Research article

SPATIO-TEMPORAL ANALYSIS OF THE SPREAD OF ASF IN THE RUSSIAN FEDERATION IN 2017-2019

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Currently, African swine fever (ASF) is one of the biggest global economic challenges in Europe and Asia. Despite all the efforts done to understand the mechanism of spread, presence and maintenance of ASF in domestic pigs and wild boar, there are still many gaps in the knowledge on its epidemiology.

This study aims to describe spatial and temporal patterns of ASF spread in wild boar and domestic pigs in the country during the last three years. Methods of Spatio-temporal scanning statistics of Kulldorff (SatScan) and Mann-Kendell statistics (space-time cube) were used to identify potential clusters of outbreaks and the presence of hot spots (areas of active flare clusters), respectively. The results showed that ASF in the country has a local epidemic pattern of spread (11 explicit clusters in wild boar and 16 epizootic clusters were detected in the domestic pig population: 11 in the European part and 5 in the Asian part), and only six of them are overlapped suggesting that ASF epidemics in domestic pigs and wild boar are two separate processes. In the Nizhny Novgorod, Vladimir, Ivanovo, Novgorod, Pskov, Leningrad regions, the clusters identified are characterized as sporadic epidemics clusters, while in the Ulyanovsk region, Primorsky Territory, and the Jewish Autonomous Region the clusters are consistent. Considering the low biosecurity level of pig holdings in the far east and its close economic and cultural connections with China as well as other potential risk factors, it can be expected that the epidemic will be present in the region for a long time. The disease has spread in the country since 2007, and now it is reoccurring in some of the previously affected regions. Outbreaks in the domestic pig sector can be localized easily (no pattern detected), while the presence of the virus in wildlife (several consecutive hot spots detected) hampers its complete eradication. Although the disease has different patterns of spread over the country its driving forces remain the same (human-mediated spread and wild boar domestic-pigs mutual spillover). The results indicate that despite all efforts taken since 2007, the policy of eradication of the disease needs to be reviewed, especially measures in wildlife.

Key words: analysis, ASF, clusters, local epidemic, outbreaks.

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INTRODUCTION

African swine fever is a contagious viral disease characterized by fever, acute course, skin cyanosis, multiple haemorrhages in the internal organs, high lethality, and affecting pigs of all species, breeds, and ages. Domestic pigs and wild boar are susceptible to ASF in natural conditions. DNA-containing virus is of the *Asfarviridae* family (ASFV), causing an infection which transmits to the whole population [1-3].

ASF represents a significant threat to national and global swine industries and food biosecurity due to the lack of vaccines and treatment methods. History of ASF outbreaks in the territory of Transcaucasia, Eastern Europe, Russia, Belgium, and China demonstrates the diversity of mechanisms and ways of ASF transmission. ASF transmission depends on various factors relating to the host, virus, and environment. Many of these factors and their impact have not been studied completely [4-7].

In Russia, ASF was first reported in late 2007. Later ASF occurred in Eastern Europe (Belarus, Ukraine, Lithuania, Latvia, Estonia, Romania, Moldova, Czech Republic, Poland), and China [8-12].

In the Russian Federation regions, the epizootic process of ASF is characterized by epizootics, sporadic outbreaks, and suspicions for an outbreak (among wild boars in the Chechen Republic, mountainous areas of Krasnodarskiy Territory and Tver region) [7,13,14].

The article aims to evaluate the features of local ASF outbreaks in Russia from 2017 to 2019.

MATERIALS AND METHODS

The Resources and Data Characteristic

Ethical approval: The conducted research is not related to animals' use.

We used database of ASF outbreaks in domestic pigs and wild boars on the territory of Russia from 2017 to 2019, based on information, and WAHIS international database. We considered outbreaks of ASF in cases of virus detection in the susceptible population (domestic pigs, wild boars) on the specific territory, associated with geographical points. The outbreak data contained such information as exact location, the emergence of the ASF outbreak date, and infected animal species. This information was represented in the form of ArcGIS database.

Geographic information systems (GIS) are used for the analysis of potential risk factors of introduction, patterns and dynamics of ASF spread, and identification of spatial-temporal clusters of local epizootics distribution. [6,14-16].

Analysis methods

To detect similar to spatio-temporal clusters outbreaks, we applied a space-time permutation scan statistic for the early detection of disease outbreaks by Kulldorff M. [17]. The method aims at the detection of areas inside of an evaluated space where ASF outbreaks are grouped more densely compared to their common distribution. The statistically significant clusters are represented as annular areas. Inside the clusters, all the outbreaks are considered local epidemics and are associated with each other in one epidemic process. For all the clusters dimensions were (Rmax = 150 km) and (Tmax = 1 year). The search of clusters was carried out for two categories of data 1) for outbreaks in domestic pigs; 2) for cases in wild boar. For further analysis, only statistically significant spatio-temporal clusters were selected from each of the categories. Clusters were selected by their significance, determined by the p-value ($\leq$ 0.05) in the space-time permutation model in the SaTScan software. For each identified cluster, the following characteristics were determined: the territorial status of the cluster in the Russian Federation; the number of outbreaks consisting of the cluster N; cluster radius R; duration of cluster T.

For each cluster, the total amount of ASF outbreaks were calculated in other populations (for clusters of domestic pigs outbreaks in wild boars and vice versa), registered inside of this cluster for the same period.

To estimate the speed of propagation in spatio-temporal clusters, we analyzed **the spatio-temporal density of outbreaks** (STDO), which denotes the number of new outbreaks in a certain territory over a fixed period of time. The calculation was carried out according to the formula: $STDO_n = (N_{nobs} / S_n / T_n) * 1000$, where N_{nobs} is the observed number of outbreaks in the nth cluster, S_n is the cluster area in km^2, and T_n is the cluster duration, in days [18].

We determined the relative risk in each cluster in the SaTScan program using a model where the risk is defined as the Observed / Expected ratio (ODE). This is the ratio of the number of ASF outbreaks that are actually fixed within the cluster to the amount that would be expected if the outbreaks were randomly distributed throughout the studied space. The higher this indicator, the more significant the cluster, i.e. there is a more compelling reason why the concentration of outbreaks is increased in this place.

Software

To detect spatio-temporal clusters, we used SaTScan software [17].

In the capacity of additional analysis of cluster detection, space-time cube method was applied using Space Mining Tools software package in ArcGIS 10.6.1 from ESRI (Redlands, California, USA).

Spots

To identify hot or cold spots, we used Getis-Ord Gi* spatial statistics in its temporal interpretation to identify statistically significant ASF outbreak hotspots (Ord and Gettis, 1995), where it is concluded about a presence or absence of a hot spot in the spatio-temporal cube.

Data processing, as well as visualization of the analysis results, was carried out with the use of ArcGIS 10.6.1 [https://www.esry.com/].

RESULTS

The ASF outbreak diagram from 2017 to 2019 is presented in Figure 1. During this period, 533 ASF outbreaks were notified in Russia, including 339 among the domestic pig population; and 194 for wild boar population. The period under analysis was characterized by ASF outbreaks not only in the European part of Russia but also in Asia. In 2017-2019 403 outbreaks have been notified in the European part of the country, including 182 among wild boars; and 130 in the Asian part, including 12 in wild boars.
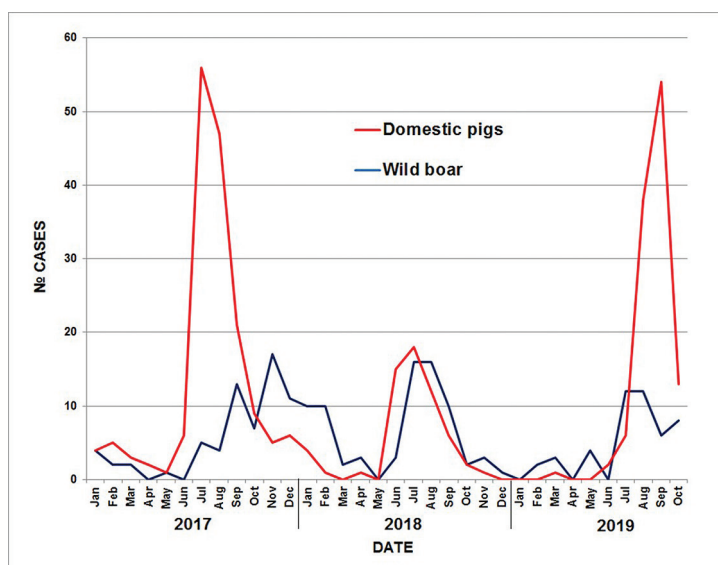
Figure 1. African swine fever (ASF) notifications in domestic pigs and wild boar (2017–2019)

Using the spatial-temporal cluster analysis method, 16 statistically significant clusters were identified in the domestic pig population. Eleven clusters have been detected in the European part and 5 in the Asian part of Russia. Only 6 of them partially match with clusters of ASF outbreaks in the wild boar population during the same period. Outbreaks in wild boar populations formed 11 clusters: 10 clusters in the

European part and 1 in the Asian part of Russia (Fig.2). All clusters in the Asian part of Russia defined as concerted. All the identified local epizootics in the wild boar population, as a rule, followed with outbreaks among domestic pigs. In the regions of the European part of Russia (Nizhny Novgorod, Vladimir, Ivanovo, Novgorod, Pskov and Leningrad regions), the identified clusters are characterized as clusters of sporadic epidemics. Only in the Ulyanovsk region, a cluster was concerted.
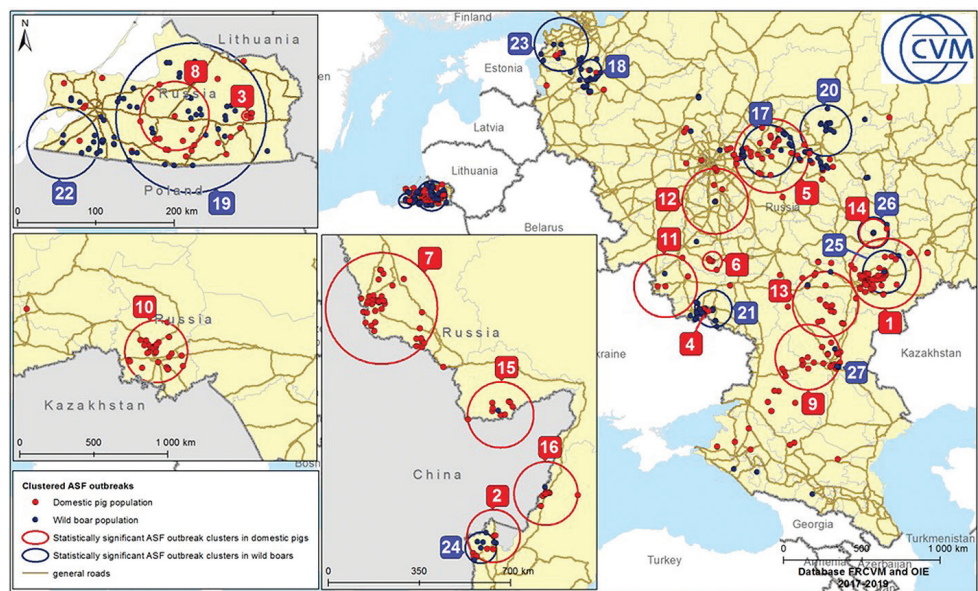
Figure 2. Space–time clusters of domestic pig and wild boar of African swine fever (ASF) notifications detected with space-time permutation statistics. Significant clusters have a P-value <0.05.

The quantitative characteristics of the obtained clusters are given in Table 1. In all susceptible animal populations, 27 statistically significant clusters were identified.

We analyzed the spatio-temporal density of ASF outbreaks (STDO) and obtained the results presented in Table 2.

Values of G (STDO) greater than unity indicate a short period of cluster formation and attenuation. Such clusters include Nos. 1, 3, 4, 6-8, 14, 16, 18-20, 22-24, 26, and 27. Clusters with a high G (STDO) value are most likely associated with the most effective active monitoring after the first outbreak of ASF happened, so subsequent ones were detected in a short time. Values of G (STDO) less than unity indicate clusters that function for a long period of time.

The results of the study of the relative risk, defined as the Observed / Expected ratio (ODE) are presented in Table 3.

Table 1. Quantitative characteristics of the clusters

№ cluster	Territorial affiliation	ASF clusters in the domestic pig population						Number of outbreaks within the cluster among wild boars
		Radius, km	Number of outbreaks in the cluster, N	Date of the beginning	Date of the end	Duration, days		
1	Central Russia	138	50	01.09.2019	30.09.2019	30		4
2	Asian Russia	72	5	01.08.2019	31.08.2019	31		7
3	Central Russia (Kaliningrad region)	4	2	01.11.2017	30.11.2017	30		0
4	Central Russia	12	10	01.06.2017	30.09.2017	122		2
5	Central Russia	133	27	01.08.2018	31.10.2018	93		17
6	Central Russia	38	6	01.01.2018	31.01.2018	31		0
7	Asian Russia	137	45	01.06.2018	30.06.2018	30		0
8	Central Russia (Kaliningrad region)	26	6	01.07.2017	31.07.2017	31		11
9	Central Russia	137	26	01.07.2017	31.10.2017	123		6
10	Asian Russia (Omsk region)	121	31	01.04.2019	31.08.2019	153		0
11	Central Russia	125	3	01.04.2017	30.04.2017	30		1
12	Central Russia	121	4	01.03.2017	31.03.2017	31		0
13	Central Russia	132	16	01.09.2018	30.09.2018	30		0
14	Central Russia	54	11	01.08.2019	30.09.2019	61		1
15	Asian Russia	85	9	01.09.2019	31.10.2019	61		1
16	Asian Russia	85	8	01.01.2018	31.01.2018	31		1
M±m	-	89,75±12,15	16,19±3,79	-	-	57,38±10,44		-

cont Table 1.

№ cluster	Territorial affiliation	Radius, km	Number of outbreaks in the cluster, N	Date of the beginning	Date of the end	Duration, days	Number of outbreaks within the cluster among domestic pigs
			ASF clusters in wild boar population				
17	Central Russia	93	10	01.03.2017	31.08.2017	184	20
18	Central Russia	36	5	01.07.2019	31.07.2019	31	2
19	Central Russia (Kaliningrad region)	55	40	01.06.2018	28.02.2019	273	23
20	Central Russia	89	13	01.09.2017	30.09.2017	30	0
21	Central Russia	75	22	01.10.2017	28.02.2018	151	4
22	Central Russia (Kaliningrad region)	26	7	01.11.2017	30.11.2017	30	1
23	Central Russia	87	8	01.10.2018	31.10.2018	31	2
24	Asian Russia	43	3	01.08.2019	31.08.2019	31	6
25	Central Russia	84	3	01.01.2017	31.01.2017	31	32
26	Central Russia	59	11	01.07.2019	31.07.2019	31	2
27	Central Russia	5	4	01.09.2017	30.09.2017	30	0
M±m	-	59,27±8,8	11,45±3,3	-	-	77,55±25,68	-

Table 2. Space-time density of ASF outbreaks in clusters of domestic pigs and wild boars.

STDO of clusters in domestic pigs:		STDO of clusters in wild boar:	
Number of clusters	G (STDO)	Number of clusters	G (STDO)
1	2.8	17	0.2
2	0.9	18	3.9
3	32.6	19	1.5
4	18.1	20	1.7
5	0.5	21	0.8
6	4.3	22	10.8
7	2.5	23	1.1
8	9.1	24	1.7
9	0.3	25	0.4
10	0.4	26	3.2
11	0.2	27	69.8
12	0.3		
13	0.9		
14	1.9		
15	0.6		
16	1.1		

Table 3. Relative risk of ASF outbreaks in clusters in domestic pigs and wild boars.

ODE of clusters in domestic pigs:		ODE of clusters in wild boar:	
Number of clusters	ODE	Number of clusters	ODE
1	42.273	17	9.272
2	29.639	18	6.754
3	135.724	19	4.312
4	79.173	20	10.291
5	50.337	21	5.718
6	497.443	22	10.963
7	24.159	23	25.907
8	737.089	24	24.558
9	33.508	25	23.388
10	49.980	26	6.901
11	131.007	27	9.355
12	626.201		
13	328.976		
14	101.019		
15	439.083		
16	24.327		

DISCUSSION

The study of the monthly dynamics of ASF from 2017 to October 2019 shows the largest peaks in year 2017 and 2019. The most significant number of outbreaks among domestic pigs and wild boars related to the same periods from July to the beginning of autumn. However, for wild boars, the peak of outbreaks remained stable during the winter of 2017-2018. Therefore, we can see changes in seasonal dynamics in the manifestation of ASF in Russia compared with previously published data [19], where it was shown that peaks of outbreaks among domestic pigs usually happen in May and the beginning of summer, and in wild boars in autumn and winter (hunting season). Changes in the seasonal dynamics of ASF could be related to the implementation of planned monitoring of ASF in wild populations.

The study of the spatial spread of ASF shows that it has both local epidemic patterns linked to commercial contacts and to the introduction of the virus into new regions without dependence on distance. The emergence of ASF in Irkutsk region in 2017 is an example of the introduction of the disease to the remote territory. Local outbreaks in the European part of Russia (including Kaliningrad region) are associated with both economic activities and the circulation of the virus among wild boars. In general, for 10 clusters of ASF among domestic pigs, outbreaks in wild boars were confirmed. Obtained data corresponds with previously published results [20,21]. Within 2 clusters of ASF in wild boars (№ 20 and № 27) no outbreaks among domestic pigs were reported. That indicates the development of ASF in wild boars clusters without risk factors associated with human activities.

In Kaliningrad region, 2 clusters of ASF in domestic pigs were included in clusters of ASF in wild boars. Taking into account that ASF outbreaks in domestic pigs were reported before outbreaks in wild boars, the source of the disease was considered to be domestic pigs and products of pig farming.

The same situation was identified in Volgograd and Belgorod regions. Originally clusters were formed by outbreaks in domestic pigs. Later outbreaks formed clusters of ASF in wild boar populations. The cluster of ASF outbreaks in wild boars (№27) was small (Rcl= 5 km) and coincide with the territory of Nature Park «Volga-Akhtuba floodplain». Probably it is related to constant monitoring of ASF in wild nature. This obstacle does not exclude the wider spread of the disease in the population of wild boars in the floodplain of the Volga river.

In Vladimir and Ivanovo regions a cluster of ASF in wild boars was formed earlier than in domestic pigs. We suggest that ASF virus persistently circulates in wild boars in these regions. Example of cluster in neighboring Nizhny Novgorod region confirms our hypothesis: cluster was formed in wild boars, but no cases in domestic pigs were reported.

In Ulyanovsk region an equal number of outbreaks were detected in wild boars and domestic pigs (11 cases) during the analyzed period. Outbreaks were bound with

the same locations and formed clusters with the same radius. The disease was first reported in the wild boar population, and after one month in domestic pigs. In Saratov region, the cluster of ASF in wild boars was also formed earlier than in domestic pigs. All these facts point out on circulation of ASFV in wild nature.

In the Asian part of Russia, 5 clusters of ASF in domestic pigs were formed, and 3 of them were associated with cases in wild boars. All clusters were bordering China, where ASF was notified since 2018. In Primorsky Territory one cluster of ASF in wild boars (№24) was formed. This cluster has a radius of 43 km and partially overlays the more significant cluster of ASF in domestic pigs. It shows that the emergence of disease in wild boars can be associated with human activities.

Comparison of clusters in wild boars and domestic pigs on the territory of Russia shows 51.4% prevalence in squares of ASF clusters in domestic pigs. It demonstrates that the economic and commercial activities of householders have a significant value in the process of disease spread and development of local epizootics.

Analysis of the spatiotemporal outbreak density (STDO) showed that most of the long-functioning clusters are formed by ASF outbreaks in the domestic pig population (50.0%). In the wild boar population, only 3 long-functioning clusters were detected (27.3%). This may indicate that outbreaks of ASF in the wild population are secondary and their occurrence is associated with outbreaks of the disease in domestic pigs.

The highest relative risk of ASF in clusters is formed by outbreaks of the disease in domestic pigs (Nos. 8, 12, 6, 15, 13). In the wild boar population, the relative risk is not high, which may be due to the low density of animals and the lack of ASF spread in their population.

In the affected regions, an ASF control strategy is being implemented, including measures:

- Federal Plan (recommendations, affected, unaffected and at risk regions);
- Regional programs (85 regions, prevention and eradication, no coordination);
- Decrease the number of pigs in unprotected sector (backyards);
- Compartmentalization (4 biosecurity levels);
- Decrease the density of wild boar (0.25 heads/1000 ha);
- Monitoring programs;
- Animal identification and electronic certification.

CONCLUSIONS

1. During the analyzed period ASF spread in regions of the Asian part of Russia, where 130 outbreaks were notified, 12 of them were among wild boars. The cluster of ASF in wild boars was formed in Primorsky Territory and was associated with outbreaks in domestic pigs.

2. Seasonality of ASF changes for both wild boars and domestic pigs. The disease mostly reported during summer and the beginning of autumn.
3. Local epizootics of ASF were identified in European and Asian parts of Russia using spatio-temporal cluster analysis.
4. Two clusters of ASF in wild boars, not associated with outbreaks in domestic pigs and human activities, were identified.
5. ASF outbreaks in the wild boar population are caused by ASF outbreaks in domestic pigs.

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Authors' contributions

BAA and ZOI have made substantial contributions to conception and design, analysis and interpretation of data. TNN and BOA have made acquisition of data. STA, GAE and DZ prepared and critically revised the manuscript. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All authors read and approved the final manuscript..

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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PROSTORNO-VREMENSKA ANALIZA ŠIRENJA AFRIČKE KUGE SVINJA U RUSKOJ FEDERACIJI U PERIODU 2017-2019

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Trenutno, afrička svinjska kuga (ASK) predstavlja u Evropi i Aziji jedan od najvećih globalnih ekonomskih izazova. Uprkos trudu koji je uložen u istraživanjima mehanizama širenja, prisustva i održavanja ASK kod domaćih i divljih svinja, još uvek su prisutne praznine u poznavanju njene epidemiologije.

Ova studija ima za cilj da opiše prostorne i vremenske obrasce širenja ASK među domaćim i divljim svinjama u Ruskoj Federaciji tokom poslednje tri godine.

U cilju određivanja potencijalnih klastera i prisustva "vrućih mesta" (područija aktivnih klastera) primenjene su statističke metode prostorno-vremenskog skeniranja (Kulldorff- Stat Scan i Mann-Kendell). Rezultati su pokazali da ASK u zemlji ima svojstva širenja lokalne epidemije (11 izričitih klastera u evropskom području i 5 u azijskom), pri čemu se od njih samo šest preklapalo, što nam sugeriše da epidemija AKS kod domaćih i divljih svinja predstavlja dva zasebna procesa. U regijama Nizhny Novgorod, Vladimir, Ivanovo, Novgorod, Pskov, i Lenjingrad identifikovani su sporadični klasteri epidemije, dok su u Ulyanovsk-u, Primorsky i u Jevrejskoj Autonomnoj Regiji klasteri bili konzistentno prisutni. Imajući u vidu nizak nivo biosigurnosti na farmama na Dalekom Istoku, kao i njegove bliske ekonomske i kulturološke veze sa Kinom, kao i ostale potencijalne faktore rizika, može se predpostaviti da će u ovoj regiji epidemija biti dugo prisutna. Oboljenje se širi u državi od 2007. god i sada se ponovo javlja u predhodno zahvaćenim oblastima. Pojava oboljenja među domaćim svinjama se lako lokalizuje, dok prisustvo virusa kod divljih životinja (nekoliko uzastopnih „vrućih mesta") otežava potpunu eradikaciju. Iako oboljenje pokazuje različite šablone širenja, načini ostaju isti (posredovano ljudima, prenos sa divljih na domaće svinje). Rezultati pokazuju da uprkos svim naporima koji su preduzeti od 2007. god, prilaz eradikaciji mora da se revidira, posebno mere koje se sprovode za divlje životinje.