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Analysis of wild boar-domestic pig interface in Europe: spatial overlapping and fine resolution approach in several countries

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Abstract

In order to define the spatial interface between wild boar and domestic pigs in Europe, the ENETWILD consortium (www.enetwild.com) described in a preliminary report the different sources of data for domestic pigs at European scale, and developed a preliminary risk map of possible spatial interaction between both groups. This model explored and assessed the use of pig distribution data from Gridded Livestock of the World database (GLW), FAO. However, in some specific countries used as cases, the GLW predictions did not reliably represent the pig abundance distribution within countries. The currently available census data of livestock at the European Union level (Eurostat) is limited to the spatial resolution at NUTS2. While Eurostat ensures that data can be potentially comparable, there is still needed to resolve definition issues regarding better spatial resolution (level of aggregation of information) and the pig production systems. In this context, the objectives of this report are (i) assessing the spatial interface between pigs and wild boar over Europe using the best quality data available (Eurostat data and ENETWILD spatial models). We (ii) secondly assessed the interface at higher spatial resolution, distinguishing pig production types in countries where data was available. Based on comparisons at different scales and quality of data, we propose future steps in both data collection and modelling approach. Precise spatial resolution of pig data is not available at European level yet, and the discrimination of extensive *vs.* intensive farms, backyards *vs.* commercial; outdoor *vs.* indoor, is essential to quantify and perform risk analyses separately for each production system and/or considering this relevant source of variation in risk at the interface. The development of a framework to collect harmonised and standardised data at European scale at higher resolution is needed.

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Key words: distribution, pig, wild boar, interface, ASF risk, Eurostat, Gridded Livestock of the word, GLW, FAO, risk assessment, spatial modelling, *Sus scrofa*

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Summary

In this report, the ENETWILD consortium (www.enetwild.com) aims at defining the spatial interface between wild boar and domestic pigs in Europe, which is essential to evaluate ASF maintenance and spread risk. ENETWILD has provided several spatial distribution model updates of wild boar with new data from gap areas, continuously verifying and validating the methodological approach. In order to define the spatial interface between wild boar and domestic pigs in Europe, the ENETWILD consortium described in a preliminary report the different sources of data for domestic pigs at European scale and developed a preliminary risk map of possible spatial interaction between both groups. This previous model explored and assessed the use of pig distribution data from Gridded Livestock of the World database (GLW) by FAO. However, in some specific countries, the GLW predictions did not reliably represent the pig abundance distribution.

The currently available census data of livestock in EU by Eurostat is limited to a maximum spatial resolution at NUTS 2 level. While being comparable, there is still needed to resolve definition issues regarding better spatial resolution (level of aggregation of information) and the categorisation of pig production systems. SIGMA project[2] (Animal Disease Data Model, EFSA 2019) aims at increasing the quality and the comparability of the data received from the Member States. In this context, the first objective of the present report is (i) **assessing the spatial interface using the best quality data available at European level, which is comparable and reliable for pig and wild boar abundance distribution** over the continent. While more precise spatial resolution of pig data is not available at European level yet, and the discrimination of the types of production systems is not always reliable to perform analyses separately for each production, (ii) **we secondly aimed to assess the wild boar-domestic pig spatial interface in specific countries as examples, where reliable and precise data for domestic pig distribution and abundance are available, including information on farm typology.**

Data and methodology: for objective (i), we used the following data:

- For pig abundance and distribution data, the Eurostat data (https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ef_lsk_main&lang=en/). Eurostat complies and make available at website the livestock density by NUTS 2 regions for EU-28, the latest, for 2016, which measures of the stock of animals (number of heads) and holdings (number).
- ENETWILD model of wild boar abundance, which provides validated predictions of wild boar abundance on a 10x10 km scale globally for Europe (ENETWILD consortium 2020).

As for objective (ii), data from Latvia, Estonia, Denmark, Czech Republic, Slovakia, Romania, and Croatia were used.

To establish the area of greatest risk of contact between pigs and wild boar, we delimited the areas with different densities according to three abundance classes (low, medium and high) for each group. In the case of domestic pigs, we separately considered the density of pigs and holdings to depict the interface (in terms of spatial overlapping). Both, the domestic and the wild boar layers, were overlapped with a GIS to classify the regions where pig and wild boar coincide using four different categories (spatial overlapping as a proxy to risk).

Results and discussion: Our map of the interface between domestic pig and wild boar at European scale (objective i) indicated that the maximum risk interface (in terms of spatial overlapping) is present over a North to South strip in Central Europe, delimited by Germany, Poland, Czech Republic, Slovakia, Hungary, Romania, Bulgaria, Serbia and Croatia. This area is coincident with the current frontline of ASF progression from Eastern to Central Europe. High risk areas were also

[2] https://www.efsa.europa.eu/en/topics/topic/data-collection-animal-diseases

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detected in North Italy and North West Spain. However, our local approaches at higher resolution (objective ii), and when possible, separately for each production systems (characterized by different biosecurity), indicated that a closest view is needed to quantify and interpret risks in sufficient detail (10x10 km grid in that case). The observed fine spatial patterns within countries presented marked patterns that cannot be evidenced by Eurostat data-based approach. Secondly, when considering the types of pig production separately, the different spatial pattern that we evidenced may reflect the spatial variation in prevalent pig husbandry systems over regions, with contrasting differences among countries. This approach, therefore, provided a more real and practical visualization of risky areas, not only in terms of spatial overlapping, but identifying where low biosecurity pig holdings may occur in concomitance with high wild boar abundances.

Conclusions: we exemplified that the interface between wild boar and domestic pigs can be depicted very precisely if reliable data on pig abundance and distribution are available. As for wild boar, validated abundance and distribution maps have already been developed by ENETWILD (although improvable). However, by now, high resolution assessment of the interface, including domestic pig production typology, is not feasible at continental level due to unavailability of high-resolution data in most countries. Therefore, the challenge is developing a framework to collect data at European scale with higher resolution, harmonized and following standards to define the interface of the pig population that are more exposed to wild boar, i.e., outdoor production.

Next steps for further modelling the wild boar-domestic pig interface:

- Concerning data on pig farm distribution and census at European level:
    - To collect data at the highest possible spatial resolution over European countries;
    - To differentiate intensive *vs.* extensive types of production, backyards *vs.* commercial, outdoor *vs.* indoor.
- As for the wild boar, efforts to improve the reliability of the abundance model focused on hunting yield data are being addressed as a continuous activity, including outputs at highest spatial resolution, and the calibration of hunting bags into densities. For that, updated wild boar hunting yield data at the finest spatial resolution as possible is essential, particularly in low quality data areas (i.e. Balkans). A network of ENETWILD collaborators already is calculating reliable density estimates for wild boar over Europe, which will be very valuable for calibration purposes.

All this will allow to more reliably depict the interface pig-wild boar interface, and therefore to better assess risks due to both components.

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1. Introduction

1.1. Background and Terms of Reference as provided by the requestor

This contract was awarded by EFSA to Universidad de Castilla-La Mancha, contract title: Wildlife: collecting and sharing data on wildlife populations, transmitting animal disease agents, contract number: OC/EFSA/ALPHA/2016/01 – 01.

The terms of reference for the present report were to define the spatial interface between wild boar and domestic pigs based on different sources of data. According to the availability and quality of livestock data, the output will be a risk map of possible spatial interaction between pig and wild boar. Extractable and updatable raster files in at least 10x10km resolution of wild boar-domestic pig should cover at least the Balkan region besides Austria, Hungary, Slovakia, Germany and Romania.

1.2. Scope of the report

The ENETWILD consortium (www.enetwild.com) implemented an EFSA funded project whose current main objective is to collect information regarding the geographical distribution and abundance of wild boar throughout Europe in order to subsequently create geospatial tools to be used in further risk assessment of diseases with a wildlife component, such as ASF. ENETWILD consortium has provided several spatial distribution model updates for wild boar with new data from gap areas, and continuously verifies and validates the methodological approach.

This report, in accordance with objective 4 of the specific contract 7, aims at defining the spatial interface between wild boar and domestic pigs in Europe. According to the availability and quality of livestock data, the output is a risk map of possible spatial interaction between pig and wild boar. In a preliminary report the ENETWILD consortium (www.enetwild.com) described the different sources of data for domestic pigs at European scale and developed a preliminary risk map of possible spatial interaction between domestic pig and wild boar (ENETWILD Consortium et al. 2020a). This model explored and assessed the use of pig distribution data from Gridded Livestock of the World database (GLW), FAO (Robinson et al. 2014, Gilbert et al. 2018). However, in some specific countries used as examples, the GLW predictions did not reliably represented the pig abundance distribution within countries. The currently available census data of livestock at the European Union level (Eurostat) is restricted to a maximum spatial resolution of NUTS 2. While Eurostat ensures that data can be comparable, there is still needed to resolve definition issues regarding better spatial resolution (level of aggregation of information) and the categories of pig production systems, for which SIGMA project[3] (Animal Disease Data Model, EFSA 2019) aims at increasing the quality and the comparability of the data received from the Member States. In this context, and with the expectations to access to higher resolution data in the near future, the objectives of the present report are (i) assessing the spatial interface in Europe using the best quality data available, which is comparable and reliable for pig (Eurostat source) and wild boar (ENETWILD spatial models) abundance distribution over Europe. We (ii) secondly aim at comparing the outputs of this modelled interface at European with those of several models at the country level where pig data was available at the higher resolution and/or included information on farm typology.

[3] https://www.efsa.europa.eu/en/topics/topic/data-collection-animal-diseases

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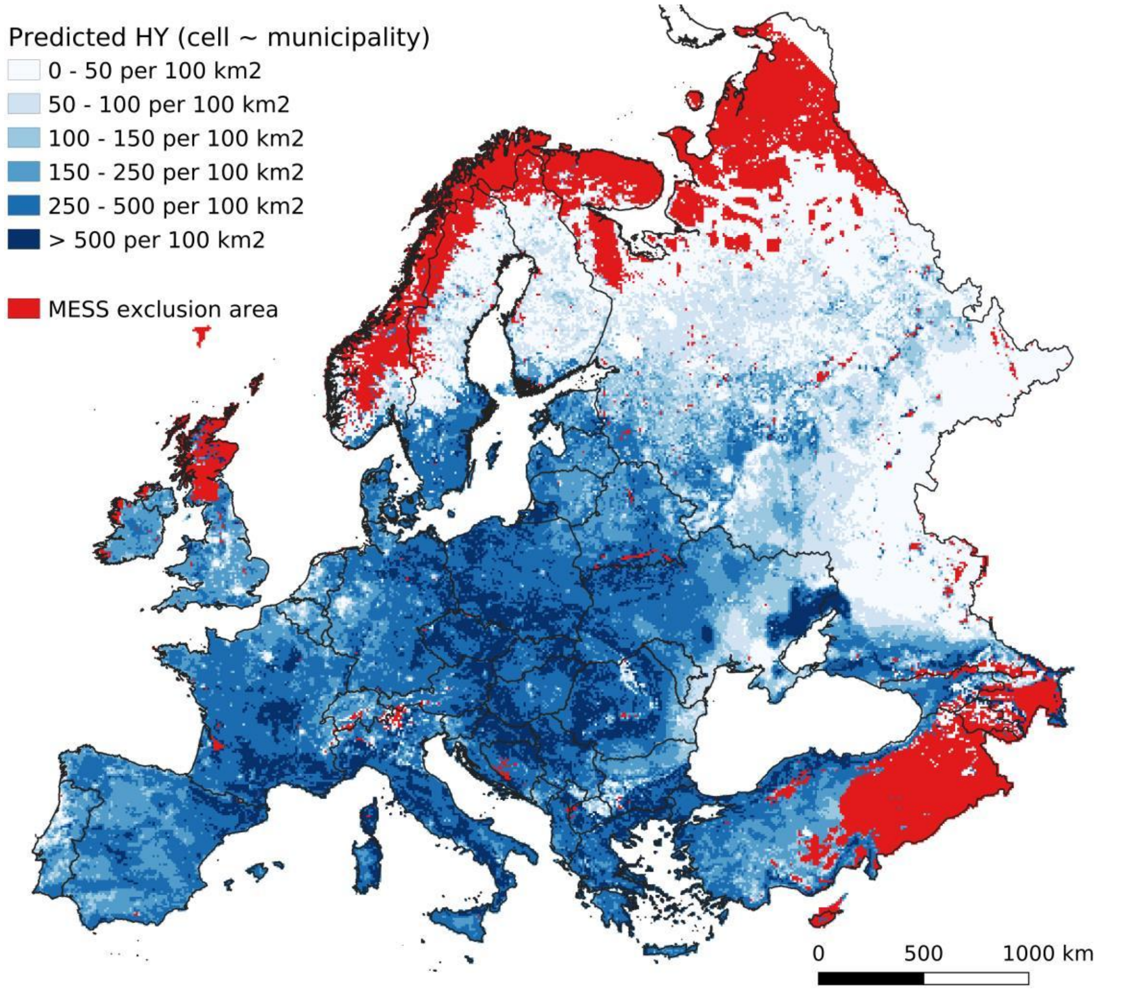
2. Data

2.1. Study area

The study area is the same used in the previous report (ENETWILD consortium et al. 2020b) and spans 11,019,700 km^2. It comprises all countries in mainland Europe approximately delimited by the Ural Mountains at the Eastern boundary which is also likely to act as a geographical barrier limiting the immigration of wild boar from Asia (IUCN map on wild boar distribution at https://www.iucnredlist.org/species/41775/10559847), and includes Mediterranean islands and the UK and Ireland. This is shown in Figure 1, together with wild boar predicted hunting yield per 100 square km. For this report the study area was divided into 10x10 km grid cells.



MESS exclusion area: insert brief definition

Figure 1: Extent of the study area and wild boar predicted hunting yield (HY; number of wild boar hunted) from model at 10x10 km EEA grid (for more details, see ENETWILD consortium et al. 2020b).

2.2. Wild boar distribution and abundance

We used the last update of wild boar abundance distribution map provided by the ENETWILD consortium at 10x10 km resolution (ENETWILD consortium et al. 2020b, see Figure 1). Statistical tests (ENETWILD consortium et al. 2020b) confirmed that 10x10 km resolutions were able to detect spatial variation in wild boar hunting bags (high model performance) and to predict

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numbers of wild boar hunted with relative precision. Briefly, bioclimatic variables and sun radiation were obtained from the Worldclim 2 project database. Land use data came from ESA/CCI-LC project, version v2.0.7 (2015) (https://www.esa-landcover-cci.org/?q=node/158). Mean altitude was extracted from the USGS Space Shuttle Radar Topography Mission (SRTM) GL30 (https://lta.cr.usgs.gov/SRTM1Arc) and snow cover was obtained from MODIS/Terra Snow Cover project (Monthly L3 Global 0.05Deg CMG, Version 6; https://nsidc.org/data/MOD10CM). Human footprint index (an index related to human population distribution, urban areas, roads, etc.) was provided by The Last of the Wild Project version 2 (http://sedac.ciesin.columbia.edu/data/collection/wildareas-v2). Vegetation growing period is based on a water balance model (http://www.appsolutelydigital.com/DataPrimer/part154.html).

2.3. Domestic pig distribution and abundance

2.3.1. Data sources and characteristics

2.3.1.1. Eurostat

Eurostat complies and make available at website the livestock density by NUTS 2 regions for EU-28, the latest, for 2016 (livestock units per hectare utilised agricultural area). Eurostat provides the **livestock density index** (Figure 2), which measures the stocks of domestic animals (cattle, sheep, goats, Equidae, pigs, poultry and rabbits). The pig density data was measured in terms of numbers of heads and holdings per km^2, respectively. The values include piglets having a live weight of under 20kg, breeding sows weighing 50kg and over and other pigs. The Figure 2 shows, for the EU-28, the pig stock density in 2016 by NUTS 2 regions, expressed as the number of heads and holdings.

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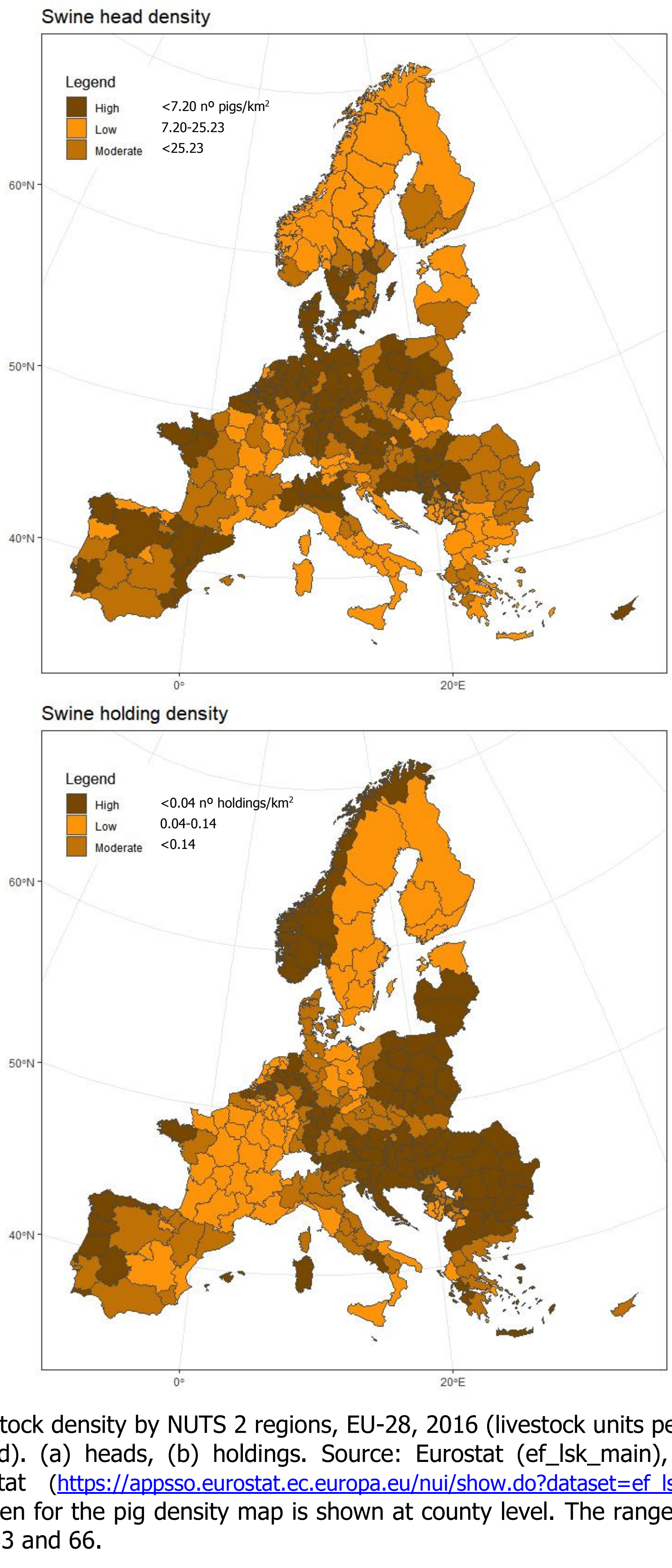

Figure 2: Pig stock density by NUTS 2 regions, EU-28, 2016 (livestock units per hectare utilised agricultural land). (a) heads, (b) holdings. Source: Eurostat (ef_lsk_main), (ef_m_farmleg). Source: Eurostat (https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ef_lsk_main&lang=en). Note that Sweden for the pig density map is shown at county level. The ranges are determined by percentiles 33 and 66.

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2.3.1.2. Other sources of pig population used in this report

Other sources of pig population data used in this report are detailed in Figure 3 and Table 1.

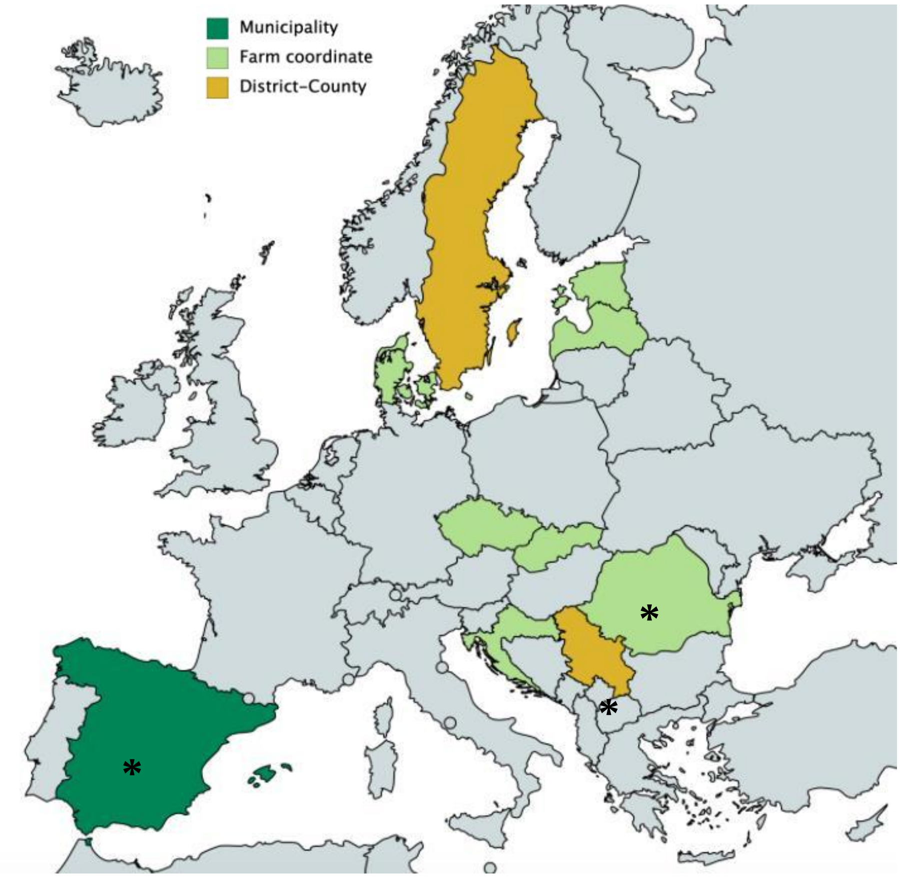

Figure 3: National data of domestic pig population used in this report, indicating the level of spatial aggregation of the data. (*) indicate the countries where information on the typology of farms is available.

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Table 1: National data of pig population used in this report collected directly from country national authority or through EFSA, indicating the level of temporal and spatial resolution of the data, sample size, and the information available.

Region/Country	Spatial resolution	Year	No. pigs	No. holdings	Typology holding
Eurostat: All EU	NUTS 2	2016	Yes	Yes	No
Croatia	Coordinates	2019	No	Yes	No
Denmark	Coordinates	2020	Yes	Yes	No
Serbia	District	2018	Yes	Yes	Backyard (<10-50), commercial (<50)
Czech Rep-	Coordinates	2019	Yes	Yes	No
Slovakia	Coordinates	2018	Yes	Yes	No
Estonia	Coordinates	2019	Yes	Yes	No
Latvia	Coordinates	2019	Yes	Yes	No
Sweden	County	2019	Yes	No	No
Romania	Coordinates	2019	Yes	No	Backyard, commercial

3. Methodology: definition of the spatial interface between wild boar and domestic pigs

As above mentioned, for **wild boar abundance and distribution data**, we always used the predictive model elaborated by ENETWILD consortium (2020b) at 10x10 km grid.

To establish the area of greatest overlapping between pigs and wild boar abundances (which does not necessarily equate to risk of contact), for both populations we first delimited the areas with the different densities according to percentiles 33 and 66 (using 95% of the density range), determining three density classes (low, medium and high) for each group. Both layers were overlapped to obtain the regions where high densities of both pig and wild boar coincide (maximum risk). Areas at the interface were also classified in more detail as follows:

Table 2. Classification of overlapping areas at the interface based on wild boar density and domestic pig density (number of heads or holdings). We first delimited the areas with the different densities according to percentiles 33 and 66 determining three density classes (low, medium and high) for each group. Both layers were overlapped to obtain the 4 categories (in different colours) of spatial overlapping as indicated in the table.

		Wild boar density		
		low	moderate	high
Domestic pig density	low	*	*	**
	moderate	*	**	***
	high	*	***	****

The spatial resolution of projections of the wild boar-domestic pig interfaces were NUTS 2 for the complete map of Europe (using Eurostat data for domestic pigs) and 10x10 km grid cells for national cases.

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4. Results and discussion

4.1. The spatial interface between wild boar and domestic pigs at European scale

As commented above, the Figures 1 and 2 respectively, represents the densities of pigs (heads/km^2) and holdings (number/km^2) (Eurostat data, 2016) at NUTS 2 level, and the abundance of wild boar (predicted hunting yield from model at 10x10 km EEA grid (ENETWILD consortium et al. 2020b). For pigs, the highest densities are found in central Europe (the areas delimited by Germany, Poland, Denmark, North Italy and Serbia), North west Spain (and other areas of this country) and the Bretagne regions. The Figure 4 represents the abundance of wild boar (hunting bag/km^2 resampled from ENETWILD consortium et al. 2020) at NUTS 2 level.

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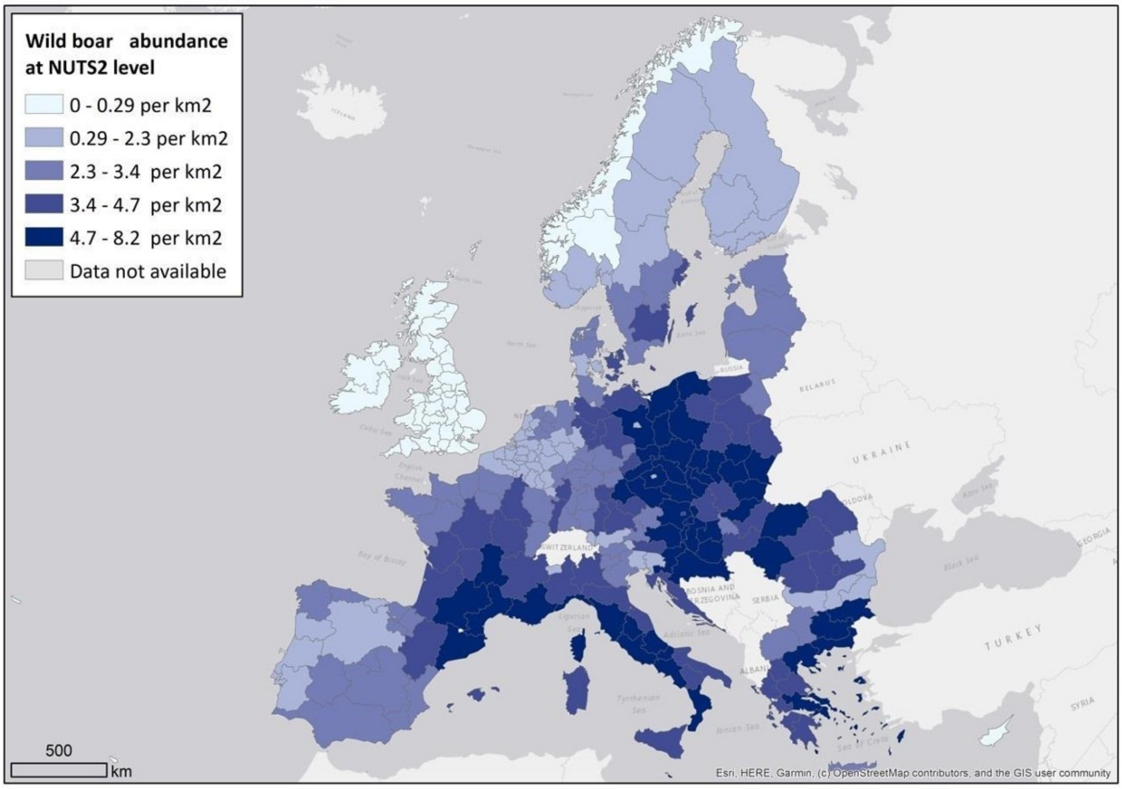

Figure 4. The abundance of wild boar (hunting bag resampled from ENETWILD consortium et al. 2020b) at NUTS 2 level.

Wild boar-domestic pig interface risk maps at NUTS 2 level (pig data is available in Eurostat at this spatial resolution) are represented in Figure 5. The map at the top indicates the interface between wild boar and pig head density (No. pigs/km^2). The map at the bottom indicates the interface between wild boar and pig holding density (No. holdings/km^2). The maps of the interface between domestic pig and wild boar in Europe indicated that the maximum risk (in terms of spatial overlapping) is scattered over a North to South strip in Central Europe, delimited by Germany, Poland, Czech Republic, Slovakia, Hungary, Romania, Bulgaria, Serbia and Croatia, which overlaps with the current frontline of ASF progression from Eastern to Central Europe. Other relevant spots of highest risk were identified in North Italy and North West Spain.

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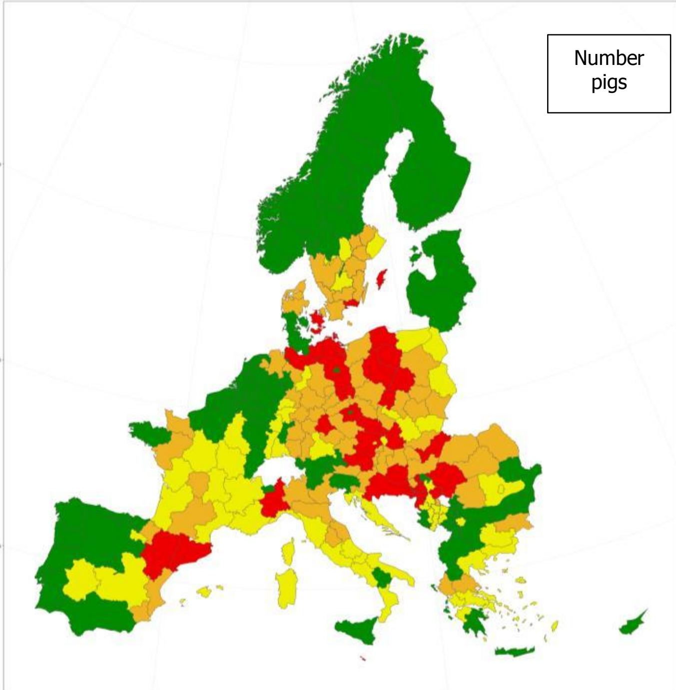
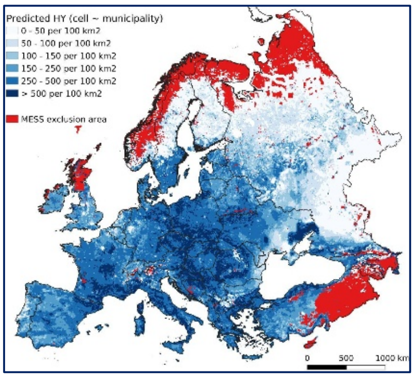


		Wild boar density		
		low	moderate	high
Domestic pig density	low	*	*	**
	moderate	*	**	***
	high	*	***	****



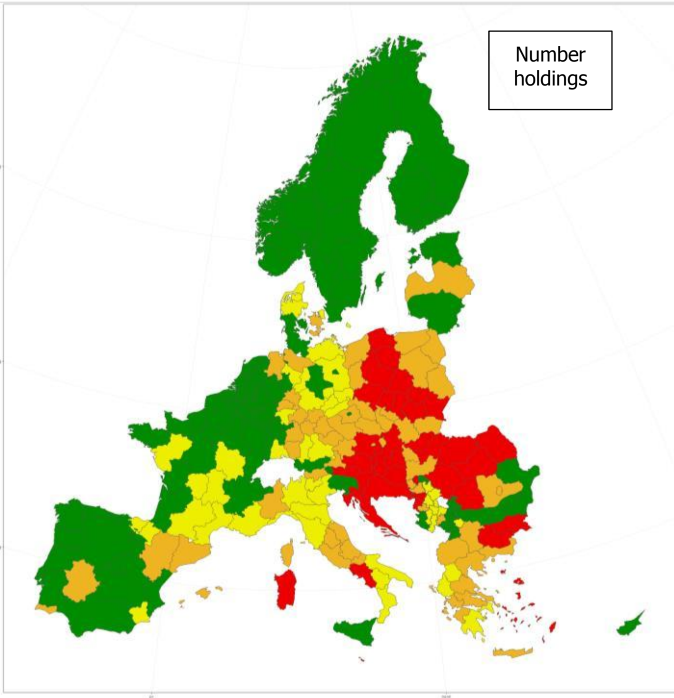


Figure 5: Wild boar-domestic pig interface risk maps at NUTS2 level. The map at the top represents the interface between wild boar and pig head density (no. holdings/km^2). The map at the bottom represents the interface between wild boar and pig holding density (no. holdings/km^2). We used 4 risk categories that are defined from low to very high risk. For visual comparison, the wild boar abundance map (hunting bag at 10x10 km grid) is shown (Figure 1). Note that Sweden, for the pig density map, is shown at county level, and Serbia, at district level for both maps, since this information was available.

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4.2. Assessing the spatial interface between wild boar and domestic pigs: case studies at country level with high resolution data on pigs

4.2.1. Pig abundance distribution at national level in case countries

The Figures 6 and 7 represent the **total number of pig heads** and **holdings** at 10x10km level for each case country, respectively. Three categories were defined according to percentiles 33 and 66 (using 95% of the density range), determining density classes (low, medium and high, except for Estonia, since most cells presented 0 value).

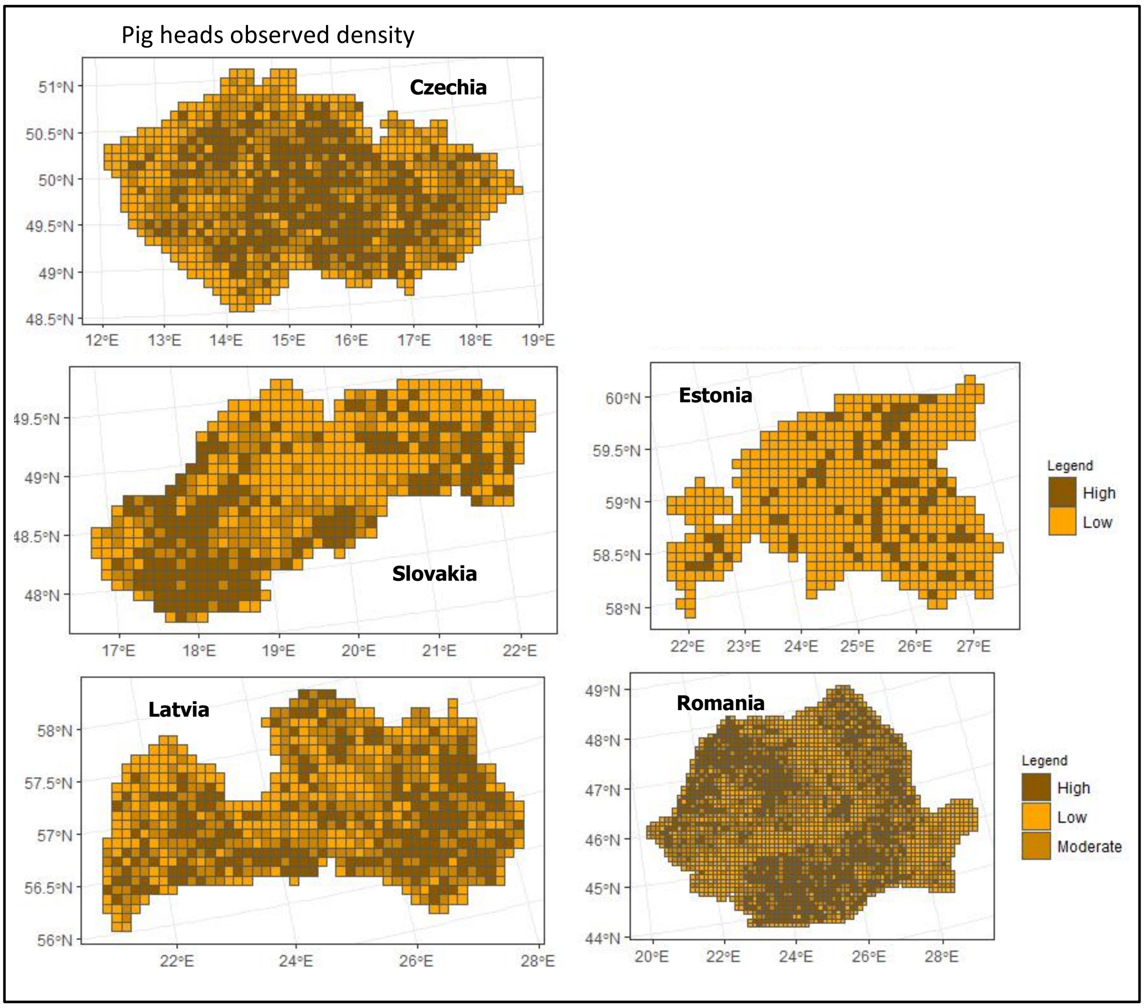

Figure 6: Representation of the total number of pig heads recorded from census. The categories were defined according to percentiles 33 and 66 (using 95% of the density range), determining three density classes (low, medium and high, except for Estonia since most cells presented 0 value).

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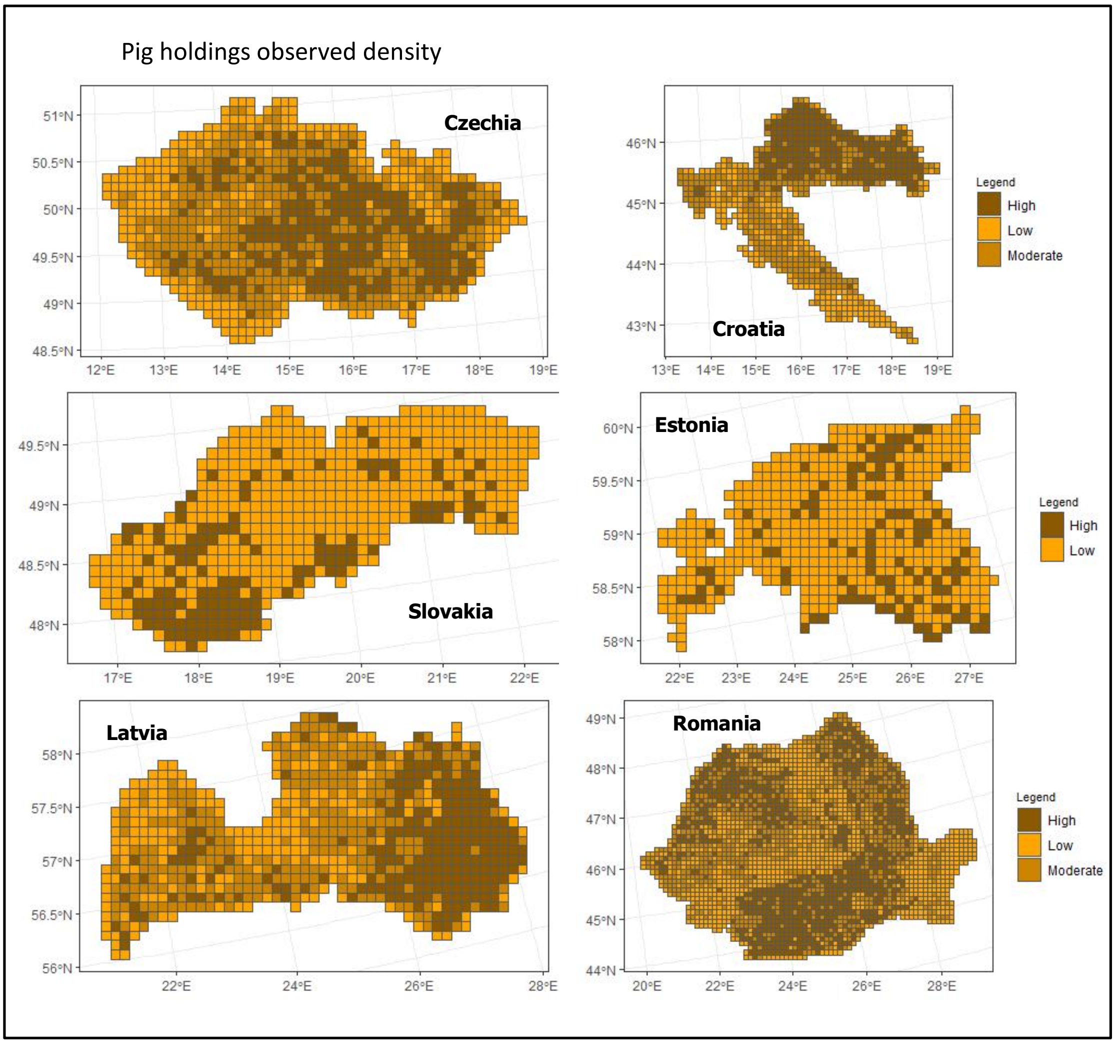

Figure 7: Representation of the total number of holdings recorded from census (data provided by EFSA and other sources). The categories were defined according to percentiles 33 and 66 (using 95% of the density range), determining three density classes (low, medium and high, except for Estonia, since most cells presented 0 value).

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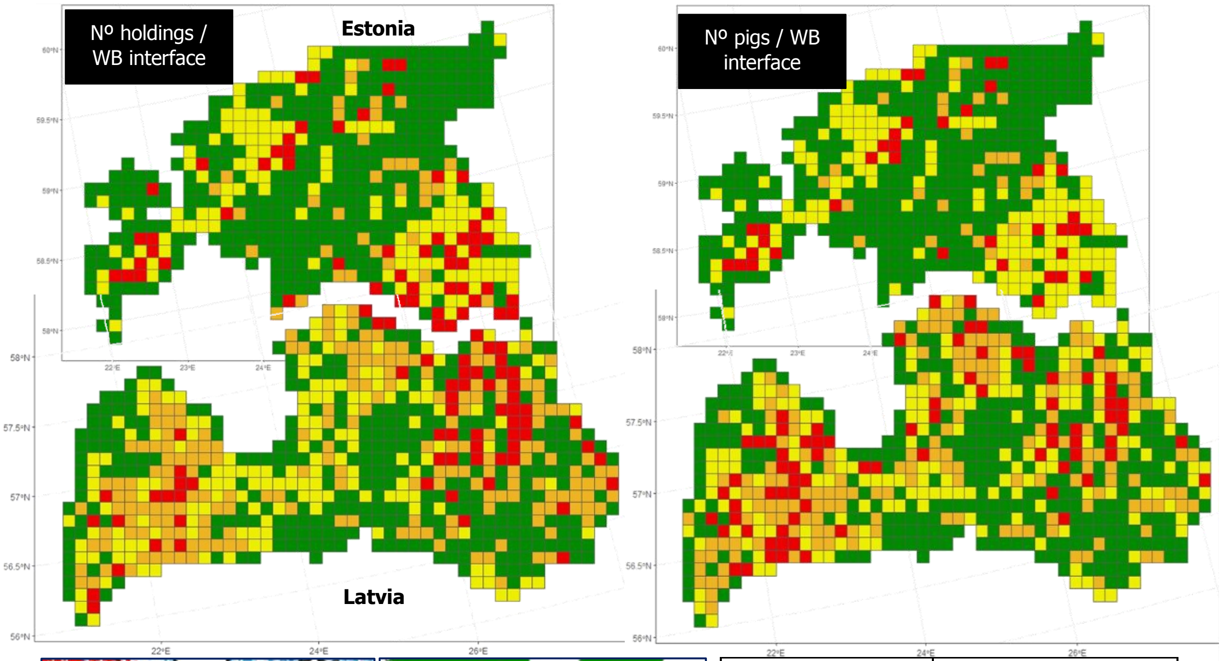
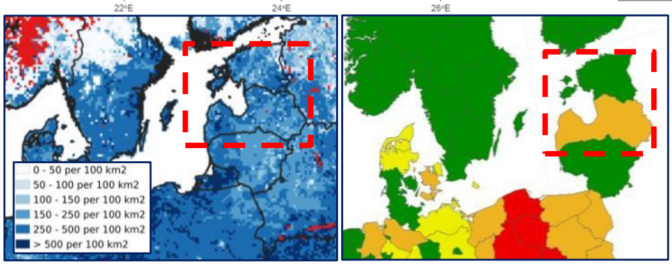
4.2.2. Assessing the interface risk maps

For comparison purposes with data at large scale (based on Eurostat), we assessed the reliability of the analysis of wild boar-domestic pig interface at country level using high resolution data, and when information was available, according to the type of pig production system.

The Figures 8 to 12 are the risk maps at 10x10 km grid of wild boar-domestic pig interface in Estonia and Latvia (Figure 8), Denmark (Figure 9), Czech Rep. and Slovakia (Figure 10), Romania (Figure 11), Croatia (Figure 12). The interface for the number of holdings and number of pigs are shown separately. For comparison, partial views on the wild boar-domestic pig interface risk maps (Figure 5, NUTS2 level) are shown, and the predicted wild boar abundance (hunting bag at 10x10 km, ENETWILD consortium et al. 2020b). We used 4 risk categories that are defined from low to very high risk based on spatial overlapping.





		Wild boar density		
		low	moderate	high
Domestic pig density	low	*	*	**
	moderate	*	**	***
	high	*	***	****

Figure 8: Wild boar-domestic pig interface risk maps in Estonia and Latvia at 10x10 km grid. The map on the left represents the interface between wild boar and pig holding density (no. holdings/km^2). The map on the right represents the interface between wild boar and heads of pig density (no. heads/km^2). For comparison, a partial view on the zone of the wild boar-domestic pig interface risk map at NUTS 2 level (based on no. of holdings, Figure 5) is shown, and the predicted wild boar abundance (hunting bag at 10x10 km, ENETWILD consortium et al. 2020, bottom left). We used 4 risk categories that are defined from low to very high risk.

The maps for these two Baltic countries (Figure 8) indicate that risk (in term of overlapping) is more marked in the eastern part, close to the border, and in separate areas near the coast within each country. The patterns, when considering density of holdings and pigs, respectively, are similar.

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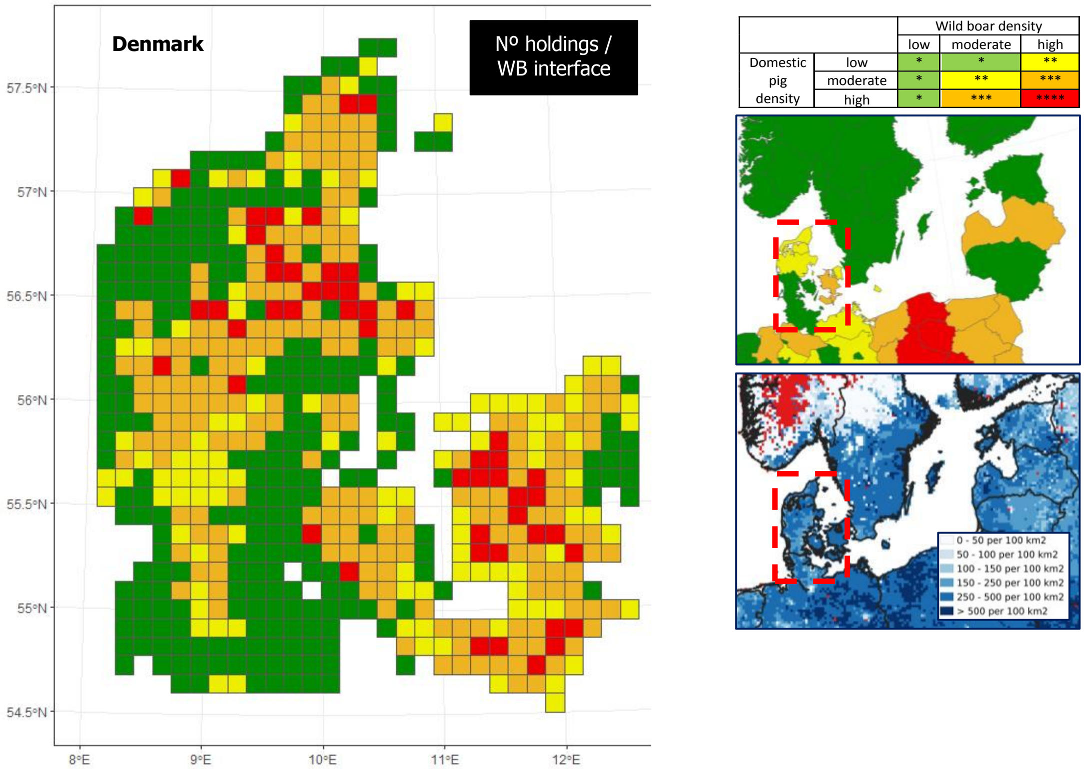

Figure 9: Wild boar-domestic pig interface risk maps in Denmark at 10x10 km grid. The map represents the interfaces between wild boar (abundance, ENETWILD consortium et al, 2020) and pig density (no. holdings/km^2). For comparison, a partial view on the zone of the wild boar-domestic pig interface risk maps at NUTS 2 level (Figure 5) is shown, and the predicted wild boar abundance (hunting bag at 10x10 km, ENETWILD consortium et al. 2020b, bottom right). We used 4 risk categories that are defined from low to very high risk.

As for Denmark (Figure 9), no information on pig population sizes were available. The depicted interface in this country, which expands widely over the country, requires further explanation. There are only few wild boar in Denmark, probably decreasing in number due to current population control policies. Wild boars were originally present and widespread in Denmark but became extinct more than 200 years ago due to hunting. The wild boar recently returned to Denmark migrating from Germany. The relatively mild maritime climate of Denmark and habitats provides good conditions for wild boar to be established. In consequence, the spatial prediction models in this country (ENETEWILD consortium et al., 2020b) indicates medium values over a large area of the country. This is reflecting the potential rather than the actual situation of wild boar in Denmark, and therefore, the interface here presented is indicating the potentiality if wild boar establishes over the country. It therefore would be needed a closer approach at higher resolution where wild boar population are actually present in Denmark.

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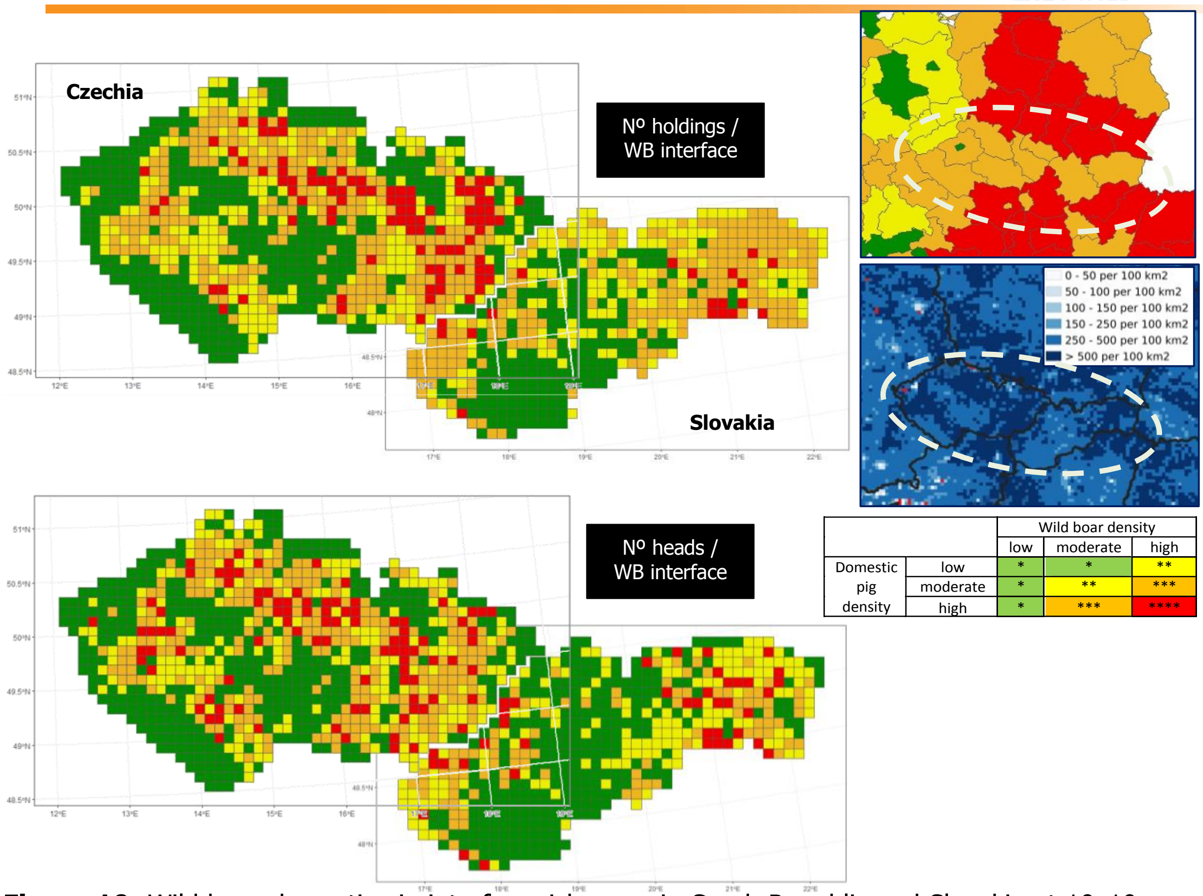

		Wild boar density		
		low	moderate	high
Domestic pig density	low	*	*	**
	moderate	*	**	***
	high	*	***	****

Figure 10: Wild boar-domestic pig interface risk maps in Czech Republic and Slovakia at 10x10 km grid. The map at the top represents the interface between wild boar and pig holding density (no. holdings/km^2). The map at the bottom represents the interface between wild boar and heads of pig density (no. heads/km^2). For comparison, a partial view on the zone of the wild boar-domestic pig interface risk maps at NUTS 2 level (Figure 5) is shown, and the predicted wild boar abundance (hunting bag at 10x10 km, ENETWILD consortium et al. 2020b, on the right). We used 4 risk categories that are defined from low to very high risk.

The wild boar-domestic pig interface risk maps in Czech Rep. and Slovakia (Figure 10) indicates a continuous transboundary band of high to very high risk from east to west. There are also high to very high-risk spots both in western Czech Rep. and in eastern Slovakia. Like in the two studied Baltic countries, the patterns considering density of holdings and pigs, respectively, are similar.

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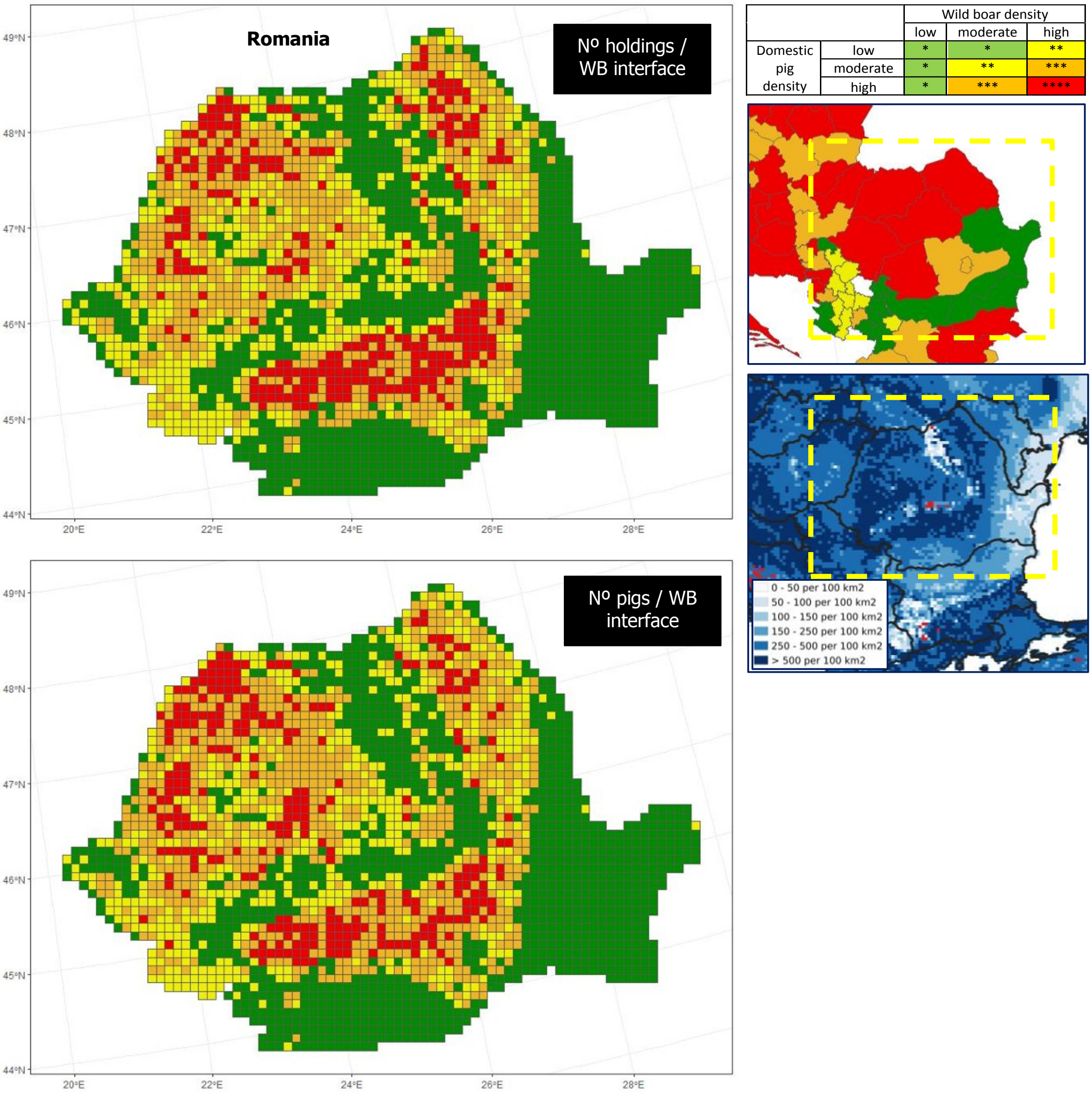

Figure 11: Wild boar-domestic pig interface risk maps in Romania at 10x10 km grid. The map at the top represents the interface between wild boar and pig holding density (no. holdings/km^2). The map at the bottom represents the interface between wild boar and heads of pig density (no. heads/km^2). For comparison, a partial view on the zone of the wild boar-domestic pig interface risk maps at NUTS 2 level (Figure 5) is shown, and the predicted wild boar abundance (hunting bag at 10x10 km, ENETWILD consortium et al. 2020b, on the right). We used 4 risk categories that are defined from low to very high risk.

The wild boar-domestic pig interface risk maps in Romania (Figure 11) indicates two large main areas of high to very high-risk areas on the East and West of Carpathian mountain chain, respectively. It is remarkable not only the large extension of these risky areas, but the high presence of high-risk spots (on the basis of 10x10 km grid). Like in the previous cases, the patterns when considering density of holdings and pigs, respectively, are relatively similar.

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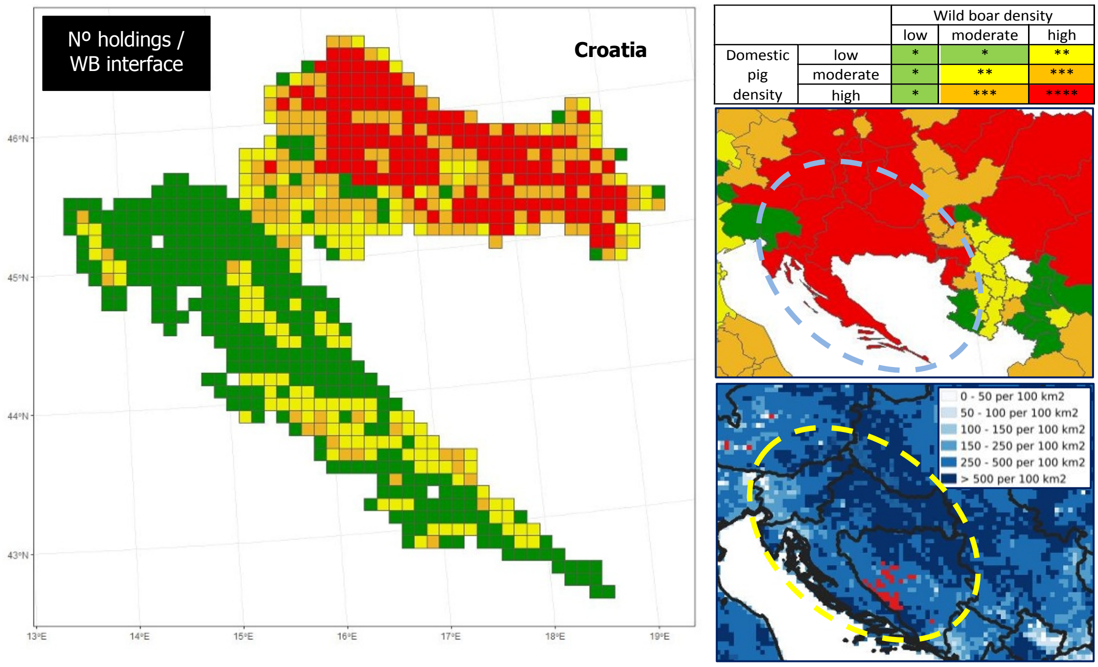

Figure 12: Wild boar-domestic pig interface risk maps in Croatia at 10x10 km grid. The map indicates the interfaces between wild boar (abundance, ENETWILD consortium et al, 2020) and pig head density (no. holdings/km^2). For comparison, a partial view on the zone of the wild boar-domestic pig interface risk maps at NUTS2 level (Figure 5) is shown, and the predicted wild boar abundance (hunting bag at 10x10 km, ENETWILD consortium et al. 2020b, bottom right). We used 4 risk categories that are defined from low to very high risk.

In relation to Croatia, the wild boar-domestic pig interface risk (Figure 12) was mapped only on the basis of pig farm distribution. The map indicates a relatively large and continuous area of high, but especially very high-risk, in the inner part of the country, whereas the coastal area presented less risks (based on spatial overlapping).

The Figure 13 shows the wild boar-domestic pig interface risk maps in Romania at 10x10 km grid according to the type of pig production (backyard, commercial), respectively.

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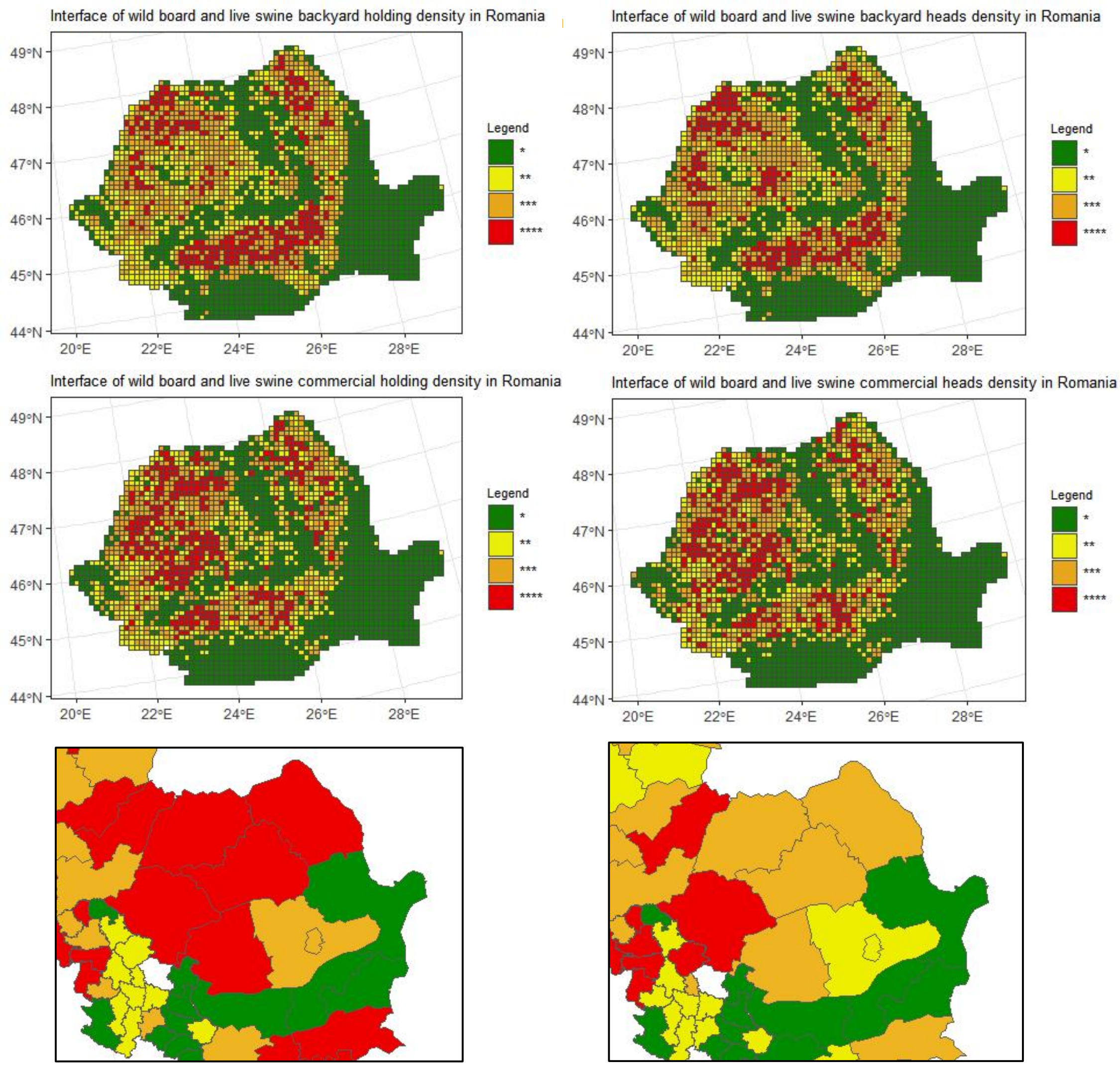

Figure 13: Wild boar-domestic pig interface risk maps in **Romania** at 10x10 km grid according to the type of pig production (backyard, commercial), respectively. The two maps at the top indicate the interfaces between wild boar (abundance, ENETWILD consortium et al, 2020) and backyard pigs (left: holding density, right: pig head density), and the two maps in the middle refers to commercial pig farms (left: holding density, right: pig head density). For comparison, the wild boar-domestic pig interface risk maps in Romania at NUTS 2 level are shown (considering no. holdings/km^{2}and no. heads/km^2, respectively, bottom, see Figure 11). We used 4 risk categories that are defined from low to very high risk.

We also represented the wild boar-domestic pig interface risk maps in Romania according to the type of pig production (backyard, commercial) (Figure 13) in terms of holding density and pig head density. The visual inspection of maps indicated that the high to very high-risk areas (placed east and west to Carpathian mountain range, respectively) for both backyard and commercial pig overlaps do correspond, and therefore backyard and commercial pigs are spatially associated in these areas of high risk of interaction with wild boar.

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4.3. Conclusions and further steps

4.3.1. Assessment of the interface based on Eurostat and National data

- Our map of the interface between domestic pig and wild boar at European scale indicated the maximum risk interface (in terms of spatial overlapping). However, our local approaches at higher resolution, and when possible, separately for each production systems (characterized by different biosecurity), indicated that a closer view is needed to quantify and interpret risks in sufficient detail. The observed fine spatial patterns within countries presented marked patterns that cannot be evidenced by using Eurostat data.
- The analysis of the types of pig production allows evidencing with sufficient detail the spatial variation in more prevalent pig husbandry systems over regions in relation to wild boar abundance. This approach reveals risky areas in terms of spatial overlapping, but also where low biosecurity pig holdings occur in concomitance with high wild boar abundance.
- The interface between wild boar and domestic pigs can be depicted very precisely if reliable data on pig abundance and distribution are available. As for wild boar, validated abundance and distribution maps have already been developed by ENETWILD.
- However, by now, high resolution assessment of the interface, attending also to pig production typology, is not feasible at continental level due to pig data unavailability for most countries. Therefore, the challenge is developing a framework to collect data at European scale with higher resolution, harmonized and following standards to define the interface of the pig industry that are more exposed to wild boar, i.e., outdoor production.
- Wild boar-domestic pig interface patterns, when considering density of holdings and pigs separately, are relatively similar, however, locally, there were differences. The higher risk detected only when the interface is modelled using the number of pigs may relate to the presence of intensive farms, which are characterized by high stocks, and normally, good biosecurity. On the other hand, when higher risk was detected only when the interface is modelled using the number of farms (but not necessarily of the total stock) in the area may relate to the presence of numerous non-commercial and/or backyards farms, normally of reduced stock and poor biosecurity. Therefore, depicting the interfaces separately for different pig production systems is essential to define scenarios of the interface, which probably require different management (i.e., in case of ASF outbreaks).

4.3.2. Next steps

- Concerning data on domestic pig distribution and census at European level it is needed:
  - To collect data at the highest possible spatial resolution over European Countries,
  - To differentiate types of production: intensive *vs.* extensive types of production, backyards *vs*. commercial, outdoor *vs.* indoor. We recommend using farm typologies as standardized by EFSA (Sigma project[4]).
- Other than spatial overlapping analysis of the wild -boar-domestic pig interface, such as connectivity analyses should be performed, which may help to prioritize sanitary interventions in the case of disease outbreak.
- As for the wild boar, efforts to improve the reliability of the abundance model focused on hunting yield data are being addressed as a continuous activity, including the calibration of hunting bags into densities. For that, updated wild boar hunting yield data at the finest

[4] https://www.efsa.europa.eu/en/topics/topic/data-collection-animal-diseases

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spatial resolution as possible is essential, particularly in low quality data areas (i.e. Balkans). A network of collaborators already is calculating reliable density estimates for wild boar over Europe, which will be very valuable for calibration purposes.

All this will allow to more reliably depict the pig-wild boar interface, and therefore to better assess health risk linked to both populations.

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