A questionnaire survey for the assessment of wild-dominestic pig interactions in a context of oedema disease outbreaks among wild boars (Sus scrofa) in South-Eastern France.

Ferran Jori¹, G. Petit¹, N. Civil¹, A. Decors², François Charrier³, François Casabianca⁴, and Vladimir Grobois¹

¹Animal Sante Territoires Risques et Ecosystemes
²Agence francaise pour la biodiversite
³CIRAD Montpellier-Occitanie
⁴Institut National de Recherche pour l’Agriculture l’Alimentation et l’Environnement Centre de Corse

April 12, 2022

Abstract

Pig outdoor farming is gaining popularity and commercial success in the EU and its expansion, together with an increasingly abundance of wild boar populations facilitates interactions between domestic and wild suids. In the Southern French Department of Ardèche, several episodes of mass mortalities due to infection with an enteropathogenic strain of Escherichia coli, causing oedema disease (OD) were reported in wild boar populations between 2013 and 2016. In order to investigate a potential link between those events and the frequency of interactions between wild boar and domestic pigs, we analysed regional vegetation and hunting bag data and implemented a semi-structured questionnaire survey among a total of 30 outdoor pig farmers and 30 hunters distributed inside and outside the identified area of OD emergence. One third of interviewed farmers (11/30) had experienced intrusions of wild boars in domestic pig premises during the previous year. Similarly, 23% of interviewed hunters reported interactions between wild boar and feral free ranging pigs in recent years and 60% reported the observation of free ranging pigs with a phenotypic feature of Vietnamese pot-bellied pigs (55%). Our analysis identified that the OD emergence area gathered several factors that could facilitate interactions between wild boar and domestic pigs, including a predominance of forested vegetation, a higher estimated wild boar density, weaker levels of farm biosecurity and a higher level of reported intrusions or interactions with wild boar in pig farms. Despite our sample was limited, our study suggests that the occurrence and dissemination of wild domestic suid interactions in this region might be higher than expected and sufficient to facilitate the circulation of shared pathogens between wild and domestic suids. Similar studies in this and other rural regions in the EU are recommended, in order to identify risk areas and anticipate preparedness for the emergence and circulation of shared swine pathogens.

Introduction

Wild boar (Sus scrofa) populations have been growing in high numbers for several decades both in Europe and in other countries of the northern hemisphere generating serious ecological, economic and sanitary costs (Ward, 1963). At the same time, the number of outdoor pig farms is increasing because of consumers’ demand for higher quality products issued from animal friendly production practices (Åkerfeldt, Gunnarsson, Bernes, & Blanco-Penedo, 2021). These two parallel developments facilitate an increasing occurrence of interactions between domestic pigs and wild boars, which can have several sanitary and environmental consequences. This phenomenon is widespread in most of the distribution area of Sus scrofa in Eurasia and this topic is raising increased international attention with the global spread of African swine fever in Europe and Asia, which...
can facilitate the circulation of this virus and other pathogens at the wildlife-livestock interface (Boklund et al., 2020; Jori, Payne, Stahl, Nava, & Rossi, 2018; Triguer-Ocaña et al., 2021). Several studies found in the literature have assessed the frequency and intensity of wild boar/domestic pig interactions from the ecological or behavioral perspective in the USA (Wyckoff, Henke, Campbell, Hewitt, & VerCauteren, 2009) and Europe (Wu et al., 2012). A recent study in Corsica characterized major types of direct and indirect contact, including sexual interactions (between male wild boars and domestic sows), agonistic (between wild and domestic boars) and indirect trophic interactions (Jori et al., 2017).

However, other sources of contacts between wild and domestic pigs such as the interaction of wild boar populations with abandoned pot-bellied pigs becoming feral have been more rarely explored in the available literature. This phenomenon is growing in developed countries purchasing pot-bellied pigs as pets but has been only reported in scientific literature very occasionally to date. (Delibes-Mateos & Delibes, 2013; Soler, Casas, Closa- Sebastià, Sanz, & Martorell, 2021).

In any case, belonging to the same species, wild boars and domestic pigs can share a large diversity of pathogens through a diversity of pathways (Jori et al., 2018; Miller et al., 2017). Some of them, such as Aujeszky disease (Boadella, Gortázar, Vicente, & Ruiz-Fons, 2012; Meier, Ruiz-Fons, & Ryser-Degiorgis, 2015) or porcine brucellosis with Brucella suis Biovar 2, have been often been controlled or eradicated in intensive domestic pig production systems, but are more difficult to control in outdoor production systems and remain prevalent in free ranging wild boar populations (Wu et al., 2012). Similarly, wild boars can also be affected by pathogens common in domestic pig farms such as hepatitis E (Charrier et al., 2018; Jori et al., 2016), porcine mycoplasmosis (Goedbloed et al., 2015) or porcine respiratory-syncytial syndrome (J. Wu et al., 2011) and become exposed to antimicrobial resistance and other environmental contaminants (Torres et al., 2020). In recent years, several fatal outbreaks have been reported in wild boars from Southern France, caused by a strain enterotoxemic *Escherichia coli* (serotype O139K82), with virulence markers and symptoms characteristic of oedema disease (OD) in domestic pigs (Decors et al., 2015; Petit et al., 2020). Those episodes of wild boar mortality in the Southern French region of Ardèche were first reported in 2013 (110 detected cases) and decreased progressively during the following years with 51 cases in 2014, 26 cases in 2015 and only 6 cases in 2016 (Decors et al., 2015). These emerging events in wild boar populations highlight the need to explore the factors associated with those outbreaks, including the potential importance of direct or indirect interactions between wild boars and domestic pigs. These types of contacts are reported when outdoor pig farming overlaps with wild boar or feral pig presence in several regions in Eurasia and the Americas (Jori et al., 2018; N. Wu et al., 2011; Wyckoff et al., 2009). Corsica is possibly one of the areas in France where these types of interactions have been often reported due to the widespread of traditional extensive farming systems in the Island (Charrier et al., 2018; Gisclard, Charrier, Trabucco, & Casabianca, 2021; Jori et al., 2017). Conversely, interactions between wild boars and domestic pigs are suspected to be less common in continental France, but no studies have explored the current importance of this phenomenon to date.

Therefore, the goal of our study was i) to report on the predominant pig farming patterns the continental French region of Ardèche, ii) to examine the potential importance of domestic pig-wild boar interactions in this rural context and iii) to explore the potential association with previous mortality outbreaks attributed to OD among the local wild boar populations.

2. Material and Methods

2.1. Study area

Ardèche is a territory of South-Eastern France (Fig. covering an area of 5,500 Km² with an altitude A) ranging between 140 and 1750 m asl and crossed by a large network of rivers and streams forest vegetation (52%) of exceptional diversity combining oak, acorn, chestnut, wild pine and red beech forests (see Fig. 2). Its climate is predominantly Mediterranean (0-28 °C) and annual rainfall ranges between 30 and 2000 mm. The region is representative of a rural Southern French environment with a strong cultural heritage where traditions are preserved, including ancestral outdoor pig farming under fruit forest trees such as oak or chestnut and wild boar hunting. In addition, a large area of abandoned chestnut trees benefits pig farmers.
Animals can therefore eat chestnuts throughout the fall season, at no cost to the farmer. Likewise, forest cover provides ideal conditions for the establishment of wild boar, which feeds in abundance on acorns, chestnuts and beechnuts (Baubet, Vassant, Brandt, & Maillard, 2008; Schley & Roper, 2003).

In Ardèche and many other rural areas in France, intensive pig farming started to develop a few decades ago, during the industrialization of pig production. Competition between regions on this intensive system based on production costs and technical performance led to a simplified map of pork production in France, with a high concentration of industrial intensive pig farms in the West of the country and the limited development of smaller scale pig production in other regions such as the study area, where outdoor systems and farm processing have been developing progressively during the last decades (Dourmad, Salaîn, Lebret, & Riquet, 2018).

Based on the detected cases of wild boar carcasses presenting lesions, clinical signs and bacteriological or genetic evidence of OD between 2013 and 2016 (Perrat et al., 2022), a polygon of 1981 Km² was spatially identified and designed throughout the manuscript, as OD area (Fig. 1B and C, Fig.3 and Fig.4).

2.2. Study design

A cross-sectional study was conducted from March to June 2018, among stakeholders located inside and outside the OD area. The sampling frame was based on databases of hunters and pig farmers provided by the regional authorities. In the case of hunters, a list containing 200 names of the leaders of the local hunting teams has been provided by Regional Association of hunters from Ardèche. A total of 30 hunters were randomly drawn from a list of 200 names: 20 hunters from the OD area and 10 hunters from outside this area. As the participation to interviews was volunteer, if some people drawn refused the interview, the next names on the list were selected.

At the time of the study, the local Animal Health authority could not provide us with an anonymous list of the total number of outdoor pig farmers in the region (n=81). The selection of farmers was then targeted towards those individuals practicing at least partial outdoor farming in a part of their facilities and therefore, potentially exposed to wild boar incursions (Fig. 1C). Based on this list of persons, one or c) two farmers were sampled by municipality. Selection of the farmers was based on information we could get from other farmers on potential candidates for our survey and their contact details on systematic snowball process the number of 30 farmers. Each candidate was preliminarily contacted by phone to request his/her availability to participate in the survey. The 30 pig farms interviewed were distributed within the OD area (n = 21) and outside (n = 9) on a “first available, first interviewed” basis (Fig. 1C).

2.3. Data collection

Data collection was based on semi-structured interviews giving the interviewee the opportunity to develop his answers but also to give his point of view (Relun et al., 2015). The questionnaire was implemented among hunters and pig farmers. The questionnaire consisted of 30 questions for hunters and 50 for pig farmers and the time required to answer the various questions of the two questionnaires was estimated at 20 and 30 minutes respectively. This questionnaire was previously tested with a hunter and a breeder to verify the understanding of the different questions and the response times. Before beginning the interview, the interviewer explained the aim of the study and emphasized that the information the hunters and the farmers provided would be processed anonymously.

The questionnaire for hunters included different questions related to the 2017-2018 hunting season except for the last question which referred to the observation of interactions within the last 10 years. The questionnaire was divided in two parts: the first was based on the description of the hunting area and on the management of hunting activities, while the second focused on the nature and frequency of the different interactions between wild boars and domestic pigs observed during last seasons.

For the questionnaire intended for farmers, all questions referred to the observations of interactions occurring between 2017 and 2018. The first part of the questionnaire was related to the farm characteristics; the second part addressed questions on management and farming practices. Finally, the third part focused on the nature...
and frequency of the different interactions between domestic pigs and wild boars observed by the farmer and the last part explored other human practices related to potential indirect interactions (slurry or slaughtering offal disposal).

A wild boar incursion, was defined as the fact of observing a wild boar in the farm or observing any evidence of potential visits (broken fence, tracks, birth of hybrids). An interaction was defined as the direct observation of wild boar or domestic pigs mating, fighting or foraging together within the farm. Reports of incursions and interactions were merged together into a single “contact” variable for the analysis. Finally, observations of wild boars by the farmers around their farms were also recorded during the survey.

**Biosecurity measures in pig farms**

The questionnaire designed for farmers included a section on biosecurity measures to assess the types of fences used to protect pig farms from wild boar incursions. The standards for the installation of fences to prevent incursions and contact between pigs and wild boars published by the Ministry of Agriculture and Fisheries consists on a combination of two electric wires surrounding an Ursus mesh type fence (Gisclard et al., 2021). The purpose of our questions was to characterize the level of biosecurity of farm facilities and its efficiency against incursions or contacts with wild boars. Farm biosecurity information recorded during the farmers’ survey (number and type of fence and the electric wires) was integrated into a three-level variable reflecting protection against wild boar intrusions. Whenever the farm had no fence, and whatever was the number of electric wires, the biosecurity level was considered as low. Farms protected by one fence and 1 to 4 electric wires were classified in the intermediate biosecurity level. Farms protected by 2 fences and 1 to 4 electric wires were classified as having an adequate biosecurity level. One farm protected by an electric fence and one farm protected by a concrete wall were also classified in the adequate biosecurity category. The spread of slurry was considered a health risk for the faeco-oral dissemination of *E. coli* strains potentially responsible for OD.

**Habitat type in the vicinity of the pig farms**

A landcover vector file available at the departmental territory direction of Ardèche (DDT07) including 17 landcover categories was used to characterize the landscape in a 1km radius around each surveyed farm. The original categories were first lumped in order to create 6 broad categories (artificial areas, cultivated areas, woodlands, shrublands, natural grasslands and water bodies). The resulting vector file was then converted into a raster file with a 50 meters resolution and the modal category within a 1 km radius around each farm’s location was eventually extracted and used to characterize the landscape. The R packages “raster” (Hijmans & Van Etten, 2012) and “rgdal” (Bivand, Keitt, & Rowlingson, 2019) were used for this step of the analysis.

**Wild boar density in the vicinity of the pig farms**

Yearly data of hunting bags (number of hunted wild boars at the commune level) and the number of hunter-days (i.e. the sum of number of hunting days over all registered hunters) were provided by the departmental (Ardèche) hunter’s association. These data were used to compute a catch per unit effort index (CPU) for each commune and each year from 2006 to 2016. The mean CPU over this 10-year period was used as an index of wild boar density in each commune from Ardèche. As this index was available at the commune level only, wild boar density index for each farm was defined by extracting the mean of the rasterized wild boar density index over relatively large 10 km radius area. Given that a wild boar’s home range can cover areas of several square kilometers (Calenge et al., 2002), this allowed for farms located near border of a commune to account not only for wild boar density in that commune but also in neighboring communes.

**Presence of domestic pigs or cross-bred animals**

The hunter’s questionnaire assessed the observation of contacts between both populations in hunting areas and the presence of domestic pigs or cross-bred individuals in hunting grounds during the last 10 years. For the former, a list of criteria suggesting potential hybridization features were provided including white spots in the fur, shape of the body, short snout, falling ears, thick fat layer and large litters. The questionnaire
requested to qualitatively characterize the frequency of observation as “Low” if only one observation reported, “Medium” if less than 5 observations were reported and “High”, if more than 5 observations were reported.

**Complementary opportunistic interviews**

In addition to those systematic questionnaires, various interviews were carried out either opportunistically in face-to-face or by telephone interviews and in order to obtain certain additional information from animal health authorities, farmers associations or wildlife management authorities. The objective was double and consisted in i) collecting additional information but also ii) cross-cutting the preliminary results obtained by the hunters and farmers questionnaires.

**2.4. Statistical Analysis**

A descriptive analysis of farming practices, environmental context (i.e. landscape and wild boar density, risk factors with regard to potential pathogen transmission characteristics and interactions with wild boars) was first performed. For this analysis, outdoor surface, number of pigs in the farm and the wild boar density index were categorised either using breaks in the distribution or thirtiles as cut-off points when no break was clearly visible. The farms were then classified in different groups using a multiple factor analysis (MFA) followed by a hierarchical cluster analysis (HCA). This approach allowed the identification of groups of farm types, that have similar farming practices, environmental context, biosecurity levels and reported events of incursions or interactions with wild boars (Table 2). In this approach, MFA allows dimension reduction by characterising each farm with synthetic variables (referred to as factors) instead of the original variables. Each factor captures the information of a number of original variables that are associated, so that the number of factors required to capture most of the information in the original data is usually much lower than the number of original variables. The contributions of the different original variables to the MFA factors reflect the links among them. Furthermore, MFA is more appropriate than MCA (multiple component analysis) when the variables are grouped (here in 4 categories: farming practices, environmental context, biosecurity level against wild boar incursions, interactions with wild boars) and the number of variables varies from one group to another. Indeed, with MFA, even when the number of variables differs among groups, the influence of the different groups on the MFA factors is balanced (Escofier & Pagès, 1994). A total of 13 original variables were used to characterise each farm. Eight, two, one and two variables were related to farming practices, environmental context, protection against wild boar intrusions and interactions with wild boars, respectively (Table 1). In the second stage, HCA was used to identify groups of farms with similar characteristics (Table 2). HCA was conducted on the farms’ MFA factors’ scores, using Ward’s method. With this method, the farms are grouped so that both the homogeneity within the group and the heterogeneity between groups are maximized (Ward, 1963). The set of characteristics statistically associated with each group of farms was identified using the statistical test for differences among group for categorical provided in the HCPC function output of the FactoMineR package. Finally, a chi-squared test was used to test for variation in the proportion of farms inside or outside the OD outbreak zone among farm types. Data processing, descriptive statistics and multivariate analyses were performed with R version 3.1.1 (R Core Team, 2014), using the package FactoMineR for MFA and HCA (Husson, Lê, & Pagès, 2017; Lê, Josse, & Husson, 2008). Several maps to represent farm locations were produced from the ggplot, ggmap and cartography packages of the R software.

**3. Results**

**Local characteristics of pig farming**

For most farmers interviewed (22/30, 74%), pig farming was the main source of income and for 26% this activity was only complementary. The majority of farms (20/30 67%) were specialized in breeding-fattening, an activity that requires considerable investment, but offers a certain autonomy, since the breeder takes care of births, breeds and fatten the pigs himself. The remaining 33% were fatteners that ensured the growth and finishing of the pigs until slaughtering. More than a third of farmers (39%) were in possession of an organic farming label and most farmers processed the meat themselves (20/30 67%). Among those, (10/24 42%) had their own processing workshop and (14/24 58%) manufactured their meat in a Cooperative. Slaughter on
the farm was practiced by 20% of farmers, once a year for their own consumption. The average size of the pig herds among the interviewed farmers consisted of 75 animals (median 50, IQR [2.4; 30.4]). The average herd was composed of 3 sows and 1 boar, with an annual progeny of 11 piglets on average and 60 pigs for fattening by breeding (medians and IQRs are provided in Table 3). The majority of farms (84%) opted for deliberately keeping a mixture of different breeds because they claimed that domestic pig hybrids provided a better yield and were more resistant to stay all year round outdoors. However, 16% of farmers claimed a preference for the Mangalitza, a rustic Hungarian breed renowned for the quality of its meat. A significant proportion of farms (42%) covered an area <3 ha, 39% have an area between 3 and 6 ha and 19% of farms have a large area > 6 ha. Among the 30 farms interviewed, a total of 7 farms had no fence. However, 6 of them were protected by 2 to 4 electric wires. A group of 18 farms had one fence and 1 to 4 electric wires and 3 farms had 2 fences and 2 to 4 electric wires. Finally, one farm had a wall and one farm a fully electrified fence. Two farms admitted that part of their farming area was not fenced, the pigs being able to leave and enter at their will. In terms of practices facilitating indirect pathogen spread in the environment, five farmers (16%) recognized releasing slurry for fertilizing crops at least once a year, while seven of them (23%) admitted releasing farm slaughtering waste into the environment, allowing scavenging by other wild or domestic animals. In addition, several risky practices were found to be more common in the OD area (abandonment of waste in the wild (n = 4), slurry spreading (n = 4) and presence of wild boars in the slurry spread area (n = 3) than in the rest of the Department. Similarly, a larger proportion of farms with low to intermediate levels of biosecurity (21/30), were located inside the OD area (Fig. 2).

Farm typology

The MFA/HCA approach allowed the identification of three types of domestic pig farms (Table 2). Type 1 (n=17) included farrow to finish farms with intermediate biosecurity measures against wild boar intrusions located in woodlands (Fig. 2) areas with high to medium wild boar densities (Fig. 3). Half of these farms reported incursions of or interactions with wild boars and most of these farms were located in the OD outbreak area. Type 2 (n=6) included farms located in high wild boar density areas and characterized by weak biosecurity measures against wild boar intrusions. Half of these farms reported incursions or interactions with wild boars and all of these farms were located in the OD outbreak area. Type 3 (n=7) included farms highly protected against intrusions of wild boars and located in cultivated areas. None of these farms reported incursions of or interactions with wild boars and most of them were located outside the OD outbreak area.

Hunting characteristics

Almost all hunters have been hunting since the age of 16, which is the legal age. Hunters also hunted predominantly in natural areas (20%), in a mixture of natural and agricultural areas (20%) or in natural and pastoral areas (17%). All hunters interviewed practiced drive hunting with dogs in a team of several hunters and two of them owned domestic pigs. The median of wild boars harvested by 28 hunting teams was 50 wild boars, IQR [30-100]. Differences between the median of hunted animals were not significant (63 vs 47.5). The main reported criterion for considering hybridization of wild boars was the observation of white spots in the fur (65%). More than a third of hunters recognized shooting hybrid wild boars (37%), if coming across crossbred individuals during hunting drives. Regarding offal management, 16/30 buried the offal waste, 2 of them left it abandoned in nature, and 10/30 gave it at least occasionally to the dogs. One of them threw it to the garbage.

Quantification of wild-domestic pig interactions

Taking the previous year as a reference, 2/3 of the farmers (20/30) had observed wild boars in proximity of the farm at a distance ranging between 1 and 200 m. One third (10/30) had observed evidence of incursions of wild boars on their farm in the previous year and 90% of those (8/30) had observed evidence of interactions between wild boars and their pigs. Those included reports of sexual interactions (reported by 8/30 farmers), fights (3/30) and trophic interactions (2/30) between wild and domestic boars. Five farmers reported observing hybrid litters as a result of sexual interactions between male wild boars and their respective sows. Among those, four farmers kept the piglets for their own consumption and one brought the sows to
the slaughterhouse before giving birth. Four other farmers declared having observed sexual and or trophic interactions between two and six years ago, respectively. Incursions of wild boars in the farm premises were mainly reported in fall (29%), followed by winter and summer (19%) while sexual interactions were mainly reported to occur in summer (6%) and fall (6%). There was a significant difference between interactions reported in fall (P < 0.05), compared with the other seasons (Fig. 4).

Regarding hunters, only one reported direct (trophic) interactions in the forest. Despite none of them observed direct agonistic interaction, six of them acknowledged that this kind of contacts could occur. Two hunters had heard or observed of wild boar incursions in some farms in the region and two had observed the presence of domestic pigs in hunting grounds. Eighteen hunters recalled observing the presence of or hunting hybrids in recent years, mostly (2/3) between 2013 and 2016. The large majority (10/18) of those reports referred to animals with a phenotype of pot-bellied pigs.

Discussion

Understanding transmission pathways between hosts is an essential step to improve the control of infectious diseases. From that perspective, investigating the nature, frequency and drivers facilitating interactions between wild and domestic pigs in our study area seems an important step to understand the potential drivers for the emergence of OD in wild boar populations. Interactions between domestic and wild suids are becoming increasingly important for the scientific community due to the social success of outdoor pig farming in developed economies (Delsart, Pol, Dufour, Rose, & Fablet, 2020) and the awareness of shared pathogens between both populations, particularly considering the global spread of African swine fever (Boklund et al., 2020; Brookes et al., 2021; Viltrop et al., 2021). However, to characterize the risk factors associated with different types of interaction, it is necessary to understand the biology and behaviour of the animal populations involved and equally, the behaviour of stakeholders managing wild and domestic suids resources.

The results obtained during this study suggest that small scale outdoor farming initiatives are widespread in the Ardèche territory and that practices facilitating interactions between domestic pigs and wild boars, were widespread in the Ardèche department and with a significantly higher presence in the OD area than outside. A third of the farmers interviewed reported intrusions or attempts from wild boars to enter the farm, while 23% of them had observed some evidence of direct interactions. The location of farms more prone to those interactions appeared significantly associated with a forested habitat (p = 0.025), a higher estimated density of wild boar (p = 0.06), a low-to intermediate biosecurity index (p = 0.0001).

Reports of hybrid litters in at least 5 farms confirmed the occurrence of sexual interactions. Incursions of wild boars in the farms were more frequently reported in autumn and winter (Fig. 4) than spring or summer. Autumn coincides with the most active reproductive season of male wild boars in Europe, reported between November and January (Drimaj et al., 2019). During this period, they can be easily attracted by sows on heat in outdoor farming paddocks, where they try to break in and mate with them (Malmsten, Jansson, Lundehelm, & Dalin, 2017; Wu et al., 2012). This seasonality of sexual interactions was also highlighted in another study in Corsica, which in France is possibly considered as an extreme case for wild boar / domestic pig interactions. In that case, 57% of the interviewed farmers (Jori et al. 2017) reported interactions between wild boars and domestic pigs and 70% of the sexual interactions were equally observed in autumn (Jori et al., 2017). Despite these figures are much higher, they also suggest that the level of interaction captured by our study is considerable and the number of identified situations facilitating direct and indirect interactions between wild and domestic suids and the potential transmission and circulation of shared swine pathogens is important.

It is likely that reported figures of interaction through questionnaires are underestimated for several reasons. First of all, an important proportion of them occur during night time and are difficult to be witnessed directly by farmers. In most cases, these interactions are detected by the observation of damages in the fence or the observation of crossbreed offspring a few weeks later. Further studies using ecological tools (camera traps and /or telemetry devices with proximity loggers) should be implemented in order to confirm and better quantify wild boar incursions in the farms and document the potential occurrence of wild boar-domestic pig...
interactions in the study area (Kukielka et al., 2013; Triguero-Ocaña et al., 2021).

Other sources of bias such as recall bias could have influenced hunters’ responses. In fact, hunters struggled more than farmers to place the observed events in time. In addition, a third of farmers (9/30) expressed a certain mistrust towards the questionnaire, despite insisting that responses would be anonymous. The majority of farmers admitted having observed sexual or trophic interactions, mostly towards the end of the questionnaire, when a higher level of trust had been achieved. Certainly, the fear of sanctions from local authorities, could have induced underreporting of the frequency of interactions in the farms. Indeed, local animal health authorities can control the farms and engage substantial sanctions if the infrastructure is not up to standard. In addition, since sexual interactions reported were only those leading to the birth of hybrids, a certain number of interactions not resulting in cross bred offspring could have been underestimated.

Our study cannot confirm the hypothesis that interactions between wild and domestic suids are correlated and therefore, responsible for the emergence of OD in wild boar. However, the occurrence of factors facilitating those interactions in the OD were highly significant (Table 2). However, several risky practices such as the abandonment of waste in the wild, slurry spreading and presence of wild boars in the slurry spread area were found to be more common inside than outside the OD area. Slurry spread is considered a particularly risky practice in the context of bacterial contamination of the environment and indirect faecal-oral transmission of pathogens such as *E. coli* (Munch, Errebo Larsen, & Aalbæk, 1987). The results of the survey do not make it possible to assess the risks linked to the route by faecal contamination. Unfortunately, our sampled population was limited and our observed trends should be confirmed with a larger and more representative sample of farmers and hunters and a deeper analysis, asking farmers for information on the area and the location of the spreading area in particular. However, they characterize a situation in which interactions occur with a certain regularity, facilitating the circulation of shared pathogens between both suid populations. Actually, a recent molecular study on the samples collected from wild boar in the study area suggests that the strain of *E. coli* causing mortality in wild boars has circulated and evolved for a certain time in the wild boar population (Perrat et al., 2022). Despite its origins are likely to be in domestic pigs, research efforts in the area have not been able to identify the source of this *E. coli* strain to date. However, our study shows that in this area practices facilitating interactions and the spillover of pathogens from domestic pigs to wild boars are abundant and widespread.

Although our farm sample was small, the predominance of infrastructures allowing the incursion of wild boars into farms was important and widespread in the territory, including those areas with high estimated densities and favourable wild boar habitat. Indeed, in our results, an intermediate level of biosecurity appeared strongly correlated (P <0.05) with the risk of wild boar incursion and trophic interactions. In that respect it is important to underline that fences are expensive for farmers, and very often, if the farming surface is important, their maintenance across the whole perimeter can represent a serious financial constraint for the farmer. Nevertheless, in the context of the African swine fever threat, it is likely that French outdoor pig farmers will be confronted with the obligation of increasing biosecurity measures, and mediation processes might be required to facilitate their local acceptance and implementation (Gisclard et al., 2021).

Wild boars can thus become contaminated by ingestion of the remains of animals infected with several pathogens (Jori et al., 2017), including African swine fever or bovine tuberculosis (Carrasco-García, Barroso, Perez-Olivares, Montoro, & Vicente, 2018). Strains of toxin producing *E. coli* are an important foodborne pathogen able to contaminate animal carcasses and intoxicate potential consumers (Brookes, Jordan, Davis, Ward, & Heller, 2016). In addition, *E. coli* has been proven to spill over between domestic pigs and wild boar populations sharing the same environment in experimental (S. Barth et al., 2017) and field conditions (S. A. Barth et al., 2018). Similarly, among hunters, half of them disposed the offal waste themselves by burying it underground which reduces the risk contaminating the environment. However, a third of them gave (10/30) the offal to their dogs and 7% of the farmers reported dropping offal waste in the environment. Many pathogens can be shared between different wild and domestic animal species through inadequate carcass waste management including bovine tuberculosis (Cano-Terriza et al., 2018), Aujezky’s disease (Charrier et al., 2021) and other feaco-oral transmitted pathogens such as OD.
Another distinctive result from our study was the reporting of free-ranging pigs with features of pot-bellied pig phenotype observed by 26% of hunters between 2013 and 2015. The practice of keeping and breeding pot-bellied pigs, frequent in many EU countries, was identified in 8 leisure states among the list of 230 registered farms. Complementary interviews with local authorities confirmed an escape incident with a farm of several specimens of pot-bellied pigs from in the study area in 2015. Considering that sexual interactions reported by hunters occurred around the town where this farm was located, the possibility of cross breeding between wild boars and pot-bellied pigs is a plausible scenario. The abandonment of exotic pets can have serious consequences for the environment (Lockwood et al., 2019) and this is also applicable in the case of pigs kept as pets (Soler et al., 2021). In many EU countries, there are numerous shelters organisations dedicated to the rescue of abandoned pot-bellied pigs specimens. Despite these incidents are in general poorly investigated, there is evidence that abandoned pot-bellied pigs have the capacity to form sounders that remain in natural habitats in Southern Europe and interact with wild boar populations increasing the population of hybrids. This is becoming a common phenomenon in many countries were pot-bellied pigs are sold as pets and has been currently described in rural areas of Southern and Northern Spain (Delibes–Mateos & Delibes, 2013; Soler et al., 2021). Based on our results, this kind of interaction is worth reporting in this study, to raise awareness about this phenomenon and encourage French and EU authorities to monitor this kind of incidents and their impact among wild boar populations.

Conclusions

This study allowed us to identify that practices and conditions facilitating interactions between wild boar and domestic pigs and the transmission of shared swine pathogens were abundant and widespread in the Ardèche Department. Despite our sample limited, many of those factors were more important in the OD emergence area that outside. Those included ecological aspects (areas of forest and higher estimated wild density), but also anthropic factors related to pig farming such a significantly higher presence of farms with leaky biosecurity measures which were confirmed by the presence of a higher number of reported incursions and episodes of interaction. On the other hand, the results of the questionnaire suggest that risky agricultural practices such as slurry spreading and dumping of offal waste from hunting or pig slaughtering do occur and can facilitate indirect spill over of pathogens to the natural environment and subsequent transmission to wild boar populations. Moreover, our study highlights the potential importance of abandoned pot-bellied pig pets which can allow the development of free ranging feral pig populations and the development of a new and unsuspected wild-domestic suid interface, which deserves higher attention and further investigation about its potential epidemiological impact. Similar studies in this and other rural regions in the EU are recommended, in order to identify risk areas and anticipate preparedness for the emergence and circulation of shared swine pathogens.

Conflict of interest

All authors from this paper declare that there was no conflict of interest

Ethical statement

Ethical statement was not applicable since only questionnaires from humans have been gathered and no sample collection nor experimental activities were necessary for this work

Acknowledgements

This works was funded by the project EPIDEWILD in the Meta-program GISA (https://colloque.inrae.fr/metaprograms-workshops_eng/Metaprograms/GISA) – Sustainable management of Animal Health (Grant INRAE French Institute for Agriculture, Food and Environment). We would like to acknowledge la Fédération des Chasseurs de Ardèche (Fabrice Etienne), the hunters and farmers that were interviewed and the local authorities of animal health and production (DSPP).

References


Fig. 1: Maps of the Ardèche Department showing A) Its location within the French territory. B) The location of the wild boar OD cases detected between 2013 (labelled 1) and 2016 (labelled 4). The envelope containing...
most of the detected cases is defined as the OD outbreak area. C) The distribution of pig farmers in the territory. Black filled symbols stand for surveyed farms (which are all outdoor farms), close grey symbols for outdoor farms that were not surveyed, open symbols for indoor farms, circles for farms rearing pigs for consumption, triangles for pet pig farms and squares for wild boar farms. The envelope defines the OD outbreak area.

**Fig. 2:** Locations of surveyed farms characterized by their type in the MFA/HCA analysis (colour) and reporting of interactions with wild boars (sign type) on a landcover background.

**Fig. 3:** Locations of surveyed farms characterized by their type in the MFA/HCA analysis (colour) and reporting of interactions with wild boars (sign type) on a wild boar density background.

**Fig. 4:** Histogram showing the seasonality of interactions with wild boars observed by farmers (n=9)
**Hosted file**


**Hosted file**


**Hosted file**