8. Management of wild boar populations in the European Union before and during the ASF crisis

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Abstract

In recent decades, wild boar populations have been increasing worldwide due to several potential causes, including human-induced and natural environmental changes and biological and ecological factors. In Europe, this phenomenon has several economic, social and environmental implications such as the increase of agricultural and forest damage, road traffic accidents and potential ecological impact on animal and plant biodiversity. In addition, wild boar population growth and expansion can contribute to the maintenance and dissemination of infectious pathogens affecting animal and human health. In this context, the emergence of African swine fever (ASF) in Europe has become a serious challenge for animal disease control. The high susceptibility of wild boar to ASF infections and the capacity of the virus to remain infective in wild boar carcasses require a combination of wildlife management and veterinary strategies in order to eradicate this virus from EU forests. The goal of this chapter is to provide a thorough overview of those efforts. After illustrating the current situation of wild boar populations in Europe, the chapter describes the different methods applied by wildlife managers in the absence of ASF. Subsequently, the chapter reviews different approaches and tools applied in the context of ASF control, with a particular focus on the strategies implemented by countries that were successful in their eradication, such as Belgium and the Czech Republic. The last section of the chapter highlights areas that require future research to improve ASF management in natural wild boar populations, which remains a serious challenge for the large majority of countries in the EU.

Keywords: wild boar, control, surveillance, depopulation, fences

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8.1 Introduction

Highly prolific and extremely adaptable to different trophic resources and environments, wild boars (*Sus scrofa*) are present in large parts of the world. They probably constitute the most common and exploited ungulate species in Europe, where they have experienced a tremendous population increase in the last decades. The reasons for their demographic expansion and population growth are multifactorial including land use, climatic and environmental changes and human practices. Traditional hunting seems insufficient for reducing wild boar population sizes, and more efficient and innovative management strategies for population control are needed. The current high wild boar densities in Europe favour proliferation and dissemination of pathogens circulating in this species with potential spill over to domestic animals and humans. In this context, African swine fever virus (ASFV) genotype II found optimal conditions for spread and long-term maintenance among wild boar populations after the introduction to Europe in 2007. From 2014 to 2020, ASFV infected wild boar populations in eleven countries in the European Union (EU): Estonia, Lithuania, Latvia, Poland, Czech Republic, Bulgaria, Belgium, Romania, Hungary, Slovakia and Germany. So far, only two of these countries have eradicated, or are in the process of eradicating, the disease in free ranging wild boar populations. It is important to highlight that the introductions to new territories were not only the result of natural spread through wild boar movements, but often facilitated by human activities. With African swine fever (ASF) having being present in the European continent for more than a decade, a substantial amount of experience has been accumulated and there are many lessons to be learned about ASF management in natural wild boar populations that can be useful for other regions of the world exposed to the virus. The first section of this chapter describes the current demographic situation of wild boars in Europe, the drivers that have facilitated the observed rising trend in population sizes and their impact at the ecological, economic and sanitary levels. The second section presents different methods to manage wild boar populations in the absence of ASF. The next two sections review different methods that have been applied to manage and control the spread of ASF in different EU contexts by managing wild boar populations (Section 8.3) or by controlling the disease (Section 8.4). The last section highlights areas that require future research to improve disease management in free-ranging wild boar populations. A specific focus is on those countries that have achieved, or are in the process of achieving, ASF eradication with a combination of wildlife and disease management methods.

8.2 Current knowledge of wild boar populations in the EU

8.2.1 Wild boar demographic trends

At the beginning of the 20th century, many native wild boar populations in Europe had become extinct or occurred at very low densities. By the mid-1980s, wild boar numbers had increased dramatically and recolonised much of the species' former range.

Wild boars can thrive in a wide range of habitats, and the species' distribution is only limited by the availability of water in hotter climates and by harsh winters at higher latitudes. Wild boars are further expected to respond to global warming by increasing their geographical range northwards (Melis *et al.*, 2006). The species is already expanding in northern countries such as Norway and

Sweden (Thurfjell *et al.*, 2009), where availability of crops in summer and autumn allows wild boars to survive the winter months (Bieber and Ruf, 2005; Fernández-Llario and Carranza, 2000). In the UK, once extinct, wild boars are now widespread as a result of illegal releases or escapes from commercial breeding farms (Wilson, 2014).

Factors associated with this expansion include increased availability of anthropogenic food sources, urban sprawl encroaching on rural areas and a reduction in hunting pressure (Cahill *et al.*, 2012; Keuling *et al.*, 2016; Massei *et al.*, 2015). A review based on hunting statistics found a simultaneous sharp increase of wild boar numbers throughout Europe between the 1960s and the mid-1970s, followed by an apparent stabilisation of numbers in the following decade. Three decades later, a similar analysis based on hunting bags in 18 European countries showed that wild boar numbers continued to increase throughout Europe (Figure 8.1). In the same period, a decline in the number of hunters, observed across most of the countries, suggested that even if hunting is still the main cause of wild boar mortality, its potential to control populations is decreasing (Massei *et al.*, 2015). Therefore, despite a lower number of hunters, the total of wild boars harvested in these countries increased by 2.8 times in 20 years, passing from 864,000 to 2.5 million between 1992 and 2012. Excluding areas with unusual hunting bags due to disease control strategies, the number of wild boars hunted across Europe is still growing.

8.2.2 Density data

Strong variations in population densities are recorded within the European continent, even inside similar regions, e.g. in the Iberian Peninsula a range from less than three to over 30 wild boars per km^2 is registered. Food availability, such as crops or supplementary feeding, are the main factors affecting wild boar productivity and consequent local population densities.

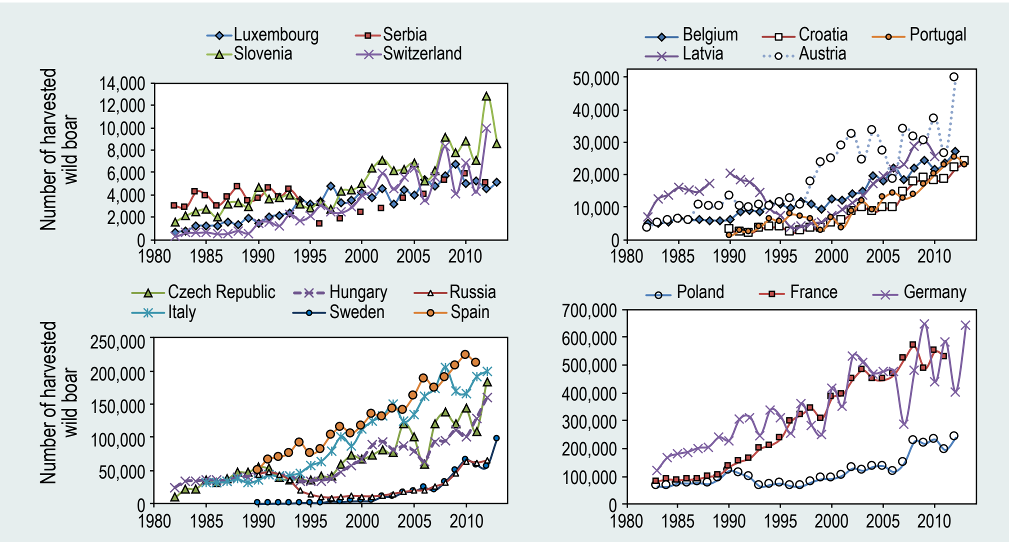

Figure 8.1. Wild boar hunting bags in European countries from 1980-2010 (Massei *et al.*, (2015) (courtesy of John Wiley and Sons, 02/06/2020).

Estimates of the size and density of wild boar populations are key factors to monitor and understand the epidemiology of wild boar diseases, such as ASF. The organisation and collection of hunting statistics and their analysis is essential not only for hunting management but also for developing wildlife policies. Hunting data are available and potentially comparable across Europe for use in predictive spatial models of wild boar density. They provide reasonable indicators of population trends. However, in practice, they are unreliable and patchy. Standardisation of procedures, methods and data collected across countries and regions provides opportunities for a common use of data across Europe and is a baseline prerequisite for a more sustainable management of the species and the effective control of diseases such as ASF. Three methods are recommended to estimate wild boar densities by the scientific consortium ENETWILD, specialised in monitoring wild species demographic dynamics in the EU (www.enetwild.com). The first one consists of the collection of hunting statistics based on hunting bags, hunting effort, size of the hunting grounds and, if possible, the number of sighted wild boars during driven hunts. This method has the advantage that most of the EU countries have available data that can be used and harmonised for regional large-scale abundance estimations. The second method consists of estimating densities with the widespread deployment of a camera trap grid, based on the Random Encounter Model approach, which can be used in relatively small areas. The third method consists of nocturnal density estimation by distance sampling along line transects using night vision equipment (applicable only in open areas with low vegetation cover).

8.2.3 Factors affecting population dynamics and growth

The significant increase and dispersal observed in wild boar populations is due to a combination of factors including extraordinary reproductive outputs, low mortality rates and environmental and sociological changes that have been occurring in the last decades and that have a cumulative effect in wild boar reproduction and survival. With the highest reproductive rate among all ungulates, annual population growth in this species may exceed 200% (Bieber and Ruf 2005; Keuling *et al.*, 2013). Wild boars are primarily seasonal breeders, with typical peaks in farrowing during winter/early spring and to a lesser extent, in late summer (Rosell *et al.*, 2012). In most populations, females produce one litter per year and typical litter sizes range between four and seven piglets (Bieber and Ruf, 2005). In Europe, a high proportion of females can reproduce in their first year and an earlier onset of puberty is observed when sows reach 27-33 kg of body weight (Malmsten *et al.,* 2017; Servanty *et al.,* 2011). Both the number of sows reproducing and litter sizes are associated with the availability of high energy food (Servanty *et al.,* 2009). The main causes of natural mortality in wild boars are food scarcity, extreme weather and, in some areas, predation by large carnivores (Bieber and Ruf, 2005; Fernández-Llario and Carranza, 2000). Adult survival rates in good environmental conditions are typically over 70%, although in poor conditions they can drop to 25-58% (Bieber and Ruf, 2005). The highest mortality rates are reported for piglets under 4 months of age. In addition to natural causes, wild boar mortality is mainly associated with anthropogenic factors, with hunting and road traffic collisions having the greatest impact on survival (Keuling *et al.,* 2013). In a population managed by hunting, wild boars rarely survive their second year of life. The generation times of wild boar are ranging from 2.3 years in heavily hunted populations to 3.6 years in lightly hunted ones (Servanty *et al.*, 2011). In most European countries, wild boar population recruitment is higher than mortality, leading to consistent annual population increases (Keuling *et al.,* 2013; Massei *et al.,* 2015). As survival depends on the availability of high-energy food (Bieber and Ruf, 2005), anthropogenic food sources such as crops and supplementary food can offset natural mortality (Veeroja and Männil, 2014). For instance, in the Czech Republic, cereals constituted more than 50% of the stomach-content biomass of wild boar. The sources of these cereals included both agricultural crops and, to a large extent, supplementary feeding provided by hunters (Ježek *et al.,* 2016). From that perspective, habitat alterations such as agricultural expansion are beneficial to wild boar population growth. However, expanding populations of wild boars are also adapting to urban and peri-urban environments because they provide access to food sources all year round, which ultimately increases annual population growth (Cahill *et al.,* 2012). Global warming is also leading to an increase in mast seeding frequency (acorns) resulting in a higher proportion of breeding females and a higher growth rate of the population inhabiting deciduous forests (Touzot *et al.,* 2020).

8.3 Overabundance of wild boar population and its consequences

8.3.1 Impacts on biodiversity

Wild boars are opportunistic omnivores with a diet mainly composed of plants but also including animal matter. Feeding behaviour includes foraging to collect fruits directly from the plants or fallen on the ground, occasionally eating grasses and leaves and rooting to feed on roots, fungi or invertebrates. Rooting activity causes important disturbances to soil and plant communities, inducing changes on habitat quality and ecosystem dynamics (Ballari and Barrios-Garcia, 2013). Impacts on forest regeneration have been reported, particularly affecting non-dominant tree species, which may have a negative impact on forest biodiversity (Bongi *et al.,* 2017) together with the reduction and modification in spatial patterns of vegetation recruitment. Damage to reforestation areas includes feeding on roots of nursery seedlings, which attract wild boars due to their rich nutrient content. Rooting also affects alpine and subalpine grasslands, modifying the diversity and heterogeneity of this habitat (Bueno *et al.,* 2010). However, although most studies indicate that wild boars are associated with decreased plant biomass, conflicting evidence exists concerning the effect of rooting on plant species diversity and composition. For instance, in Sweden the number of plant species increased following wild boar rooting (Welander, 2000). Similarly, in the Spanish Pyrenees alpine grasslands, wild boar rooting created large gaps that increased plant community heterogeneity and maintained high levels of plant diversity (Bueno *et al.,* 2010).

In addition to their impact on vegetation diversity, wild boars can also have an impact on invertebrate and vertebrate fauna. The destruction of nests and predation on eggs of endangered ground nesting birds or reptiles is known as one of the most deleterious effects of wild boar (Graitson *et al.,* 2019). Overall, large populations of wild boar have the potential to produce an environmental impact on animal and plant biodiversity (Barrios-Garcia and Ballari, 2012).

8.3.2 Damage to crops and pastures

Damage to croplands is one of the most important sources of conflict between agricultural farmers and wild boars, involving significant economic losses to compensate and prevent agricultural damage. The wild boar diet comprises a wide range of crops including maize, sunflower, rice, potatoes, and many species of fruit, such as grapes, with strong seasonal and regional variations.

The amount of crops consumed depends on availability, and represents a range of 37-88% of the wild boar diet in Europe (Barrios-Garcia and Ballari, 2012). Crops provide high-energy food, which has been associated with an increase of mean litter size compared with populations feeding in forests, contributing to the population growth rate (Rosell *et al.,* 2012). Wild boars can also affect pastures by ground rooting activities, which can extend to significant depths and widths and hamper the movements of agricultural machinery or reduce the value of the areas available for cattle grazing (Bueno *et al.*, 2010).

8.3.3 Traffic accidents

The rising numbers of wild boars throughout Europe have resulted in growing numbers of road collisions, although there is a marked regional variation. In some Mediterranean regions, wild boars are responsible for up to 85% of all traffic accidents involving wildlife. In northern and central Europe, wild boars make up a smaller portion of the total accidents, although a sharp increase in vehicle collisions has been observed in some countries, such as Sweden, where these accidents increased by 250% between 2003 and 2011 (Gren *et al.,* 2016). Wild boar-vehicle collisions show marked temporal patterns with higher frequencies from October to January, coinciding with the main rut period of wild boar and the hunting season (Langbein *et al.,* 2011). This is also a social and economic concern, the average cost of wild boar collisions being estimated between 2,700 and 9,000 €. Furthermore, in Spain wild boar accidents cause three times more injuries per collision than those induced by other solitary species (such as roe deer), probably due to the gregarious behaviour of wild boars (Sáenz-de-Santa-María and Tellería, 2015).

8.3.4 Urban incursions

In recent years, the number of conflicts due to incursions of wild boars into urban settlements has been increasing in many large cities in Europe as well as in other parts of the world (Pei *et al.,* 2010). By 2010, at least 44 cities in 15 countries had reported problems related to the presence of wild boar or feral pigs (Cahill *et al.*, 2012). Attracted by waste containers and litter bins, food offered by people or pet food from cat colonies, wild boars present in natural areas adjacent to cities progressively colonise urban environments, often using corridors such as streams or other green areas. Apart from damage to grass, garden irrigation systems and other urban infrastructure, some of the most significant problems arising from these incursions are the risk of attacks to humans or the potential transmission of zoonotic pathogens to people.

8.3.5 Disease implications

Many ecologists consider diseases to be a natural process to regulate wildlife populations when these grow beyond their carrying capacity. Overabundance reduces available trophic resources, which induces weakness and death of the weakest individuals in the process of natural selection. In addition, lack of trophic resources induces stress, which has a negative impact on the immune system, facilitating multiplication of potential pathogens. There are many examples illustrating the association between overabundance and occurrence of disease in ungulate populations (Gortázar *et al.,* 2006; O'Brien *et al.,* 2006). Wild boars are exposed to a large diversity of pathogens and some of them can affect other species of mammals, including humans (Jori *et al.,* 2018, 2020; Ruiz-Fons, 2017). The current situation of overabundance of wild boars in Europe is particularly favourable for the emergence and spread of infectious diseases in the large continuous ecosystems in Europe (Pittiglio *et al.,* 2018). During the last 30 years, the number of disease notifications in wild boars in Europe has significantly increased. In this context, the challenge represented by the current ASF crisis in Europe is not surprising.

8.4 Reducing wild boar population numbers in the absence of African swine fever

In the context of the current overabundance, there are several methods to manage wild boar populations with the common goal of mitigating their economic, ecological or agricultural impact. However, in principle, these measures are not designed to control the spread of infectious diseases in a wild boar population.

8.4.1 Hunting

Recreational hunting is the most widely method used to control wild boar numbers in Europe. This includes hunting on foot or from high seats and driven hunts using dogs, the latter mostly employed in areas with dense vegetation (Geisser and Reyer, 2005; Massei *et al.,* 2011). Some methods allow targeting specific age classes and sexes. As wild boar behaviour is essentially nocturnal, individual hunting at night is permitted in some countries. Depending on the region, this is done by using a light source or night vision devices. As juvenile survival has the largest effect on recruitment, applying increased hunting pressure on juveniles appears to be the most effective option for reducing wild boar numbers (Geisser and Reyer, 2005; Servanty *et al.,* 2009). A harvest model developed for a French wild boar population showed that the most efficient way to limit the growth rate was to target medium-sized females (Gamelon *et al.,* 2012). However, recreational hunters tend to select large males rather than females or juveniles when hunting from high seats or waiting for wild boars to visit bait stations (Keuling *et al.*, 2013). Recreational hunters play an important role in decreasing wild boar numbers, and their in-depth knowledge of local areas may help in early detection of carcasses during disease outbreaks (EFSA *et al.,* 2018a). However, hunters are also responsible for bad practices such as illegal releases and translocations of wild boars aimed at re-stocking populations, and the use of supplementary feeding to maintain high densities of wild boar (Oja *et al.,* 2015, 2017).

Hunting may affect the spatial behaviour of wild boars by increasing dispersal and long-distance movements (Casas-Díaz *et al.,* 2013). Some authors found that repeated hunting and direct chasing with dogs increased movement in wild boar social groups (Scillitani *et al.,* 2010). These behavioural changes may in turn increase contact between individuals and have negative consequences for disease transmission (Keuling *et al.,* 2008). Keuling *et al.* (2013) suggested that for hunting to produce a marked effect on wild boar population size, at least 65% of the starting population would need to be removed each year. When densities of wild boars are high, shooting can be an efficient way of removing large numbers of animals in a short time. Removing wild boars at a local scale may reduce their impacts in the short-term, but may attract more individuals from the surrounding areas and may thus not be effective at reducing the long-term effects (Tolon *et al.,* 2009). Therefore, coordinated wild boar population control should be carried out, ideally, at regional scale.

8.4.2 Trapping

Wild boars are relatively easy to trap, particularly when they occur at high densities. Trapping has been used to control populations of wild boars and feral pigs, often in combination with shooting. Trapping can remove large numbers of animals in a relatively short time (Massei *et al.*, 2011). Many types of traps exist on the market, ranging from single animal traps to corrals that can hold large groups (Figure 8.2). The latest generation of traps are equipped with new technologies that allow trap operators to become informed by cell phone message or e-mail when an animal has entered the trap. Wild boars can be captured using drop-nets, suspended over bait piles and triggered remotely. Capturing whole sounders simultaneously can reduce the risk of disease transmission by avoiding social disruption. Trapping success is affected by many factors including wild boar density, season, trap type and location, density of traps, trap effort and bait type (Parkes *et al.*, 2010). Trapping requires intense labour to achieve substantial population reduction. This implies checking traps at least once per day to ensure captured animals are humanely culled and that non-target species are released. In residential areas, or where shooting may be publicly opposed or illegal, trapping is useful for removing live animals. However, in this context, people against lethal animal measures can easily damage or boycott capture operations.

In recent decades, animal welfare concerns have shifted public attitudes towards non-lethal methods to reduce wild boar numbers (Massei and Cowan, 2014). For instance, 44% of interviewed Berlin residents believed wild boar numbers should be reduced, although 67% of these respondents were against any lethal methods of removal (Kotulski and König 2008). Similar

Figure 8.2. Self-constructed round-shaped trap with an eight-metres diameter used in Belgium to capture large wild boar sounders. The time to build a trap was around three hours and the material needed for its construction costed around 1000 Euros. The network of around 150 traps allowed culling more than 1,300 wild boar (photo: Public Service of Wallonia, Belgium).

views have been expressed in Barcelona, where plans for lethal removal of wild boars had to be withdrawn due to public opposition (Cahill *et al.,* 2012). Trapping may be an appropriate method to remove problematic animals or as additional technique to capture juveniles, but it is considered relatively inefficient for population control on a large scale.

8.4.3 Translocations

Translocation of wildlife is often advocated by the public to resolve human-wildlife conflicts. Translocation is labour intensive, as it involves trapping and transport of animals. In many cities in Europe, translocation is used to remove problematic wild boar families (sounders) that become habituated to urban environments. However, there is little scientific evidence to support the humaneness of translocations, which often have adverse effects on the animals moved, such as malnutrition, dehydration, increased predation and subsequent immunosuppression (Massei *et al.,* 2010). There is limited research to confirm the success of translocations to new environments. Translocations also have the potential to spread diseases within and between populations (Kock *et al.,* 2010), and the practice is illegal in many European countries. Therefore, translocation is not recommended as a realistic and valid solution to solve wild boar overpopulation.

8.4.4 Fertility control

Fertility control has been increasingly advocated as a humane alternative to lethal control of wild boar (Massei and Cowan 2014; Pepin *et al.,* 2017). Immunocontraceptives formulated as single-shot intramuscular injections, stimulate the production of antibodies against the Gonadotropin-Releasing-Hormone (GnRH), responsible for ovulation and spermatogenesis. As a result, treated females do not reproduce. In captive trials, a single dose of GnRH-based immunocontraceptive induced infertility in female wild boar for at least four to six years with no adverse side effects on their behaviour (Quy *et al.,* 2014). Contraceptives could be considered for contexts where lethal control is not an option, such as in areas where shooting is not practical or publicly acceptable (Massei and Cowan, 2014). The development of orally delivered contraceptives has shown some effect in maintaining low density of wild boar after the implementation of culling programs (Pepin *et al.*, 2017) and this application is currently being investigated. Nevertheless, contraceptives are not currently registered yet to be used in feral pig or wild boar in Europe. In addition, considering that their effects are only noticeable in the long term, they are not considered a method of choice in case of an urgent need to reduce wild boar population size.

8.4.5 Use of toxicants

Poison baits are commonly used as an alternative in combination with other methods in countries where wild boars or feral pigs are invasive alien species and considered as pests (Lavelle *et al.,* 2018; Snow *et al.,* 2016). These methods are not allowed in the EU, but can be derogated in the case of emergencies (Regulation 528/2012, Article 55). The derogations must consider humaneness, environmental impact, the impact on non-target species and biodiversity (Gentle *et al.,* 2014). In Australia and USA, the best result has been obtained using sodium nitrite, which is orally absorbed, humane (quick and painless), with low environmental residues and no secondary poisoning risks (Snow *et al.,* 2016, 2017). The risks of consumption by non-target species can be reduced using selective delivery systems that limit the access of sympatric species to the bait.

Experience in Australia and the USA shows that this is a very efficient and cost-effective method to reduce feral pig populations.

8.4.6 Comparison of methods

Several studies on wild boar control measures have highlighted the need to combine methods to ensure success of population reduction (for a review see Massei *et al.*, 2011). Each technique presents different advantages and disadvantages (Table 8.1) that should be considered when selecting a population control method. Different study sites, contexts and goals require the combination of different techniques; in addition, methods that are useful to reduce numbers in the absence of ASF (e.g. drive hunts) are not necessarily recommended when the disease is present.

8.5 Methods influencing wild boar movement and behaviour

In this section, we present different methods to physically separate wild boar populations or control its movements through food provision or erection of physical barriers.

8.5.1 Artificial feeding

Diversionary and supplementary feeding are used respectively to decrease wild boar damage to crops, by encouraging animals to feed elsewhere, or to concentrate wild boar in a particular area and increase the number of animals available for hunting (Geisser and Reyer 2005; Ježek *et al.,* 2016; Massei *et al.,* 2011). In France, it was found that using maize in diversionary feeding resulted in a 60% reduction in wild boar damage to vineyards (Calenge *et al.,* 2004). Other studies found that diversionary feeding resulted in either limited or no reduction of damage to crops, and that it may cause adverse effects on biodiversity such as a significant increase on predation risk of ground bird nests in the proximity of sites with supplementary feeding (Oja *et al.,* 2015). One of the disadvantages of supplementary feeding is that the food needs to be provided on a regular basis to act as a suitable attractant, which can incur high costs for labour and resources. Moreover, supplementary feeding may increase survival rates and enhance reproductive success of wild boar (Geisser and Reyer, 2005), thus contributing to population growth. For instance, in the Czech Republic, Ježek *et al.* (2016) suggested that the 84,665 feeding sites (12/1000 ha) present on the national territory could significantly contribute to increased survival rates in this species. In addition, artificial feeding can lead to increased pathogen transmission at feeding points (Ježek *et al.,* 2016; Navarro-Gonzalez *et al.,* 2013). In the context of the current ASF epidemic, the European Food Safety Authority, EFSA has recommended a complete ban on feeding of wild boar to reduce habitat carrying capacity (EFSA *et al.,* 2018b; EFSA *et al.,* 2020)

8.5.2 Fencing and other measures to reduce wild boar movement

Fences are widely used to prevent wild boar access to croplands and infrastructures, such as highways, high-speed railways and airfields (Figure 8.3). Different types of fences can be effective against wild boar if they are appropriately designed and regularly maintained (Rosell *et al.,* 2019). Fencing type should be selected according to management goals, local conditions and duration of the required effects.

Table 8.1. Advantages and disadvantages of main methods for reducing wild boar populations.

Method	Advantages	Disadvantages
Hunting	• Reduction of large numbers in a short time • No cost for governments • Possible to involve members of local rural communities in wild boar management • Possible to target large females	• Growing social opposition against hunting • Bad practices associated with hunting (e.g. supplementary feeding) • Driven hunts with dogs may increase wild boar dispersal • Low acceptance from hunters to eliminate their game resource (recreational hunting)
Trapping	• Possible to capture complete sounders • Allow high level of biosecurity • Culling can be done under humane conditions	• Low acceptance from hunters to eliminate their game resource • Non-selective method: juveniles captured first and more easily than adults • Non-specific method: Other mammals can be captured in the trap • Requires a certain level of expertise • Traps may be tampered with by the public • Some animal welfare cost
Translocations	• Publicly acceptable • Fast-acting at local level • Usable in residential areas	• Labour-intensive • May translocate pathogens/diseases • Animal welfare costs of trapping, transport, and post release survival • May encourage illegal introduction of wild boar
Fertility control by injectable contraceptives	• Injections with a long-term effect are feasible • No social disruption • Usable in residential areas • Species-specific • May decrease disease transmission	• Slow acting at population level Applicable only at small scale and experimentally • Expensive due to trap-inject-release effort • Same animal welfare cost as trapping
Fertility control by oral contraceptives	• No social disruption • Usable in residential areas • Species-specific bait delivery system available • May decrease disease transmission • Applicable at large scale • Relatively inexpensive • Publicly acceptable	• Not commercially available • Slow acting at population level • May concentrate animals around bait points
Toxicants	• Reduce high numbers of animals within a short time	• Not allowed in Europe • Products are not specific to wild boar • Low social acceptance • Possible animal welfare costs

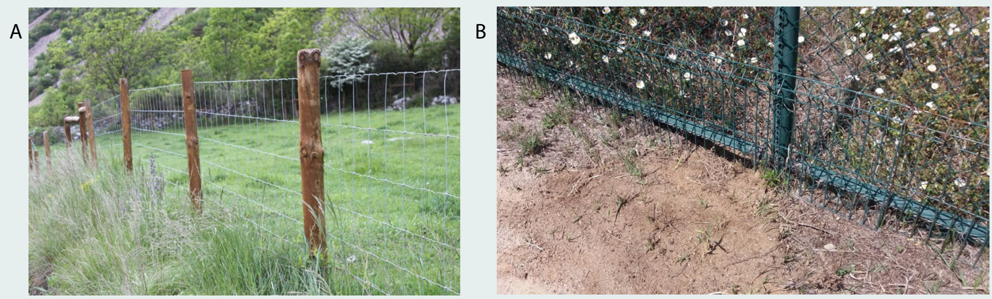

Figure 8.3. Some examples of wild boar proof fences: (A) knotted fences suitable for mitigating damage to pastures are deployed in Catalonia, Spain (photo: C. Rosell); (B) reinforcement fence installed on an existing perimeter fence (photo: F. Navàs).

Mesh wire perimeter fences have been extensively monitored on transport infrastructure. The most effective fences against wild boar are knotted rectangular mesh fences buried to a depth of 20-25 centimetres (cm) into the soil (Figure 8.3A). Progressive density is recommended with a distance of 15 cm between vertical wires and from 5-10 cm at the bottom to 15-20 cm at the top between horizontal wires. Wild boar fences must reach 140-160 cm height. Quarterly maintenance is required.

Reinforcement of existing fences is required when these are not buried or are constructed with chain-link mesh that can be bent by individuals opening holes and passing through them. A proven, effective reinforcement consists of panels of rigid welded mesh (five cm between vertical and 30 cm between horizontal wires), installed outside existing fences and anchored to them up to a height of 60-90 cm (Figure 8.3B). First, the horizontal wires at the bottom need to be cut, leaving vertical spikes that must be stuck into the ground to a depth of 20-25cm.

Electric fencing consists of a power supply system and conductive wires that cause an electric discharge to wild boars upon physical contact with them, dissuading them from crossing the electrified line. A minimum of two wires installed between 25 and 50 cm above ground level are required to deter wild boar access. Appropriate energiser, providing a pulse of 4-8 Joules and with 12 Volts battery, is required to deter wild boar movements. The system needs frequent maintenance to avoid vegetation touching the wires.

Maintenance is a critical issue to guarantee long-term effectiveness of all fence types. Fences must be periodically inspected and damage repaired. While fences along roads and railways are maintained by infrastructure operators, extensive fences are difficult to maintain and many vulnerable points appear, for example river crossings. In addition, fences impact biodiversity by preventing wildlife movements and migrations of other species and reducing ecological connectivity (Woodroffe *et al.*, 2014).

Odour repellents can equally be applied to reduce wild boar movements (Bíl *et al.*, 2018). Several substances are commercialised with different levels of efficiency: while some products show a temporary effect for several weeks, others have not proven to be effective at all. Often, wild boars become habituated and their effectiveness is lost after several applications. Hence, their use is not recommended if a long-term effect is needed.

Sound repellents activated by movement sensors are being applied to prevent animal-vehicle collisions and to protect croplands. The effectiveness varies depending on each particular device. Those not activated by sensors that emit periodic 'scaring sounds' have proven to be ineffective.

8.5.3 Wildlife corridors in transport infrastructure

Habitat fragmentation has been identified as one of the main factors causing biodiversity loss. The barrier effect of linear transport infrastructure is reduced by the construction of wildlife corridors that are combined with guiding fences and permit reduction of wildlife mortality due to animal-vehicle collisions while increasing ecological connectivity. Wild boars use many types of corridors: wildlife underpasses and overpasses as well as multi-use structures combining wildlife use with drainage, forestry or cattle paths (Iuell, 2003). A preference for large overpasses and underpasses has been recorded, but in some areas wild boars also use narrow structures. Wildlife corridor management may be a critical issue providing (or not) possibilities for wild boars to move across the landscape. In a fragmented landscape, wildlife corridors are important to ensure long-term population persistence. Some techniques could be used to avoid corridors being used by wild boars for short periods such as ASF outbreaks, when wild boar movements should be restricted.

8.6 Management of wild boar populations applied in the context of African swine fever control

This section describes a series of measures applied to manage ASF in different EU countries, in some cases in the context of a focal introduction, and in others in a context of wider dissemination. Strategies described are a combination of wild boar management and disease control methods. Despite the fact that successful eradication of ASF virus after a focal introduction remains the exception rather than the rule, these measures have proven useful to contain the spread of the diseases to different degrees. It is worth emphasising that there is no single recipe for successful control or eradication of ASF. Based on the EU experience, the success of restoring disease freedom after an ASF introduction in a given territory has been the result of a combination of procedures that had to be changed and adapted continuously according to the epidemiological progress of the disease and to the geographical and socio-ecological context of the territory.

8.6.1 Zoning

According to international animal health regulations, zoning or regionalisation for disease control purposes allows the identification of specific geographical areas within a country or region as having a defined status with respect to a particular disease linked to specific disease control actions (OIE, 2019). These areas (sometimes also called zones) are often concentric around a confirmed or suspected focus of infection, with the most intensive disease control activities taking place in the inner area. An infected area is the area where the disease is present and a free area is an area where the disease is absent. Buffer areas are created between an infected and a free area. In some cases, they can be surrounded by another concentric area placed under a higher level of surveillance called control or surveillance area (Figure 8.4).

Based on the EU Council Directive 2002/60/EC of 27 June 2002, in the case of confirmation of ASF in wild boars in an EU country, the identification and establishment of an infected area (sometimes called high-risk area) should be implemented as soon as possible. In addition, the Strategic approach to the management of ASF for the EU (working document SANTE/7113/2015 – Rev 12) has been developed with the aim of establishing harmonised measures in response to the epidemiological situation with regard to ASF in the EU. This strategy is based on the scientific output from the European Food Safety Agency (EFSA *et al.*, 2018b) and states that this implementation must be adapted to local circumstances depending on the country or region in question. The measures implemented in each of the management areas, as well as the names and size of the areas and the timing of implementation of measures, may differ between different countries and can change over time based on the epidemiological situation (Dixon *et al.*, 2020) and the effect of the measures implemented (Table 8.2).

8.6.2 Methods to restrict wild boar movement

Using fences to reduce the risk of ASF spread through wild boar movements might be useful in case of a localised point source incursion. The aim is not to completely halt wild boar movements, which might be unrealistic if the fence perimeter is long and the terrain is rough, but rather to reduce wild boar movements as much as possible. In addition to fences, habitat management and ban of forest activities can also contribute to reduce wild boar mobility outside an infected area.

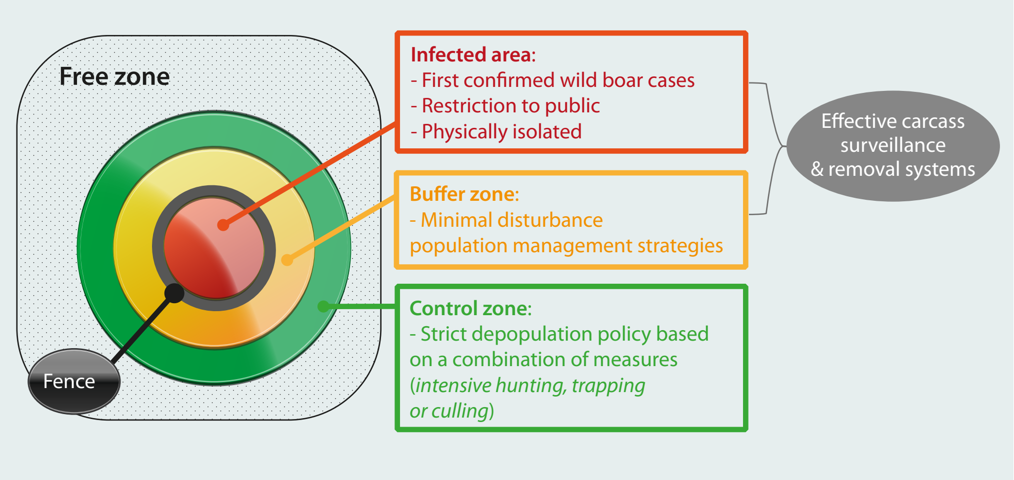

Figure 8.4. Schematic representation of disease management areas suggested to define concrete geographic areas where specific disease control strategies will be implemented in order to address focal ASF incursions, based on OIE recommendations (Source: Dixon *et al.*, 2020 based on OIE, 2019). The size of the areas and the combination of measures to be implemented in each area require regular monitoring and updates, based on the progress of the epidemiological context. The fence indicated is a control strategy that could be used to both prevent movement of wild boars and delineate the restricted area.

Table 8.2. Summarised information on different regionalisation and disease management strategies proposed by certain European countries for the control of ASF after detection of an outbreak in wild boar population.

Country	Terminology for infected and non-infected areas	Restrictions and applied measures
Czech Republic	• Highest risk area (core area) includes all the infected cases (fenced area). • High risk area (buffer area) around the highest risk sub-area, calculated considering the maximum annual increase of the home ranges of the wild boars living in the fenced area. • Low risk area infected area with low risk, corresponded to demarcation of Part II (according to Implementing Decision (EU) 2017/1162). • Intensive hunting area defined by the layout of highways (8,500 km^2)	• Fencing around infected/highest risk area • All infected area: – increased passive surveillance (rewards are given to those persons finding wild boar carcasses); – hunting ban (any species, any hunting method); – ban on wild boar feeding; – ban on entrance for the general public into the ASF highest risk areas; – disposal and sampling of wild boar carcasses in selected rendering plants; – individual hunting (snipers) at the final stage of the epidemic phase; – sampling and testing for both ASF and CSF in any wild boar carcass found; – intensive hunting area: intensive hunting.
Bulgaria	• Infected area of 20 km radius around the case. • Buffer area 20 km around the infected area. • Surveillance areas Whole region/province.	• Ban on hunting, possibility of sanitary shooting of wild boar by appointed hunters trained on biosecurity and trapping. • Searching for wild boar carcasses by appointed hunters, trained on biosecurity. • Ban on movement of domestic pigs, semen, ova, embryos, meat or products originating from the infected area. • Sampling of domestic pigs (for serological and virological testing) within the infected area. • Enhanced biosecurity measures.
Belgium	• Infected area (IA) based on a radius of 15 km around the place where the first confirmed positive carcass was discovered. • A month later, the IA was subdivided into three concentric areas: – core area corresponding to an area where all the carcasses of wild boars positive for the virus were found; – buffer area corresponding to a 6 km strip around the Core area completely fenced; – an enhanced observation area in the distal part, its size is variable and its perimeter can be established following physical or administrative limits.	• In addition, the territory surrounding these three areas was the subject of vigilance measures, namely: – hunting, movement and logging restrictions; – passive surveillance; – active search for wild boar carcasses; – compulsory reporting of any wild boar found dead. • The Administration took the necessary measures to ensure that virus detection was carried out on any wild boar found dead. All carcasses were compulsorily destroyed under official control.

8.6.2.1 Transboundary fencing

Since the introduction and spread of ASF in the EU, long distance transboundary fencing has been used by several countries to protect their national territories from virus incursion from their neighbours, despite their questionable efficiency and negative environmental impacts (Section 8.5.2). Bulgaria, for instance, erected a 133 km fence along the border with Romania. Similarly, shortly after the introduction of the virus in Belgium in September 2018, France erected a total 170 km of fences along the Belgian border. At the end of 2019, Germany erected a 120 km electric fence, after several infected wild boar cases were found in Poland less than 50 km from the German border.

Fences are politically tempting in the context of an emerging disease (Mysterud and Rolandsen, 2019) because they are a highly visible measure and, in the short-term, they can efficiently reduce disease transmission by direct contact. Unfortunately, when a long transboundary fence is built as a response to an emergency, plans for measuring its efficiency, calculating its maintenance costs and assessing its biological impact in terms of wildlife conservation are rarely considered (Jakes *et al.,* 2018). Therefore, it is recommended to perform a cost-benefit analysis and seek advice on the potential environmental consequences before taking the decision to implement such a high impact and resource consuming measure.

8.6.2.2 Focal fencing

Focal fencing should be applied as quickly as possible after an outbreak or focal introduction has been detected and the infected area has been defined and can be surrounded by a physical barrier. The objective of such fences is to prevent wild boar population movements in and out of the infected area. The type of fence can vary as long as it provides movement restriction (Section 8.5.2). Since this focal fence is unlikely to encompass the entire home ranges of wild boar sounders living in the infected area, attempts of some individuals to cross the fence can be expected. Therefore, a high level of monitoring and surveillance to prevent, detect and eliminate potential infected animals crossing the fence is recommended. Fencing around a focal introduction can save some time, especially when densities are high. Indeed, even if some positive cases are detected later outside the fence, partitioning the infected area with physical barriers can be useful for improving the efficiency of culling activities in the post-epidemic phase, as shown in Belgium (Figure 8.3). In other cases, focal fencing combined with intensive hunting can be useful to reduce or eliminate wild boar populations from a given area such as implemented in Belgium and the Czech Republic (Figures 8.5 and 8.6).

8.6.2.3 Habitat management

Section 8.5.1 of this chapter provided a short overview of the effects of wild boar habitat management on the dynamics of wild boar population. It should be noted that those measures do not have an immediate effect on the population and are only noticeable after one or two generations. Therefore, they have in general very little utility in the context of an ASF emergency where urgent effects in the short term are needed (Jori *et al.*, 2020). The only exception is the provision of diversionary feeding and baiting in a given area to prevent wild boar movements. This approach was used in the Czech Republic to aggregate potentially infected animals in the infected

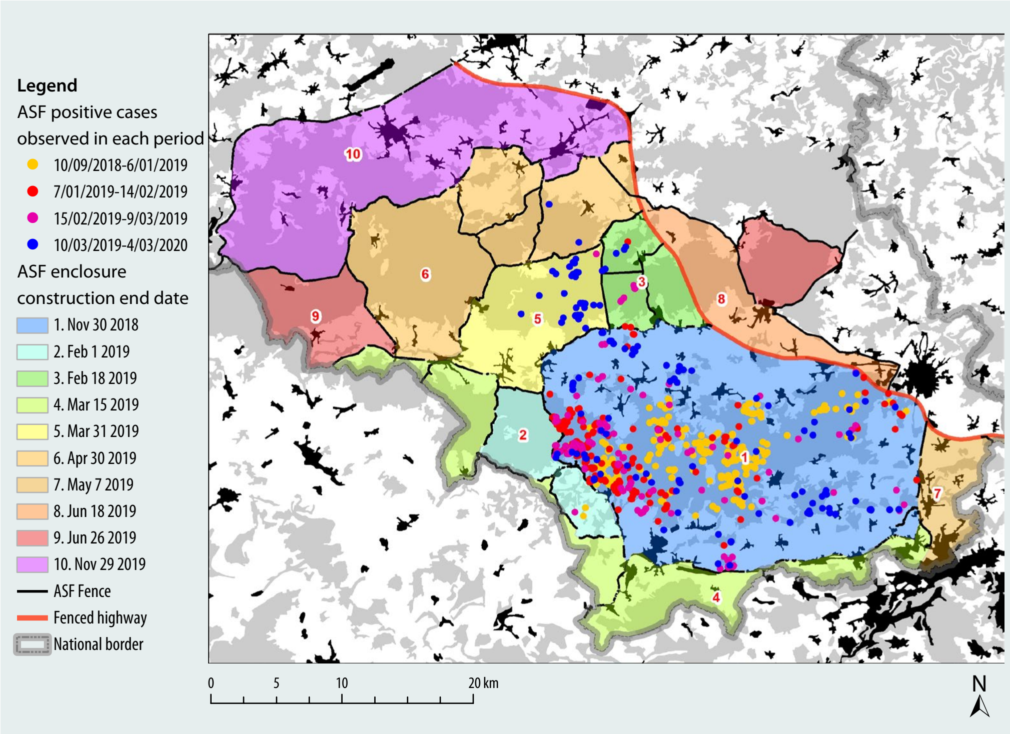

Figure 8.5. Cartographic representation of wild boars positive for African swine fever (dots) in Belgium and the network of fences (black lines) intended to slow down the spread of the disease. The colour codes of the dots correspond to periods ending with the first observation of a fence crossing. The colour codes of the enclosures (fenced areas) correspond to the completion dates of the fence. Fences in France and Luxembourg (not shown) are connected to the Belgian network (map provided by Public Service of Wallonia, Belgium).

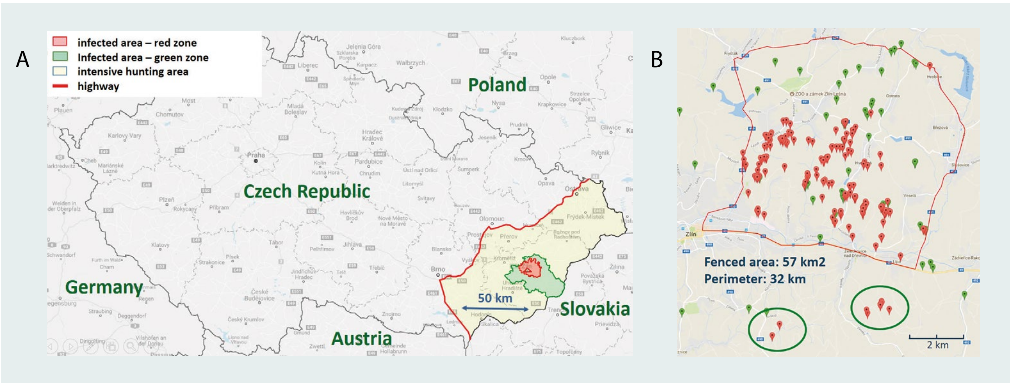

Figure 8.6. Maps showing details of the infected area in the Czech Republic: (A) location of the different areas (high-risk, low-risk and intensive hunting area) in the east of the country; (B) details of the fenced high-risk area with locations of positive (red dots) and negative (green dots) animals culled or found (maps provided by Petr Vaclavek).

area to facilitate culling. In that case, crop fields were left unharvested in order to maintain wild boar populations in the area and prevent dispersion. Nevertheless, it should be considered that supplementary feeding could also attract wild boar living in the surrounding non-infected areas. Therefore, this method should only be applied if food availability in the adjacent areas is high and the infected area is efficiently fenced.

8.6.2.4 Forest access ban

Following ASF introduction, provisional access to infected forests or forests adjacent to infected areas should be banned to prevent potential spread of the virus. This ban is applied to any forest activity, including hunting, trekking or extractive activities in order to limit the transportation of contaminated objects such as tools, vehicles and other equipment outside of the infected area and to prevent wild boar movements. Indeed, in Germany, collective driven hunts, particularly with dogs, led to an increase in wild boar home ranges and the potential dispersion of infected animals outside the focal area (Keuling *et al.*, 2008). Therefore, it is recommended to maintain this ban for several months and lift it only at the end of the epidemic phase, when the majority of the animals in the focal area have succumbed to the virus.

8.6.3 Methods for reducing wild boar populations

In large and continuous forest landscapes, it is unrealistic to consider achieving a substantial reduction in the numbers of the targeted wild boar population. However, under certain circumstances and by applying a combination of zoning and fencing, lethal population management methods have been successful in reducing wild boar populations effectively. Recent studies suggest that in an ASF outbreak the natural reduction of the population is fairly drastic and the reduction is enhanced by but not dependent upon control measures (Morelle *et al.,* 2020).

8.6.3.1 Hunting to control populations

Depending on the evolution of the epidemiological situation, different and even opposed hunting strategies can be applied in the same territory. In infected areas that are not physically contained by fences or geographical barriers (highways, rivers), hunting should be avoided by all means, in order to limit the spread of the disease (Section 8.6.2.4). However, if an infected population is circumscribed into a small area, hunting to reduce population size can be attempted at the end of the epidemic phase, when the remaining wild boar populations are limited. The same approach can also be applied in the buffer area around the infected area to reduce population size as much as possible. Different measures to reduce wild boar numbers can be applied, alone or in combination, with the help of a coordinated multidisciplinary team involving specifically trained local hunters, wildlife managers, animal health authorities and other government officials (Guberti *et al.,* 2019).

8.6.3.2 Intensive hunting policy

In areas surrounding an infected area, it can be beneficial to attempt a drastic reduction of the wild boar population by any possible method. The most obvious and accepted method in the EU is to intensify hunting pressure. This can be achieved for instance by increasing the number of hunters engaged in radical population reduction policies. Experience from infected countries suggests that it might be difficult to obtain compliance of hunting clubs and associations to implement unselective shooting and intensive hunting measures. Therefore, it might be necessary to hire professional or elite shooters or staff from other government institutions with professional shooting skills (army, police). The use of specialised equipment, such as silencers and night vision devices has proven successful to improve hunting efficiency with minimal wild boar disturbance and dispersal (Box 8.1). To increase efficiency, culling efforts should be concentrated and sustained in time and space. The use of fences to restrict animal movements can facilitate the reduction of wild boar numbers more efficiently. Such an intensified culling operation must be carefully planned with the perspective to remove and destroy a large number of carcasses in a limited amount of time. Therefore, anticipating sufficient human and material resources is recommended.

8.6.3.3 Trapping

Because traditional hunting techniques are not sufficient to drastically reduce wild boar populations (Section 8.4.2), it can be useful to combined hunting with other tools such as trapping. The use of large traps designed to capture several individuals at every catch is particularly interesting in this regard. In Belgium, circular corrals with a diameter of eight metres (Figure 8.2), were used with success. A network of traps can be placed every 300 hectares on former feeding points in large forested areas far from crop fields or close to points of interest for wild boar, such as mud puddles. Compared to other lethal methods, such as hunting, trapping has the advantage of allowing easier implementation of biosecurity measures as well as a higher level of animal welfare, and is thus probably better accepted by the general public. However, in EU countries some hunters could be against the concept of culling (i.e. shooting) trapped animals and might boycott trapping efforts. In addition, as mentioned in Section 8.4.2, effectiveness of the method is variable depending on the availability of alternative trophic resources. Therefore, its use might be restricted to suitable seasons and areas. Finally, it is important to highlight that the implementation of this method requires considerable time, effort and human resources, since baiting and trapping efforts need to be monitored and maintained regularly.

8.6.4 Combination of different methods

All the methods reviewed in this section can be applied alone or in combination. There is no single formula and their application and combination in space and time will depend on the goals imposed by the specific epidemiological and geographical context. In the Belgian control area (Box 8.2), for instance, combining intensive hunting and trapping with fencing provided efficient results. Conversely, in the buffer area, only trapping was performed before the arrival of the epidemic wave.

Box 8.1. Case of the Czech Republic.

The focal introduction of ASF in the Czech Republic is the only case in which ASF spread in wild boar has been successfully eradicated to date in the EU. The focal character of the incursion facilitated early detection and timely implementation of strict measures in a relatively localised affected area, resulting in very limited spread of the disease. Measures were continuously adjusted, based on the epidemiological situation and disease progress. Passive surveillance through collection and testing of wild boar carcasses was considered key to the final success, allowing immediate definition of the perimeter of the infected area after the disease had been confirmed. The wild boar population within the infected area was initially kept as undisturbed as possible. In addition, 115 hectares of crops were left unharvested in order to keep wild boars inside the core area. Active surveillance and depopulation of wild boars in the infected area started only after the epidemic had decreased. At the end of this process, active searching for carcasses was considered very important in order to ensure the removal of any potential long-term source of infection in the area. In addition to these population management procedures, measures such as fencing and intensive hunting were applied.
Zoning: Demarcation of the highest-risk area, called 'core area' in Czech Republic, was combined with intensive passive surveillance and carcass search. The core area was defined by a polygon that encompassed all found dead ASF-positive wild boar. Upon identification of the core area, a buffer area was defined around it. The determination of the buffer area was performed with the help of hunting experts and it was based on wild boar annual home range and natural corridors in the landscape (roads, villages, etc.).
Fencing: Ten kilometres of electric fence (voltage 6,500-11,000 V), combined with odour fences (Bíl *et al.*, 2018), were placed on the outer periphery of the highest-risk area (57 km^2) in order to limit movement of wild boar outside these boundaries as much as possible (Figure 8.4). It was difficult to assess the contribution of fences to the eradication of the disease but given the successful outcome, it was assumed they had a positive effect. There were 11 positive animals detected outside the fenced area, suggesting potential fence leakage in some places. Nevertheless, these were isolated cases localised in the neighbourhood of a village that could not be entirely fenced off. It concerned one small sounder of wild boars living in that area. Local hunters had been observing some night-time movement of wild boars through the village. The activity of police snipers that were part of the eradication effort might also have provoked unusual behavioural patterns in wild boars in the fenced area. The construction of a massive wire fence was discussed but finally discarded because of its high costs and the long time estimated for its deployment. Since the area concerned hosted a high density of wild boars, the construction of a massive wire fence over a long perimeter including private land would have been too slow and problematic.
Intensive hunting: The hunting ban in the fenced high-risk area was lifted at the end of the epidemic peak (11 weeks after the first detected cases), with the aim of depopulating the area as quickly, silently, and efficiently as possible. The government authorities decided to use police snipers trained in hunting biosecurity that split into eight two-man teams shooting wild boar at three-day intervals. All the shot animals were safely moved to the nearest road, and then transported to be sampled at the rendering plant. Targeted wild boars were located with helicopters and drones, supported by ground teams equipped with night vision devices. Snipers used weapons with silencers and intended to be as precise as possible in aiming at the head in order to minimise bleeding and environmental contamination with the virus. The ground veterinary teams immediately received GPS locations of shot animals for prompt carcass collection and disposal. During the10-week operation, police snipers shot 157 wild boar and the infected area was almost completely depopulated. This experience confirmed the efficiency of implementing intensive hunting at the final stages of the epidemic phase in order to contribute to disease eradication.

Box 8.2. Highlights of the Belgian experience in the control of ASF.

In Belgium, installation of fences was part of the ASF control strategy from the first case notification in September 2018. The fences used were 120 cm high wire mesh. In total, about 300 km were erected on an area of 1,100 km^2, to which could be added the fence of the Brussels-Luxemburg motorway of around 40 km. From the outset, the fences were seen as a means to hinder the dispersal of wild boars and not as impassable obstacles. The fences contained multiple weak points, such as gates and rivers, which were not secured.

The strategy for the construction of the fencing network was considered in a dynamic way. Initially, the fences were installed to break the epidemic wave, which was progressing rapidly given the continuity of the forest massif and the abundance of wild boars. The first layer of fences was built in November 2018. The location of the fences was based on the results of surveillance to avoid fencing within the infected area. The hoped-for interruption of wild boar movements was achieved, but fence crossings did occur especially in rural areas where the number of gates was higher. This resulted in an expansion of the infected area on three occasions (January, February and March 2019). Each enlargement automatically resulted in the installation of new fences to contain these new incursions, without necessarily waiting for surveillance results, in order to save time (Figure 8.5).

Once the epidemic phase was over (April 2019), new fences were erected approximately 5-10 km from the edge of the infected area. At the same time, the construction of other fences ensured the transboundary connection with French and Luxembourg fence networks. In this way, the former infected area was completely circumscribed by simple fence lines combined with 20 huge management enclosures. This complete containment of the remaining wild boar population in the infected area facilitated the efficient implementation of passive surveillance and depopulation efforts. During the epidemic, in the infected areas, organised searches for carcasses and trapping were the only operations conducted (until May 2019). During the post-epidemic (after May 2019), night shooting with generalised use of baiting points and camera alerts was also implemented to cull the remaining and scarce wild boar specimens. In the free areas, in addition to passive surveillance, a succession of depopulation methods was used according to the season: driven hunts in autumn and winter, trapping in spring and summer, and night shooting all year long. The combination of these techniques, consistently applied within the fenced areas, allowed almost complete reduction of the population of wild boars. More than 6,000 wild boars were removed from September 2018 to March 2020 in the ASF management area (Part II + I = 1,100 km^2): around 3,100 were shot in driven hunts, 1,200 by trapping, 500 by night shooting and 1,200 were found dead.

The development of a dynamic fence network, in combination with depopulation measures and organised search for carcasses, considerably helped to reduce the spread of the disease.

8.7 Disease management methods applied to wild boar populations

8.7.1 Passive surveillance

In the context of ASF, passive surveillance is the process of monitoring the presence of wild boar carcasses in the forest, which is generally implemented with the help of a team of experienced forest workers or hunters (Jori *et al.*, 2020). This approach is considered to be an essential step in ASF prevention, control and eradication measures (Chenais *et al.*, 2019; Gervasi *et al.*, 2019; Guberti *et al.*, 2019). In free areas, passive surveillance is key for early detection and all of the primary ASF cases in wild boar in the newly infected countries during the current epidemic were detected by this method (EFSA *et al.,* 2018b). A passive surveillance system is effective in field conditions if there is a clear suspected case definition, strong collaboration with field operatives, a procedure for managing samples and carcasses and a follow-up of the results. The official suspected case definition of ASF in the domestic pig sector is based on evidence of the disease indicated by tangible facts such as symptoms, lesions or response to diagnostic tests: '[…] *any pig or pig carcass exhibiting clinical symptoms or showing post-mortem lesions or reactions to laboratory tests carried out in accordance with the diagnostic manual which indicate the possible presence of African swine fever*' (EU Council Directive 2002/60/EC of 27 June 2002).

However, when dealing with free ranging wildlife, it seems more convenient to employ a case definition based on the suspicion of a potential case, with a lower requirement for evidence of the pathogen: '[…] *any found carcass out of the context of hunting, including road killed animals and any diseased wild boar shot for sanitary reasons*'. The broader the suspected case definition, the more sensitive the surveillance system will be. The inclusion of road killed animals is a matter of debate (Schulz *et al.,* 2019). This decision depends on the competent authorities and on the human and material resources available to manage these carcasses. In contrast, wild boars shot for sanitary reasons (sick animals or individuals presenting abnormal behaviour) have to be included as a priority in passive surveillance. A structured procedure for managing carcasses and transporting samples from the field to the laboratory is crucial (Chapter 5). In some field investigations, some hunters have been trained in biosecurity procedures before taking samples and removing carcasses for disposal. Within an ASF crisis context, it is advisable that sampling and carcass handling are carried out by competent authorities or trained personnel. Practically, a hotline or similar online tool must be set up and widely disseminated to facilitate the notification of discovered carcasses. The competent authorities or services (veterinary and forestry services) are then responsible for the next steps, which include tracing, transporting the carcasses to the laboratory, sampling and destroying the carcass under the required biosecurity procedures to prevent secondary spread. This procedure must be operational before any outbreak, and sustainable in the long term. Follow-up of passive surveillance results is needed to assess the effectiveness of the system. Indeed, in absence of ASF, the discovery of a carcass is often an incidental event and it is difficult to determine if the rate of discovery corresponds to the rate of natural mortality. Assuming natural mortality of 10% per year (Keuling *et al.*, 2013) and the hypothesis that only 10% of carcasses are detected, it has been suggested that effective passive surveillance should be able to detect 1% of the whole estimated wild boar population in a given area, in the absence of ASF. However, these suggested figures are only a bulk estimation based on expert opinion (Guberti *et al.*, 2019). More evidence-based assessment is currently needed to ascertain what level of passive surveillance is required to ensure the early detection of index cases in wild boar and to what extent that target would be feasible and realistic to be implemented in practice.

In infected areas, passive surveillance is also crucial for ASF control. Active search for carcasses, removal and testing allows delimitation of the infected area, helps to follow the epidemic phases and reduces the viral load in the environment. Indeed, the high tenacity of the virus in the carcass and in the environment is considered the main reason for maintenance and spread of the virus even in areas with very low wild boar densities (Guberti *et al.*, 2019). ASF virus (ASFV) has been shown to persist in blood (540 days at 4 °C), spleen (204 days), bone marrow (180 days), skin/fat (300 days) and frozen meat (1000 days). The virus further survives the process of putrefaction, with longer persistence in carcasses in cold winter temperatures than in summer. Moreover, soil and water (mud puddles in which carcasses can be found) from underneath a contaminated carcass may also play a role in the persistence of the virus (reviewed in Chenais *et al.*, 2019). These carcasses are exposed to scavengers including wild boars, with studies showing evidence of direct contact (wild boar sniffing and poking carcasses) and even confirmed cannibalism (Cukor *et al.*, 2020a; Probst *et al.*, 2017). Any type of contact is likely to transmit the virus. Hence, carcass removal should be carried out as soon as possible. In infected areas, passive surveillance should be systematically implemented to increase the probability of finding carcasses. Such enhanced passive surveillance is time-consuming and requires significant human resources, especially if the infected areas are large. Carcasses may be located in inaccessible environments or hidden both in summer (in high vegetation) and in winter (under snow). However, recent studies demonstrated that there are specific environments where dead wild boars are most likely to be found. Sick wild boars have feverish and depressed behaviour that leads them to search for cooler and moist areas. Therefore, selected deathbeds will be in forests rather than in open landscapes, near water sources and in quiet places away from roads (Cukor *et al.*, 2020b; Morelle *et al.*, 2019).

During the ASF epidemic in Belgium, active search for carcasses was designed (cartographic monitoring) and implemented by the regional authorities with occasional participation of the army. Hunters and landowners were requested to notify any dead wild boar. Practically, a map of priorities was adapted every two weeks according to previous results (localisation of the last positive fresh cases, passive surveillance results from previous weeks) and sent to the field coordinators. Some criteria were also considered (such as topographic wetness index, heat load index and distances from rivers) to target specific environments according to the ASF carcass model previously described (Morelle *et al.*, 2019). This model was built to respond to the emergency and was based on the first 200 positive cases in Belgium and on the datasets from the Czech Republic and Poland. As soon as the carcass was detected, the precise geographic location was reported to the team in charge of carcass removal and destruction.

8.7.2 Carcass management and biosecurity

At all stages of passive surveillance, biosecurity procedures must be respected to avoid spreading ASFV. It is also essential to prohibit access to pig holdings by any person who has been in contact with a wild boar (living or dead) in the prior 48 hours.

Even in free areas, any dead wild boar must be considered as potentially ASF positive especially in areas bordering infected areas. Ideally, people (hunters, forest rangers or walkers) who discover a dead wild boar should notify competent services without approaching or touching the carcass. Samples for ASFV analysis can be collected at the discovery site, at a collection centre or at the rendering plant. After sampling the carcass can be safely destroyed *in situ* (deep burial or burning if authorised by competent authorities) or individually packed and sent to a rendering plant following biosecurity procedures. It is important that forestry officers have received prior training in biosecurity for carcass management.

In infected areas, biosecurity measures must be strengthened. For carcass searches, workers must be equipped with boots and clothes specifically dedicated to this activity and which will be cleaned and disinfected daily. Carcass removal, packaging and transport require qualified personnel and specific equipment (boots, overalls, gloves, masks and packing material). Transport vehicles must be exclusively dedicated to this task in the infected area. These teams need to be trained to pack and transport carcasses according to strict biosecurity rules. Approved biocides must be used for disinfection of materials, vehicles (after cleaning) and the soil under the carcass. All people involved must undergo preliminary biosecurity training adapted to their tasks.

8.7.3 Stakeholder communication

Achieving control of ASF in the wild requires engagement with a large panel of stakeholders (Jori *et al.,* 2020). It is essential to identify and involve these stakeholders already during the contingency planning. To engage efficiently it is further important to understand what motivates each stakeholder group to participate in detecting and controlling ASF. Sincere interest, participatory dialogue and open communication are needed to obtain such understanding. In this regard, regular, relevant and transparent communication can actually be an incentive for certain stakeholders. Good communication and feedback to hunters have for example been reported as more motivational than other (financial) incentives. To boost motivation for early detection and control it can be useful to raise stakeholders' awareness about the different advantages of controlling the disease, such as the economic impact for the pork industry or the access and freedom of use of the forest and wild boar hunting activity (Jori *et al.,* 2020). Among the various stakeholders, hunters stand out as especially important for early detection, and at later stages surveillance and control of ASF. However, relying only on hunters for early detection can be challenging. Indeed, given the drastic measures that will be implemented in the event of a positive case being discovered, namely a ban on access to the forest, many hunters might be reluctant to collaborate or even tempted to hide potential cases. A good level of communication with hunters and hunter organisations is instrumental and thus deserves special attention (Keuling *et al.,* 2016).

Considering the epidemiological patterns of national and international spread of ASF in wild boars (as described in Chapter 9), raising awareness of ASF transmission risks among different sectors is paramount for prevention, early detection and for achieving successful control (Chenais *et al.,* 2019). Those sectors should include the general public, but also sectors involved in domestic pig farming, wildlife management or different forest activities (hunters, runners, dog walkers, ornithologists, forests managers, berry pickers, etc.). Communication messages should be as simple as possible, and include the global dimension of ASF, its epidemiology and ecology, the economic impact and the absence of treatment and vaccine. Scientific messages must be communicated in a language that is reachable and adapted to non-specialists (Dietz, 2013). Communication further needs to be adapted to the different stakeholders and tailored for long-term application. If ASF becomes established in a territory and the crisis lasts for several years, there is a risk that stakeholders will become habituated to the endemic disease situation.

In this case, compliance with prevention and control measures is likely to decrease, requiring repetition and adaptation of the messages. It is also important to keep awareness and application of preventive measures high over a prolonged time in areas at risk.

8.8 Need for future research

8.8.1 Future trends for improving carcass detection and reporting

In the context of an outbreak, the tendency of diseased animals to hide can considerably reduce the success of finding wild boar carcasses, and thus influence both the efficiency of passive surveillance and the motivation of the persons involved in carcass searches. Methods and ideas for improving the probability of wild boar carcass and disease detection will differ between countries. Methods can include having voluntary hunters (paid or unpaid) to search for carcasses even during periods with low hunting activities, provision/availability of easy-to-use sampling material and infrastructures for carcass disposal. In many countries, hunters are asked to volunteer to search for carcasses. If this community does not see any advantage in reporting or taking samples from dead wild boar, passive surveillance will not be successful. There is a need to develop research aimed at improving the efficiency of carcass detection, including the perception of hunters towards this activity, the use of mobile phone applications, and active search with trained dogs and the use of computer modelling to identify areas with a higher probability of carcass presence.

8.8.2 Oral administration of pharmaceuticals to wild boar

Oral administration of pharmaceuticals (ASF vaccine, contraceptives or other products to reduce wild boar populations) will require efficient administration methods to deliver the products in the wild using baits and selective delivery systems. For a bait to be efficient, it should be attractive, palatable and accessible to wild boar, but also unavailable or safe for other sympatric species living in the same ecosystem. It should also be resistant to local climatic and environmental conditions. Because wild boars have access to other natural sources of food, the best season for animals to become interested in baits needs to be identified. This season is usually coincident with the period of food scarcity and may vary depending on the forest structure, the climate and geographic conditions, as well as the presence of other sympatric competitor wildlife species. In Mediterranean ecosystems it is usually summer, while in continental Europe it is mostly winter. In the EU, extensive experience in wild boar baiting and oral vaccination was achieved during the wild boar classical swine fever vaccination programmes in Germany and France (Rossi *et al.,* 2015). Ideally, the bait needs to be provided with selective delivery systems that prevent their consumption by other non-target species (Campbell *et al.,* 2011; Massei *et al.,* 2010). Some other systems have been tested to deliver vaccines against bovine tuberculosis in wild boar in Spain (Beltrán-Beck *et al.,* 2012; Díez-Delgado *et al.,* 2018). Some systems developed in Australia and the US to administer toxicants to feral pigs could potentially be used to administer other pharmaceutical products (Lavelle *et al.,* 2018; Snow *et al.,* 2016). In any case, those systems need to be tested in different ecosystems and climatic conditions before being widely implemented. For instance, a bait developed and tested in humid cold conditions might be unsuitable in a hot and dry environment. Similarly, some selective delivery systems such as those tested with success in Australia or the UK, might not work so selectively in some European habitats where wild boars coexist with other large mammals such as bears or wolves.

8.8.3 New technologies to record and restrict wild boar movements

Fencing to reduce wild boar movements is a tool that contributes to the control and eradication of an ASF outbreak. Wire mesh and electric fences have proven effective if appropriate technical specifications are followed. Other innovative methods to deter wild boar are being tested based on different stimuli that could be olfactory, light or sound. Many of them have been revealed as ineffective while others provide acceptable results that should be further developed. Devices provided with sensors and activated only when wild boar are recorded are being investigated. The use of drones has also a high potential to assess wild boar location and help in wild boar management. Those techniques are not only applicable in the context of an ASF outbreak but also to reduce wild boar damage to croplands and conflicts in urban areas.

8.9 Final remarks

The battle against ASF in the wild boar population in the EU has been a source of frustration, but also an opportunity to learn more about this complex disease, its epidemiology and dynamics in a new environment. For many animal health authorities, wildlife management services and hunting associations the control of ASF in free ranging populations remains a major challenge. The ability of the virus to persist in the environment complicates the control and eradication of the virus from forest ecosystems in the currently affected European countries (Chenais *et al.*, 2018). In addition to long-term persistence, awareness about the disease needs to remain high throughout Europe due to the common occurrence of long-distance jumps with unexpected disease emergence of the virus into new territories. The experience of the Czech Republic and Belgium suggests that preparedness, early detection and prompt action are instrumental in containing the spread of the disease and can serve as examples of success stories. However, the risk of spread throughout the continent and the associated challenge to prevent this risk remain very high.

EU expertise accumulated in the field of wild boar management during decades has been an invaluable help for deploying strategies to contain and monitor the disease within wild boar populations. The need for an urgent response in the field has obliged animal health authorities, hunting associations and wildlife managers to work together with a common goal, and to share expertise, methods and tools arising from these different disciplines. In this process, the need to engage and maintain a high level of communication has been repeatedly emphasised. Another fundamental aspect in this multidisciplinary collaboration has been the importance of passive surveillance in order to detect the first cases, monitor the progress of the disease or even evaluate or confirm the success of control methods within a given wild boar population. This area still has room for improvement and can benefit from applied research in different fields such as the use of searching dogs, the development of innovative techniques to restrict wild boar movements, or the use of mobile phone technology or computer modelling to improve carcass detectability.

Finally, it is worth mentioning that despite wild boars being fascinating animals and a fundamental part of Eurasian forest ecosystems, the increasing population trend in Eurasia and its consequences are raising growing concerns. Improving our capacity to reduce wild boar population numbers, mitigate its effects, including the control of ASF and other wild boar pathogens will certainly be one of the most serious challenges for wildlife management and animal health disciplines in the next decades.

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