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Density of wild boar population and spread of African swine fever in the Russian Federation

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SUMMARY

African swine fever (ASF) is a transboundary viral disease affecting all species of the *Suidae* family. It greatly undermines global pig industry and causes a significant damage to the ecology of the wild boar (*Sus scrofa*) which is a natural reservoir of the ASF virus and is an intermediate link in the epizootic process. Depopulation of wild boar is one of the measures taken to prevent spread of ASF in the Russian Federation. A threshold density of the wild boar population of 0.25 head/1000 ha (0.025 head/km^2), according to the National Plan on the ASF Eradication in the Russian Federation, was achieved by 2020 in many RF Subjects. However, further analysis of the ASF epizootic situation shows that the measure has failed to eradicate the infection completely. A regression analysis showed statistically significant positive relationship between recurrent ASF outbreaks in the wild boar population and its density in a number of model subjects (N = 6). At the same time, there is no such dependence in other model subjects (N = 3), and ASF outbreaks were recorded in wild boars at a density significantly lower than the recommended threshold value. A review of foreign and national scientific publications has shown that such control methods as depopulation is just one part of the whole set of measures taken to eradicate ASF in the wild. The measure is effective only when 70–80% of animals are culled in a short time, which is practically impossible due to the high costs and some peculiarities of the population control and depopulation process. Based on the results obtained, it can be concluded that a decrease in the number of wild boars does not guarantee to stop further spread of infection in the Russian Federation and it should be considered as just a part of the whole set of anti-epizootic measures taken together with other anti-epizootic measures to eliminate and prevent ASF.

Keywords: African swine fever, density of wild boar population, depopulation, logistic regression, elimination strategy

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Плотность популяции дикого кабана и распространение африканской чумы свиней в Российской Федерации

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РЕЗЮМЕ

Такое вирусное трансграничное заболевание всех представителей семейства свиньи (*Suidae*), как африканская чума свиней, наносит колоссальный ущерб не только мировой свиноводческой отрасли, но и экологии кабана (*Sus scrofa*) – животного, являющегося природным резервуаром вируса и участником эпизоотического процесса. Одной из мер по предотвращению распространения африканской чумы свиней на территории Российской Федерации является депопуляция дикого кабана. Рекомендуемое «Планом действий по предотвращению заноса на территорию Российской Федерации африканской чумы свиней и ее распространения» значение плотности популяции кабана в 0,25 особи/1000 га (0,025 особи/км²) для многих субъектов страны было достигнуто к 2020 г., но, как показывает анализ эпизоотической ситуации по африканской чуме свиней, данная мера не привела к полному искоренению инфекции в Российской Федерации. Регрессионный анализ показал, что в ряде модельных субъектов (N = 6) прослеживается статистически значимая положительная взаимосвязь между наличием повторяющихся вспышек африканской чумы свиней в популяции дикого кабана и ее плотности. В то же время в других модельных субъектах (N = 3) такая зависимость отсутствует, а вспышки африканской чумы свиней регистрировались среди диких кабанов при плотности, существенно меньшей рекомендуемого значения. Обзор зарубежной и отечественной научной литературы показал, что применение методов контроля численности кабанов, таких как депопуляция, является лишь частью комплекса мер по искоренению африканской чумы свиней в дикой природе и эффективно лишь при изъятии 70–80% особей в короткие сроки, что практически нереализуемо в силу высоких экономических затрат и нюансов применения методов контроля и сокращения популяции. Исходя из полученных результатов, можно сделать вывод, что снижение численности дикого кабана не является гарантией прекращения дальнейшего распространения инфекции на территории Российской Федерации и должно́ рассматриваться в составе комплекса мер, направленных на ликвидацию и предупреждение заноса африканской чумы свиней, наряду с другими противоэпизоотическими мероприятиями.

Ключевые слова: африканская чума свиней, плотность популяции дикого кабана, депопуляция, логистическая регрессия, стратегия ликвидации

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INTRODUCTION

African swine fever (ASF) is a viral, transboundary disease affecting all species of the *Suidae* family and causing both an enormous damage to the national pig industry and to the ecology of the wild boar. Affected and convalescent pigs and wild boar and as well as those ones shedding the virus without clinical signs during an incubation period are the source of the pathogen. Extensive research into the role of the wild boar in ASF spread has revealed that this animal is an important, but not the key factor in the disease spread in the Russian Federation [1–3]. The wild boar is known to support ASF enzooticity in the territory [4–6]. The ASF outbreaks recorded in the wild in the Russian Federation throughout the whole period of the disease control are still mostly sporadic. Environmental risk factors preserve and maintain virulence of ASF virus in the environment and thereby complicate the disease elimination [7]. Mostly, the infection sources remain unknown due to both peculiarities of backyard pig farming and hunting farms, characterized by uncontrolled movement of animals, migration of wild boar, transportation of pig products and hunting trophies [4, 7, 8]. While lack of biosafety policies on pig farms is considered the main factor in the disease spread [9–13], the presence of wild boar in the ecosystem plays an important role in ASF transmission to the domestic pigs, as recognized by many countries [9, 14, 15]. Circulation of ASF virus in the wild boar population is typical for the Russian Federation and some of its subjects [16]. Recently, such a mechanism of ASF epizootics has been clearly observed in the Far East [17–19].

Currently, discussions are under way as to the relationship between ASF spread and density of the wild boar population. Taking into account experience of the European countries, there is a strong dependence of the virus transmission on density of the wild boar population; however, this dependence is not always observed [20]. Due to peculiarities of ASF epizootic process, this trend mainly depends on:

– network structure and social interactions in the most susceptible wild boar population and between age and gender groups;

– unclear pattern of the animal-to-animal virus transmission and post-mortem virus stability in dead boar, depending on the environmental conditions (for example, air temperature).

Studies in Poland, Germany and Italy, T. Podgórski et al. [21] reveal that the frequency of contacts within social groups was 17 times higher than between animals from different groups. These interactions suggest a mature metapopulation in which intra-group transmission happens faster, and the spread of infection between groups is limited and prolonged. The authors also found that young wild boar interact with each other more frequently in the population and such contacts can speed up the infection transmission. A wild boar population management strategy that affects the social-spatial structure of the population, for example, extra feeding, may reduce the time of virus transmission, because the likelihood of contacts between different groups increases.

Thus, ASF outbreaks reported in Poland from 2014 until mid-2016 may have resulted from a higher density of wild boar population (1–4 boar/km^2) in the east and a lower density in the west (< 0.4 boar/km^2). Z. Pejsak et al. [22] assumed that a density of more than two animals per square kilometer is required in order to ensure stable circulation of the virus among wild boar in Poland.

The theory of threshold density values does not give clear answers on principles of ASF virus spread, virus persistence in the wild boar population and transmission of the pathogen to other susceptible populations, including domestic pigs. Model approaches are based on such key conditions as homogeneous and random interaction between the sick and healthy animals, which is unlikely to really happen in the wild. Beside the density of the wild boar population, the virus transmission dynamics in the population can be influenced by such factors as post-mortal ASF virus stability in the dead wild boar, the population social structure, mechanical carriers, and etc. Therefore, the threshold values of the boar density will not necessarily reflect the possibility of transmission in a particular area. In addition, due to their social behaviour, animals can group together even in those areas and territories where population density is low, thus, zones with more wild boar will appear creating conditions for new ASF outbreaks.

Studies of the wild boar population ecology conducted within ENETWILD project [13, 23] and EFSA [24] have revealed that field observations are the only available alternative approach to study population density thresholds in the context of ASF prevention and control.

Strategically important disease control measures include, *inter alia*, wild boar depopulation, i.e. reduction of wild boar density to a certain threshold at which intrapopulation virus transmission will stop or significantly slow down due to a decrease in the reproduction coefficient [25–27].

Based on the current analysis of ASF epizootic situation in the Russian Federation, it can be said that the disease has spread both in wild boar and in domestic pigs almost throughout the whole territory, including even those regions where, as stated, density of the boar population is very low. Therefore, the purpose of this study is to examine the relationship between ASF outbreaks in wild boar and the wild boar population density in the Russian Federation.

In order to achieve the purpose, the following objectives have been set:

1) to conduct a retrospective analysis of the ASF situation in wild boar in the RF subjects and to determine those model and ASF-enzootic RF subjects, where wild boar populations have been continuously affected by the disease for several years;

2) to collect data and analyze relationship between dynamics of the wild boar population density in the model Subjects of the Russian Federation and the number of ASF recurrent outbreaks;

3) to determine whether there is a statistically significant relationship between occurring ASF outbreaks and changes in the density of wild boar population resulting from hunting activities, as well as depopulation, which is an important measure for ASF elimination;

4) to review scientific literature on the wild boar ecology in the ASF-affected environment with the purpose to systematize the methods applied to reduce ASF virus circulation in the population.

MATERIALS AND METHODS

Based on the use of PRISMA (http://www.prisma-statement.org/PRISMAStatement/PRISMAStatement.aspx) statement for systematic reviews and meta-analyses [28], a literature search was conducted in Web of Science, PubMed, Scopus and Google Scholar databases to find relevant information on the methods and tools potentially applied to ensure freedom of the wild boar population from ASF. The search query included the following keywords: African swine fever, population density of wild boar, depopulation, logistic regression, elimination strategy, while no publication date filter was applied. A literature search was also carried out in RSCI bibliographic database (Russian Science Citation Index) using Science-Index. For this purpose, we firstly reviewed headings and summaries, then analyzed full texts of the papers identified as relevant.

Model regions. Based on a retrospective epizootological analysis of the ASF epizootic situation, the following subjects of the Russian Federation were selected as model regions, where ASF outbreaks in wild boar recurred from 2013 to 2021, and for them data were available on long-term changes in the number of animals and population density during the epizooty (at the municipal level): the Vladimir, Yaroslavl, Ryazan, Nizhny Novgorod, Samara, Saratov and Amur Oblasts, as well as the Khabarovsk and Primorsky Krais.

Within this study, an outbreak is defined as an occurrence of one or more ASF cases in an epizootological unit (municipal district of the Russian Federation). At the same time, a case is defined as an individual animal infected with the pathogen, either with clinical signs or without them[1].

Data on ASF registration in the wild boar population are taken from the official reports of the Federal State-Financed Institution FGBI "Veterinary Center" (Moscow)[2].

Data on the size and density of wild boar population in municipal districts are taken from the regional websites of the Ministry of Natural Resources and Hunting Committees[3].

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[2] Epizootic situation. Registered cases of highly dangerous and socially significant animal diseases. Available at: https://центр-ветеринарии.рф/o-nas/informatsiya/epizooticheskaya-obstanovka.

[3] The Ministry of Natural Resources of Russia. Available at: https://www.mnr.gov.ru.

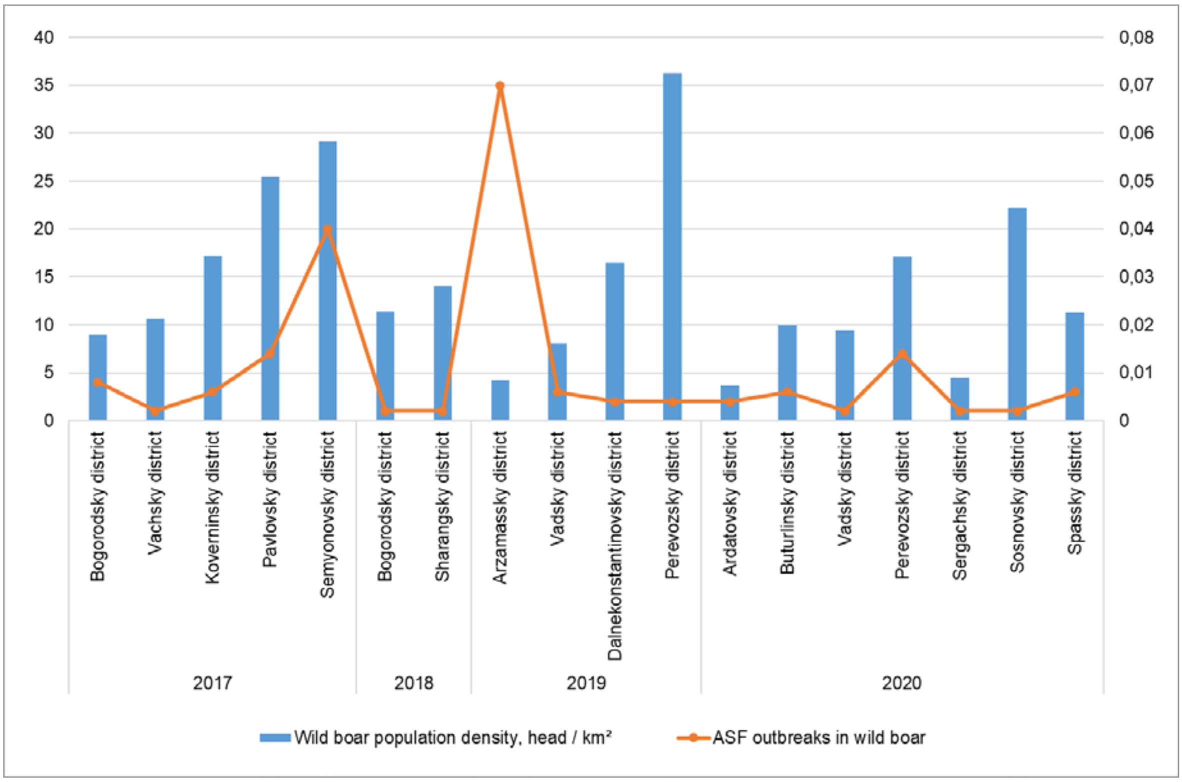

Fig. 1. Frequency of ASF outbreaks in the wild boar population of the Nizhny Novgorod Oblast (2017–2020)

Epizootological information on ASF outbreaks and data on size and density of the wild boar population covered the period from 2013 to 2021.

We used generalized linear logistic regression (GLLR) method to model relationship between ASF outbreaks registered in wild boar and the dynamics of the population density. The method examines the relationship between a dichotomous variable ("yes/no") and one or more explanatory factors [29–31]. For the purpose of this study, the explanatory variable refers to the presence/absence of registered ASF outbreaks in the wild boar population in a particular municipal district, and the explanatory factor refers to the population density of wild boar in the municipal district for the corresponding year. The significance of the explanatory variable was assessed using the Student's *t*-test (statistical criterion $p_t < 0.05$ indicates the significance of the variable as an explanatory factor). The overall statistical significance of the models was assessed using Hosmer – Lemeshow goodness-of-fit test that determines the ratio between the numbers of expected and observed events in subgroups of the model population. Statistical reliability of this test at $p_{hs} > 0.05$ demonstrates sufficient predictive ability of the model.

In addition to model significance and reliability, we calculated an odds ratio (OR) for a positive outcome in each subject and compared this coefficient based on the explanatory variable contained in the model (wild boar population density).

Logistic regression in R programming language[4] was used to model the relationship between ASF outbreaks and the wild boar population density at the municipal level.

Data on ASF outbreaks and wild boar population density in model regions were mapped with the help of ArcGIS for Desktop 10.8.1 geographic information system (ESRI, Redlands, California, the USA).

RESULTS

Retrospective epizootological analysis. Scientific literature screening focused on techniques that ensure freedom of wild boar population from ASF helped to select 45 reviews from international scientific citation databases and 40 scientific papers from the RSCI database that meet the search criteria. Summarizing results reported in these studies, we described in section "Discussion" different opinions on the role of wild boar population density in ASF spread and its persistence in the population.

A retrospective epizootological analysis showed that, from 2013 to 2021 according to the FGBI "Veterinary Center", totally 2,036 ASF outbreaks occurred in the model regions, of which 1,181 occurred in the population of domestic pigs and 855 in wild boar.

The highest total numbers of ASF outbreaks in wild boar was observed in the Saratov (128), Samara (95), Volgograd (84) Oblasts, the Primorsky Krai (80), Amur (69), Voronezh (52), Moscow (52) Oblasts and the Khabarovsk Krai (47).

An epizootological analysis of the ASF situation in the model regions showed stationary nature of the disease outbreaks in wild boar. The stationary nature of outbreaks is mainly typical for endemic diseases, characterized by the ability of the causative agent to exist long in certain

[4] R-4.1.1 for Windows. Available at: https://cran.r-project.org/bin/windows/base.

territories among wild animals permanently living there. Outbreaks of the disease may recur at various intervals because conditions for their recurrence exist. Frequency of ASF outbreaks in wild boar in the same areas of the model regions makes it possible to define them as stationary, for example, in the Nizhny Novgorod Oblast (Fig. 1).

Modeling relationship between ASF outbreaks and population density of wild boar. Modeling relationship between ASF outbreaks and population density of wild boar was carried out at the municipal level:

1) for all the selected model subjects in general;
2) for every subject individually.

General modeling for all model subjects showed both statistical insignificance of the boar population density as an explanatory factor ($p_t = 0.42$) and the unsatisfactory result of the Hosmer – Lemeshow test ($p_{hs} < 0.01$) revealed poor explanatory ability of the model. This allows us to conclude that it is impossible to establish in general a clear correspondence between the density of wild boar populations and repeated ASF outbreaks within the model region (Table).

At the same time, modeling for some subjects of the Russian Federation showed that most subjects (70%), 6 out of 9 (the Khabarovsk Krai, the Primorsky Krai, the Amur Oblast, the Vladimir Oblast, the Ryazan Oblast, the Saratov Oblast) demonstrate statistically significant ($p_t < 0.05$) positive dependence of ASF outbreaks on density of the wild boar population (Fig. 2).

The results obtained for odds ratio indicate that the dependence of ASF outbreaks on density of the wild boar population may be observed more in the Vladimir, Ryazan and Saratov Oblasts, as well as in the Khabarovsk and Primorsky Krais. At the same time, the greatest statistical reliability of dependence of the phenomenon on the explanatory factor (population density) was observed for the Vladimir Oblast, Primorsky and Khabarovsk Krais. That is, it can be concluded that the higher odds ratio

Table
Modeling dependence of ASF outbreaks on the density of wild boar population in the Russian Federation (2013–2021)

Subject of the Russian Federation	ASF outbreaks registered in (years)	Number of ASF outbreaks/number of cases in the wild boar population	Odds ratio (OR)	p_t-value GLLR models
Vladimir Oblast	2013 2015 2016 2017 2018	2/13 1/12 17/38 8/41 1/1	6.58×10^6	0.002**
Yaroslavl Oblast	2013 2015 2019 2021	22/52 2/61 1/4 4/4	47.94	0.442
Ryazan Oblast	2015 2016	22/52 44/341	12,456.52	0.018*
Nizhny Novgorod Oblast	2016 2017 2018 2019 2020 2021	1/5 20/35 2/2 5/42 9/18 1/1	2.61	0.326
Samara Oblast	2020 2021	60/163 2/9	7.92	0.116
Saratov Oblast	2015 2016 2017 2021	4/10 8/26 5/10 1/7	121.75	0.009**
Amur Oblast	2019 2020 2021	1/18 8/32 1/1	113.07	0.05*
Primorsky Krai	2019 2020 2021	20/41 42/128 10/20	81.31	0.005**
Khabarovsk Krai	2019 2020 2021	6/7 18/29 3/3	824.68	0.004**
Model Subjects	2013–2021	351/916	1.15	0.420

GLLR is a generalized linear logistic regression model;
OR – odds ratio (1/0), with a value of $p_t < 0.05 - n^*$, $p_t < 0.001 - n^{**}$.

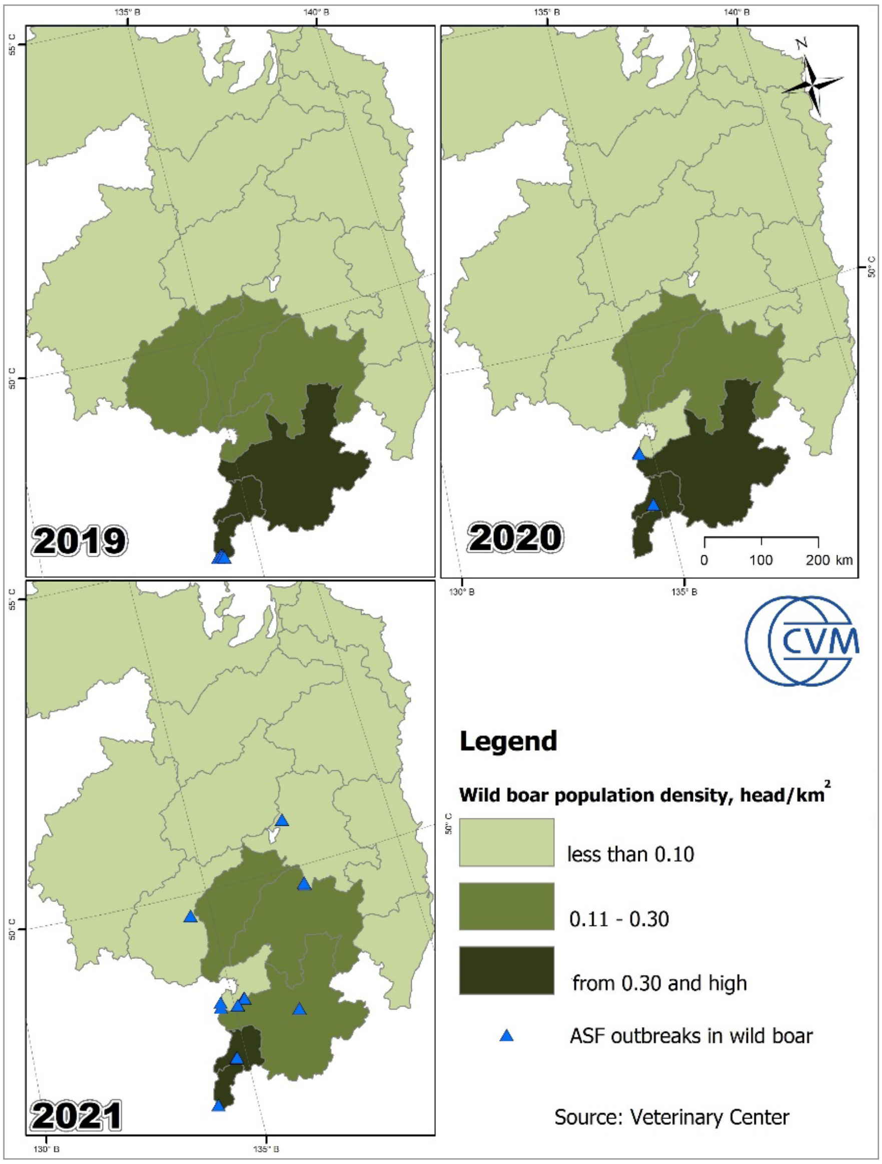

Fig. 2. Changes in the ASF epizootic situation in the Khabarovsk Krai related to the density of the wild boar population (2019–2021)

is (when OR > 1), the higher the chances are to identify the risk factor and the dependence of the recorded ASF outbreaks on the density of the wild boar population.

However, three out of the nine model subjects (the Nizhny Novgorod, Samara and Yaroslavl Oblasts), demonstrated no such dependence. In these model subjects, ASF outbreaks were reported even in the areas where the wild boar population density is significantly lower than the recommended value of 0.25 head/1000 ha (0.025 head/km^2), as approved by Order of the Government of the Russian Federation dated 30.09.2016 No. 2048-r (as amended on 04.02.2021) "Action Plan to prevent introduction of African swine fever into the Russian Federation and its spread in the country"[5].

[5] Order of the Government of the Russian Federation dated 30.09.2016 No. 2048-r (as amended on 04.02.2021) "On approval of the action plan to prevent introduction of African swine fever into the Russian Federation and its spread in the country". ConsultantPlus. Available at: http://www.consultant.ru/document/cons_doc_LAW_205372.

Figure 3 shows as an example the dependence of ASF outbreaks in wild boar on population density from 2017 to 2020 in the Nizhny Novgorod Oblast. In all the cases reviewed, the models demonstrated a satisfactory result of Hosmer – Lemeshow test ($p_{hs} > 0.05$), suggesting sufficient predictive ability of the models.

DISCUSSION

The epizootic situation on ASF is currently tense in the subjects of the Russian Federation, due to outbreaks reported both in domestic pigs and wild boar. Despite the measures taken to prevent ASF spread in the wild, ASF introduction in the wild boar population is still reported in previously disease-free areas. The recorded ASF outbreaks and the decreasing trend of wild boar population density in the tested model subjects indirectly confirm the assumption that wild boar play some role, but not a major one in ASF spread. The following measures are regularly taken to control ASF in the areas previously affected by

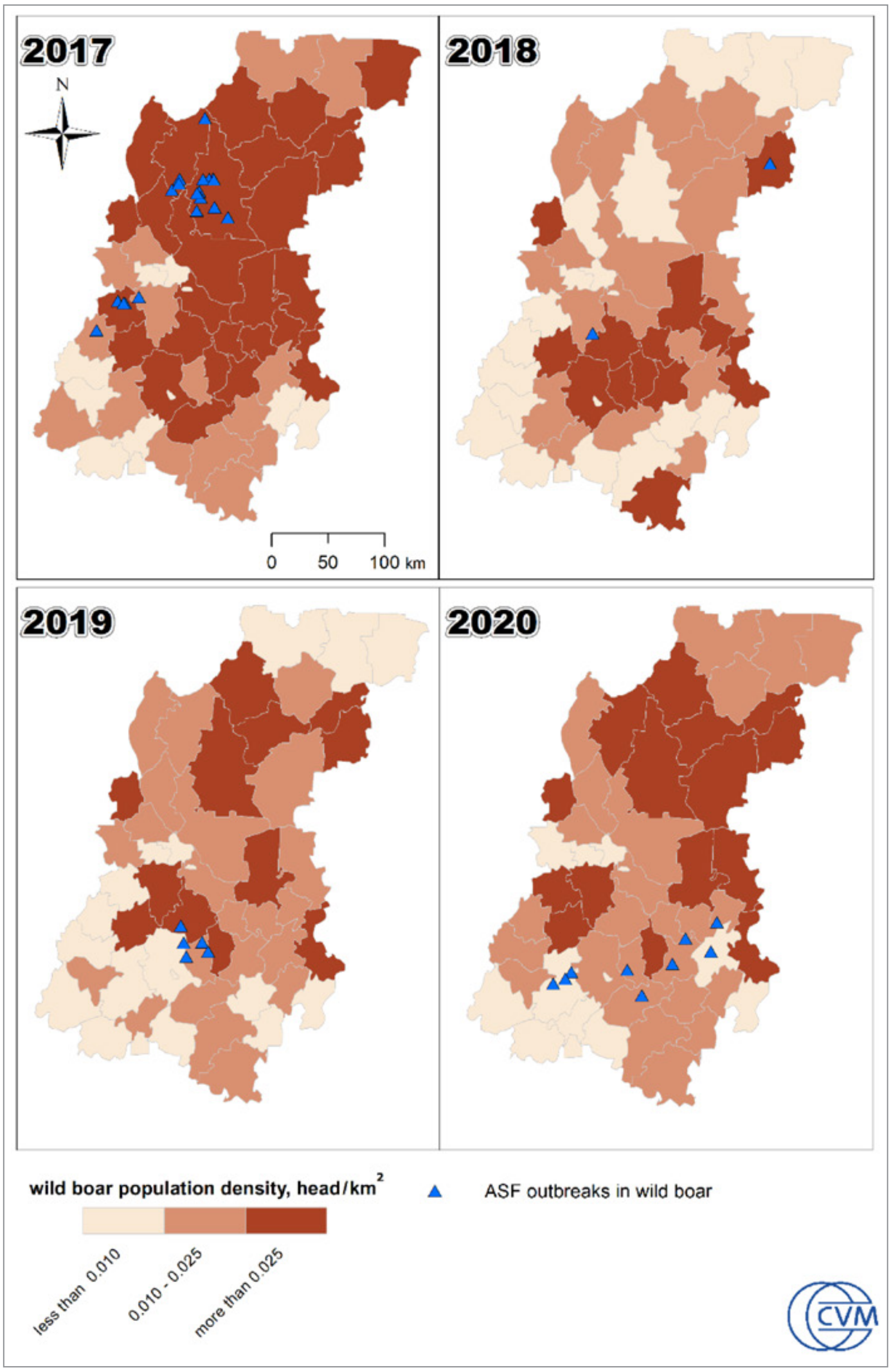

Fig. 3. Changes in the ASF epizootic situation in the Nizhny Novgorod Oblast related to the density of the wild boar population (2017–2020)

the disease: the wild boar population reduction, targeted hunting of female wild boar and removal of dead carcasses. These measures effectively reduce the risk of infection.

Although some researchers suggest a threshold density of wild boar population, which can stop ASF spread in certain areas [21, 22, 26, 32], other authors believe that even if the value is reached, there is no guarantee that the epizootic chain will break [11, 20, 24, 33]. The current national legislation on prevention and control of ASF provides for animal population reduction in ASF-affected territories to the recommended value of 0.25 head/1000 ha, which can be achieved by intensive depopulation of wild boar in the tested regions.

Some researchers have shown that it is currently impossible to establish a threshold density for the wild boar population that can be considered critical to maintain the virus in the environment and keep its spread. Based on the analysis of domestic and foreign literature, various strategies for managing wild boar at certain stages of the ASF epizootic scenario are proposed [34–36]. Preventive measures, taken to depopulate and stabilize the wild boar population before ASF introduction, will help both to minimize the likelihood of infection in the population and to reduce the costs and efforts required for potential emergency actions aimed at the disease eradication (lowering costs of searching for dead carcasses) [37–39]. Passive surveillance is the most effective method for early detection of ASF in the disease-free territories (search, safe removal and destruction of dead boar). Following ASF introduction into a particular region, no measures shall be taken in a short while in relation to wild boar populations (for example, a ban shall be imposed on hunting of all species, no crops shall be harvested to ensure food and shelter in the affected area), and only healthy wild boar population can be sharply reduced in ASF-free areas [26, 40]. Following a decline of ASF epizooty, when confirmed by passive epizootological surveillance, active population management should be applied. The positive trend, detected in the dependence of ASF outbreaks in wild boar in some RF model subjects, suggests there is a local-spatial effect of the wild boar density on ASF spread.

In general, considering dependence of ASF outbreaks on the population density for all the selected model subjects, no positive trend was observed, however, in some areas a regression analysis revealed a positive relationship. As for depopulation as a strategic measure to contain ASF, it can be assumed that its large-scale use can backfire and result in new outbreaks due to an increase in the average radius of the wild boar habitat [41].

This fact allows us to make a conclusion that the wild boar depopulation is a necessary strategic measure for ASF control and eradication, but only in certain disease-free areas bordering on the infected ones. In our opinion, an effective strategy to eliminate and prevent ASF spread in the wild should be based on the following principles:

– to ensure regular passive monitoring of ASF in the wild;

– to conduct mathematical and geographical modeling in order to establish the relationship between ASF outbreaks and wild boar population characteristics (density, structure);

– to control wild boar numbers and strictly comply with biosafety rules while hunting and dealing with dead carcasses;

– to isolate affected territories (recent studies have confirmed that wild boar demonstrate the same ASF pattern as the domestic pigs, i.e. the disease is acute, which reduces their role in the spread of infection);

– if ASF is introduced into a previously disease-free region, it is recommended to completely stop drive hunting, not to feed wild boar and, in general, not to take any actions to regulate the population size;

– to prevent further spread across the territory, number of wild boar can be significantly reduced in the areas adjacent to the affected areas before the disease introduction.

Incompleteness of data on population density provided on the municipal level in all the RF subjects is a major barrier to establishing dependence of emerging ASF outbreaks on the wild boar population density. As the data required become available, we will continue to fill in the data gap, in order to find the answer to the question, whether emerging ASF outbreaks depend on the density of wild boar population, and we will extrapolate the results obtained to the whole territory of the Russian Federation.

CONCLUSION

Statistical analysis has shown that there is no strong dependence of ASF outbreaks on the population density of wild boar in the model regions, although such dependence exists for a number of subjects of the Russian Federation. The obtained results suggest that reduction of wild boar population to the recommended density threshold does not prevent further spread of ASF and should be considered as one of the options in the set of measures together with the use of fences, suspension of feeding of wild boar and ban on drive hunting. Depopulation can be applied only in disease-free areas adjacent to the affected subjects (districts).

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