areas from ASF risk areas (between Part I and Part II). Since November 2016, driven hunts in ASF-affected areas have been allowed but only when biosecurity requirements are respected as defined by order of the State Forest Service (as suggested by the Chief Veterinary Officer). The following biosecurity requirements are in effect:

1. Before a driven hunt, the hunt leader must ensure a place and equipment for:

- destruction of by-products from hunted wild boar;
- carcass dressing and storage;
- washing and disinfection of transport, boots, knives and other equipment.

Before each driven hunt, the hunt leader must instruct all hunters on the mandatory biosecurity and hygiene requirements to be followed during and after hunting.

2. Wild boar by-products:

It is prohibited to leave any wild boar by-products, including internal organs, offal or skin, in the forest. The hunt leader must ensure the destruction of all wild boar by-products by burial, burning or collection in specific places or containers.

3. Carcass dressing and storage:

The hunt leader must ensure:

- that the primary treatment of a hunted wild boar only takes place in a location where its disinfection is possible afterwards;
- that the hunted wild boar is stored in an appropriate premises until laboratory results are available and the identification of the wild boar carcass is complete;
- that there is no division or consumption of the carcass before a negative laboratory test result for ASFV and antibodies is received.

4. Washing and disinfection:

The hunt leader must ensure:

- disinfection of transport or parts of the transport that have been in contact with the hunted wild boar or blood;
- disinfection of the equipment that has been used for the transportation of the hunted wild boar or material that has been used for covering the carcass during transportation;
- washing and disinfection of hunters' boots before leaving the hunting lodge;
- washing and disinfection of the equipment that has been in contact with the hunted wild boar, including ropes, hooks, knives and aprons;

- the use of disinfectants that inactivate ASFV;
- that each hunter washes their clothing after hunting if they plan to hunt outside the ASF-affected area;
- that vehicles previously used to transport hunted wild boar or hunting equipment are allowed for the transportation of feed or for agricultural purposes only after appropriate cleaning, washing and disinfection.

5. Use of hunting dogs:
The use of hunting dogs in ASF-free areas is allowed only when at least five days have passed after they were used in ASF-infected areas.

The State Forest Service carries out random controls on the implementation of biosecurity requirements during driven hunting.

Latvia's experience shows that the main difficulties for most hunters are:

- a lack of equipment for the storage of hunted wild boar carcasses, especially during summer months (coolers, refrigerators);
- acceptance of the concept of hunting biosecurity;
- rapid adaptation to new conditions and requirements (ASF);
- a change of previous traditions and attitudes.

Help and assistance provided to hunters:

- One year before ASF introduction in Latvia, the joint stock company, Latvia's State Forests, donated EUR 1 million for ASF prevention and readiness. After several discussions, it was decided that most of the money would be used to purchase refrigerators for hunting clubs in ASF risk areas. A small part of the donation was used for training and to increase the awareness of hunters all over the country, which was provided by hunting associations.
- Initially, the Food and Veterinary Service provided hunters with disinfectants.

National legislation on hunting biosecurity:
The regulation of the Cabinet of Ministers on biosecurity requirements for hunting wild boar was prepared, agreed with hunters and adopted at the beginning of 2018. In general, the regulation includes the requirements that are currently set by order of the State Forest Service. In addition, a clearly defined procedure for controls on the implementation of hunting biosecurity requirements will be established through the collaboration of the State Forest Service and the Food and Veterinary Service.

The movement of carcasses within the infected area, from the spot they are found to a designated carcass collection point, must be carried out to prevent further spread of the virus. The burial or burning area should be located taking into account the availability of facilities to disinfect vehicles, personnel and equipment. Vehicles (particularly the underside or the bed, if carcasses are transported in the cab) and personnel (shoes, equipment) should be cleaned and disinfected before leaving the infected area.

Photo 9
The transport of wild boar carcasses should minimize the risk of further spread of the virus.

Photo 10
Simple tools can be used to safely transport hunted wild boar or animals that have been found dead.

Photo 11
Single burial with disinfectant on the carcass and around the burial area.

Carcasses should be placed in durable plastic bags and then transported into plastic or metal tanks suitable for repeated disinfections. The tanks enable the carcasses to be moved through the forest more easily. Stones, snow or vegetation cannot damage the plastic bags and infected fluids cannot leak out. Vehicles must be disinfected before leaving the infected area. Containers must be regularly cleaned and disinfected before they can be reused.

The carcass and the spot it was found should be disinfected to minimize the ASF viral load. These procedures are easy to implement in all seasons with the exception of winter when carcasses are frozen, are often covered with snow and temperatures are below 0 °C and the disinfectant freezes. In such situations, anti-freezing agent is added to the disinfectant to stop it from freezing. Propylene glycol can be used as a diluent.

Each country has approved and/or authorized a list of biocides that are effective against ASFV; only these authorized biocides should be used and in accordance with the producer's instructions.

Carcass disposal: incineration or rending and on-the-spot burial or burning

Incineration or rendering is the most effective and easiest way to dispose of carcasses. Rendering is a process that converts waste animal tissue into stable, usable materials. It is a closed system for the mechanical and thermal treatment of animal tissues that results in stable, sterilized products, such as animal fat and dried animal protein, by grinding tissue and sterilizing it by heat under pressure.

Although rendering is the most economical method to dispose of carcasses, the movement of infected carcasses to the rendering plant carries some risk of the disease spreading, so precautions must be taken. Not all countries have rendering plants, and existing rendering plants may not always accept wild animal carcasses. For this reason, agreements with rendering plants should be sought beforehand or other alternative methods of carcass

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Photo 12
Disinfection of the burial area.

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Photo 13
Wild boar carcasses are placed in plastic bags and carried to the nearest road.

Photo 14
Carcasses are then transported to the carcass collection point.

disposal should be used. Carcasses can be sampled directly in the rendering plant, which minimizes the risk of local viral contamination.

Incineration is a treatment process that involves the combustion of organic substances contained in waste materials (or carcasses in this case). During the incineration process, carcasses are converted into ash, flue gas and heat.

Containers

Carcasses can be managed by using containers. Special containers (with a 400–600 litre capacity) should be strategically distributed nearby the nearest paved roads. Carcasses can then be placed in the containers directly by hunters using appropriate vehicles and following biosecurity procedures. Hunters should inform the local veterinary service, which then plans the disposal of the carcasses. Usually, the company that manages the rendering plant or incinerator directly collects the carcasses, with the veterinary service supervising the process. The containers must be robust, lockable and leak-proof. The use of containers is relatively easy and quick to implement. When strategically placed, containers help prevent the spread of ASFV outside the infected area.

Photo 15
In Latvia, an incinerator was placed in a highly infected area.

© Vittorio Guberti

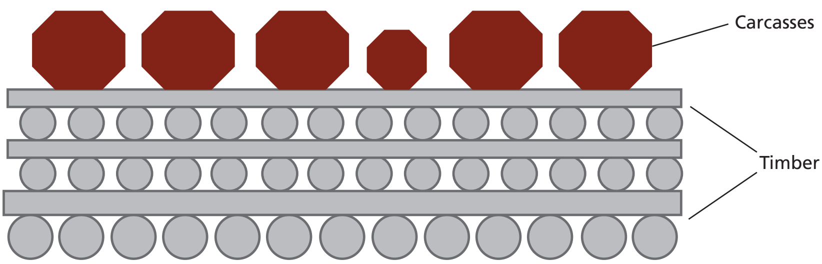
Photo 16
In some highly infected areas, pyres were prepared in advance.

On-the-spot burning

Any burning must minimize environmental pollution and comply with fire safety regulations. The practice may be banned in many countries. Burning carcasses in an outdoor area using combustible materials as a primary fuel source can be carried out in several ways: pyre burning; pit burning; above-ground incineration (fireboxes or a mobile incineration device); or a combination of these methods.

When constructing a pyre or digging a pit for burning carcasses, it is important to maximize the airflow. Primary fuel sources must be combustible materials such as dry wood or coal briquettes that have a low or negligible environmental impact. Plastics, tyres and other potentially toxic inflammable materials can be used with the approval of the competent authorities (usually the ministry of the environment). Straw or hay should be used only to start the fire, due to the smoke these materials produce. Liquid fuels are often needed to initiate the burning.

FIGURE 22
Sketch of a pyre construction



Source: **Australia, National Biosecurity Committee,** 2015. *Australian Veterinary Emergency Plan. Operation Manual Disposal.* Version 3.1. https://www.animalhealthaustralia.com.au/wp-content/uploads/2015/09/DISP-08-FINAL24Aug15.pdf.

Trained personnel must be involved in the process and the burning area must be carefully selected and cleared. Activities should only be carried out when firefighting tools and related facilities are available. On-the-spot carcass burning is a slow process, as it requires time to select and clear the area, transport large quantities of hardwood, complete the burning of the carcass and prevent the fire from spreading.

The complete burning of a wild boar carcass can take up to 68 hours. After the carcass has been burned, ashes should be buried and the potentially contaminated surroundings disinfected.

Burial

On-the-spot burial is another carcass disposal method. The procedure should be agreed with the environmental service and clear instructions on how to bury the carcass should be made available.

Single pit

This method is used when individual dead wild boar are found. Burial pits should be deep enough to ensure that a soil layer of at least 1 m can be placed on top of the carcass to prevent scavenging. The bottom of the pit should be at least 1 m above the seasonal maximum groundwater level to avoid contamination. The availability of groundwater maps and instructions will help minimize such risks. Carcass decomposition is faster when plastic bags are removed as these take years to decompose. The minimum distance between the pit and watercourses, lakes or ponds should be indicated by the environmental protection service. Carcasses should be disinfected once in the pit and covered by pressed soil.

On-site trench burial

This method is generally used when several carcasses are found in the same area or when weather conditions prevent the digging of several single pits (e.g. in the winter, when the ground is frozen). An excavator usually digs the trench and carcasses are placed on the bottom and covered with soil. The high number of carcasses requires a formal environmental

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Photo 17
Carcass burning in a trench.

authorization. To avoid the reuse of trenches, their location must be registered using geographical coordinates. There is no limit to the number of carcasses that can be disposed of in a single trench, but it must be dug to the required size and depth (1.8–2 times the entire volume of the carcasses to be disposed of with at least 1 m of soil cover and at the prescribed distance from groundwater). Before covering the trench with soil, carcasses must be disinfected. Plastic bags are not recommended because of their lengthy decomposition rates.

Mass burial

This method applies the same rules set for domestic pigs in commercial farms. Mass burial is appropriate when the local geological characteristics prevent leakage and when transportation to the incinerator or rendering plant is not possible. The burial area and the carcasses must be disinfected with appropriate disinfectants. The abdomen of fresh carcasses must be opened to limit the side effects of gas production during putrefaction.

INDIRECT CONTAMINATION OF THE HABITAT WITH AFRICAN SWINE FEVER

In any ASF-infected environment, the virus could be present in several matrices. Infected material, such as faeces, blood, grass and mushrooms, is likely to be mechanically transported outside the infected area, thus representing an indirect risk for further spread of the virus. Mushroom or forest berry collectors, as well as forest workers and hunters, are the most at risk of indirectly spreading the virus.

Previous data on the infectivity of faeces have been recently reconsidered (EFSA, 2010a; Davies, 2017; Olesen, 2018). The most recent research demonstrates that only 10 percent of the faeces from an infected wild boar contain the virus, with its survival relatively short at room temperature (higher than 18 °C). According to these data, the probability of stepping

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Photo 18
Trench burial needs the use of an excavator.

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Photo 19
Plastic containers with informative documents about the wild boar attached to the container.


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Photo 20
Wild boar in containers.

on infected faeces and carrying the virus outside infected areas during summer or early autumn months is negligible.

However, during winter months, the risk in northern and eastern European countries could be higher, as low temperatures allow longer survival of the virus (weeks or months instead of a few days) and more virus-contaminated faeces may accumulate in colder periods of the year. In winter months, wild boar are also more likely to cluster around feeding and baiting points, meaning their daily home ranges are reduced, resulting in a higher probability that the environment will be locally contaminated with infected faeces. Around 50 percent of wild boar faeces are located in a small area (up to 0.4 hectares) surrounding feeding points (Plhal *et al.*, 2014). Hunters often visit feeding or baiting points to refill or check them or to set up cameras to estimate the size of the wild boar population. In such circumstances, the probability of stepping on infected material and transporting the virus outside the infected area is increased and should be avoided and managed.

Non-hunters (visitors or workers of the infected forest or area) should be informed about the possibility of being contaminated by the virus when exploiting resources in the infected forest or area, whereas domestic pig owners exploiting resources the area should be informed about the risk of the mechanical transmission of the virus as part of pig biosecurity. Information should be provided on posters or signs at the entrance to the infected area, with bullet points on how to mitigate the risk of ASF.

An easy and likely already largely applied measure is the use of different clothes and boots while visiting an infected or at-risk area that should be changed before leaving the area. Boots should be placed in a robust plastic bag to avoid any contamination of cars while driving home and then brushed and washed with soap and hot water until the soles are clean.

Hunters should be aware that several activities carried out in the infected area risk the mechanical transportation of the ASFV outside the habitat. Some precautionary measures should be applied, such as avoiding the use of a private car for the transportation of feeding items directly to the spot, and carefully disinfecting boots and any possibly contaminated materials on return to the hunting lodge or dressing facilities.

KEY MESSAGES

1. Countries at risk should develop a clear strategy for finding (passive surveillance) and disposing of carcasses before the introduction of the virus.
2. Competent authorities must facilitate the reporting of carcasses, raise awareness and organize effective communication channels.
3. In infected areas, rendering is an easy and effective method to dispose of carcasses. Containers can help in the temporary storage of carcasses, which are to be sampled at the rendering plant by an official or authorized veterinarian.
4. Other carcass disposal methods include incineration, burning and burial.
5. The human exploitation of forest resources poses a risk for the mechanical transportation of the virus outside the infected forest. Very simple and basic biosecurity measures can minimize this risk.

Chapter 6
Biosecurity during hunting

Marius Masiulis and Vittorio Guberti

Large numbers of wild boar are hunted in infected forests each year. Without biosecurity measures, these boar represent an important risk of spreading ASF as a source of the virus. During hunting, the virus can contaminate cars, boots or objects and then be mechanically transported outside the infected forest. This chapter describes the main strategies and logistic organization that can minimize the risk of the virus spreading during hunting in infected forests when implemented at the hunting ground level.

Hunting is usually regulated by environmental or forestry services. Veterinary services are rarely involved unless transmissible animal diseases are detected in the wild animal populations. Veterinary legislative acts regulate several diseases that affect both wildlife and livestock, including ASF. The role of the veterinary service primarily relates to ensuring that all appropriate procedures for confirming or ruling out the presence of the disease are followed. Veterinary services are also responsible for providing information to pig owners and hunters, and conducting epidemiological investigations for suspected cases (wild boar showing abnormal behaviour or found dead), including laboratory testing.

When ASF is confirmed in wild boar, the virus should be controlled through the specific management of the wild boar population. European Union countries must develop an eradication plan that includes the establishment of biosecurity measures to be enforced during hunting. Countries should also develop and implement basic hunting biosecurity measures, regardless of the presence of ASF. The development of a proper biosecurity approach during hunting requires time and resources and may be difficult to organize in an emergency situation.

Close communication with hunters is important. Although the hunting of wild boar could represent a useful ASF management tool, hunting infected wild boar poses the threat of the virus spreading further. Hundreds of infected wild boar have been hunted in eastern and northern Europe in recent years. In such an epidemiological landscape, hunters act as a link between the wild infected habitat and the anthropogenic habitat, increasing the risk of ASF outbreaks among domestic pigs.

MANAGEMENT PLAN FOR WILD BOAR HUNTING

Each hunting ground (irrespective of its size) should develop its own basic and simple biosecurity plan. This plan should consider the road network, location of hunting towers, feeding and baiting points, availability of hunting lodges and related animal dressing facilities and storage of offal (containers or animal waste pits).

Hunters in the infected area should address the following points (Bellini, Rutili and Guberti, 2016):

- training on ASF preventive measures;
- wild boar transportation from the hunting spot to the dressing facility;

- dressing room/area requirements and equipment;
- the proper disposal of offal;
- safe on-site storage of hunted wild boar until an ASF-negative test result;
- procedures for the disposal of ASF-positive wild boar;
- procedures for cleansing and disinfecting facilities.

MINIMIZING THE SPREAD OF AFRICAN SWINE FEVER OUTSIDE INFECTED AREAS THROUGH HUNTING GROUND BIOSECURITY PLANS

In ASF-infected and at-risk areas, it is not possible to determine whether a hunted wild boar has ASF. All hunted wild boar must therefore be treated as if they are infected, which means applying a complete set of feasible and sustainable biosecurity measures during all hunting phases.

TRANSPORTATION OF WILD BOAR FROM THE HUNTING SPOT TO THE DRESSING FACILITY

Wild boar parts should remain in the hunting spot. In fact, it should be strictly forbidden to open the animal's abdomen and to leave any internal organs in the area. The entire body of the hunted wild boar should be safely transported to the dressing area or facility.

Safe transportation of the carcass should prevent the flow of any liquids, in particular blood, that may contain ASFV. Plastic or metal tanks are recommended, not plastic bags, which are often damaged by vegetation. Dedicated vehicles should transport hunted wild boar from the hunting spot to the dressing area. These vehicles should never leave the infected hunting ground or area. If these dedicated vehicles are not available, trailers or inexpensive external animal transport devices can be used. The means of transportation used to collect hunted wild boar must be cleaned and disinfected after each hunt.

The use of private cars to transport wild boar inside the infected hunting ground should be forbidden as they could be contaminated and thus indirectly spread the ASFV over great distances. Private cars should be parked outside the area where the dressing procedures are performed, preferably on paved road.

Photo 21
Hunting lodge with a separate dressing and storage room (right).

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Photo 22
In ASF-infected and at-risk areas, hunted wild boar should be safely transported to avoid further spread of the virus.

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Photo 23
Blood drops contain a very large amount of the virus.

© Marius Masiulis

Photo 24
In field conditions it is often difficult to limit the viral contamination of objects and tools.

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Photo 25
Procedures must also be considered for other animals (e.g. foxes), especially if contaminated with wild boar blood.

© Vittorio Guberti

Photo 26
A normal pickup truck can transport wild boar, minimizing the risk of further spread of the virus.

REQUIREMENTS AND EQUIPMENT FOR THE DRESSING AREA/FACILITY

Each hunting ground must have at least one equipped dressing area or dressing facility, authorized by the competent veterinary authority. The dressing area can be open-air or a closed facility, but must be dedicated exclusively to animal dressing. It must also be easily recognizable and only used by those in charge of dressing the animal.

An open-air dressing area should be:

- set in an area with permanent dry soil, have a roof protecting it from rain, snow and sun, and organized in a way that prevents contamination of the surrounding areas with infected blood or fluids;
- fenced with lockable gates to prevent the entry of wild boar, scavengers and unauthorized persons;
- provided with water;
- provided with a disposal pit or container for offal and waste.

Photo 27
Non-fenced open-air dressing area with a disposal pit

Photo 28
Basic fenced open-air dressing area with a disposal pit.

Photo 29
Fenced disposal pit.

Closed dressing facilities are another type of dressing area that hunters usually equip in part of the hunting lodge or nearby it.

A closed dressing area should:

- prevent access of domestic and wild animals;
- have walls and floors that can be easily cleaned and disinfected;
- have an area for the cleaning and disinfection of the dressing tools and equipment;
- have a container for the storage of animal by-products before their disposal;
- have disinfection barriers (mats) at the entrance, filled with disinfectant.

Persons in charge of dressing should:

- wear disposable or washable clothes and boots that are easy to disinfect;
- use tools that are exclusively for dressing, clean and disinfect them after use and not bring them outside the hunting ground;
- wash and disinfect every tool, apron and footwear used in the dressing area before exiting the fenced area;
- place all disposable items in plastic bags and dispose of them;
- use only authorized disinfectants.

PROPER DISPOSAL OF OFFAL

The offal of ASF-infected wild boar is the source of the ASFV and, if not handled with appropriate biosecurity measures can be a source of virus spread.

All animal parts must be removed from the forest. The easiest method is to bury parts in a designated pit that must be approved by the environmental protection authority or veterinary service. The pit should be close to the dressing area and directly excavated in the ground with consideration given to the groundwater level. The size of the pit must be able to contain the expected amount of offal per hunting season and must also be deep enough to prevent the scavenging of other wild animals (including boar). The pit area should be fenced and have a lockable gate. This method of offal disposal is practical wherever digging is possible.

When completely full, a pit can be closed and a new one excavated. Alternatively, and where allowed, its contents can be removed and safely disposed under the supervision of the

Photo 30
Closed, well-equipped dressing room.

Photo 31
Closed dressing room with storage facilities.

veterinary service. Containers are a valid alternative to pits. Usually sealable and leak-proof plastic containers (500–600 litres in size) are placed close to dressing areas and then emptied when needed following the instructions provided by the veterinary service. Reused pits or containers are of evident advantage when rendering plants accept animal waste and offal.

SAFE ON-SITE STORAGE OF HUNTED WILD BOAR UNTIL AN AFRICAN SWINE FEVER-NEGATIVE TEST RESULT

In ASF-infected areas, hunted wild boar cannot leave the hunting ground without an ASF-negative test result. Official veterinary laboratories must carry out ASF tests. The results obtained by commercial kits that are available on the market in some countries are completely unreliable and their use is inappropriate for the eradication of the infection.

Each hunting ground should be equipped with refrigerators in which, after dressing and sampling, the entire wild boar is stored and individually identified. If the carcass is divided into several pieces (this is not recommended), each piece must be clearly identified, with the number of pieces obtained from a single wild boar registered. No part of the animal (including trophies) can leave the hunting ground before the hunted wild boar has an ASF-negative test result.

Storage and sample activities must be organized to avoid the release of ASF-negative animals while test results are still pending for other individuals. Animals should be stored as batches and released only when each entire batch tests negative for ASF. The procedure is easy to manage when hunting is carried out exclusively during weekends and requires more careful planning for different timings (hunting, sampling, testing and release of ASF-negative animals).

Cold storage facilities or refrigerators for hunted wild boar carcasses can be installed in closed dressing facilities or in a hunting lodge and must be cleaned after the removal of carcasses or meat.

In Poland, the veterinary service provided transportable storage rooms for wild boar. The carcasses can be dressed outside these room, with offal collected in containers and animals stored until laboratory results are received.

Photo 32
Wild boar individually marked (blue mark on the chest) waiting for laboratory results.

Photo 33
Storage of wild boar pieces (tracing individual wild boar is more complex).

© Vittorio Guberti

Photo 34
Transportable storage rooms in Poland (provided by the veterinary service).

Note: Wild boar can be dressed outside the room and offal can be collected in containers. Stored animals will be kept until laboratory results are communicated.

PROCEDURES FOR THE DISPOSAL OF WILD BOAR WITH AFRICAN SWINE FEVER AND FOR CLEANING AND DISINFECTING FACILITIES

In the event of a positive ASF result, all the stored carcasses (or pieces of meat) must be safely disposed of by the veterinary service. The dressing area, cold storage facilities or refrigerator must also be cleaned and disinfected. Since the inactivation of the virus in the dressing area, in refrigerators and from clothes, vehicles and tools is based on cleaning and disinfection, hunters should be trained and provided with written instructions.

© Vittorio Guberti

Photo 35
In some infected hunting grounds, hunters are equipped with disinfectants (and are also accompanied by a dog).

Preliminary cleansing is needed before the use of any disinfectants. Mechanical brushing with a detergent solution is highly effective in cleaning contaminated surfaces and objects and is important for disinfection to be effective. Only freshly prepared disinfectant solutions should be used and for the required time necessary to be effective (up to 60 minutes contact time).

DISINFECTANTS RECOMMENDED FOR AFRICAN SWINE FEVER VIRUS

The following list of disinfectants are recommended (see Haas *et al.*, 1995; Heckert *et al.*, 1997; Shirai *et al.*, 1997, 2000):

- chlorine (sodium hypochlorite);
- iodine (potassium tetraglicine triiodide);
- quaternary ammonium compound (dodecyl dimethyl ammonium chloride);
- vapo-phase hydrogen peroxide;
- aldehydes (formaldehyde);
- organic acids;
- oxidizing acids (peracetic acid);
- alkalis (calcium hydroxide and sodium hydroxide);
- ether and chloroform.

TABLE 6
Registered commercial disinfectants

Product name	Active components	Use
Virkon S®	Sodium chloride Potassium peroxymonosulfate	ASFV in animal feeding/watering equipment, livestock barns, pens, stalls, stables, equipment, hog farrowing pen premises, hog barns/houses/parlours/pens, animal quarters, animal transport vehicles, agricultural premises and equipment, and human footwear.
Ecocid S®	Triple salt of potassium monopersulphate Sulphamic acid Malic acid Sodium hexametaphosphate Sodium dodecyl benzene sulphonate	Surface and water system disinfectant, any type of animal housing, greenhouses and veterinary surgeries.
Virocid®	Alkyl dimethyl benzyl ammonium chloride Didecyl dimethyl ammonium chloride Glutaraldehyde	Wide application range for the daily disinfection of: • animal houses and materials; • animal transport and materials; • storage and processing rooms for feed and food; • food transport; • boots and wheels via dipping baths.


© Marius Masiulis

Photo 36
Disinfection of an open-air dressing area.


© Marius Masiulis

Photo 37
Disinfection of a storage facility.

© Vittorio Guberti

Photo 38
Disinfection of boots.

KEY MESSAGES

1. In the infected areas, each hunting ground must develop a simple, basic, biosecurity management plan. The main goal is to prevent the viral contamination of the environment and the mechanical transportation of the virus outside the hunting ground through hunting and related activities.
2. Each hunting ground must organize a wild boar dressing area and offal and wild boar storage facilities.
3. Hunted wild boar should be individually identified and safely stored in the hunting ground until tested negative for ASF.
4. If a hunted wild boar tests positive for ASF, all the stored animals, regardless of the species, must be disposed of under the supervision of the veterinary service.
5. Hunting must be reauthorized when cleansing and disinfection of the infected hunting ground facilities are completed.

Chapter 7
Data collection

Vittorio Guberti, Sergei Khomenko and Marius Masiulis

The quality and standardization of the data accompanying samples are relevant since they enable a better understanding of the epidemiology of ASF in wild boar populations. High quality data allow appropriate comparisons to be made among areas and countries, as well as an assessment of the efficiency of the applied control measures. This chapter describes the main data to be collected and how these can be harmonized when obtained from different sources.

WILD BOAR DATA ACCOMPANYING SAMPLES

The aim of data collection is to improve understanding of animal diseases and the capacity to control and eradicate them. Data collection and analyses are an essential part of any animal disease surveillance programme, acting as a useful tool to measure the efficacy of control and eradication strategies, and eventually to highlight weak points.

In such a framework, a standardized data-collection protocol would benefit any analyses and decision-making. Standardized data would also enable a better understanding of how infected populations behave when ASF is present, along with the development of management strategies for the disease. Although standardized data collection may be an added workload for both hunters and veterinary services, unstandardized methods reduce data reliability and prevent comparability among infected countries.

Figure 23 shows a possible data-collection form with the essential data to be collected. In addition to the essential data, it is important to include the latitude and longitude of the spot where the animal was shot or found dead. Geographic data are relevant when studying the spatial and temporal evolution of the infection. Latitude and longitude are easy to register using a basic smartphone. In affected hunting grounds, hunting towers could be georeferenced and thus used as a proxy for the spot of interest. Specialized mobile applications can be a very helpful solution to facilitate the reporting process for hunters in terms of sample collections from hunter-harvested animals or carcass findings.

STANDARDIZED AGE CLASSES

At present, wild boar carcasses or hunted wild boar are aged using several methods that are highly affected by observer judgment and the individual variability of wild boar. Estimating the age of a wild boar by its weight or colour increases the unreliability of the reporting system, as such methods are not objective or standardized.

Teeth eruption is the most robust age estimator for any wild boar population. The main aim is to distinguish the age class and not the specific age of an individual. Due to high hunting pressure, the average lifespan of wild boar belonging to hunted populations is very low (about two years). In a typical population of hunted wild boar, around 50 percent are younger than 2 years, with the 50 percent older than 2 years rarely being older than 4 years. Due to the negligible number of older animals it is not necessary to determine their age using more complex methods, such as cementum annuli counts. According to the simplest application of the tooth eruption method, four age classes can be defined:

- no definitive molars present;
- one definitive molar present;
- two definitive molars present;
- three definitive molars present.

Definitive molars are easily counted in any field condition and in animal, as the approach does not need technical tools. This method gives standardized age classes that are easily comparable in the same population, among different populations and in different years and seasons.

Photo 39
One definitive molar
(second molars have not yet completely erupted).

Photo 40
Two definitive molars.

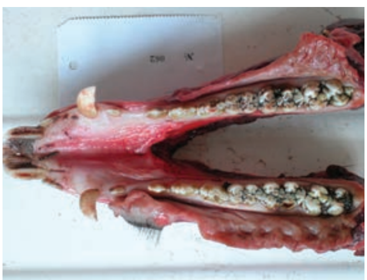


Photo 41
Three definitive molars.

FECUNDITY

Fecundity could be defined as the percentage of pregnant females in a specific population. Fecundity data should be collected according to the age class category of the females to follow the reproductive performances of the infected population. Increased hunting could enhance the early recruitment of young females (< 1 year old) in the reproductive population, thus limiting the efficiency of this population management strategy. Suggested ASF control measures include the selective hunting of adult females in areas where it is possible to collect fecundity data. When dressing animals, the uterus can be opened to check for the presence of a fetus. Pregnancy is easier to observe at the end of the winter months when the delivery season is approaching and fetuses are visible.

FERTILITY

Fertility can be defined as the average number of fetuses or piglets for fecund females. Counting the number of fetuses in any shot pregnant female is extremely simple and can be easily done during dressing. During wild boar observation, the sight of each sow and the number of accompanying piglets (striped only) should be recorded and made available as raw data at the end of the main hunting season.

Age-related fecundity and fertility data give an indication of the actual reproductive capacity of the involved wild boar population and thus enable its future trends to be predicted. These data also indicate shifts in the first age of reproduction or an increase in the average fertility, offering a better understanding of resilience to ASF. Ultimately, these data can be used to assess the effectiveness of the wild boar population management strategy being implemented.

STANDARDIZED DATING OF CARCASSES (RATE OF CARCASS DECOMPOSITION)

The role of carcasses in the epidemiology of ASF in wild boar has been previously highlighted. Currently, the date of carcass finding is set as the date of the infection, despite the fact that carcasses could be very old. This method can lead to imprecision in the dating of the infection and a wrong epidemiological assessment of the situation. Temperature, humidity, sunlight and the presence of scavengers (both invertebrate and vertebrate) can accelerate or reduce the time of carcass decomposition. If the decomposition status of animals is recorded in a standardized way and is coupled with the date of finding, it would be possible to avoid significant discrepancies in the dating of the infection, especially in infected areas and when carcass searches are planned and organized rather than an opportunistic activity. A simple designation of three decomposition categories could be included in the data-collection form when a carcass is found.

TABLE 7
Characteristics of wild boar carcasses at various stages of decomposition

Stage	Characteristics
1) Fresh	No odour, fresh
2) Decomposed	Bloated abdomen, presence of maggots, moderate-to-strong odour, liquefaction of tissue until black putrefaction, removal of the flesh from bones
3) Dry	Little or no odour, dried skin, exposed bones

A standardized approach for reliable carcass dating should be included in the training of hunters in ASF-infected areas and hunting grounds, but such a defined procedure is yet to be developed. One obstacle to this is the seasonal variability in the rate and nature of the decomposition process itself. In summer months, the biological decay of carcasses is rather quick, with scavenging insects and their larvae facilitating the process. In winter months, vertebrate scavengers, whose species composition and activity may also vary among places and times, mainly destroy carcasses. As a result, carcasses with very different ages can be at the same stage of decomposition when found. In complicated cases, exclusively specific analyses (an entomological forensic approach) could help to precisely determine age. In general, in areas persistently endemic for ASF carcasses, the process of dating can be strongly compromised. Doubtful carcasses (which are particularly common in early spring) should therefore be identified as "uncertain date" to enable their exclusion from analyses in the future.

Photo 42
Decomposed carcass.

Photo 43
Decomposed carcass.

Photo 44
Dry carcass.

Photo 45
Dry carcass with scavenger insects.

FIGURE 23
Example wild boar data-collection template

WILD BOAR N. __________

MUNICIPALITY ______________________________

LOCALITY ______________________________

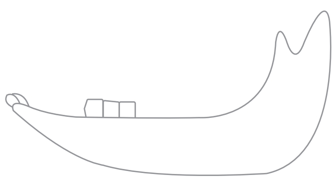
HUNTING GROUND ______________________________

PERSON COLLECTING SAMPLES: ______________________________

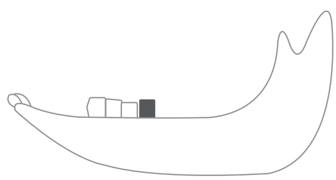
LATITUDE AND LONGITUDE ______________________________

DATE: ______________________________

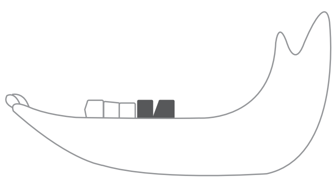
	Wild boar data		**Gender**		**Sampled organs**
N. laboratory ________	Wild boar data	☐	Male	☐	
	Single hunt from tower	☐			
	Single hunt by searching	☐			
N. hunted wild boar ________	Found dead	☐	Female	☐	
	Shot healthy	☐	Pregnant	☐	
	Shot abnormal behavior	☐	N. fetus ________		
	Decomposition stage		1)		
			2)		
			3)		
			4)		
			5)		



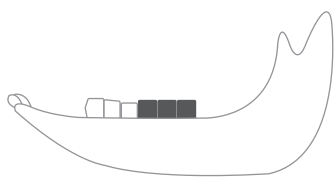
No definitive molar = age class A



1 definitive molar = age class B



2 definitive molars = age class C



3 definitive molars = age class D

Source: **Guberti, V., Khomenko, S., Masiulis, M. & Kerba S.** 2019. *African swine fever in wild boar ecology and biosecurity.* FAO Animal Production and Health Manual No. 22. Rome, FAO, WOAH and EC. https://doi.org/10.4060/CA5987EN.

KEY MESSAGES

1. Each hunted wild boar or carcass found dead must be individually sampled and accompanied by a specific set of data.
2. The age of the animal should be determined by teeth eruption only.
3. Pregnancy and the number of fetuses must be carefully recorded; the data will enable a better understanding of the evolution of the wild boar population dynamic in affected areas.
4. The decomposition stage of carcasses must be identified to help approximate the date of death of the infected individual.

Chapter 8
Effective communication between veterinary services and hunters

Suzanne Kerba

Given that ASF is a highly contagious infectious disease with no cure and no vaccination options, effective risk communication and educational initiatives are critical tools in preventing its spread (Costard et al.*, 2015). This chapter considers these tools.*

So how can veterinary services effectively communicate with hunters about ASF? Responsible hunting and disposal practices will ensure that boar populations continue to thrive and serve as a source of sport and food in the years to come. These same practices support a healthy environment for agriculture and domestic pig farming (De Nardi *et al.*, 2017). Engaging hunters is critical as we work towards the eradication of ASF disease.

It is critical to identify your goals in communicating with hunters. Establishing a Single Overarching Communication Outcome (SOCO) provides a road map for sharing technical information and guidance (WOAH and World Health Organization [WHO], 2015). This road map represents the actions you want to see implemented by your target population as a result of your communication. To establish your SOCO, you need to answer three main questions:

1. **Why do veterinary services want to stop the spread of ASF?**
   - *ASF represents a serious threat to pig farmers worldwide.*
   - *There are no treatments or vaccines for ASF.*
   - *The disease can cause massive economic losses.*
   - The disease has been spreading in eastern Europe and the European Union.
2. **What is the change veterinary services want to see as a result?**
   - *An increased awareness of the dangers of ASF among farmers, hunters, transporters and the general public.*
   - *An increase in surveillance and reporting among farmers and hunters.*
   - *An increase in practices of ASF prevention.*
   - *No more introduction of ASF into countries and regions free of disease.*
3. **Why communicate now?**
   - *There has been notification of an outbreak in the country.*
   - *There has been notification of an outbreak in the neighbouring country or in the region.*

Based on this example, your SOCO could be: **Hunters take appropriate actions to monitor, prevent and control a potential ASF outbreak.**

Risk communication is the real-time exchange of information, advice and opinion between experts or officials and people who face a threat (from a hazard) to their survival, health, economic or social well-being (Stoto *et al.*, 2017). In the context of ASF, the role of veterinary services in risk communication is to provide information, listen to hunters and communicate in ways that recognize and respect the important role that hunters play in ASF prevention and eradication.

Communicating for behavioural change requires knowledge of what motivates our target audiences (Ueland, 2018). Thus, knowing what hunters believe is critical to understanding how best to communicate with them about ASF and their role in stopping the spread of disease. Using formative research in the design and planning of communications helps us understand our audiences and what motivates them (Snyder, 2007). This information will help you to tailor adequate messages and choose relevant channels of communication and education to ensure a successful risk communication.

What do we know about boar hunters? Research shows that they perceive the following issues as barriers to reporting the discovery of illness in boar (Vergne *et al.*, 2014):

- lack of awareness of the possibility of reporting;
- lack of knowledge about how to report;
- lack of a level of agreement that a reason for them to report a hunted wild boar is because it shows suspicious lesions or disease;
- perception that the act of reporting is troublesome.

BUILDING STRONG COMMUNICATION MESSAGES FOR HUNTERS

Based on previously described insights, veterinary services will draft adequate messages to be delivered to hunters.

For example, these messages could be:

- *You are important and valued partners in efforts to eradicate ASF.*
- *Your use of responsible hunting, reporting and disposal practices has a direct impact on the success of efforts to prevent the spread of ASF disease.*

It is then necessary to **adapt these** messages to hunters in such a way as to reinforce their value and importance as stakeholders. Potential messages may include:

- *Responsible boar hunting, reporting and disposal practices reflect the honourable role of hunters as stewards of nature and its resources.*
- *To be a hunter is to belong to a group that is connected to the environment in a unique and integral way.*
- *Success in eradicating ASF requires the active involvement of the hunting community – both individually and as a group.*

Characteristics of a strong risk communication message include these elements:

Complete and specific

- *Gives hunters what they need to know to make an informed decision.*

Relevant

- *Appropriate to the situation; timely.*

Concise

- *Short and to the point.*

Understandable

- *Encoded (adapted) in such a way that hunters understand it.*

Memorable

- *Encoded (adapted) in such a way that hunters remember it.*

Positive

- *Empathetic and encouraging.*
- *Courteous and respectful of hunters' culture, values and beliefs.*

To be efficient, messages need also to take into account:

The context and environment in which hunters and veterinary services are communicating:

- *Is there an outbreak of ASF disease or an event that may heighten awareness and prompt action?*
- *Do hunters feel any sense of urgency about ASF?*

Potential interference getting in the way of ASF messages from veterinary services to hunters:

- *Are rumours or misinformation undermining accurate messages from veterinary services to hunters?*
- *Are veterinarians listening to hunters and being proactive in responding to rumours or misinformation?*

TWO-WAY COMMUNICATION

As scientists and veterinarians, we often act as if knowledge alone is enough to produce results. We deliver evidence and guidelines, and we expect people to understand and follow the information we provide (Brownell, Price and Steinman, 2013). However, what people know ***and*** think affects how they act. People's perceptions, motivations and skills all influence their behaviour. To be effective, scientific communications must reflect both facts and values (Dietz, 2013).

As sources of ASF communication with hunters, veterinary services must establish themselves as trustworthy providers of reliable information, respectful of the role of hunters and taking care to actively talk to them in clear, understandable ways.

Characteristics of an effective communicator (WHO, 2015)

Expertise – *you are knowledgeable; you know what you are talking about.*

Good character – *you are trustworthy and honest and open in your communication.*

Goodwill – *you express empathy and you are respectful of people in your audience, how they feel and what they believe.*

Identification – *you communicate with people in a way that makes them identify with you and relate to you.*

Relationships between veterinary services and hunters must support an environment of trust and confidence. Best practices for effective risk communication (Peters *et al.*, 2013) include these elements:

Create and maintain trust

- *You care about me.*

- *You know and address my concerns.*
- *You are reliable.*

Acknowledge and communicate – even in uncertainty

- *You are not concealing information from me.*

Coordinate your communication

- *You agree with other credible experts.*

Be transparent and accurate with all communication

- *You are telling me the truth.*
- *You are seeking solutions.*

Always include messages of self-efficacy

- *I have an active role in making an informed decision.*

Two-way communication includes the importance of listening to the target audience to better understand them (rumour listening, etc.), as well as to evaluate the impact of your risk communication effort. For this to be effective, you need to **establish in advance a mapping of your stakeholders and of their influencers**, and to **collect feedback** on how hunters respond to ASF messages and guidance.

- *What are hunters saying to veterinary services in response to their communication about ASF?*
- *Are veterinary services listening to hunters and using their feedback to improve future communication?*
- *Are messages from veterinary services motivating hunters to follow guidance and implement responsible hunting, reporting and disposal practices? If not, why?*

Stakeholder mapping involves identifying key audiences, and determining the priorities, challenges and values important to each of them. The process also involves identifying the most influential stakeholders and working to ensure that their input is used to shape communication efforts. Relationships between stakeholders, and the strength of those relationships, impact the perceptions and behaviours of everyone involved. Two-way communication between appropriate shareholders provides a balance of opinions, increasing the likelihood that hunters and veterinary services reach a common ground in their efforts to stop the spread of ASF.

CHOOSING COMMUNICATION CHANNELS

Once you have crafted your communication messages to hunters, it is time to determine the tactics and channels you will use to reach them. Channels may include:

- radio, television, print materials;
- word of mouth;
- communication with clubs and organizations;
- social media;
- awareness campaigns;
- stakeholder engagement;
- partner engagement;
- social mobilization;
- community engagement.

Not all channels will be appropriate for communication associated with ASF. As you go about putting together a plan for ASF communication aimed at hunters, consider the channels that meet hunters where they are – respecting their language, recognizing their social networks and honouring their cultural values.

The following questions can help you identify risk communication channels that will effectively help to reach hunters:

1. **Will this channel help me reach hunters?**
   - *Am I using a channel they respect and/or pay attention to?*
2. **What level of impact does this channel have on hunters?**
   - *Do they see value in this channel's position in the community?*
3. **Will using this channel advance my goals?**
   - *Prevent the introduction of ASF into countries and zones free of disease.*
   - *Build awareness of ASF and its risks.*
   - *Inform on signs and symptoms.*
   - *Advise on prevention techniques.*
   - *Outline hygiene regulations and practices.*
   - *Encourage the adoption of mitigation strategies.*
   - *Enhance biosecurity.*
   - *Increase reporting hunters.*

RISK COMMUNICATION AND STIGMA

Whenever there is an outbreak of ASF or the discovery of an infected pig or boar, people invariably seek information about the origin of the disease. Where did this outbreak start? Which forests or farms are implicated? These are legitimate concerns, and veterinary services have an obligation to actively listen and to respond promptly and honestly.

As they respond, veterinary services must also consider the possibility that hunters who report infected animals may face stigma, which means they may become needlessly associated with the threat of ASF. People experiencing stigma may face criticism, and they may suffer stress, anxiety and emotional pain from social rejection (Smith, 2007). Fear of stigma may also make farmers hesitant to report disease (Guinat *et al.*, 2016).

People who stigmatize others generally feel that the problem facing someone else is a problem that they themselves can control (Reynolds and Seeger, 2005). For example, farmers who stigmatize other farmers whose pigs have contracted ASF may believe that they can control an outbreak themselves. Entire regions and communities (including hunters) may be stigmatized if people start identifying them with a perceived risk.

It is the role of veterinary services to balance the real risk of ASF with the needless association of one person or identifiable group with the disease itself. Veterinary services must take an active role in dispelling misconceptions and correcting faulty assumptions. When stigma arises, it is the responsibility of veterinary services to counter it with scientific facts and appeals for fairness. Hunters who face stigma associated with ASF must be able to rely upon veterinary services for proactive support.

This includes using messages such as:

- "The discovery of illness demonstrates that we are ALL at risk of ASF."
- "These circumstances are not defined by any one group in a particular place or area."
- "This situation reinforces the importance of using responsible biosecurity and disposal practices. We must all work together to stop the spread of ASF."

KEY MESSAGES

1. Successful communication between veterinary services and the boar hunting community are critical as we work together towards the eradication of ASF disease.
2. Risk communication and community engagement involve hunters in creating effective solutions that support their efforts to use responsible biosecurity and disposal practices. Working together in a coordinated way enhances the likelihood that we will be successful in our shared vision of a world free from the threat of ASF.

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FAO ANIMAL PRODUCTION AND HEALTH MANUALS

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African swine fever (ASF) is a devastating haemorrhagic viral disease affecting domestic and wild pigs of all ages and sexes. This disease causes massive economic losses, threatens food security and trade, and presents a serious challenge for the pig production sector in affected countries. ASF also threatens the biodiversity conservation of several Asiatic wild *Suidae*. Since ASF was first introduced in Georgia in 2007, the disease has spread to many countries in Europe, Asia and the Pacific, and in 2021, it was detected in the Caribbean states of the Dominican Republic and Haiti, both in the Americas. In much of its Euro-Asiatic range, the African swine fever virus (ASFV) infects wild boar, which sometimes act as the main – if not the only – epidemiological reservoir of the infection, keeping it in the environment regardless of the presence of infected domestic pigs. The presence of the virus in wild boar populations is a continuous health threat for the sympatric domestic pig population, posing a challenge for veterinary and wildlife services that have had little success in attempting to eradicate infections among wildlife, especially in the absence of an effective vaccine. Finally, areas in which ASFV is detected in wild boar remain infected for at least one year after the last recorded case. This is a much longer period than that of domestic animals and puts a strain on the services involved, requiring a considerable amount of work and human and financial resources.

The second edition of the handbook provides insights on surveillance and disease management in wild boar based on experiences with ASFV eradication in Belgium and Czechia, as well as other recent experiences in the prevention and control of the disease in wild boar in Europe.

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