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Dynamics of the African swine fever spread in Poland

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Abstract

Introduction: African swine fever (ASF) is a lethal haemorrhagic disease of Suidae, present in Poland since 2014. The natural reservoir of ASF in Europe is the wild boar (*Sus scrofa*); however, human activity facilitates long-distance introductions of the disease. In ASF control it is important to identify areas at increased risk of infection. Such identification and estimation of the disease's progress and subsequent spread will help to identify the specific preventive action needs in given zones. Serving this purpose, this study is a spatial and statistical analysis of ASF spread through noted outbreak data. **Material and Methods:** The spatial-temporal analysis was conducted on the basis of data including the time and location of all ASF outbreaks both in wild boars and domestic pigs in Poland in 2014–2021. **Results:** The analysis indicates possible routes and directions for further ASF spread in Poland, estimates the annual increase of the affected area (approx. 25,000 km^2 every year since 2017) and marks trends. The strong method-independent correlation between the year and the surface area affected by African swine fever indicated a near-linear generalised trend. **Conclusion:** Given the growth trend, we can expect ASF to expand further into new territories of the country; however, it is important to realise that there is still a significant area to protect, because 60% of Poland remains ASF-free.

Keywords: ASF, spread, spatial analysis, geostatistical analysis, Poland.

Introduction

African swine fever (ASF) is a lethal haemorrhagic disease of Suidae, which has been present in Poland since 2014 (29). There are 24 different genotypes of the ASF virus (ASFV) described (31). All of them are present and endemic in Africa (15); however, two of them – genotypes I and II – are also present on other continents. Genotype I caused the first wave of the epidemic in Europe (which started in 1957 in Portugal) and remains prevalent on Sardinia (Italy) (15, 19). Genotype II circulates in Europe, Asia and on the island of Haiti, and is a major threat to the global pig industry (31).

The current worldwide epidemic of ASF started in 2007. The first affected country was Georgia and later the disease spread to neighbouring countries in the Caucasus region and the Russian Federation. The disease reached the European Union (EU) in 2014, first affecting Poland and the Baltic states (Lithuania, Latvia and Estonia) (15, 23, 25, 29, 31). In a few years the disease affected other EU countries: the Czech Republic, Romania (2017), Bulgaria, Hungary, Belgium (2018), Slovakia (2019), Greece, Germany (2020) (33) and recently continental Italy (2022) (40). In August 2018, ASF was detected in China – the world's largest pig producer – and also affected neighbouring countries (31). In 2021 ASF was detected in the Dominican Republic (17) and in the same year in Haiti (31).

The natural reservoir of ASF in Europe is the wild boar (*Sus scrofa*). According to the European Food Safety Authority (EFSA), the average speed of ASFV transmission related to natural virus circulation in the wild boar population of Poland and the Baltic states is from 8 to 17 km per year (5). During the reproductive season the contact rate between animals and migration rate are much higher; therefore, researchers have hypothesised that it might accelerate the spread of ASF (10, 30). The average litter size ranges from 3 to 7 (and sometimes even from 11 to 15) in wild boars, and the species' fecundity might spare the wild boar population any severe effect of deaths caused by ASF (10). However, data from Estonia indicate that drastic reduction of the wild boar population using an artificial method, such as hunting, might slow down or even stop the ASF epidemic. This might be achieved only after the reduction of the wild boar population density to 0.1 wild boar/km^2 on the hunting grounds (9), which is not easy in areas with high afforestation (9, 12, 34, 36).

Unfortunately, wild boars are not the only problem. Human activity plays a major role in long-distance ASFV introduction (1, 10, 41). There are several examples of such ASF "jumps": in the Czech Republic (2017); in Belgium (2018) (2); in the Piedmont region of Italy (2022) (42); and in Poland, from the east of the country to the Warsaw metropolitan area (2017) (13) and to Lubusz province (2019) (12). Lack or inadequacy of biosecurity on a farm may facilitate the entry of the virus. In this context, all the ASF control efforts of reduction of the wild boar population and passive and active surveillance monitoring may be undermined by mistakes in biosecurity (12, 42). The disease was also reported on farms with high biosecurity, in Poland as well in other European countries (5, 7, 42).

The EU ASF epidemic started in 2014, subsequently affecting mainly the middle and eastern countries of the community (29). In the Baltic states, the disease has been recorded over almost their whole area (32). In Latvia, Lithuania and Estonia, a decline in the number of ASF-positive wild boars and a rise in the number of serologically positive animals among them has been observed (11, 35). One of the explanations for this phenomenon is the vertical transmission of anti-ASFV antibodies to young wild boars; however, it does not clarify its occurrence in adult wild boars (41). In recent years, a significantly higher number of serologically positive wild boars than molecularly or virus-positive ones was observed in Estonia, where in the period from February 2019 to October 2020 all ASF-positive results were identified by serological analysis (only the presence of antibodies against ASFV) (34). In recent years, during an initiative to close down illegal pig farms on Sardinia (Italy), where ASFV has been endemic since 1978, 36.5% of the pigs were identified as anti-ASFV serologically positive, while only 1.2% of the animals were virus positive (14). Such a large proportion of potential survivors betrays endemicity of the disease, which is actually confirmed in the case of Sardinia and the Baltic states (11, 32). In contrast, in Germany where ASFV has only been noted since 2020, most ASF-positive wild boars are molecularly or virus positive, which indicates the epidemic to still be in an early phase (32).

ASF has been present in Poland since 2014, as it has been in the Baltic states; however, approximately half of Polish territory is still ASF free (11, 12). The situation is slightly different to that in the Baltic states, where the disease seems to be endemic, and also different to that in Germany, where it is clearly epidemic (11, 32, 33). In Poland in the period 2014–2020, an increase in serologically positive wild boars (as in the endemic phase of ASF) is observed in the areas where the disease has been circulating for a longer time; however, the number of molecularly or virus-positive animals is still significantly higher than the serologically positive number (as in the epidemic phase) (11, 41). In addition, in 2020 and 2021 ASF outbreaks in domestic pigs occurred in large numbers in Poland (respectively 103 and 124 outbreaks), while they did not occur or did so sporadically in neighbouring Germany and in the Baltic states (16, 38). In the current year (2022) up to 7 September, 14 ASF outbreaks in domestic pigs in Poland were notified (16).

In terms of disease control in Poland, it is important to identify and map areas where domestic pigs are at increased risk of infection. Identification of these areas and estimation of the progress and the spread of the disease will help the veterinary services and decision-making administrative bodies to identify the appropriate preventive actions to take in unaffected areas. The large number of studies carried out in Poland has provided reasonably precise data, which, when analysed with geostatistical tools, make it possible to monitor the epidemic situation, predict the spread of the disease and consider potential connections.

The analysis of the past years may indicate the routes and directions of the further ASF spread in Poland, both in wild boars and domestic pigs. The aim of the study was to analyse the ASF spread in Poland spatially and statistically by mining an operating database of ASF outbreaks.

Material and Methods

Spatial-temporal analysis was performed on time and location data for all ASF outbreaks in wild boars and domestic pigs in the country in 2014–2021 (Figs 1 and 2). These data were collected and processed for this purpose in a database created specifically for the task, and the appropriate point layers of the maps representing ASF outbreaks were built with the use of commercial geographic information system (GIS) software. At the mapping stage, these data were integrated into a map of Poland showing the administrative divisions and containing additional data layers, such as locations of water reservoirs, the Vistula river or large cities. The sectors currently subjected to ASF restrictions were also laid onto the map in their three types subjected to various restrictions in accordance with Annex II to European Commission Implementing Decision 2021/605/EU (4) (Fig. 3). The maps developed in this way were subjected to further spatial analysis: the areas of ASF occurrence were outlined in the form of 10-kilometre buffer zones. These zones were areas with a radius of 10 km as the sum of the minimum assumed areas of the 3-km protection zone and the 7-km risk zone around the points where the disease was identified. They were aggregated to homogeneous polygons, trimmed to the borders of Poland, and then their surface area was calculated as the basis for further statistical analyses. All these operations were repeated at annual intervals on the data for the period 2014–2021. This enabled the spread of the disease to be visualised year by year.

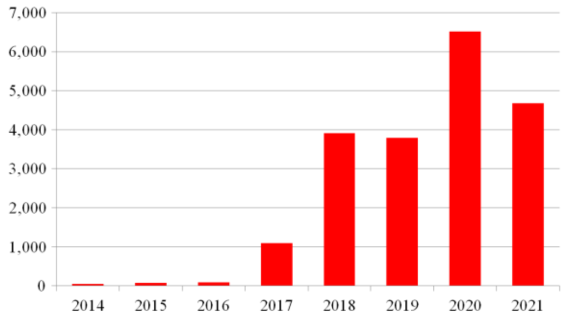

Fig. 1. Number of wild boars identified positive for African swine fever in Poland by year

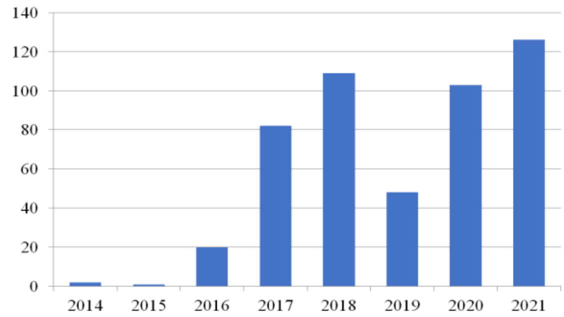

Fig. 2. Number of ASF outbreaks detected in domestic pigs in Poland by year

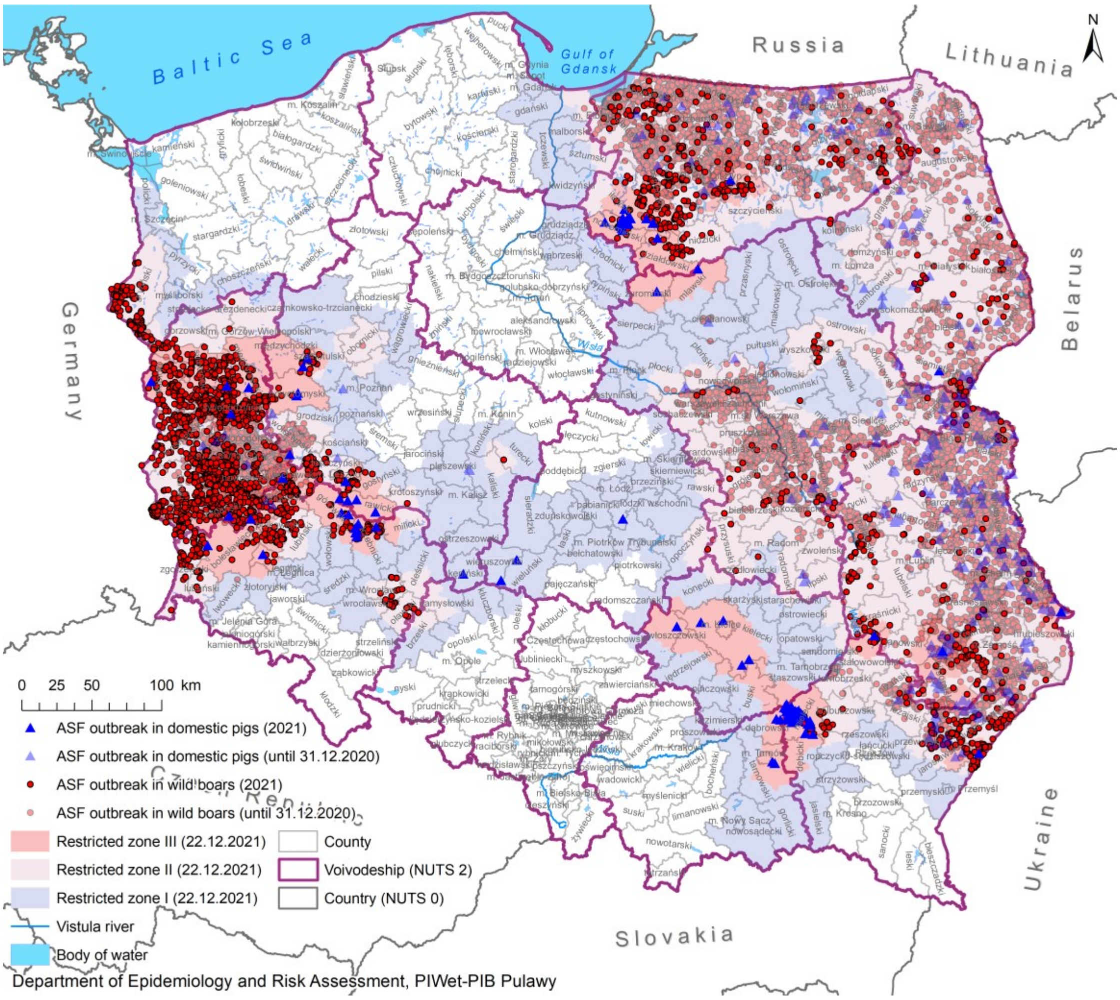

Fig. 3. African swine fever (ASF) outbreaks in domestic pigs (blue) and wild boars (red), and restriction zones (as of 31/12/2021). Outbreaks in 2021 are shown in intense colours, and outbreaks in 2014–2020 in pastel colours. NUTS – nomenclature of territorial units for statistics

Three types of sector were analysed, designated as the one-year geographical extent of outbreaks in domestic pigs and wild boars, the multi-year cumulative geographical extent of outbreaks in domestic pigs and wild boars, and the multi-year cumulative geographical extent of outbreaks only in wild boars. Based on 10-kilometre buffer zones, the annual percentage of the area of Poland affected by African swine fever was calculated to serve as the basis for inferring the size of the increase in this area. Then, the areas where the disease occurred in a given year were analysed, cross-referencing them to the number of events (outbreaks in domestic pigs and positive wild boars), which allowed for the assessment of their density/dispersion in each year. These were derived from the sum of the number of outbreaks in domestic pigs and the number of positive wild boars, as well as the number of positive wild boars alone, being divided by the surface area of the ASF-affected terrain in a given year for density and by the cumulative surface area for dispersion. The 50- and 100-km buffer zones around the outbreak points recorded from the beginning (2014) to the ends of 2020 and 2021 were also outlined, allowing a visual analysis of the virus expansion in the last year. These areas were also compared with each other and their annual expansion was estimated. Demarcation of the terrain free of the disease up to the time of the last data showed the specific parts of the country in which to take preventive measures to stop the spread of ASF, which are the places where it may occur in the following years. Excel 2016 (Microsoft, Redmond, WA, USA) was used to process data on disease outbreaks, while spatial analyses were performed in ArcGIS 10.4.1 for the desktop environment with the Spatial Analyst and Geostatistical Analyst extensions (Esri Inc., Redlands, CA, USA).

For the formal confirmation of the increasing trend over time in the size of the areas affected by ASF, Pearson's linear correlation coefficients were calculated by checking that all the required assumptions of the method used were met. The significance level alpha = 0.05 was adopted. This statistical analysis was performed using Statistica version 13 (TIBCO Software Inc., Palo Alto, CA, USA).

Results

The maps in Fig. 4 show the ASF outbreaks detected in domestic pigs and wild boars in Poland year by year.

Figure 5 visualises the areas affected by African swine fever by year. These are zones delineated by a 10-km buffer around the point locations of all outbreaks in a given year. Figure 6 shows the overlap of these zones, which displays the annual expansion of the virus in the country. Table 1 collates the numerical data on these zones, with the separation of zones designated in this way only for wild boar outbreaks. A steadily expanding trend in surface area for each of the types of sector can be observed, including annual area increases: in 2015, the area affected by ASF was 102% larger than in 2014, in 2016 it was 154% larger than in the previous year, in 2017 165% larger, in 2018 109%, in 2019 48%, in 2020 28% and in 2021 5%.

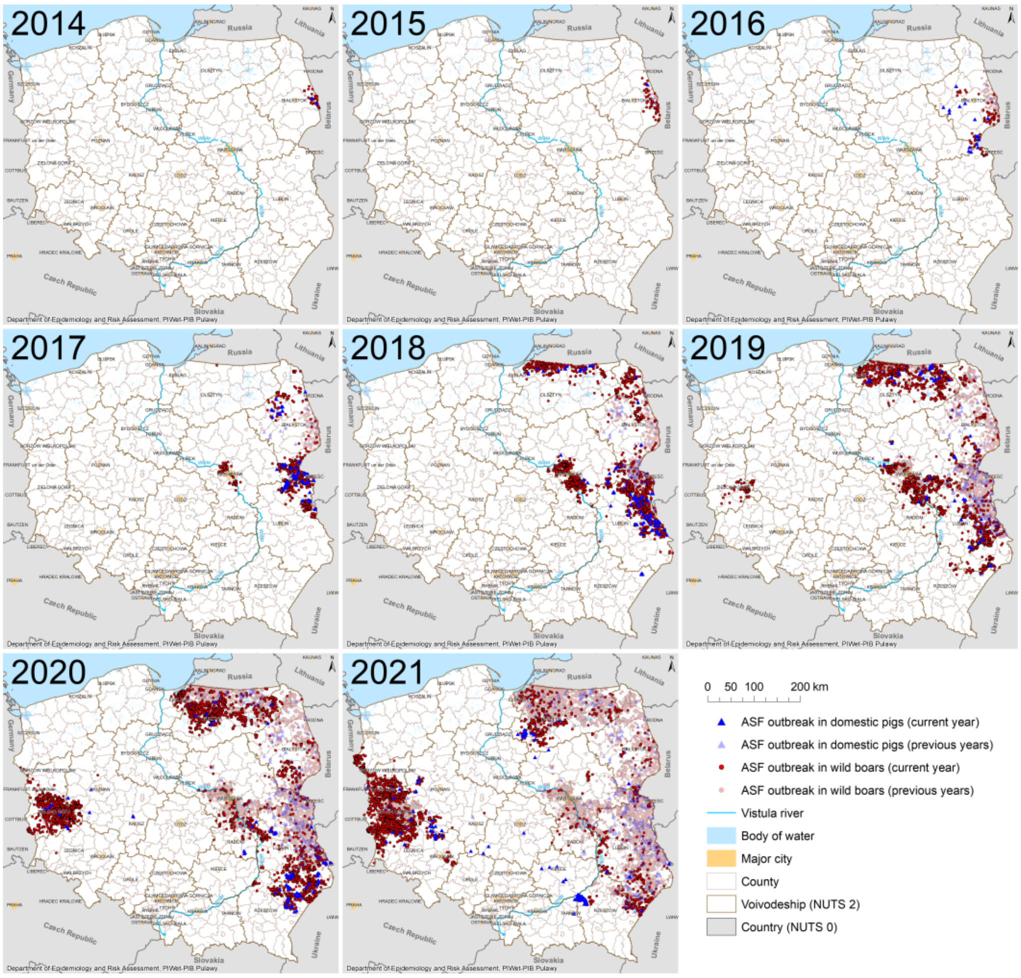

Fig. 4. The progress of African swine fever (ASF) in domestic pigs (blue) and wild boars (red) in the years 2014–2021. Outbreaks in a given year are shown in intense colours, and outbreaks in previous years in pastel colours. NUTS – nomenclature of territorial units for statistics

Table 1. The combined surface area of all 10-km radius buffer zones around African swine fever outbreaks (in km^2)

Year	Outbreaks in domestic pigs and wild boars – single-year area	Outbreaks in domestic pigs and wild boars – multiple-year cumulative area	Outbreaks only in wild boars – multiple-year cumulative area
2014	1,499.6	1,499.6	1,499.6
2015	3,021.7	3,040.6	3,040.6
2016	7,664.6	8,866.7	6,972.0
2017	20,276.4	23,200.5	21,720.7
2018	42,299.1	47,269.9	45,014.8
2019	62,746.2	75,356.9	73,542.8
2020	80,003.1	98,945.1	96,602.8
2021	83,892.4	124,952.2	119,234.8

Table 2. Shooting of wild boars in Poland (37)

Hunting year (from April 1 to March 31)	Hunted wild boars (in thousand head)
2000/2001	93
2005/2006	138
2008/2009	226
2009/2010	218
2010/2011	233
2011/2012	196
2012/2013	240
2013/2014	242
2014/2015	291
2015/2016	342
2016/2017	312
2017/2018	341
2018/2019	266
2019/2020	332
2020/2021	249

It might seem that this dynamic is slowing, because for the last five years we have observed that the percentage increase in the annual affected area has significantly diminished. Additionally, in the last year there was an increase of only 1.2 percentage points over the previous year's statistic in the ASF-affected surface area of Poland (Fig. 5). However, the cumulative values (red and grey graph bars) show that the speed of expansion into new areas has not changed for several years. It should be borne in mind that with an increase of >0%, this percentage is calculated from a larger base each year, *i.e.* the same 1% means more km^2 each year. Furthermore, it has become evident that with the expansion of the virus to new areas, fewer outbreaks have been recorded in the old areas of ASF presence, this having been particularly evident in 2021. Therefore, even with a zero or negative increase in the annual area affected by ASF, an increase in cumulative surface area can be expected. This will be discussed in more detail in the following part of the analysis.

The calculated Pearson's linear correlation coefficients confirmed the upward trend in the surface areas of all three analysed sectors of African swine fever occurrence (Fig. 8). The analysis of the correlation between the year and the surface area of the annual sector for outbreaks in domestic pigs and wild boars, the year and surface area of the multiple-year cumulative sector for outbreaks in domestic pigs and wild boars, and the year and the surface area of the multiple-year cumulative sector for outbreaks in wild boars only gave the value of $r = 0.97$ in each case. All the coefficients were statistically highly significant ($P < 0.0001$ for the *t*-test).

The proportionality of the number of outbreaks in domestic pigs and wild boars or in wild boars alone to the surface area of the affected sector (Fig. 9) trends downwards after the end of 2018. In that year, 340% of the previous year's ASF outbreaks were recorded. Although the increase in the area covered by the disease was relatively unchanged at that time, the severalfold higher number of detected outbreaks in wild boars in the new and previous area resulted in a much greater increase in the numerator in the analysed ratio. In 2019, slightly fewer ASF-positive wild boars were detected, and in 2021 fewer than in 2020 (Fig. 1), with a relatively constant increase in the cumulative surface area of the terrain affected by ASF.

A significant, and perhaps the most direct, interpretation of the proportions given above is the density of outbreaks in a given year, *i.e.* the number of events per square kilometre. For wild boars, comparing this number to the cumulative area, which does not decrease with the next year and at best remains constant (Fig. 9b), and taking into consideration a lower or a much lower number of outbreaks than before, a strong decreasing trend in density is observed. However, a decrease this pronounced can also be triggered by events related to new outbreaks in domestic pigs. There have been situations, most often as a result of human activities, in which a significant number of ASF outbreaks in domestic pigs occurred in a new, often large area, where the presence of the virus had not been recorded previously. This, in turn, causes the denominator (the surface area of the affected sector) to be overestimated when the numerator (the number of outbreaks) rises only slightly, which also results in a downward density trend in such an analysis, although based only on single-year figures (Fig. 9a). The downward trend may, of course, also be due to fewer and fewer outbreaks, which would be a cause for optimism, especially in the case of the cumulative area. However, it would be so only on the condition that the case numbers reflected the real situation and were not the result of failure to detect outbreaks. In turn, an upward trend may be a source of satisfaction if it results from the inhibition of the virus' expansion into new areas and/or the improvement of ASF detection, especially among wild boars. It is also worth noting that in the last season (2020/2021), the smallest wild boar shoot in seven years was carried out (Table 2). A reliable population estimation of game animals would reveal if a downward density trend were only a result of the reduction of the wild boar population in Poland.

The year 2021 turned out to be a record year in terms of the number of outbreaks in domestic pigs (Fig. 2), surpassing 2018 by almost 16%. A three-year rising outbreak number trend emerges from the statistics and repeats itself: 2016–2018 and 2019–2021. There are many indications that for 2022 a lower number of domestic pig outbreaks will be recorded compared to 2021 and 2020, and even to 2019, a salient one being the notification of only a dozen outbreaks by 7 September.

Returning to the issue of the annual areas affected by ASF (10-kilometre buffer zones around the outbreaks), it is worth looking at the surface areas from the last two years for prognosis (Fig. 10). With a slight increase in the area in 2021 compared to 2020 (83,892.4 km^2 *vs.* 80,003.1 km^2, *i.e.* about 4.9%), there is as large an increase as 26,007.1 km^2 (26.3%) in the total cumulative area for all years of the epidemic. It is enough to look at the map to realise what this results from, because a significant part of the surface area in 2021 is constituted by new sectors, and at the same time in a comparable surface area of previously affected sectors no new outbreaks of the disease were recorded in 2021. The new areas affected by ASF in the year 2021, compared only to 2020, have a surface area of 30,519.8 km^2, and the surface area common to 2020 and 2021 is 53,372.6 km^2. Hence, the terrain in the year 2020 where no outbreaks were recorded in 2021 covered 26,630.5 km^2. The surface area of the entire 2014–2020 period where there was no outbreak in 2021 was 41,059.8 km^2. The common terrain for the 2014–2020 and 2021 sectors is 57,885.3 km^2. The area affected by ASF in the years 2014–2021 was exactly 40% of the country's area, and the area where the disease occurred in 2021 alone was 26.8% of it. These and other exact values for all the years can be found in Fig. 7 as percentages of the country's area.

The latest maps (Figs 11 and 12) present the 50- and 100-km buffer zones around all ASF outbreaks at the ends of 2020 and 2021. The surface areas of the 50-kilometre buffer (Fig. 11) were 180,994.8 km^2 at the end of 2020 and 229,255.5 km^2 at the end of 2021 (58% and 73% of Poland's surface area, respectively). The surface areas of the land designated by the 100-kilometre buffer (Fig. 12) were 252,556.1 km^2 at the end of 2020 and 288,202.0 km^2 at the end of 2021 (81% and 92% of the country's surface area, respectively).

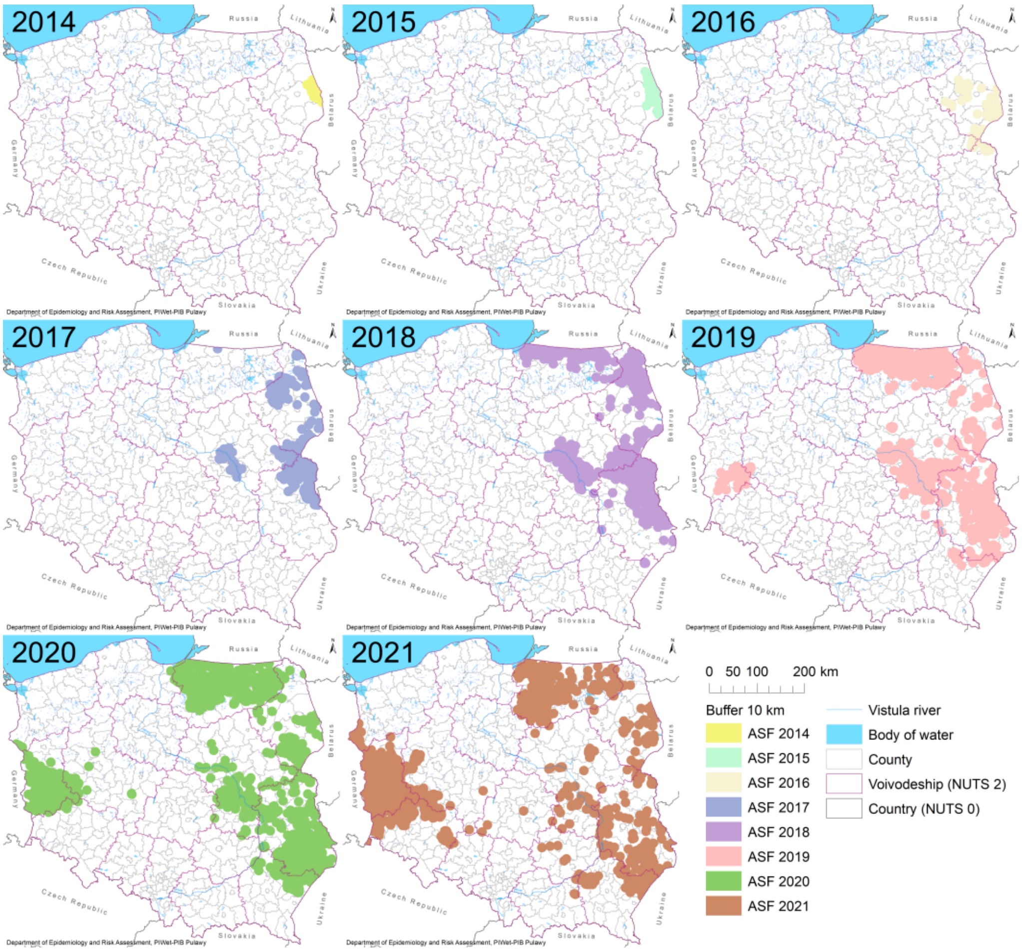

Fig. 5. Areas of African swine fever (ASF) occurrence in the years 2014–2021 shown as zones within 10 km of the outbreaks in domestic pigs and wild boars. NUTS – nomenclature of territorial units for statistics

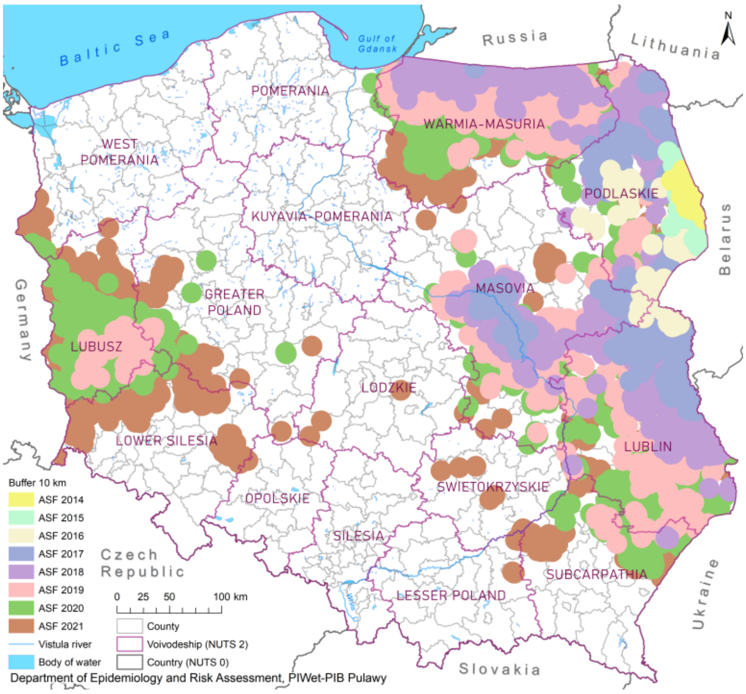

Fig. 6. Annual areas of African swine fever (ASF) occurrence in domestic pigs and wild boars layered over a common map (oldest layer at the top). NUTS – nomenclature of territorial units for statistics

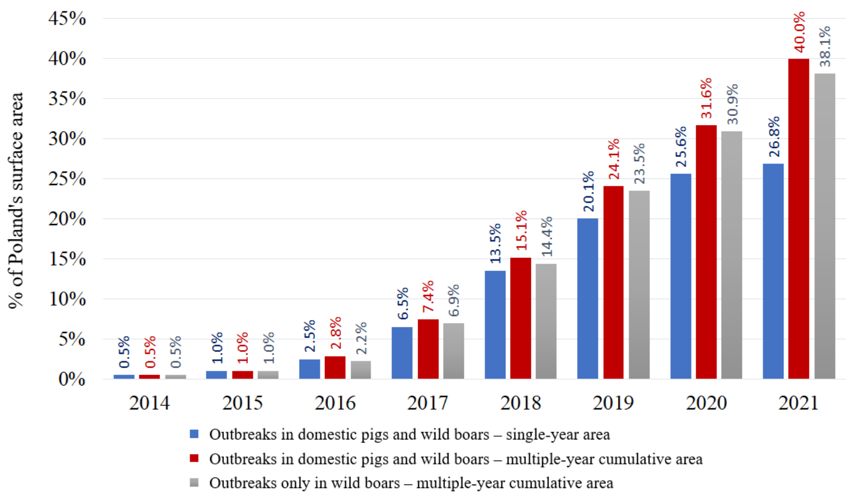

Fig. 7. The combined surface area of the 10-km radius buffer zones around the points where African swine fever occurred over the years in percentages of the surface area of Poland

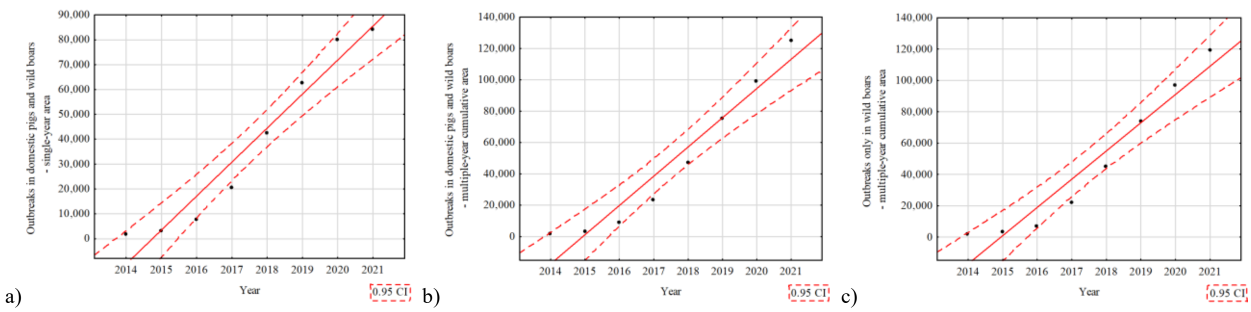

Fig. 8. Scatterplots for Pearson's correlation between the year and the surface area of the African swine fever occurrence zone: a) single-year area for outbreaks in domestic pigs and wild boars; b) multiple-year cumulative area for outbreaks in domestic pigs and wild boars; c) multiple-year cumulative area for outbreaks in wild boars only

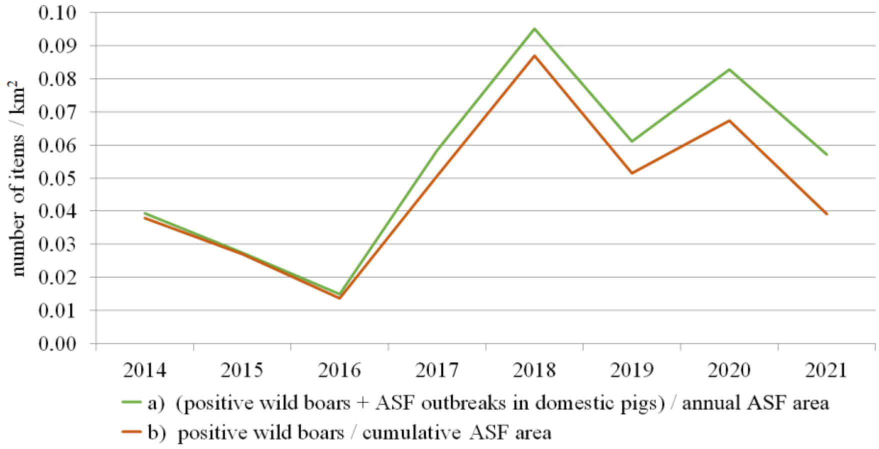

Fig. 9. a) Ratio of the sum of African swine fever (ASF)-positive wild boars and ASF outbreaks in domestic pigs in a given year to the surface area of 10-km-radius buffer zones around the points of these events (units/km^2) – green line. b) Ratio of the number of ASF-positive wild boars in a given year to the cumulative area (from the beginning of 2014) within a radius of 10 km from the sites of ASF outbreaks in wild boars (units/km^2) – orange line

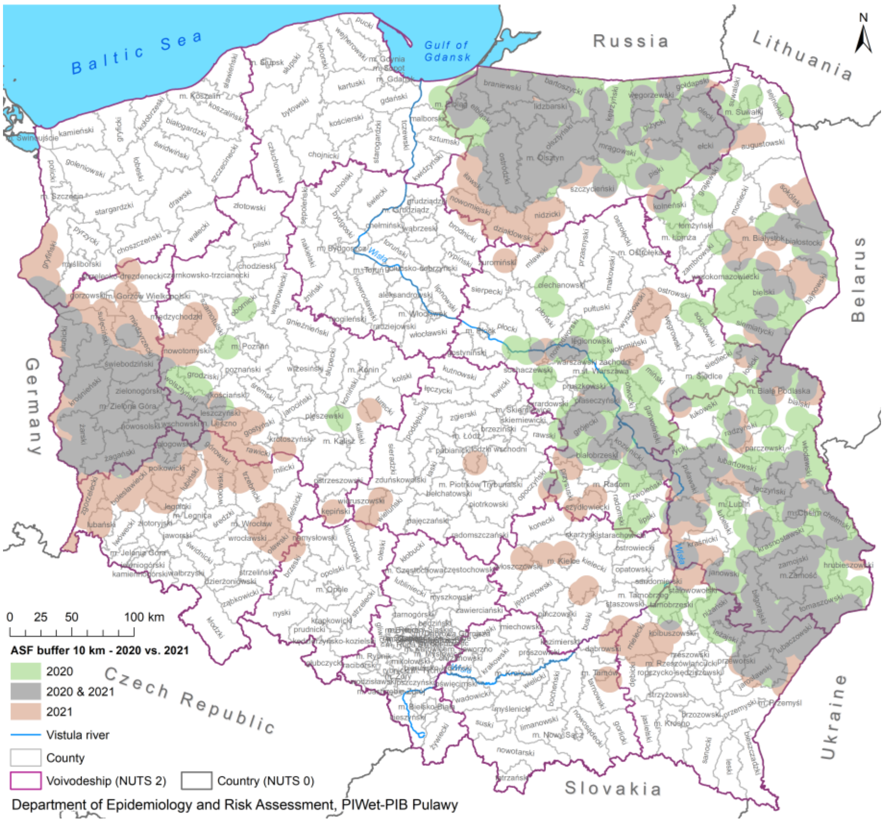

Fig. 10. Comparison of the African swine fever (ASF) occurrence areas (10-km zones around the outbreaks) between 2020 (green) and 2021 (beige). The common area is marked in grey

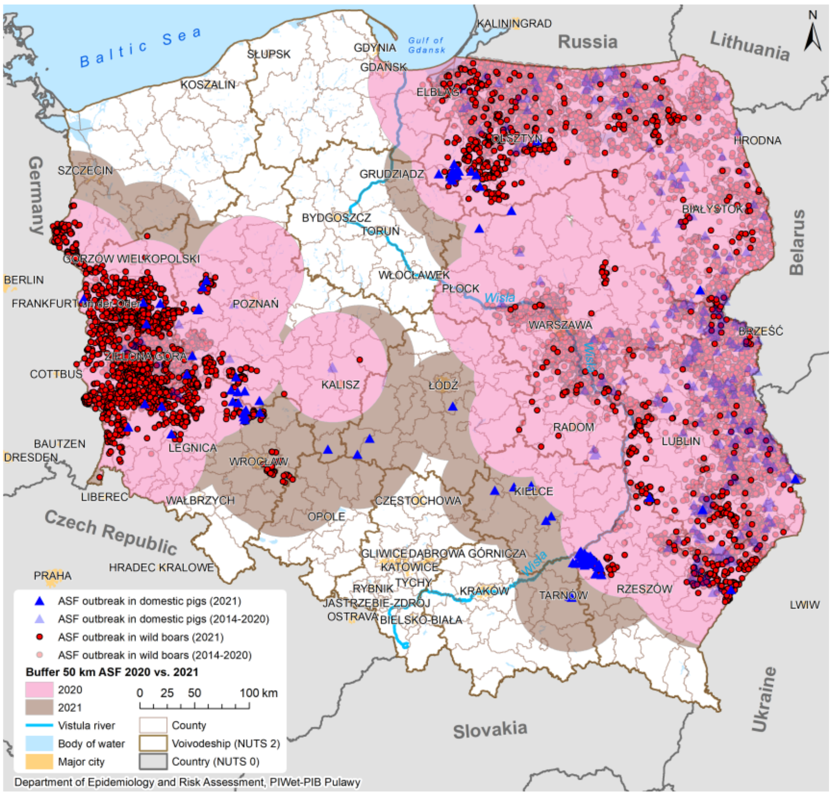

Fig. 11. 50-km buffer from African swine fever (ASF) outbreaks in cumulative periods of 2014–2020 *vs*. 2014–2021. Pink shows the area for 2014–2020 (it is also the common part for both periods, *i.e.* for the buffer zones drawn at the ends of 2020 and 2021). Light brown represents the buffer surface area increase in 2021. NUTS – nomenclature of territorial units for statistics

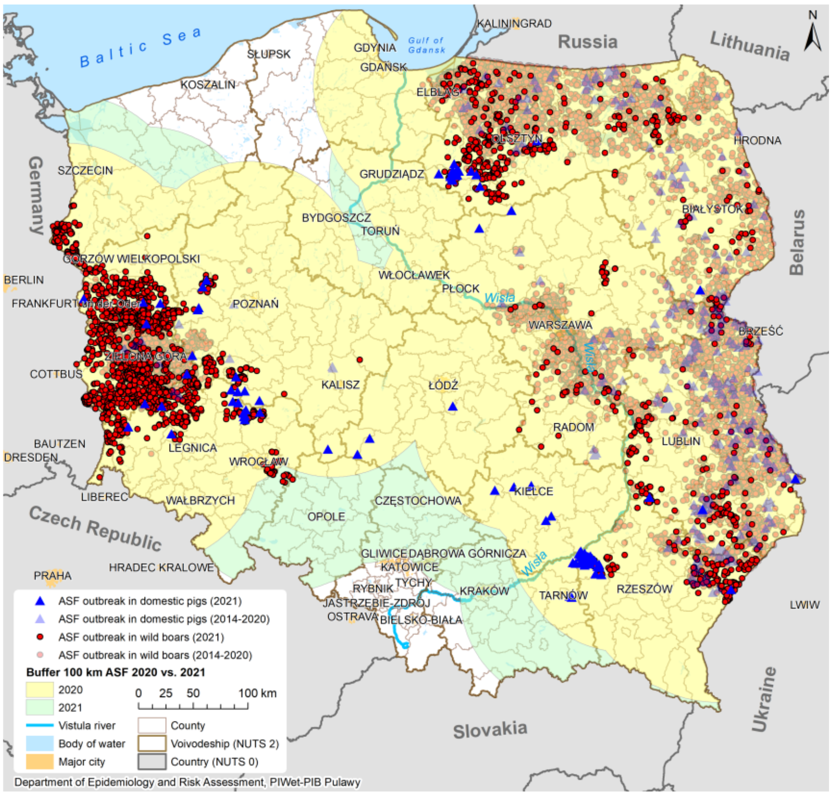

Fig. 12. 100-km buffer from African swine fever (ASF) outbreaks in cumulative periods of 2014–2020 *vs.* 2014–2021. Yellow shows the area for 2014–2020 (it is also the common part for both periods, *i.e.* for the buffer zones drawn at the ends of 2020 and 2021). Light green represents the buffer surface area increase in 2021. NUTS – nomenclature of territorial units for statistics

Discussion

ASF has been present in Poland for more than eight years. The legislative measures intended to stop the virus spread were changed in this time, being adapted to the current situation. According to recent Polish regulations reflecting EU law, after an ASF outbreak in domestic pigs a 3-km radius hazardous area and a peripheral 7-km radius infected area (making in total a 10-km restricted zone) are created, imposing a restriction on pig movement there enforceable in law (18). Similarly, a surveillance zone is created in other European countries and in South Korea of a 3- to 7-km radius from an ASF outbreak (6, 20). In case of ASF outbreaks in wild boars, 3- and 10-km radius zones are also created in which carcasses are searched for; however, there are no legal regulations as strict as those in the case of domestic pig outbreaks (6, 42).

In order to limit the virus spread, in 2015 the EFSA recommended the radical reduction of the wild boar population over distances extending to 100 and even 200 km from the last ASF outbreak. In the control area (with a 50-km radius), all carcasses should be removed and the wild boar population must be reduced to 20% of its pre-outbreak size (21). The more recent recommendation indicates the limitation of wild boar population to the level of 0.1 animal/km^2 (9).

ASF has been present in Poland since 2014, the same year as in the Baltic states (6, 23, 25, 26). However, the situation in these northern countries is slightly different to that in Poland. Currently almost the whole territory of the Baltic states is covered by ASF zones. In the case of Lithuania, there are only small ASF-free areas near Klaipeda, while in Latvia such areas are located near Liepaja, Ventspils and Riga. In Estonia there are no parts without ASF restrictions; however, the only area remaining in ASF restricted zone I (4) is the island Hiiumaa (3). In contrast to the Baltic states, in Poland there are still large areas remaining which are not affected by ASF, as is shown in Fig. 3.

The first two years of the epidemic brought a large increase in ASF outbreaks in wild boars in the Baltic states compared to Poland: 2,249 in Estonia, 2,068 in Latvia, 534 in Lithuania and only 188 in Poland (6). In the short period of time until the end of 2016, almost the whole of Estonia, most of Latvia and half of Lithuania became affected by ASF (6, 26, 27, 34). By the year 2020 almost the whole territory of Lithuania was affected by ASF in a worsening of the year-end situation in 2018 when 84% of the country had noted outbreaks (22, 28). In the same period the situation in Poland was different. Until the end of 2016, only the eastern part of the Podlaskie province and the north-eastern part of the Lubelskie province had seen ASF cases, which is shown in Fig. 4 (29, 39). The different speeds of ASF spread in Poland and the Baltic states might be connected with the higher density of wild boars in the north-east of Europe, the afforestation and the relative sizes of the countries (Poland is several times larger than the Baltic countries) (1, 29, 32).

The natural movement of ASFV in the wild boar population was also analysed by the EFSA. In the reports from 2014 and 2015, when the disease spread was accelerating in the Baltics, its average rate was estimated at approximately 50 km/year (8, 21, 29). However, as was mentioned before, in the most recent years the average speed of the virus spread has been 8 to 17 km per year (5). The slowdown of ASFV dispersion has been observed in Poland (Fig. 4); however, the disease does not stop and there is a 95% probability of finding another ASF-positive wild boar in Poland at a distance of approximately 3 km from the last outbreak (42).

In 2019 when ASF reached the western part of Poland (Lubusz province), in order to slow down the movement of the virus, solid fences were erected at 10 km radially from the ASF outbreak. However, as presented in Figs 4–7, it did not stop the disease spread (7). In the cases of the Czech Republic and Belgium, where similar fences were used, the situation was quite different. Both countries had ASF limited to small areas, which were easier to control. The disease was detected in advance a short time after its introduction (when the number of outbreaks was at its initial low level) (32). In Poland in contrast, there were a lot of a new outbreaks detected in a short time over great distances, which indicates the longer presence of the virus in the wild boar population in a given area (11, 24, 42).

In a publication from 2018, Pejsak *et al.* (29) described the four years of ASF in Poland. In their analysis they suggested that the unpredictable activity of humans might have contributed to ASF spread and that the culling conducted by the Polish Hunting Association would not have been enough for ASF eradication in Poland. They assumed that ASFV would be present in Poland in the wild boar population for several years (29). This prediction has been confirmed in our analysis. As is shown in Figs 4–6, there were new long-distance ASF introductions in Poland in the most recent years, connected supposedly with human activity. After presenting the genetic analysis of ASFV, Mazur-Panasiuk *et al.* (24) described the routes of virus introduction to Poland and sequentially into new parts of the country. Their work indicates that the long-distance spread of ASF is likely to originate from human activity (24). Despite the intense hunting of wild boars (Table 2), even in the ASF restricted areas (zones II–III implemented according to 2021/605/EU (4, 12), the total number of ASF-positive wild boars was increasing until 2020 (Table 1, Fig. 7) (11). One of the explanations of this phenomenon is the high reproduction rate of wild boars, in which the litter size may be 11 to 15 piglets (10).

Other researchers from Poland have also tried to summarise and analyse the ASF epidemic in Poland (11, 38, 42). Woźniakowski *et al.* (43) focused on the cause of ASF long-distance spread and the spread in domestic pig herds. Similarly to Pejsak *et al.* (29), Woźniakowski *et al.* (43) stressed the role of humans in ASF spread indicating, however, the lack of knowledge or awareness among the farming community as a direct reason for ASF appearance in new areas. The researchers assumed that in the current phase of the epidemic, it is impossible to eradicate ASF in the wild boar population, but that it can be stopped in the domestic pig population by effective biosecurity (43). The data from 2021 has shown new ASF outbreaks in domestic pigs, which indicates that biosecurity still has to be improved (Figs 2 and 3).

Szymańska *et al.* (38) summarised seven years of the ASF epidemic in Poland. Their research indicated that, despite the work carried out by veterinarians, hunting associations and the administrative bodies, ASF spread rapidly (38), which is also confirmed by our analysis (Fig. 7). As a reason for the disease spread in domestic pigs they underlined insufficient biosecurity on pig holdings (38). In addition, Frant *et al.* (11) also observed that probably there is the beginning of the endemicity of ASF in Poland, which can complicate the current situation in the country even more.

Taking into consideration the upward trend, in 2022 we can expect further expansion of ASFV into new areas of Poland. We are observing how much human activity on the part of pig farmers can contribute to the transmission of the virus over long distances. Analysing the results of the expansion in the cumulative areas affected by ASF over the years, it comes to notice that since 2017, this area has increased annually by approximately 25,000 km^2. The area based on the 50-km buffer around the outbreak points increased by 15% in the last year and now covers 73% of the territory of Poland (Fig. 11). It should be noted that the 2021 terrain of new outbreaks in pigs and also in wild boars significantly exceeded the area delineated on the basis of outbreaks by the end of 2020, and even the area of the 100-kilometre buffer (Fig. 12); although in 2021 the outbreaks in domestic pigs were contained, the outbreaks in wild boars south-east of Wrocław had evaded control by this time. Another year of similar expansion could result in the entirety of Poland being covered with a buffer zone of 100 km, *i.e.* there would be no point on the map of Poland that was more than 100 km away from the site of an ASF outbreak. This is a strong prediction especially since only 8% of the country's surface area remains as regions meeting this criterion.

In terms of the annual number of outbreaks in wild boar, we have observed high variability in recent years. It is also difficult to reach conclusions about any trend in this matter, as these data are not representative for long-term analyses. This is because they largely depend on policy and the effectiveness of actions taken, primarily planned sanitary culling as well as location and disposal of wild boar carcasses. Fortunately, the analyses of surface area, especially those of multiple-year cumulative areas, are far less affected by this variability in outbreak numbers.

In the Baltic states, which are much smaller countries than Poland, ASF has covered almost their entire territory in a short time. High afforestation and a large population of wild boars at the early stage of the epidemic accelerated the spread of ASF (6, 8). In the cases of the Czech Republic and Belgium, where the disease was eradicated, the implemented preventive measures, fencing and reduction of the wild boar population were easier to undertake. African swine fever was detected at the beginning of the epidemic in a small area, in contrast to the detection history in Poland, where the disease was found in distant territories (2, 11, 24). It is important to realise that there is still a significant area to protect, because 60% of Poland remains ASF free.

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