9. African swine fever epidemiology, surveillance and control

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Abstract

The introduction of genotype II African swine fever (ASF) virus (ASFV) into the Caucasus in 2007 resulted in unprecedented disease propagation via slow geographical expansion through wild boar populations, short- and long-distance human-mediated translocations, and incursions into naïve wild boar and domestic pig populations. The disease is now widespread in eastern and central Europe as well as in Asia, including China. The global dimension of the current epidemic shows that all countries need to be prepared for an introduction. In its natural habitat in Africa, ASFV is maintained within an ancient cycle between soft argasid ticks and the common warthog. Once introduced to the domestic pig population, direct and indirect virus transmission occurs with or without involvement of the tick vector in the pig-tick and domestic pig epidemiological cycles respectively. In the domestic pig cycle, human activities involving pigs or pig derived products are the dominating driver of virus transmission. ASF epidemiology in the presence of wild boar and northern European climates has proved to have specific characteristics, described in the wild boar-habitat epidemiological cycle. In this cycle wild boar carcasses and the resulting contamination of the environment play key roles in virus persistence. In both the wild boar-habitat and the domestic pig epidemiological cycle, fully implemented biosecurity is the key for stopping virus transmission and controlling the disease. Positive examples from the Czech

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Republic and Belgium show that control and eradication of ASF from the wild boar-habitat cycle can be achieved. Both these cases, as well as the example of Sardinia, where ASFV genotype I now seem very close to eradication after more than 40 years presence, further underline the importance of involving, engaging and understanding all stakeholders in the value chains from farm and forest to fork in order to accomplish ASF control and eradication.

Keywords: ASF, transmission, wild boar, genotype II, epidemic pig disease

9.1 Introduction

First described in 1921 as a disease affecting domestic pigs, African swine fever (ASF) was restricted to the African continent until 1957 when it showed up in Lisbon, Portugal (Manso Ribeiro and Rosa Azevedo, 1961; Montgomery, 1921). After a global tour during the decades that followed, ASF was again restricted to Africa from the late 1990s, with the exception of the island of Sardinia, Italy, where it had persisted since 1978. The introduction of an eastern African swine fever virus (ASFV) genotype II into the Caucasus in 2007 (Rowlands *et al.*, 2008) was therefore unexpected and resulted in unprecedented disease propagation via slow geographical expansion through wild boar populations, and long-distance, human-mediated translocations and incursions into naïve wild boar and domestic pig populations. The disease is now widespread in eastern and central Europe and, since 2018, in China and many other countries in Asia (Chenais *et al.*, 2019a; Dixon *et al.*, 2019; Gogin *et al.*, 2013; Zhou *et al.*, 2018). This epidemic (from now on in this chapter referred to as the 'current epidemic') involves both domestic pigs and wild boar, although in some parts of Europe the infection is maintained in wild boar populations independently of domestic pigs (Chenais *et al.*, 2018). To date, 12 European Union (EU) countries have reported cases in wild boar or outbreaks in domestic pigs caused by ASFV genotype II. Of the member countries affected so far (September 2020), the Czech Republic has achieved control and eradication (Charvátová *et al.*, 2019), and in Belgium the infection appears to be under control and eradication to be close (Dellicour *et al.*, 2020). In the Baltic states, downward trends are observed regarding outbreaks in domestic pigs and cases in wild boar (Oļševskis *et al.*, 2020; Schulz *et al.*, 2019b).

In its natural habitat in southern and eastern Africa ASFV exists in an ancient cycle between the biological vector, soft argasid ticks of the *Ornithodoros moubata* complex, and its natural mammalian host, the common warthog (*Phacochoerus africanus*) (see the sections on arthropod vectors and susceptible suids respectively) (Wilkinson, 1984). In rare spill-over events the disease can be transmitted to domestic pigs via the ticks. Once introduced to the domestic pig population, direct and indirect virus transmission occur with or without involvement of the tick vector in the pig-tick and domestic pig epidemiological cycles respectively (Penrith and Vosloo, 2009; Plowright, 1981). Human activities in the domestic pig value chain involving pigs or pig derived products are the dominating driver of virus transmission in Africa as well as globally (Mulumba-Mfumu *et al.*, 2019; Penrith *et al.*, 2019).

In this chapter an overview of ASF epidemiology is given, with focus on the characteristics of the current epidemic, brief orientations of some historic and current local epidemic patterns in Europe, and how ASF is controlled and surveyed in domestic pigs in EU today.

9.2 Susceptibility of Suidae

All African species of wild pigs are often considered to be naturally resistant to ASFV. However, the level of scientific information confirming this is highly variable, and only in exceptional cases have ASFV infections been confirmed in representative population surveys or experimental infections (Table 9.1) (Jori and Bastos, 2009). Most information is available concerning the common warthog (*Phacochoerus africanus*). This is particularly true for warthog populations in Southern and East Africa which cohabit with ticks of the *Ornithodoros moubata* complex, allowing for the occurrence of the well-studied warthog-tick sylvatic cycle (Plowright, 1981). Warthogs get infected as young piglets when bitten by infected soft ticks sharing their burrows. The virus becomes localised in peripheral lymph nodes and adult warthogs do not excrete sufficient virus to be able to transmit the disease directly (Plowright, 1981; Thomson, 1985). In other areas of the African continent, such as West and Central Africa, the sylvatic cycle has not been confirmed to occur, and information confirming resistance or circulation of the virus in natural populations of warthogs from those areas is almost inexistent (Jori *et al.*, 2013). The case of other African wild pig populations is similar: only one species present in Southern Africa, the Southern bush pig (*Potamochoerus larvatus*), has been proven to be naturally resistant by experimental infection (Oura *et al.*, 1998). For all the other wild pig populations, including other bushpigs (*Potamochoerus porcus*) or populations of giant forest hogs (*Hylochoerus meinertzhageni*), data on

Table 9.1. Proven, suspected or unknown susceptibility to African swine fever for different members of the *Suidae* and *Tayasuidae* families.

Family	Genus	Species[1]	Susceptibility	Continent	Reference
Suidae	*Phacochoerus*	*P. africanus*	Proven resistant	Africa	Thomson, 1985
		P. aethiopicus	Unknown	Africa	
	Potamochoerus	*P. larvatus*	Proven resistant	Africa	Montgomery, 1921
		P. porcus	Unknown	Africa	
	Hylochoerus	*H. meinertzhageni*	Suspected resistant	Africa	Heuschele and Coggins, 1965
	Sus	*S. scrofa*	Yes	Eurasia	
		*S. verrucosus**	Unknown	Asia	
		*S. cebifrons**	Unknown	Asia	
		*S. celebensis**	Unknown	Asia	
		S. barbatus	Unknown	Asia	
		*S. oliveri**	Unknown	Asia	
		S. ahoenobarbus	Unknown	Asia	
		S. philippensis	Unknown	Asia	
		*Porcula salvania**	Unknown	India	
	Babyrousa	*B. babyrussa*	Unknown	Asia	
		*B. togeanensis**	Unknown	Asia	
Tayasuidae	*Tayassu*	*Tayassu pecari*	Suspected resistant	America	Fowler, 1996
	Pecari	*Pecari tajacu*	Suspected resistant	America	Fowler, 1996
	Catagonus	*C. wagneri**	Suspected resistant	America	Fowler, 1996

[1] * means endangered species.

the circulation of ASFV that could provide an indication of potential susceptibility or resistance are not available. Episodes of mass mortality due to ASF have never been reported for any species of wild African suidae, supporting the hypothesis of widespread natural resistance.

The resistant status of African suids towards ASF infection contrasts with the high susceptibility to ASFV seen in European wild boar (*Sus scrofa,* from now on in this chapter referred to as 'wild boar'), but is unsurprising as they belong to the same species as domestic pigs. This susceptibility was noticed already during the first incursion of ASFV genotype I in Europe in the 1960s. On that occasion, however, mortalities were limited in space and time and the virus disappeared from wild boar populations after a few weeks if there were no further contacts with domestic pigs (Pérez *et al.*, 1998). *Tayasuidae* (peccaries and javelinas) are reported to be resistant to ASFV and during the incursion of the virus in Brazil, no cases in those species were ever reported (Fowler, 1996).

With ASF becoming endemic in new regions, any country with pig production is at risk for introduction. This risk is particularly high for Asia, which maintains the largest population of domestic pigs in the world, mainly kept under low biosecurity (Dixon *et al.*, 2019). In this scenario, the potential role of wild pigs in the dissemination of the disease, and its consequences, needs to be considered. Many Asian countries hold large populations of wild boar, but also important remaining populations of endangered wild pig species, see Table 9.1 (Meijaard *et al.*, 2011). In Asia, the Suidae family comprises 12 wild species (including several subspecies of wild boar). Except for a critically endangered population of pygmy hog (*Porcula salvanius*) in the Indian subcontinent, all the other eight species of Suidae (*Sus* spp.) and three species of *Babyrousa* spp. are distributed across different islands in Indonesia and the Philippines. Since ASF is spreading very quickly across this region, the risk of these populations being exposed to ASFV is high. Their susceptibility for ASFV has never been studied, but considering the high tropism of the virus for pig cells and the fact that they are immunologically naïve, the probability of the virus being fatal to these populations is high. Outbreaks of ASF anywhere outside its presently known geographical range should be closely monitored to anticipate whether ASF could add further pressure to already highly threatened endemic pig species.

9.3 Epidemiological parameters

9.3.1 Transmission

Infected domestic pigs and wild boar excrete the virus with all body fluids and excretions including oronasal fluids, faeces and urine. The virus excretion starts about two days before onset of clinical signs. The virus load is particularly large in blood of infected animals, thus the haemorrhages and sometimes bloody diarrhoea caused by the infection result in extensive contamination of the environment.

Transmission through direct contact in domestic pigs and wild boar has been repeatedly demonstrated in animal experiments and in field observations. It is thought that direct transmission usually occurs oronasally. It has also been demonstrated that oronasal infection of pigs usually requires a relatively high virus dose to be successful (~100 haemadsorbing units

(HAU)) (Olesen *et al.*, 2017). In an experiment with wild boar Pietschman and co-workers (2015) demonstrated that only weak and runty animals could be directly infected with very low doses (<10 HAU) of ASFV by the oronasal route. Nevertheless, direct contact seems to play an important role in transmission of the virus within wild boar sounders (family groups). Wild boar sounders are, however, territorial and tend to avoid other sounders. Therefore, physical contacts between discrete sounders are scarce and not believed to contribute to the spatial spread of the virus as much as infected carcasses (slow, local spread) and human mediated spread (fast, long distance spread) (Lange *et al.*, 2018). The maintenance of ASF in European wild boar populations is believed to be mainly driven by contacts of susceptible animals with infected carcasses and contaminated environment (Chenais *et al.*, 2018). Direct contacts of domestic pigs with infected wild boar have not played a major role in disease transmission during the current epidemic. Such contacts may be of more importance in areas where free range pig keeping is practised and direct contacts between wild boar and domestic pigs thus are more likely to occur (EFSA, 2018, 2020). Airborne transmission has been shown to occur only over short distances such as between pigs kept in the same barn (Olesen *et al.*, 2017).

Attempts to infect pigs indirectly through contaminated environment have not been very successful. In a recent experiment, infection of naïve contact pigs by ASFV contaminated environment could not be demonstrated (Eble *et al.*, 2019). Olesen and co-workers (2018) demonstrated transmission through the environment to sentinel pigs introduced into contaminated pens one day after removing the infected pigs but not after three or more days. At the same time, reports from field outbreak investigations in affected countries indicate that indirect transmission via contaminated fomites (vehicles, clothes, equipment and various materials) is the predominating identified plausible route of introduction of the infection into pig farms, particularly for larger commercial farms (EFSA, 2020; Nurmoja *et al.*, 2018; Oļševskis *et al.*, 2016; Zani *et al.*, 2019). Transmission via pig feed (grain, fresh forage) has also been suspected. In small farms, the feed is often prepared on site and pigs are frequently fed with freshly harvested forage. The latter has been suggested to constitute an important route of introduction of the virus into farms in areas where wild boar are affected by ASF (Boklund *et al.*, 2020). In larger farms in Estonia, it has been suspected that cereal feeds may have become contaminated in the process of milling and mixing of feed on farm (Nurmoja *et al.*, 2018). Contaminated bedding material could potentially also carry the virus into farms. In general, it has been suggested that contamination of the environment surrounding pig farms with ASFV increases the risk of a farm becoming infected, indicating once again the importance of indirect transmission of the virus (Boklund *et al.*, 2020; Nurmoja *et al.*, 2018). In an Estonian study the risk of a pig farm to become infected was positively associated with the number of affected wild boar in the surrounding area (Nurmoja *et al.*, 2018). In a study by Boklund and co-workers (2020) in Romania close proximity to outbreaks in domestic farms was a risk factor in commercial and backyard farms. In backyard farms, wild boar abundance around the farm, number of domestic outbreaks within two kilometres around farms and short distance to wild boar cases were also significant risk factors (Boklund *et al.*, 2020). The conclusion made by the authors is that these significant risk factors should be understood as proxies for a high level of virus contamination in the environment.

Translocation of ASFV through live animal movement has been rare during the current epidemic while long distance introductions to new countries and territories on several occasions have been associated with people bringing along contaminated pork or wild boar products, and food waste being deliberately or unintentionally fed to domestic pigs or wild boar (Chenais *et al.*, 2019a). Once introduced, if the virus gets established in domestic pig or wild boar populations the probability of indirect transmission via contaminated environment and fomites increases.

Currently, there is no evidence that ASFV persists long-term in a latent state in animals surviving the infection, or that survivors play any epidemiological role, either in the current epidemic, or in previous ones (Ståhl *et al.*, 2019). Some animals with a chronic form of the disease may, however, excrete the virus for prolonged periods (up to two months). In animals recovering from the disease (true survivors) virus excretion has been shown to last up to 70 days. Longer excretion periods seem to be associated with less virulent strains. However, in an experimental study with the moderately virulent Malta/78 isolate, no transmission from donor to in-contact pigs occurred more than 30 days after they had developed pyrexia (Wilkinson *et al.*, 1983).

9.3.2 Arthropod vectors

The natural reservoir and biological vector of ASFV in South and East Africa is the soft tick *O. moubata*. In the ASF-epidemic on the Iberian Peninsula *Ornithodoros erraticus* acted as a biological vector. Other species from the *Ornithodoros* genus have experimentally been proven to be competent vectors, but never found to play an epidemiological role in the field. *Ornithodoros* spp. ticks are common in Africa, the Middle East (from Turkey to the north to western Iran), and some areas of Southern Europe (EFSA AHAW Panel, 2015). Hard ticks cannot act as biological vectors for ASFV, but they feed on wild boar as well as domestic pigs, and have been shown to contain the virus after feeding on infected animals (Olesen *et al.*, 2020). The transmission potential of hard ticks is unknown; however, it is known that they do not feed again for a long time after having had a blood meal. The potential for other bloodsucking arthropods or insects to serve as mechanical vectors has been widely discussed. ASFV has been found in hog lice (*Haematopinus suis*) collected from experimentally infected pigs. Hog lice normally spend their entire brief lives on the same pig and would only be transferred to another pig by close contact (Bonnet *et al.*, 2020). It is unlikely that they have any epidemiological significance. Stable flies (*Stomoxys calicitrans*) have been shown to transmit ASFV mechanically (via bites) and via ingestion in experimental settings. Evidence from the field, however, is lacking. In flies collected from infected farms in Lithuania the virus could not be detected whereas trace amounts of virus DNA could be detected in insects collected from an outbreak farm in Estonia (Olesen *et al.*, 2020). Furthermore, horse flies that are common in forest environments could be detected in low numbers in non-affected pig farms in Estonia (Tummeleht *et al.*, 2020). Nevertheless, the role, if any, of blood-feeding insects in the transmission of ASFV in field conditions and in the introduction of the virus into pig farms still needs to be elucidated.

9.3.3 Incubation period, morbidity and mortality

Clinical manifestation, morbidity and mortality in domestic pigs and wild boar caused by ASFV genotypes I and II are similar, as demonstrated in numerous animal experiments (Blome *et al.*, 2013). In general, the incubation period for ASF is considered to be between 5 to 15 days. In experimental studies with genotype I and II viruses it ranged between 1 and 33 days, depending mainly on route and dose of infection (Dórea *et al.*, 2017). The incubation period tends to be shorter after intradermal and intramuscular inoculation compared to oronasal or oral infections.

Higher doses of virus mostly result in shorter incubation periods compared to lower doses (Dórea *et al.*, 2017).

The morbidity among pigs experimentally infected with virulent strains of the ASF genotype I or II viruses has been 100% (Dórea *et al.*, 2017). However, the severity of the disease caused by the infection has been somewhat variable depending on the virus strain. Strains classified as moderately virulent and causing subacute disease in most of the experimental pigs have been discovered in the Baltic states. There are also examples of attenuation of field virus strains resulting in asymptomatic infections in challenged domestic pigs (Gallardo *et al.*, 2019; Zani *et al.*, 2018).

Similarly to the morbidity, the mortality among infected animals (the case-fatality rate or lethality) is dependent on the virulence of the virus strain. The highly virulent strains dominating in the field cause a case-fatality rate approaching 100%. In challenge experiments conducted with highly virulent strains since 2007 only single animals have survived and recovered. However, virus strains showing reduced virulence or attenuation have caused case-fatality rates ranging from 0 to 50% in animal experiments (Gallardo *et al.*, 2018; Zani *et al.*, 2018). The morbidity and mortality observed in the field among infected pigs and wild boar are not identical to what is measured in animal experiments. In the field, the infection status of the animals is generally not known, and the morbidity and mortality are calculated based on the number of animals in the group under consideration, i.e. the population at risk (PAR). Thus, the morbidity and mortality estimates are dependent on how the PAR is defined and how large it is. If the PAR is defined as all pigs of a large farm (stable) or unit, the morbidity and mortality estimates may result in very low numbers (less than 1%), whereas the mortality and morbidity in the pen of pigs where the disease was discovered, or in a small back yard farm, may be similar to that observed in experimental studies (up to 100%). Morbidity and mortality estimates are also dependent on the time period that elapsed since the start of the outbreak. Due to accumulation of the cases in time, the morbidity and mortality estimates will increase with time. Therefore, if the disease has been detected in a very early stage of an outbreak in a larger farm, the observed morbidity and mortality of the disease may be very low even if the outbreak is caused by a virulent strain of the virus. Consequently, morbidity and mortality estimates observed in the field should be interpreted with caution and strictly in the context of the outbreak. Generally, morbidity and mortality levels observed in larger farms often do not exceed the normal morbidity and mortality levels of the specific farm until several weeks have passed since the introduction of the virus. During the current epidemic, mortality and morbidity rates reported from outbreaks in Estonia have been in the range of 29.7 to 100% in small back yard farms and 0.04 to 25% in commercial farms (Nurmoja *et al.*, 2018). In conclusion: the first indication of the introduction of ASFV on a farm is not always high mortality or morbidity, and the absence of these signs should not lead farmers and veterinarians to exclude the possibility of ASF. It has to be emphasised that ASF, however, can cause high morbidity and mortality among pigs even of larger herds after prolonged spread of the virus (for several weeks) within the herd or in case of simultaneous infection of pigs from the same source like contaminated feed (swill) or water.

Estimating morbidity and mortality among wild boar populations in the field is even more difficult as the number of animals in the PAR is not exactly known. Therefore, such estimates are largely based either on expert opinion or mathematical models. Field observations indicate that the morbidity and mortality within sounders are high, as several wild boar carcasses have been found together. Nevertheless, occurrence of seropositive wild boar indicates that the case fatality rate among wild boar in the field is not 100%, and that a fraction of animals survives the infection and the disease.

9.3.4 Contagiousness

Field evidence and animal experiments have demonstrated that in most cases ASFV spreads slowly within a pig herd, staying in one pen or part of the stable for weeks. The transmission is accelerated when bleeding occurs in sick pigs and a large amount of virus is released into the environment with the blood. The spread of the virus across a larger pig herd may take weeks or months, depending on how the pigs are separated in the building. Along with the spread of the infection in a herd the morbidity and mortality gradually increase. ASF should thus be considered a moderately contagious disease (Depner *et al.*, 2020; Schulz *et al.*, 2019a).

Transmission studies conducted in recent years, involving various virus strains and experimental conditions, have resulted in rather similar transmission parameters, all indicating moderate or low contagiousness of the infection. In an experiment with the highly virulent strain of ASFV genotype II basic reproduction ratio (R_0) within pens ranged from 5.0 to 6.1 and between pens it was found to be 0.5 (Pietschmann *et al.*, 2015). These estimates coincide with the results obtained by Guinat and co-workers (2016) who estimated the pig-to-pig R_0 for the Georgia 2007/1 ASFV strain using data obtained from another challenge experiment. The models showed that the pig-to-pig R_0 was 5.0 (95% CI 2.4-9.1) and between pen 2.7 (95% CI 0.7-5.2) (Guinat *et al.*, 2016). Nielsen and co-workers (2017) recalculated these transmission parameters taking into account that during the challenge experiment animals were only tested every other day, ending up with similar point estimates for parameters but somewhat different confidence intervals (Nielsen *et al.*, 2017).

There have been several attempts to estimate R_0 for ASFV genotype II from field data. Based on outbreak data in domestic pig herds from Russia during the period 2007-2010 the R_0 was estimated to range from 8 to 11 within farms and from 2 to 3 between farms (Gulenkin *et al.*, 2011). Using field data on cases in wild boar R_0 was estimated at 1.58 (95% CI 1.13-3.77) in Russia (Iglesias *et al.*, 2016), 1.95 for Czech Republic, and 1.65 for Belgium (Marcon *et al.*, 2020). Estimates from field data include uncertainties requiring special attention in the statistical analysis, such as unknown infection dates of index cases, and are further influenced by local conditions affecting contact rates between animals and animal groups (farms or herds) such as herd characteristics (size and production type), management practices in domestic pigs and population density of wild boar. Also, intervention measures may influence the estimates (isolation of domestic herds or removal of wild boar carcasses). Therefore, R_0 estimates obtained from field data should be considered in their particular context. Nevertheless, the estimates obtained in different countries are notably similar and comparable with those obtained in experimental conditions.

9.3.5 Transmission patterns

As mentioned in the section above, within domestic pig herds an ASF outbreak develops relatively slowly in the initial stage. It may take two or more weeks until the mortality and morbidity notably exceed the normal levels of the herd. In wild boar the spread follows a pattern of a propagating epidemic. There are two examples where the development of the disease in a wild boar population has been well recorded within a restricted area: in Czech Republic in the Zlin region, where the affected area was ~60 km^2, and in southern Belgium where the disease was spreading in an area of ~1,600 km^2. In the Zlin region, the epidemic had two peaks before it was eradicated, the first after approximately four weeks following the first detection of the disease and the second after five months. In Belgium, the epidemic developed very slowly reaching its single peak after little more than four months following the first detection (Charvátová *et al.*, 2019; Dellicour *et al.*, 2020) (Figure 9.1).

The temporal evolution of ASF in wild boar populations has been studied based on the Estonian disease notification data (PCR or antibody positive) at different spatial resolutions (EFSA, 2017). The smoothed temporal trend at county level (the average area of a county is 3,000 km^2) indicated the first peak in notified ASF cases around six months after the first case was reported, and a gradual reduction of the number of cases over the following two years. At around 30 months after the first reported case a second, smaller peak could be observed, but the number of cases subsequently decreased rapidly (Figure 9.2).

The detection of ASF cases in wild boar and outbreaks in domestic pig farms in the current epidemic has not been evenly distributed over the year. Outbreaks in domestic pigs have exhibited strong seasonality, with highest incidence during the summer months in all European countries in Europe where domestic pigs have been affected. In wild boar, summer and winter peaks in numbers of detected ASF cases can be observed (Figure 9.3).

The winter peak can be explained with the main hunting season lasting from autumn to early spring, with most hunting being performed in the winter months. In areas under restriction due to ASF all hunted animals are tested for ASF. More wild boars are thus tested during the hunting season. Likewise, more carcasses are detected during the hunting season when hunters are more present in the forests. Reasons for the summer peak could be the increase in population density after the breeding season in spring, and animals moving closer to farmlands to feed on the fields and thus becoming easier to detect. The observed number of cases may, however, be biased due to different reporting frequency in different seasons. Therefore, trends in proportions of positive findings are more informative for assessment of seasonal trends. The analysis of trends

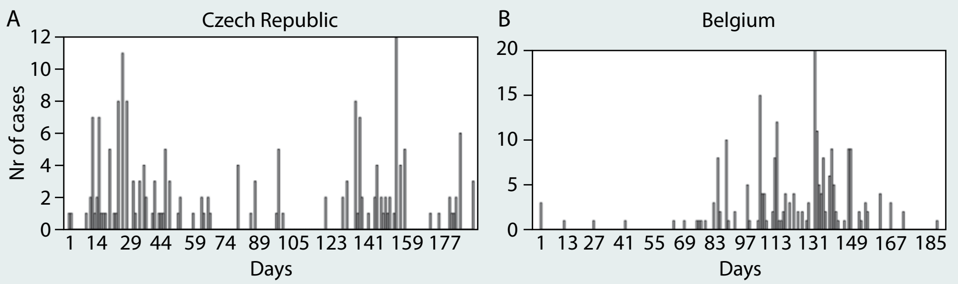

Figure 9.1. Number of infected wild boar carcasses found in the Zlin area, Czech Republic, and in Virton Forest, Belgium, during the ASF epidemic. Adapted from Marcon *et al.* (2020).

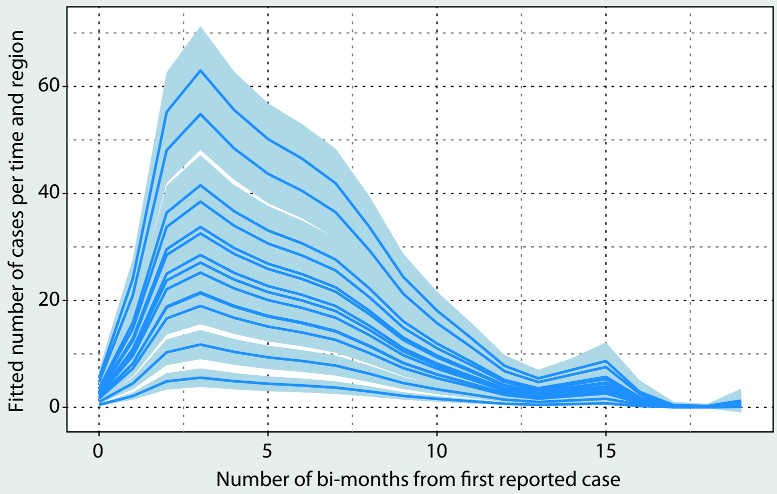

Figure 2. Smoothed 38 months temporal trends of ASF cases (PCR or antibody positive) in wild boar per county during the period of January 2014 to August 2017 in Estonia based on official surveillance data. Starting point for each trend line is the date of the first reported case in a county. Bi-months refers to a time interval of two months.

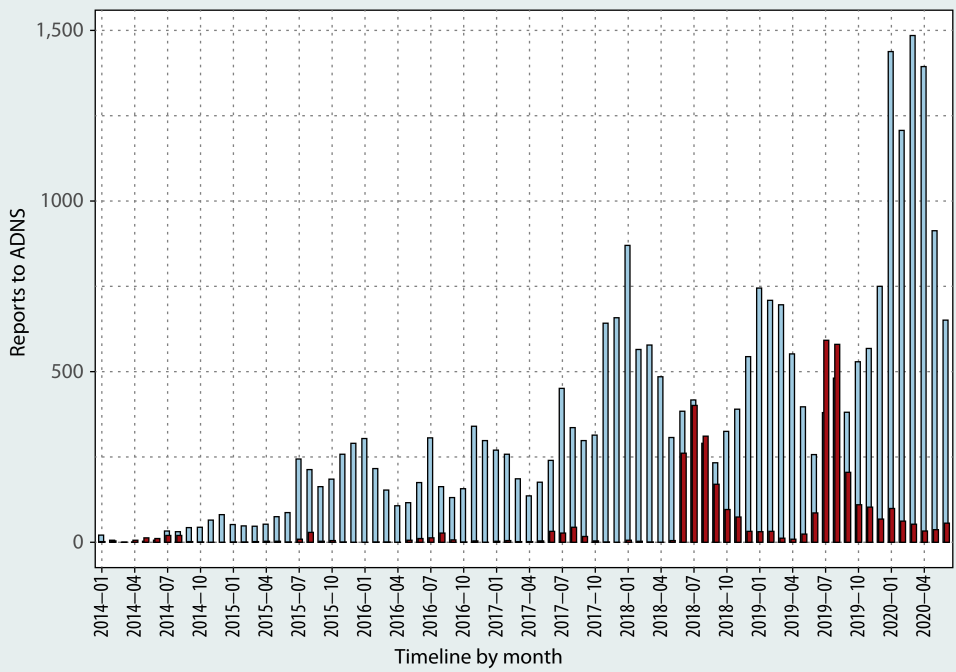

Figure 9.3. Notifications of outbreaks in domestic pigs (red bars) and cases in wild boar (blue bars) in the European Union. Data extracted from the Animal Disease Notification System (ADNS) from January 2014 until June 2020.

in proportions of positive cases, including samples only from affected areas, performed by EFSA (2020) has revealed more or less similar seasonal variation among wild boar found dead in Estonia and Latvia, where both summer and winter peaks could be observed. In contrast, in Lithuania and Poland the summer peaks were not evident among animals found dead. Among hunted wild boar the prevalence levels have been steady in all four countries, with significant drops in proportion of positive cases only for spring months. Data from other affected countries (Romania, Hungary, Czech Republic and Belgium) do not show the same trend. In these countries the occurrence of ASF was generally lower in summer months with a single peak observed in winter.

Based on these observations it may be concluded that there is a seasonal variation in incidence of ASF among wild boar, dependent on environmental and climatic conditions as well as ecology and management. In cooler climates the decomposition of wild boar carcasses and inactivation of the virus in the environment takes longer, increasing the infectious period for these virus sources, which in turn increases the probability of effective contacts for susceptible animals (Probst *et al.*, 2020). The wild boar hunting season may differ between countries, but in general most wild boar hunting is done in autumn and winter. If an infected wild boar is hunted, blood from the shot wound, body fluids spilled during dressing, as well as hunting remains left in the forest can contaminate the environment with large amounts of virus. Additionally, hunting in infected areas may cause dispersal of wild boar and push infection into new susceptible populations. Furthermore, the mating season of wild boar lasts from October to January in most of Europe, coinciding with the main hunting season. During that period males get into contact with females and fighting between males may take place, increasing the probability of effective contacts between infected and susceptible animals. Furthermore, food availability may have an effect on contacts between sounders. If natural food is scarce it may lead to wild boar roaming in larger areas in search of food. If supplementary feeding is provided it may cause aggregation of wild boar at feeding sites. These consequences may each increase the probability of contacts and possibly fights between sounders that in turn may contribute to the higher incidence of ASF among wild boar seen during the winter (EFSA AHAW Panel, 2018). Some of the factors that may increase the disease incidence among wild boar in summer are mentioned above, like increase of the population density after the farrowing in spring. After the birth of the new generation, the sub-adult females may disperse, leaving the maternal group to form new sounders, resulting in increased probability of direct contacts. In addition, in the summer field crops ripen, and wild boar move to feed on fields, making contacts between sounders more likely. Lastly, blood sucking insects, although not convincingly proven, may play a role in the incidence increase by mechanically transmitting the virus to susceptible host.

The factors that potentially enhance virus spread in wild boar populations during the summer season may also be the reasons for the increase in incidence of outbreaks in domestic pig farms during the same time period. Pig farm activities are seasonal, and those related to the summer season may lead to more likely and frequent contacts with infected wild boar or the environment contaminated by them. For example, during the warmer season of the year, freshly cut forage can be fed to pigs; pigs having outdoor access are let out; crops are harvested and farm vehicles and machinery move frequently between the farm and potentially contaminated fields. The role of blood sucking flying insects in the transmission has not been confirmed, see Section 9.3.2 on arthropod vectors.

9.3.6 Speed of disease propagation in wild boar populations

The speed of propagation of ASF in wild boar populations has been assessed using different analytical methods. Using network analysis the median speed of the local spread of the virus (excluding likely human mediated long distance translocation events) was estimated to be between 2.9 and 11.7 km/year in Belgium, the Czech Republic, Estonia, Hungary, Latvia, Lithuania and Poland (EFSA, 2020). Marcon and co-workers (2020) estimated the infection wavefront velocity in the Belgium wild boar epidemic using an interpolation procedure that resulted in an overall wavefront velocity estimate of 0.39 km/week (20.3 km/year) ranging from 0.1 to 1 km/week (5.2-52 km/year) in different parts of the infected area. Niine and co-workers (unpublished data) estimated the average linear speed of expansion of the infected area (including likely human mediated spread) in Estonia during the ascending phase of the epidemic in 2014-2017, using the difference in the radii of the infected area in consecutive weeks as a measure of speed. The average speed of expansion of the infected area was found to be 0.64 km/week (33.1 km/year) ranging from 0.32 to 0.84 km/week (17.1-44.0 km/year) in different years. Large seasonal variation in speed of propagation could be observed in Estonia with notable winter and summer peaks.

The speed of the infection spread is not equal in all directions of the infected areas. The expansion of the affected area follows the area of wild boar suitable habitat and depends on wild boar density. However, other ecological and anthropogenic factors likely have effect on the direction and speed of the spread of the disease. In Belgium, the main direction of the spread of the infection was towards the north and the west. Marcon *et al.* (2020) demonstrated that artificial barriers like roads and fences had significant restricting effect on the spread of the infection in the wild boar population. The speed of expansion of areas with infected wild boar has been different in different EU countries, seeming to be more rapid in the northernmost countries (Estonia and Latvia) and less rapid in Lithuania, Poland and Hungary. Reasons for this still need to be clarified.

9.4 The role of wild boar in African swine fever epidemiology

The role of wild boar in ASF epidemiology varies between regions. Wild boars are highly susceptible to ASFV infection in both natural and experimental infections. Sick wild boars excrete the virus in the same quantities as domestic pigs and the transmission parameters established in experimental conditions for wild boar are similar to those verified for domestic pigs.

During the ASFV genotype I epidemic in Europe from the 1950s to '90s, wild boar was not considered to play any major role in spreading the virus to domestic pigs or in maintaining the virus locally. ASFV tended to persist in the wild boar population only when the virus was circulating in domestic pigs in the same area. As soon as the virus was eradicated from domestic pigs it also disappeared from the wild boar population. It was found that wild boar could transmit the virus mainly to free range domestic pigs through direct contacts or contacts with infected carcasses (Costard *et al.*, 2013; Jori and Bastos, 2009). A similar pattern has also been observed on the island of Sardinia, where the ASF genotype I virus has persisted in limited areas in free range domestic 'brado' pig herds (FRP) and among wild boar in the same areas (Laddomada *et al.*, 2019). However, the depopulation of the FRP-herds has led to a strong decline of ASFV in the local wild boar population (see Section 9.5.2 on Sardinia).

At the start of the current epidemic in 2007 (see below) the disease spread mainly among domestic pig farms with low biosecurity. Incidental virus spill-overs to wild boar populations were observed, but it was presumed that the epidemic would follow the pattern of former European epidemics and spontaneously fade out from the local wild boar population following disease eradication from the domestic pigs, due to high case fatality rate and the absence of long-term carriers (Costard *et al.*, 2013). Nevertheless, already in 2008 the first concerns regarding a more significant role of wild boar in dissemination and persistence of the virus in domestic pig and wild boar populations were expressed based on field observations in the Caucasus and Russia (Beltrán-Alcrudo *et al.*, 2008).

Soon after the ASF incursion into the Baltic States and Poland in 2014, it became evident that the infection can survive locally for a long period in wild boar populations independently of outbreaks in domestic pigs. Wild boar surveillance data have shown that the disease moves in the form of a slow epidemic wave (~1-5 km/per month) through local wild boar populations, killing most of the animals in the area. However, the disease does not disappear completely in the back of the epidemic wave but continues to spread in the affected area with low incidence for several years (Figure 9.2), even without disease transmission in domestic pigs. This indicates the existence of specific ecological conditions enabling such a long term circulation of ASFV in wild boar populations at least in northern temperate climates, and has led to the suggestion to add a distinct cycle, the 'wild boar-habitat cycle', to the list of three previous transmission cycles of ASF including 'sylvatic cycle' in Africa, 'tick to pig cycle' in areas where competent biological vectors can transmit the virus, and the 'domestic pig cycle' (Figure 9.4) (Chenais *et al.*, 2018).

Figure 9.4. The four epidemiologic cycles of African swine fever and main transmission agents. (1) Sylvatic cycle: the common warthog (*Phacochoerus africanuus*) and soft ticks of *Ornithodoros* spp. The role of the bushpig (*Potamochoerus larvatus*) in the sylvatic cycle remains unclear. (2) The tick-pig cycle: soft ticks and domestic pigs (*Sus scrofa domesticus*). (3) The domestic cycle: domestic pigs and pig-derived products (pork, blood, fat, lard, bones, bone marrow, hides). (4) The wild boar-habitat cycle: wild boar (*S. scrofa*), pig- and wild boar-derived products and carcasses, and the habitat. The figure is reproduced from Chenais *et al.* (2018) and published with permission from Emerging Infectious Diseases.

In the wild boar-habitat cycle both direct transmission between infected and susceptible wild boar and indirect transmission through carcasses and contaminated environment in the habitat may occur. Indirect transmission, particularly through infected carcasses, seems to play a key role in the cycle. Direct transmission seems less important for several reasons: physical contacts between sounders are not frequent, particularly after the epidemic has depleted an area of most of the wild boar; mathematical simulation of disease transmission suggests that if direct transmission between sounders would occur frequently, the disease spread in wild boar populations would be much faster than what is actually observed (Lange *et al.*, 2018); less virulent or attenuated strains of ASFV seem to disappear fairly quickly from the wild boar population (Zani *et al.*, 2018), indicating that if the virus is not generating enough carcasses it is not able to persist in the wild boar population. In this regard the combination of high case-fatality rate, long-term virus persistence in animal carcasses and the environment, as well as the relatively low contagiousness preventing complete depopulation of the host population, seem to interact in a way that maximises both local persistence and constant geographical spread (Figure 9.5) (Depner *et al.*, 2020).

Cool and moist climates favour environmental persistence of the virus and indirect transmission. As mentioned, spread of ASFV in wild boar populations poses a great risk for domestic pigs in the area. Outbreak investigations have revealed that direct contacts between wild boar and domestic pigs have been rather exceptional during the present epidemic, and that in most cases the introduction of the virus to pig herds has occurred via indirect transmission routes (Boklund *et al.*, 2020; EFSA AHAW Panel, 2018; Nurmoja *et al.*, 2018; Oļševskis *et al.*, 2016). Unexpectedly, most outbreaks in domestic pigs occur during the warmest season of the year, not when the conditions in the environment are generally cold and humid, i.e. optimal for virus persistence. As discussed above, despite the unfavourable weather conditions, sharing the environment (like fields in harvest season where the virus load is high due to increased wild boar population density and ASF incidence among wild boars), apparently creates an effective link to pass the virus between wild boar and domestic pigs.

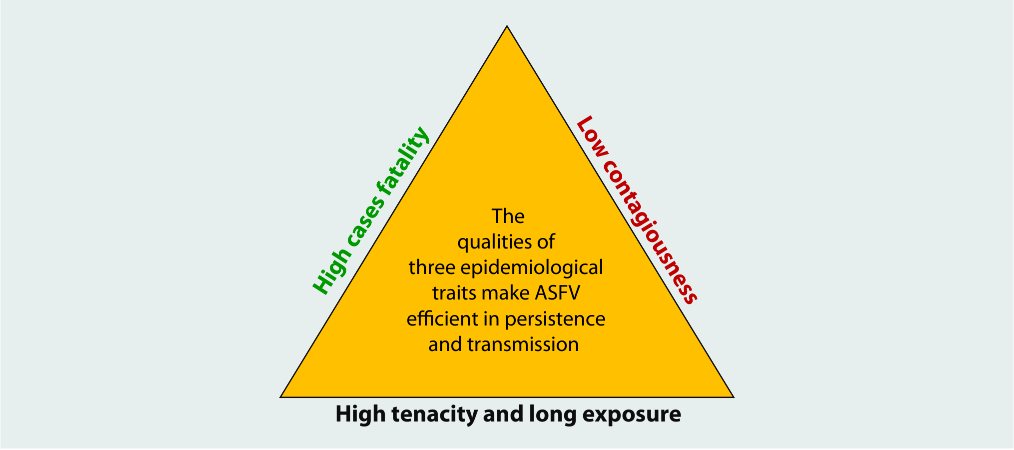

Figure 9.5. The persistency triangle illustrating how epidemiological characteristics make eradication of ASF in wild boar population challenging (Depner *et al.*, 2020). © World Organisation for Animal Health (OIE).

In summary, wild boar has played an important role in spreading ASFV across, and maintaining it in, large territories during the present epidemic. However, it has to be emphasised that this spread has been strongly supported by human activities. In case of long-distance spread, wild boar has been the victim and not the cause of virus propagation. Spread of ASFV in wild boar populations poses a risk for infection in domestic pig herds, but also in this situation human mediated transmission tends to play the key role. ASFV can persist in the wild boar-habitat cycle without continuous new introductions, but it seems possible to break the cycle. Evidence from Estonia and Latvia suggests that if the wild boar population density is kept low enough (with hunting efforts) for a sufficiently long period after the epidemic wave has passed, the infection is likely to die out (Oļševskis *et al.*, 2020; Schulz *et al.*, 2020).

9.5 Historic and present African swine fever epidemics in Europe

9.5.1 African swine fever in the Iberian Peninsula (1957-1994)

ASF occurred for the first time ever outside Africa in Portugal, near Lisbon, in 1957. It was concluded that the infection originated from feeding pigs with uncooked swill from planes originating from Angola, the swill containing meat from infected pigs (Manso Ribeiro *et al.*, 1958).

The eradication measures implemented by the Portuguese Veterinary Authorities during the first outbreak comprised strict quarantines and slaughter of affected herds, affected piggeries were cleaned and disinfected and a long delay was imposed before repopulation (Boinas, 1986). Control of pig movements in a 'sanitary control zone' was imposed around the first outbreak but, due to intense commercial pressures, control was not complete and new outbreaks appeared in other districts. In spite of this, by 1958 the Veterinary Services had achieved control of the disease and there was no further evidence of ASF in Portugal for about two years. It was clear that the key measures for controlling and eradicating the disease were early identification of infected herds, isolation, restriction of pig movement to markets and to other farms, and stamping out infected populations. Additionally, disinfection and sanitation of the pig housing before restocking prevented re-infection. Two years later, in 1960, the disease reoccurred in Portugal (Manso Ribeiro and Rosa Azevedo, 1961). Analysis of the virus genomes of the outbreaks in 1957 and 1960, although both from genotype I, showed large differences and corroborated the hypothesis of two separate virus introductions (Wilkinson *et al.*, 1993). From Portugal, the disease spread to Spain where the original outbreak was diagnosed close to the Spanish border with Portugal, in 1960 (Polo Jover and Sanchez Botija, 1961). The same set of sanitary measures used in the 1957-58 eradication programme was re-imposed in Portugal when ASF reappeared in 1960, but this time they were not successful. In both Iberian countries ASF became established as an endemic disease affecting herds throughout the territories. Eradication was only achieved more than three decades later (1993 in Portugal and 1994 in Spain) after the enforcement of stricter sanitary measures, extensive surveys for detection of infected animals, slaughter of infected herds with depopulation and fair compensation, implementation of surveillance and protection zones, herd census, increased biosecurity of farms, enhanced animal movement control and increased awareness and collaboration of pig producers (Arias and Sánchez-Vizcaíno, 2002; Boinas, 1994).

During the 1957/58 outbreaks in Portugal, and those in Spain and Portugal in the early 1960s, infection caused a very acute clinical disease leading to death of virtually 100% of pigs within seven days after the onset of clinical signs (Manso Ribeiro and Rosa Azevedo, 1961; Polo Jover and Sanchez Botija, 1961). As the disease was established in the two countries, sub-acute, chronic and sub-clinical forms of the disease became more frequent (Sanchez Botija, 1982; Vigario and Caiado, 1989). This change has been attributed both to spontaneous decrease of virus pathogenicity and a newly developed live attenuated virus vaccine that was used in the extensive Iberian pig production areas in the southern regions of Portugal in the early 1960s. The reversion of virulence of the vaccine virus isolate, and its subsequent spread to the pig population lead to the development of carrier pigs (Manso Ribeiro *et al.*, 1958). The vaccine was withdrawn after a very short time.

In the traditional old pigsties used in Iberian pig production systems a haematophagous soft tick, *Ornithodoros erraticus*, can be found (Boinas *et al.*, 2011). The tick can harbour ASFV for up to five years and is thus a possible source of disease when feeding on susceptible pigs. Tick presence was associated with repeated outbreaks in farms in Spain (Pérez-Sánchez *et al.*, 1994), and its presence was considered the most probable origin of a sporadic outbreak in the south of Portugal in 1999 when some infested premises were repopulated with pigs after the country had been declared ASF free (Boinas *et al.*, 2011). These regions also had a higher wild boar density and greater opportunity of contact between them and free ranging pigs in production systems with generally low biosecurity. On the Iberian Peninsula in the 1980s, wild boar was not considered a risk factor for disease transmission, supported by epidemiological surveys reporting wild boar to be responsible for only 5 to 6% of the ASF outbreaks in Portugal and Spain (Ordas *et al.*, 1983; Perestrelo Vieira, 1993). Due to these specific risk factors for ASF, the south-western portion of the Iberian Peninsula, where extensive pig production predominates, were the last remaining ASFV infected areas before the eradication. In addition, in the final stages of the eradication, these areas were the object of a joint 'Coordinated ASF Eradication Programme' between Portuguese and Spanish Veterinary Authorities (Arias and Sánchez-Vizcaíno, 2002; Boinas, 1994).

9.5.2 African swine fever in Sardinia

ASFV genotype I was introduced into south Sardinia in 1978 via contaminated food waste from the Iberian Peninsula. It rapidly spread to several areas of the island, mainly due to uncontrolled movements of domestic pigs. ASF found ideal conditions to become endemic in the 'brado' FRP population, kept in the inner mountainous areas of central Sardinia, where these pigs interact closely with wild boar. Disease prevention in high biosecurity farms has almost always been successful, while ASF outbreaks frequently occurred in poor-biosecurity backyard farms regularly exposed to contact with FRPs. Evidence supports a hypothesis that, compared to FRPs, wild boar played a secondary role as virus source (Laddomada *et al.*, 2019). Indeed, a large amount of data in the last forty years suggests that, in Sardinia, ASFV was not able to persist in wild boar populations alone for more than a few years if this population was not re-infected by FRPs or domestic pigs. Any role for *Ornithodoros* spp. ticks in ASFV transmission in Sardinia has been excluded.

Until recently, any attempt to eradicate the disease encountered strong resistance by the FRP-keepers, who considered this traditional way of keeping pigs as a part of their cultural identity

(Cappai *et al.*, 2018). As from 2015, a new ASF eradication plan (EPASF-15-20) has been implemented, fully empowered by the Sardinian Regional Government, and supported by the National Government. Based to a large extent on conventional veterinary measures adapted to the local condition, the new strategy favoured financial incentives for good husbandry practices and biosecurity more than compensation to affected farmers. Furthermore, the EPASF-15-20 took into account the socio-economic and cultural aspects associated with ASF occurrence (Cappai *et al.*, 2018; Loi *et al.*, 2019a,b). Veterinary controls were strengthened all along the pig production chain in an increasingly rigorous manner, particularly in backyard pig farms. More stringent rules were applied to hunting, including safe disposal of wild boar offal. Control measures were accompanied by very intensive activities of education, awareness and communication, targeted to farmers, hunters and the local population. Open-air, double fenced pig farms were authorised and subsidised, as an alternative to keeping FRPs.

As an integrated part of the EPASF-15-20, almost 5,000 FRPs were culled from November 2015 to February 2020. Testing of these pigs confirmed that ASFV was endemic in this population located in a few municipalities in central Sardinia, with very high prevalence of virus- and seropositive animals (Laddomada *et al.*, 2019). As a consequence of the intensive control measures and of the progressive reduction in the density and number of the FRPs, the overall epidemiological situation has largely improved also in wild boar. At present (July 2020) the ASF situation can be summarised as follows:

- Domestic pig farms. The last outbreak (detected by means of RT-PCR) occurred in September 2018. On a few later occasions (the latest in November 2019), seropositive pigs were detected in pig farms or at slaughter, but no virus genome could be detected in these farms or animals.
- FRPs. The last PCR-positive pigs were detected in January 2019. To date, this population has been reduced to 100-200 pigs, divided into small groups. This very sparse population no longer seems to play any role in ASFV transmission.
- Wild boar. The disease control measures applied in the last five years have been associated with a clear decrease in ASFV and ASF antibodies detection during both passive and active surveillance. This favourable trend became even clearer after the FRP-population was reduced to negligible numbers. The last PCR-positive wild boar was detected in April 2019 during passive surveillance, while absence of ASFV and continuous, strong decline of seroprevalence has been confirmed in over 6,000 wild boars tested during the hunting season November 2019-January 2020.

Although the EPASF-15-20 has led to very positive results, it cannot be excluded that ASF still occurs at very low level in wild boar populations in some remote areas. It is thus necessary to continue and intensify ASF surveillance. The favourable trend indicates that complete eradication will most likely be achieved in the near future, provided that the current disease control measures continue to apply.

9.5.3 African swine fever in Europe outside EU

9.5.3.1 Caucasus

The first signs of ASFV returning to mainland Europe appeared in March 2007, in the seaport of Poti, Georgia (Rowlands *et al.*, 2008). According to official reports, the virus was introduced via ship waste containing pork products, with the first cases occurring in pig farms close to the port (from now on in this section, 'reported' means officially reported to the World Organisation for Animal Health (OIE). Reports are available at www.oie.int). The causative agent was identified as ASFV genotype II, otherwise circulating in Mozambique, Madagascar and Zambia (Rowlands *et al.*, 2008). The majority of pigs in the Caucasus are kept by poor subsistence farmers in backyard systems with low general biosecurity levels, with free-range management being widely practised. Slaughter is carried out on the premises, even in larger commercial farms. These factors, in combination with active transboundary movements and markets, facilitated quick spread of the infection (25-35 km per month) after the first introduction in 2007 (Beltrán-Alcrudo *et al.*, 2018). Delayed diagnosis and control measures led to unmanageable propagation of the disease. From June to August 2007, Georgia reported 58 outbreaks in domestic pigs. According to OIE, they were resolved completely in January 2008, but the virus re-emerged in Georgia twice (in 2010 and 2011), resulting in outbreaks in different areas (Vepkhvadze *et al.*, 2017). The situation regarding ASF in wild boar in Georgia is unknown (Vepkhvadze *et al.*, 2017). After Georgia, the virus was detected in Armenia in early August 2007. It is believed that the virus was introduced by transboundary movement of infected pigs and wild boar. Similarly, to Georgia, there were three waves of ASF epidemic in Armenia, in 2007, 2010 and 2011. The latter outbreaks affected the wild boar population and domestic pigs close to the Georgian border (Sanchez-Vizcaino *et al.*, 2013). In 2019 the presence of the virus in Armenian territory was still suspected despite of lack of official reports of outbreaks.

In Azerbaijan the majority of the population is Muslim, consequently the country has very low numbers of domestic pigs. Nevertheless, in late January 2008, the presence of ASF was officially confirmed in a village in north-western Azerbaijan, about 180 km east of the Georgian border. It is the only reported outbreak from the country. In June 2011 Azerbaijan self-declared freedom from ASF to the OIE, while media reported some more ASF cases in the Nagorno-Karabakh (a region with a political status of disputed territory) located in the Lesser Caucasus mountains from 2007 to 2013 (Grigoryan, 2013).

In December 2008 the virus had covered about 500 km and reached wild boar populations in north-western Iran. ASFV isolates from Iran expressed 100% similarity with those from Georgia, possibly brought into Iran by infected wild boar crossing the Aras River from Armenia (Rahimi *et al.*, 2010).

Repeated outbreaks in 2007-2019 in the north and south Caucasus, including a case in Kabardino-Balkarian Republic in 2019, suggest that the virus is still circulating in the Caucasus region. The exact mechanism of virus persistence is still unknown. Involvement of *Ornithodoros* spp. has not been proven, but cannot be excluded.

9.5.3.2 Russia

It took the virus about nine months to pass through Georgia and cross the Caucasus mountains reaching Russia. The very first case of ASF in Russia was registered in wild boar in November 2007. From the wild boar population, the disease entered the domestic pig population in the Republic of North Ossetia-Alania and spread further northward, affecting both domestic pigs and wild boar. Since its introduction in 2007, the ASF epidemic in Russia is characterised by unpredictable long-distance jumps followed by local epidemics. Delayed intervention strategies and inappropriate financial compensation have led to underreporting by small-scale farmers and inappropriate disposal of dead or infected pigs (including illegal selling of apparently healthy pigs) increasing the transmission (FAO, 2013). A key epidemiological role of backyard farms is supported by several statistical models (Korennoy *et al.*, 2014; Vergne *et al.*, 2016, 2017), as well as by observations of seasonality of ASF outbreaks in both domestic pigs and wild boar, coinciding with periods of increased economic activity in this sector. Therefore, the main factors influencing the progressive spread of ASF in Russia were illegal movement of contaminated pork products, large number of backyard holdings, swill feeding and free-range management practices, as well as poor preparedness of regional veterinary services. These factors all contributed to the wide distribution of the disease from Kaliningrad on the Baltic Sea to the Russian Far East. To achieve control of the disease, the majority of small farms with low biosecurity were gradually eliminated.

Since the introduction in 2007 the biological properties of the virus have not changed substantially. Both field observations and laboratory studies indicate that circulating viruses remain highly virulent, manifesting clinically mainly as the acute form with short incubation period (three to five days) and the course of the disease lasting around ten days (Belyanin *et al.*, 2011). In most cases clinical symptoms are nonspecific (anorexia, depression, affected breathing with wheezing, high temperature, in some cases cyanotic discoloration, paresis of the hind limbs, abortion and rhinitis), complicating disease diagnosis.

9.5.3.3 Belarus

So far two ASF outbreaks in domestic pigs have been notified in Belarus, both in 2013. No cases in wild boar have been reported. There are some indirect signs that this might not be a true representation of the ASF situation in Belarus. According to data from the National Statistic Committee of the Republic of Belarus, the number of domestic pigs decreased significantly in 2014-2015 (Federal Service for Veterinary and Phytosanitary Surveillance in Russia, 2018) and again in 2019-2020. Likewise, information collected from open sources in 2013-2014 by the Federal Service for Veterinary and Phytosanitary Surveillance in Russia reveals many cases of ASFV PCR positive pork products imported to Russia from Belarus in 2014-2018 (Federal Service for Veterinary and Phytosanitary Surveillance in Russia, 2020). In addition, a decision of the government of Belarus to significantly reduce the wild boar population indicates possible concerns about disease transmission in this species.

9.5.3.4 Ukraine

The first ASF outbreak in Ukraine was notified in July 2012 in the Zaporozhye region on the Black Sea coast. Two years later a wild boar was found dead on the riverside on the border with Russia. At the end of 2016, several outbreaks affecting domestic pigs and wild boar occurred in the southern part of Ukraine, bordering Hungary. In 2018, ASF had affected domestic and wild boar populations of all Ukrainian regions.

8.5.3.5 Moldova

The first ASF outbreaks in Moldova were registered in small backyard farms in the northern parts on the border with Ukraine in September 2016. Feeding swill containing leftovers from infected pork and pork products originating from Ukraine has been hypothesised as the introduction route. Currently, most of the outbreaks in domestic and wild pigs are concentrated along the border with Romania.

The emergence of ASF from Georgia and the Caucasus region can to some extent be explained by the domestic pig husbandry systems in the affected countries with many small-scale farms with pigs frequently roaming free, the common socio-economic relationships between the countries in the region based on shared history and culture, as well as the neglected status of veterinary service systems in the post-Soviet era.

9.5.4 African swine fever in the EU 2014-present

On January 24th 2014, ASFV was confirmed in two wild boar carcasses found by the Lithuanian veterinary authorities. Three weeks later, on February 17th and 18th, two cases in wild boar were confirmed in Poland. These four cases of wild boar found dead represented the start of what would become the second major epidemic of ASF within the EU, approximately 20 years after the end of the first. During the following months ASF also appeared in Latvia (by the end of June) and in Estonia (September). In Lithuania, Poland and Latvia the virus was first detected in wild boar found dead not far from the national borders with Belarus, suggesting multiple separate initial introductions of ASFV to the EU, most likely through transboundary movements of infected wild boar. At the time, Belarus had only notified two outbreaks of ASF, both in backyard pigs and far from the border to the EU. However, it has been speculated that the disease was also present in the Belarussian wild boar population, and that depopulation campaigns were carried out in an effort to control the disease. Intensive hunting is known to lead to dispersion of wild boar, and such a depopulation campaign may thus have facilitated the progressive geographical spread of the disease (EFSA AHAW Panel, 2014; Pejsak *et al.*, 2014).

The first years of the epidemic in the EU were characterised by slow geographical expansion of the disease within the affected member countries, dominated by cases in wild boar, and only sporadic outbreaks in domestic pig farms. In contrast to what was initially predicted, the epidemic thus seemed to be driven by wild boar, and ASFV circulation to be maintained within the affected wild boar population independently from outbreaks in domestic pigs (Chenais *et al.*, 2019a). In this new epidemiological scenario, described as the wild boar-habitat cycle, infected wild boar carcasses and the virus contaminated environment are believed to constitute the long-term source of the virus needed to maintain the virus circulation over time (Chenais *et al.*, 2018).

Whereas local disease expansion occurred through natural movements of infected wild boar, longer distance translocations of the virus, locally or regionally within affected countries or to more distant and previously unaffected parts of the EU, were most likely related to human activities (EFSA, 2018). ASFV contaminated meat products originating from an affected area and left in the environment in reach for hungry wild boar are often mentioned as a likely source of virus for naïve populations, although alternative routes of introduction are also possible, and the true route rarely known. The incursions of ASFV to the wild boar population around the city of Zlín, in the eastern parts of the Czech Republic, during the summer of 2017, and to the wild boar population in the province of Luxembourg in southern Belgium during the summer of 2018, are both believed to be the result of such human mediated spread. On both occasions, the disease was confirmed very unexpectedly in wild boar found dead far away from the nearest reported case, more than 400 km and 800 km, respectively. Similarly, the incursions of the virus to Romania in 2017, to Hungary and Bulgaria in 2018, to western Poland in 2019 and to Greece in 2020 were associated with human activities.

In spite of extensive measures implemented to control the disease in the affected countries and to prevent further spread, the geographical expansion within the EU has continued. After the first long distance translocation of the virus, to the Czech Republic in 2017, at least one new country has become affected each year: the Czech Republic and Romania in 2017, Hungary, Bulgaria and Belgium in 2018, Slovakia in 2019, and Greece and Germany in 2020. The total number of reported wild boar cases has increased from year to year, from around 250 in 2014, to almost 4,000 in 2017 and almost 6,500 in 2019. However, at the same time the number of outbreaks in domestic pigs has been limited in most of the affected countries, and any extensive secondary spread within the pig sector has been prevented. Romania constitutes the exception. After a second incursion of the virus during summer 2018 in the area around the Danube delta, a dramatic epidemiological evolution emerged. A first outbreak was confirmed in a backyard farm in Tulcea county on June 10th, and on June 12th a first case in wild boar was reported (EFSA, 2018). Four months later the number of reported outbreaks in domestic pigs had reached almost 1000, whereas less than 100 cases in wild boar had been confirmed. Since then, the disease has spread widely within the country, mainly affecting backyard holders, but also a number of large and very large commercial farms. The observed epidemiological pattern remains different from the other affected countries in the EU, with outbreaks among domestic pigs by far outnumbering cases in wild boar (3,211 in pigs compared to 1,422 in wild boar by 1 July 2020). Most likely this observed pattern is associated with the characteristics of the pig sector in Romania, with a very large proportion of the more than four million pigs kept in backyard farms with low levels of biosecurity, and with disease spread between farms driven by human activities. Thus, the situation in Romania reflects the domestic pig epidemiological cycle of ASF, rather than the wild boar-habitat cycle that dominates in most of the other affected countries in the EU.

To date 12 EU countries have reported cases of ASF in wild boar or outbreaks in domestic pigs within the current epidemic. The economic consequences have been vast (see Chapter 7), and the situation is not yet under control. During the last few years, however, positive signs in the development of the epidemic have appeared in some of the affected countries. In the Czech Republic, early detection and timely implementation of relevant control measures, including e.g. restricted access to the area, intensive surveillance, hunting and fencing, allowed the epidemic to be contained within a small area in the District of Zlín, where it was first introduced. Through enhanced biosecurity requirements on domestic pig farms, outbreaks in domestic pigs could be prevented. The last ASFV positive wild boar, out of a total of 230, was found less than 10 months after the first and, one year later in March 2019, the country was again declared free from ASF (Charvátová *et al.*, 2019). As in the Czech Republic, the ASF epidemic in Belgium was initiated by a long-distance translocation of the virus and a localised incursion into the wild boar population. After confirmation of ASFV in two wild boar carcasses found in the province of Luxembourg, located only 12 km from the border with France, a control strategy based on the successful Czech experience was implemented. And just as in the Czech Republic, the strategy seems to have worked. The epidemic has been contained within a rather limited area, and without spill over to domestic pigs. The last fresh positive case was found in August 2019, 11 months after the first (Dellicour *et al.*, 2020). Thus, Belgium also seems to be well on the way towards regaining freedom. Likewise, in Estonia and Latvia positive trends have been observed. In Latvia the numbers of outbreaks in domestic pigs as well as cases in wild boar are decreasing markedly, especially in the eastern parts of the country that was infected first (EFSA, 2020; Oļševskis *et al.*, 2020; Schulz *et al.*, 2020). In Estonia no cases had been detected for 19 months then two positive cases in wild boar were detected in August 2020 in one hunting ground in the western parts.

9.6 Regulatory framework for prevention and control of African swine fever in the EU

ASF is one of the five diseases listed in the new animal health law of the EU (EC, 2016), considered to be highly transmissible with risk for transboundary spread. The other diseases are foot and mouth disease (FMD), classical swine fever (CSF), African horse sickness and highly pathogenic avian influenza (HPAI). These five diseases all pose risks to animal health and have the potential to cause major economic losses (with HPAI having additional public health implications). Control of ASF follows the common concept for controlling infectious diseases as stated in Directive 92/119/EEC (EC, 1992). Roughly, as soon as the presence of the disease is suspected, immediate actions have to be taken to confirm or exclude ASF. Once the disease is confirmed, the infected holding has to be depopulated. Further spread must be prevented by tracing contact holdings, monitoring movements of animals and potentially contaminated products, and by establishing surveillance and protection zones around the outbreak. The CSF directive (Council Directive 2001/89/EC; EC, 2001) has been used as a model for drafting the ASF directive (Council Directive 2002/60/EC; EC, 2002) and the ASF measures currently in place in the EU thus follow the measures foreseen to control and eradicate CSF. The measures are based on the assumption that ASF, like CSF, is a highly contagious disease, which rapidly spreads from pig to pig or from farm to farm. The aim of all activities is to eradicate the disease inside the affected area(s) and, at the same time, allow trade and movement of animals and animal products outside the restricted regions so that ’business as usual‘ can continue. In summary, the measures should not only lead to the eradication of the disease, but also protect the pig industry outside the restricted regions, keeping trade and business going.

The measures foreseen in the EU legislation set a minimum standard. National authorities can implement additional and more severe measures if deemed necessary, as can the European Commission. This was the case during the current epidemic.

9.6.1 Control of African swine fever in domestic pigs

Suspicion of ASF is raised if a pig exhibits clinical signs, shows post-mortem lesions or reactions to laboratory tests that indicate the possible presence of ASFV. In such a case, the holding has to be placed under official surveillance until the ASF situation is clarified. The most important measures in case of suspicion include to count all the pigs in the various categories on the holding and compile a list of the number of pigs already sick, dead or likely to be infected in each category, and further to construct a map of the holding for the epidemiological investigations. All pigs shall be restricted to their living quarters and no pigs or pig products should leave the holding until the final results exclude the presence of ASF. In addition, the movement of persons and vehicles to or from the farm should be restricted and appropriate means of disinfection used at the entrance and exit of stables.

Upon confirmation of ASF immediate measures have to be taken in the affected holding. All pigs on the holding have to be euthanised without delay and a sufficient number of samples taken for further epidemiological investigations, in particular for tracing the virus introduction and for estimating the high-risk period (HRP, the likely length of time that ASF has been present on the farm prior to the notification). Further, an epidemiological inquiry should be conducted to estimate the HRP, determine the possible origin of the virus, trace possible contact holdings that could have been infected from the same source and determine if vectors (e.g. soft ticks) or feral pigs (wild boar) caused the infection. Live pigs, slaughtered pigs, meat, meat products, semen, ova or embryos, etc. which left the holding during the HRP should be traced and cleaning and disinfection of the holding (see Chapter 11 for details on the procedures) should be performed.

A protection zone with a radius of at least three km and a surveillance zone with a radius of at least ten km has to be established around the outbreak site. When establishing zones, the authorities must take account of the results of the epidemiological inquiry, the geographical situation (particularly natural or artificial boundaries), the location and proximity of holdings, patterns of movements and trade in pigs, availability of slaughterhouses and facilities for processing carcasses as well as the facilities and personnel available to control movement of pigs within the zones. The latter is particularly important if the pigs to be euthanised have to be moved away from their holding of origin. The measures in the restricted zones primarily aim to identify further holdings that might be infected with ASFV. A census of all holdings has to be carried out as soon as possible and pigs on all holdings examined clinically. All dead or diseased pigs have to be examined for ASF. Furthermore, random samples for laboratory examination have to be taken from all holdings in the protection zone, and in case of suspicion, from holdings in the surveillance zone. A second important set of measures aim to prevent a possible virus escape from the restricted areas by implementing a standstill policy. Movement and transport of pigs is prohibited and pigs may not be moved from the holding in which they are kept. Also, other domestic animals may not enter or leave the holdings (in the surveillance zone only during the first seven days of restriction). Trucks or vehicles are not allowed to leave the zones without being cleaned and disinfected. Persons entering or leaving pig holdings have to comply with appropriate hygiene measures to reduce the risk of ASFV transmission.

The measures can be lifted only if the sampling and testing programme has been completed and the presence of ASF has been ruled out. However, restrictions cannot be lifted earlier than 30 days after cleaning and disinfection have been completed in the infected holding in the protection zone, and 20 days in the surveillance zone. Restocking of pig holdings which were infected with ASFV can take place not earlier than 40 days after cleaning and disinfection have been completed. It is advisable to introduce sentinel pigs before repopulating the farm.

9.6.2 Surveillance of African swine fever in domestic pigs

The main strategic aims of surveillance in domestic pigs are early detection of potentially infected holdings, and to prove freedom from disease in a previously infected region or country. Surveillance is compulsory in the protection and surveillance zones around outbreak holdings, as well as in holdings located in areas that are under restrictions due to the presence of ASF in wild boar.

Nowadays surveillance is mainly based on passive surveillance, testing sick and dead animals for the presence of ASFV. This has proved to be the most efficient strategy (Danzetta *et al.*, 2020). The passive surveillance approach is based on the very high case fatality rate of ASF (>90%), which means that almost all infected animals will become sick and die. Contagiousness, on the other hand, is relatively low and only few animals in a holding are affected at the beginning of an infection (initial low mortality) (Chenais *et al.*, 2019a; Schulz *et al.*, 2019a). Seropositive animals are found only during an advanced stage of the epidemic. Therefore, active surveillance based on random sampling for serological testing is not recommended anymore for early detection of ASF. Nevertheless, the EU legislation on ASF diagnosis (Decision 2003/422; EC, 2003) has not been updated and random serological testing of holdings within the protection and surveillance zones is still requested for lifting restrictions.

However, in areas under restriction due to ASF in wild boar, it is recommended to conduct passive surveillance and to sample diseased animals (animals showing clinical signs resembling ASF, e.g. fever or haemorrhagic lesions), dead animals (at least the first two deaths each week in each production unit with post weaning pigs or pigs older than two months) as well as animals with ante or post-mortem signs that raise suspicion at home slaughtering (EC, 2014, 2015).

In regions affected by ASF in wild boar, inspections of domestic pig holdings should take place at least once per year through interviews with farmers by an assigned veterinarian who also performs a census of the pigs, checks their identification and assesses the biosecurity of the farm while observing and, if necessary, examining the pigs.

9.6.3 Control and eradication of ASF in wild boar

The practical applications of controlling ASF in wild boar are described in detail in Chapter 8. In 2021, the European Council Directive 2002/60/EC (EC, 2002), which has so far been applied in case of ASF in wild boar in the EU, will be replaced by Regulation 2016/429 and its delegated act 2020/687 (EC, 2014, 2020). This legislation confirms the main elements of Directive 2002/60/EC, including the establishment of an expert group that shall assist the authorities in developing an eradication plan with the major objective of preventing virus transmission to domestic pigs and achieve ASF eradication from the affected wild boar population. The current epidemic has highlighted that containment and eradication of ASF from wild boar populations may be a major challenge and that the disease may persist in an affected area for several years. Under these circumstances it is not yet clear when disease prevention and control measures, including trade restrictions concerning domestic pig farms, can be safely lifted in an area where ASF appears to have been successfully controlled and eradicated from wild boar.

9.6.4 Conclusions and recommendations

In the new animal health law of the EU (Regulation 2016/429; EC, 2016) disease-specific rules for prevention and control apply for the listed diseases. Furthermore, preventive and control measures should be 'tailor made' in order to address every disease's unique epidemiological profile, consequences and distribution within the EU. In the past, ASF was often described as a highly contagious disease with high mortality affecting large number of pigs within an epidemiological unit. However, analyses of the domestic pig outbreaks in the current epidemic, as well as experimental studies, have revealed that the contagiousness is rather low, and that under field conditions ASFV transmission between animals can be a slow process (Chenais *et al.*, 2019a; Schulz *et al.*, 2019a). Consequently, ASF control and eradication measures need a different approach compared to highly contagious diseases, such as FMD or CSF (Figure 9.6).

Spread of ASFV in domestic pigs is mainly facilitated by human activities and insufficient farm biosecurity. Therefore, epidemiological tracing of contact farms is paramount for identifying secondary infections and stopping disease spread. A holding located outside a restricted area but linked to an infected farm through human activities can be under higher risk than a holding with good biosecurity within a protection or surveillance zone. Based on the experiences gained during the last years a correction of disease control measures, particularly concerning tracing and detecting of potentially infected holdings is needed. Detailed epidemiological farm investigations combined with a surveillance scheme based on enhanced passive surveillance would be advisable. In particular, updated guidelines are needed for sampling procedures in holdings where pigs

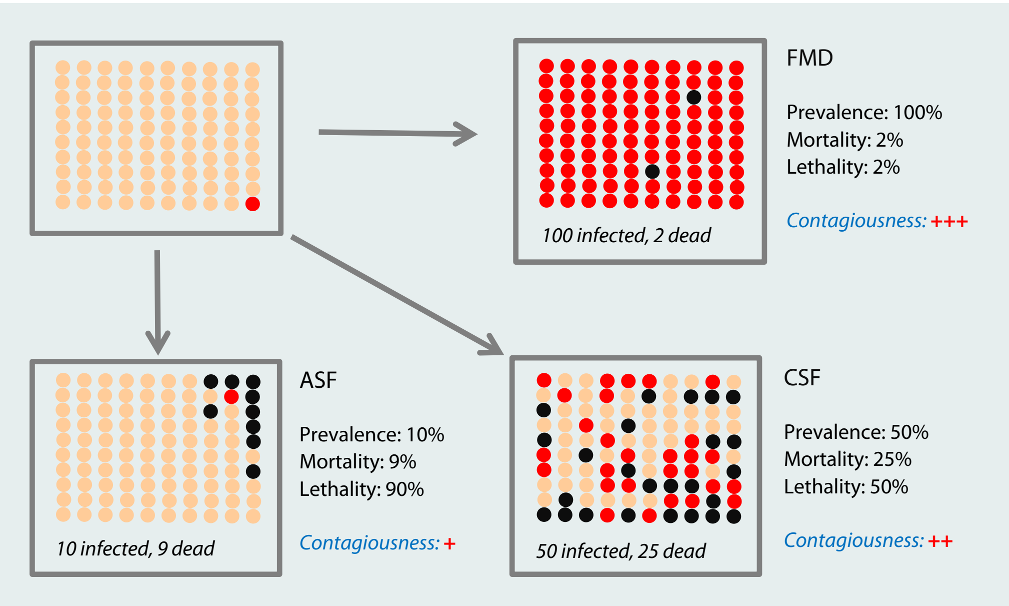

Figure 9.6. Exemplified disease spread of three major pig diseases highlighting the epidemiological differences between foot and mouth disease (FMD), classical swine fever (CSF) and African swine fever (ASF). Red dot = infected animal, black dot = dead animal.

are euthanised following confirmation of the disease; in holdings located in the protection and surveillance zones before lifting the restrictions; when pigs are euthanised as a prevention measure on a suspect holding; before authorisation is given to move pigs from holdings located in protection or surveillance zones and in case these pigs are slaughtered or euthanised; and in holdings being repopulated.

In this context, it is also advisable to redefine the size of the restriction zone, for example the effect of the surveillance zone on the prevention of ASF spread should be evaluated. Random sampling of holdings for serological screening within the restricted areas, as it is stated in the present EU legislation (Decision 2003/422/EC; EC, 2003), will not provide certainty of virus freedom. Apart from wasting human and laboratory resources, the effect of such a measure might instead be a false sense of security.

The better early detection surveillance schemes for detecting potentially infected holdings are implemented, the earlier infected farms are found, meaning that only one or a few animals will be virus positive on detection. This leads to a paradoxical situation regarding the acceptance of the depopulation measures, which have to follow without any delay. Due to this dilemma, alternative culling schemes for large farms with only few infected animals should be developed. For that to be possible, good management, strict internal biosecurity measures and intelligent farm surveillance schemes need to be in place.

9.7 Final remarks

Before 2007, ASF was known as a transboundary emerging disease, geographically limited to the African continent and Sardinia (with the exception of the epidemic on the Iberian Peninsula and the connected outbreaks in the latter half of the 20th century). Unfortunately, at the date of writing, the disease is widespread in large parts of Europe and Asia (Dixon *et al.*, 2019). The global dimension of the current epidemic, including the long distance translocations and incursions, shows that all countries need to be prepared: human-mediated dispersal to domestic or wild boar populations can occur at any time and to any country, regardless of the distance from ongoing infections in wild boar populations (Chenais *et al.*, 2019a).

The introduction of ASF to Georgia, and subsequently to the EU, sparked a new era of global ASF research, leading to descriptions of the specific characteristics of ASF epidemiology in the presence of wild boar and Northern European climates, as well as the identification of the wild boar-habitat epidemiological cycle (Chenais *et al.*, 2018, 2019a). The wild boar-habitat epidemiological cycle is thus almost a hundred years short of epidemiological research compared to the ancient sylvatic cycle and the domestic pig epidemiological cycles of ASF, and the transmission risks from this cycle to the domestic pig cycle are still not fully understood. Having said that, the major challenge in achieving control of ASF in Europe seems now not necessarily technical, but rather relating to the specific needs and circumstances of stakeholders in the domestic pig production and wild boar value chains in affected areas. Especially in the parts of Europe where pig production is still dominated by smallholder systems involving mostly poor farmers, low-cost control options fully adapted to the local context and highly accepted by the end users are required to achieve control (Chenais *et al.*, 2019b). National legislation as well as EU regulations set out clear solutions for controlling ASF. However, if these rules are not implemented at the local level where the disease is transmitted during the daily activities of people, they are of no value for disease control and eradication. Stakeholders in the pig production and wild boar value chains are largely aware of these legislations and regulations, but implementation is despite that far from fully executed. It is becoming clear that epidemiological knowledge alone is not sufficient to control ASF, and that understanding of local sociocultural, economic and political dimensions, as well as individual keys to effective communication is equally important (Chenais *et al.*, 2019a; Jori *et al.*, 2020; Loi *et al.*, 2019b). In both the wild boar-habitat and the domestic pig epidemiological cycle of ASF, fully implemented biosecurity is the key for stopping virus transmission and controlling the disease. The positive examples from Sardinia, the Czech Republic and Belgium show that control and finally also eradication of ASF can be achieved, but also that to reach this goal, all stakeholders in the value chains from farmer and forests to fork need to be involved, engaged and understood.

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