Transboundary and Emerging Diseases

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ORIGINAL ARTICLE

Quantitative Risk Assessment for the Introduction of African Swine Fever Virus into the European Union by Legal Import of Live Pigs

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Summary

The recent incursion and spread of African swine fever virus (ASFV) in the Russian Federation and Caucasus region, close to European Union (EU) borders, have increased the concerns regarding the probability of ASFV introduction into the EU. There are many potential routes of ASFV entry into EU, but here we specifically aimed to assess the probability of ASFV introduction by legal trade of pigs, which historically has been one of the most important ways of exotic diseases introduction into the EU. A stochastic model was used to estimate the monthly probability of ASFV introduction for each country of the EU. Results of this model suggest an annual probability for ASFV introduction in the whole EU by this way of $5.22{*}10^{-3}$, which approximately corresponds with one outbreak in 192 years. The risk of ASFV introduction via live pigs was highest in Poland (69%), particularly during the months of November and December. As expected, Russian Federation is the country that most contributes to this risk, representing 68% of the overall annual risk. Methods and results presented here may be useful for informing risk-based surveillance and control programmes and, ultimately, for prevention and control of potential ASFV incursions into the EU.

Introduction

African swine fever (ASF) is a notifiable, viral infectious disease which affects domestic pigs and wild suids and results in severe sanitary and economic consequences in affected countries (Penrith and Vosloo, 2009). ASF is a haemorrhagic disease caused by a DNA virus, ASF virus (ASFV), which is a unique member of the *Asfarviridae* family (Dixon et al., 2005). ASFV affects all ages and breeds of pigs and produces a wide range of clinical signs, varying from a peracute/acute (90–100% of mortality) to a chronic form with inapparent carriers. Transmission of ASFV may occur either by direct contact with infected animals or by indirect contact with contaminated meat or fomites or with biological vectors (i.e. ticks of genus *Ornithodoros*). Because there is no vaccine available for ASFV, the prevention of the disease entry into disease-free areas is critical and mainly based on the avoidance of the introduction of potential infected pigs or pig products, as well as appropriate disposal of pork waste from aircraft and ships and other fomites (Sánchez-Vizcaíno, 2006).

African swine fever virus was firstly described by Montgomery in Kenya, in 1921. Since then, the disease has become endemic in most sub-Saharan countries. In 1957, ASFV reached Europe, resulting in outbreaks in Portugal, Spain, France, Belgium, Malta, Netherlands and Italy, and it remained endemic on the Iberian Peninsula from 1960 to 1995. The sanitary and economic losses of this endemic period were enormous, with more than 2 323 018 slaughtered pigs (MAPA, 1966–1994) and, at least, €65 million losses in Spain (Arias and Sanchez-Vizcaino, 2002). Further outbreaks occurred in Europe and Central and South America during the 1970s and 1980s, but all of them were eradicated, except in Sardinia (Italy), where the disease still persists today. The epidemiological situation changed dramatically in 2007, when ASFV was reintroduced to the European continent, on this occasion in the Caucasus region. The hypothesized route of ASFV introduction was contaminated swill from ships that was ingested by free roaming pigs near the port of Poti (Georgia) (Beltran-Alcrudo et al., 2008). After this first incursion into Georgia, the disease has spread to Armenia, Azerbaijan and the Russian Federation (RF) with more than 260 notified outbreaks and 76 000 affected animals in three years (OIE, 2011a). The economic consequences of the ASF epidemic for the Russian pork industry, until October 2009, were estimated at RuR 25–30 billion ($US 0.8–1 billion)) (USDA, 2010). Furthermore, two of the outbreaks occurring in October 2009 and in December 2010, were located very close to the EU border (approximately 150 km) (OIE, 2009a, 2010a). The likelihood of ASF becoming endemic in RF has been estimated as high, because of the uncontrolled course of the disease, the demonstrated active spread of ASFV in the wild boar population, and the large volume of uncontrolled trade of pigs and pig products taking place across the country (EFSA, 2010; Wieland et al., 2011).

An important route for the introduction and spread of animal diseases is the movement of live animals or their products. For that reason, the World Trade Organization (WTO) and the World Organization for Animal Health (OIE) encourage the countries to follow the guidelines specified in the Sanitary and Phytosanitary Measures Agreement (SPS), as well as to perform risk assessments to support their preventive and control policies. Following these guidelines, the trade of pigs and pig products from an ASFV-infected country or zone to a disease-free country or area is not permitted (OIE, 2009b). Once a region is declared as ASFV infected, an immediate ban of movements of live pigs and pig products is implemented. Considering this principle, the possibility of ASFV introduction by legal trade of live pigs or pig products may only occur during the 'high-risk period' (HRP), which is the period of time from the initial infection (i.e. index case) until the official diagnosis and notification of the disease for a region (Horst et al., 1998). During the HRP, trade of pigs and pig products are not restricted and ASFV can freely spread to other areas/countries. Considering the distances covered and frequency of animal movements, a HRP of 1 or 2 weeks may result in an extensive spread of a disease. In fact, the movement of animals during the HRP has been responsible for the spread of diseases such as foot and mouth disease (Bouma et al., 2003); classical swine fever (Greisser-Wilke et al., 2000) or bovine spongiform encephalopathy (Smith and Bradley, 2003) within EU regions in the last 10 years.

The EU is the second largest pig producer in the world, behind China, and the second largest exporter of pigs behind United States (FAO, 2009) (e.g. in 2009 157 043 100 kg live pigs were exported) (EUROSTAT database). The introduction and spread of a disease such as ASFV into the EU would severely impact negatively on the EU pig sector and the economy of the EU. Given the high risk of endemicity of ASFV and continued spread in the Russian Federation (EFSA, 2010), there is a need to estimate the potential risk of ASFV introduction into the EU as well as to define the geographical areas and time periods at highest risk so as to be able to prevent potential ASFV incursions and support future policies.

This study aimed at quantifying the risk of ASFV introduction into the EU associated with legal movement of pigs. The framework proposed here was planned to be combined with risk assessments for other ASFV routes of introduction into the EU (i.e. import of pig products, illegal trade of pigs and pig products, fomites, etc.) and may be easily updated and adapted for other regions or countries.

Methods

Data sources and unit of analysis

The selected spatial and temporal unit of analysis was country and month, respectively. This level of aggregation was assumed to be the most appropriate to support EU policies and the most suitable, given the available information. Information regarding the number of live pigs imported by month and country during the last 5 years (2005–2009) was obtained in the EU official database Trade Control and Expert System (TRACES). Data from the Statistical Office of the European Union (EUROSTAT database) was used to validate the model in the sensitivity analysis. The number of destination countries (d) considered in the current analysis was 27, corresponding to the 27 member countries of the EU; and the number of origin countries (o) analysed was five, those for which imports of live pigs were registered for the last 5 years.

Model formulation

The probability of having at least one outbreak of ASF, namely the probability of introduction (PI), in one of the 27 EU countries because of import of an ASF-infected (but non-detected) pig during the HRP was estimated per country of origin of imported pigs ($o = 5$), per month ($m = 12$) and by country of destination ($d = 27$), assuming a binomial process (OIE, 2010b) of the form:

$$\mathrm{PI} = \sum 1 - (1 - p_{odm})^{n_{odm}}$$

where n_{odm} is the number of live pigs imported from country of origin o to country of destination d during the month m, and p_{odm} is the probability of introducing an infected pig from country o to country d during month m and having an effective contact from an infected to a susceptible pig in the destination country d.

The probability p_{odm} was estimated as the product of three conditional probabilities. The probability of importing an ASFV-infected pig from country o before detection of infection (P_1); the probability that an ASFV-infected pig survives (P_2) and the probability that an imported pig has a contact with a susceptible animal in the country of destination d (P_3) which results in transmission of ASFV. This approach was similar to the model used for the estimation of introduction of classical swine fever in Spain (Martínez-López et al., 2009). All assumptions, input values, parameterization and references used in the model are presented in Table 1 and are explained in detail in the next sections.

We have to assume that model results are always conditioned to the quality and update of the data available. In this case, results will be conditioned to historic data trade records and the available information from the current situation of the disease. Other three major assumptions used in the model are explained in the following paragraphs for better comprehension of the model: regarding the probability of infection in the source country, if there were no reports of ASF in the considered country, 88 years without disease were assumed (since the initial report of the virus, in 1921). For the estimation of ASF undetected outbreaks, historical data from previous ASF outbreaks was used, assuming a similar surveillance capacity in all the origin countries. Related with the disease, for all the measures and probabilities (survival, detection), it was assumed that ASF will be present in an acute form of the disease, as it is currently occurring in Caucasus region and Russian Federation and as it occurred in the first stages of infection in European countries. The model was constructed using @Risk version 5.5 (Palisade Corporation, Newfield, NY, USA) in Microsoft Excel (Microsoft Office 2007 Professional Edition). Results were obtained after 10 000 iterations using the Monte Carlo simulation approach, and maps to visualize the results were generated using ArcGIS 9.2 (ESRI).

Probability of selecting an ASFV-infected pig from country o before detection of ASFV infection (P_1)

The probability of selecting an ASFV-infected pig from origin country o to be exported to EU country d before detection of ASFV infection during a particular month m (P_1) was modelled using a beta distribution. The shape of this distribution was given by the number of estimated infected pigs prior to ASF detection in the country of origin o, and the total number of pigs in country o (OIE, 2011b).

The number of infected pigs in country o was estimated using the data available on the epidemiological history of the disease and as a result of multiplying four independent parameters (Table 1). First, we calculate the probability of having a not yet detected ASFV epidemic in the source country (Po), which is the probability of country o being infected (but not detected) in month m. The probability Po was parameterized using a beta distribution of the form Beta (α_1, α_2), where α_1 is the number of months with at least one undetected ASF outbreak in the country of origin, and α_2 is the number of months considered in the analysis (i.e. number of months for which information was available in the OIE database (OIE, 2011a,c).

Once the probability of infection in country o in month m was defined, the most likely number of undetected outbreaks in country o in month m was estimated (Ou). The parameter Ou was estimated by considering the number of undetected outbreaks prior to the first notification of the disease to the OIE (OIE, 2011a) and was an estimation of the most likely number of infected but not detected pig herds before official notification of the disease. The value of Ou was parameterized by using a pert distribution of the form Pert (minimum, most likely, maximum).

The number of pigs and the number of pig herds in source country o was used to estimate the average herd size in country o (To). The number of pigs and pig herds was parameterized by using a normal distribution of form Normal (μ, σ), where μ is the average number of pigs (or pig herds) and σ is the standard deviation of the number of pigs (or pig herds) in country o during the last 5 years, respectively (OIE, 2011b; FAOSTAT, 2011; Statistics of Russian Federation, 2011).

Finally, we estimated the intraherd ASFV prevalence (Hp), which represents the proportion of ASFV-infected animals in an infected (but not detected) herd. This parameter was modelled by a pert distribution of the form Pert (min, most likely, max) with min, most likely and max values of 0.022, 0.4 and 0.8, respectively, which were obtained from the published literature (Wooldridge et al., 2006) and field observations from current outbreaks in Russian Federation (Blagodarsnosti, 2011).

Probability of survival of selected ASFV-infected pig (P_2)

The probability P_2 is the product of two independent probabilities, which are the probability that an infected pig survives ASFV-infection (Ps), and the probability that a pig survives the transport from the country of origin to the country of destination (Pt). The probability Ps, was calculated by using the mortality rates of different virus isolates

Table 1. Description and parameterization of model inputs

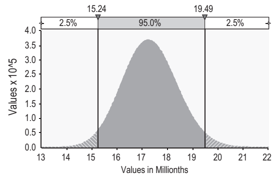
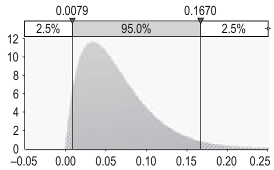
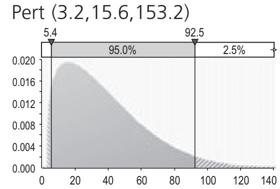
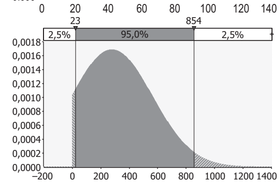
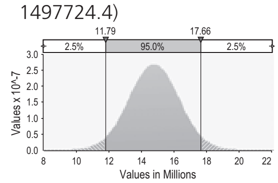
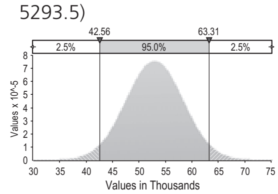
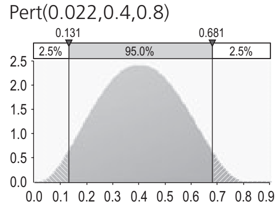
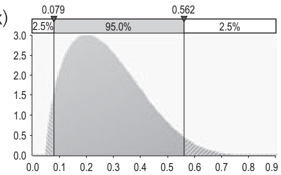
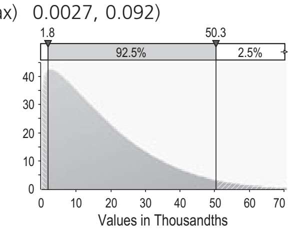
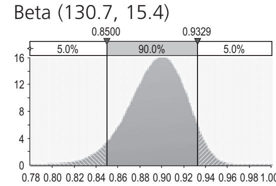
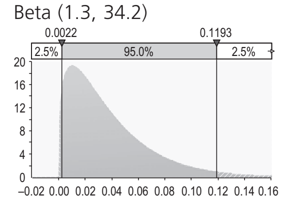
Notation	Definition	Source	Parametrization	Data values for Russian Federation (September)
P_1	Probability of selecting an ASF-infected pig from country *o* in month *m* before detection of ASFV infection	NI = $Po \times Ou \times To \times Hp$No = pig population	Beta (α_1, α_2)α_1 = NI + 1α_2 = No−(NI + 1)	
Po	Probability of infection in country of origin	OIE (2011a), OIE (2011c)Where: *X*: number of outbreaks by month; *M*: number of months considered	Beta (α_1, α_2)$\alpha_1 = X + 1\alpha_2 = M-(X + 1)$	Beta (2, 30) 
Ou	Number of undetected outbreaks before official notification	OIE (2011a)	Pert (min, most likely, max)	Pert (3.2,15.6,153.2) 
To	Average herd size in country *o*		Normal = No/So	
No	Pig population size in country *o*	OIE (2011b), FAOSTAT (2011)	Normal (μ, σ)	Normal (14728567.5, 1497724.4) 
So	Number of pigs establishments in country *o*	OIE (2011b), Statistics of Russian Federation (2011)	Normal(μ, σ)	Normal (52934.5, 5293.5) 
Hp	Intraherd prevalence	Wooldridge et al. (2006), Blagodarsnosti (2011)	Pert (min, most likely, max)	Pert(0.022,0.4,0.8) 
P_2	Probability of survival of selected ASFV-infected pig	$Ps*Pt$		

Table 1. *Continued*

Notation	Definition	Source	Parametrization	Data values for Russian Federation (September)
Ps	Probability that an ASF-infected pig survives infection	Spickler and Roth (2006)	Pert (min, most likely, max)	Pert (0.05,0.2,0.8) 
Pt	Probability of ASFV-infected pig surviving transport	Murray and Johnson (1998)	Pert (min, most likely, max)	Pert (0.0005, 0.0027, 0.092) 
P_3	Probability of an imported ASFV-infected pig comes into contact with other domestic pigs in the destination country resulting in disease transmission	$P_q + [(1-P_q)*P_u]$		
P_q	Probability that pigs were not quarantined	Martínez-López et al. (2009); L. Romero, personal communication	Beta (α_1, α_2)	Beta (130.7, 15.4) 
P_u	Probability that an ASF-infected animal remains undetected during quarantine	Martínez-López et al. (2009); L. Romero, personal communication	Beta (α_1, α_2)	Beta (1.3, 34.2) 
n_{odm}	Imports of live pigs from country *o* to EU country *d* during month *m* (during last 10 years)	TRACES database	Normal (μ, σ)	
p_{odm}	Probability that an ASF-infected pig from country *o* enters a farm in country *d* during month *m*	$n = n_{odm} p = P_1 \times P_2 \times P_3$	Binomial (*n*, *p*)	

described in the literature (Spickler and Roth, 2006). The probability of surviving the transport (*Pt*) was also obtained from the literature (Murray and Johnson, 1998). Both probabilities were modelled by using pert distributions.

Probability that an imported ASFV-infected pig comes into contact with other domestic pigs in the destination country d (P_3) resulting in disease transmission

Whereas P_1 and P_2 were used to estimate the probability of release of an ASFV-infected pig, P_3 measured the probability of exposure of a susceptible pig in the EU. Because we considered only live pigs imported into farms (not to slaughterhouses) in our analysis, the value of P_3 only depended on biosecurity measures (i.e. quarantine) applied in the destination farms and was estimated as follows:

$$P_3 = P_q + (1 - P_q) * P_u$$

where P_q is the probability of not quarantining an imported pig and P_u is the probability of not detecting an

ASFV-infected pig when performing quarantine. Because of the absence of available data regarding the biosecurity practices for imported pigs applied in each of the EU countries, the probability of P_q for all EU countries was assumed to be the same as the one estimated for Spain and published in Martínez-López et al. in 2009. This was considered to be a reasonable standard value, based on the assumption that similar to Spain, other EU countries apply medium to high level of biosecurity measures for pigs imported from third countries.

The probability of not detecting an ASFV-infected pig by clinical signs during quarantine (P_u) was assumed to be the same as for classical swine fever virus (CSFV) (Martínez-López et al., 2009), as the diseases have similar clinical signs (Sánchez-Vizcaíno, 2006).

Sensitivity analysis

The effect that variability and uncertainty on input data and model parameters has on model outcomes was evaluated by using sensitivity analysis. Most quantitative risk assessment models developed for the European Union use official EU statistics (i.e. EUROSTAT) as the source of information for animal movement records. To compare the outcomes of the model using the more accurate TRACES data and the EUROSTAT information, the model was run using EUROSTAT data from the last 5 years. No other input parameters were changed.

In parallel, because of the large number of input parameters used in the model, a two-step sensitivity analysis was performed. First, regression coefficients (β_i) between each input and the annual probability of ASFV introduction in the EU were calculated to quantify the influence that changes in input values have on model outcomes (Vose, 2000). Second, the inputs that were most likely to influence the final results ($\beta_i \geq 0.1$) were further analysed using a one-way sensitivity analysis, in which their base values were changed in eight consecutive steps, from a minimum of 50% of reduction to a maximum of 50% increase. Results are reported by graphs and spider plots (Fig. 1).

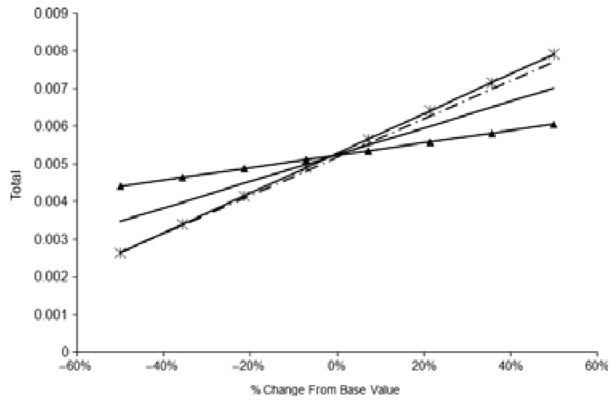


Fig. 1. Sensitivity analysis. Graph represents changes in the overall probability of African swine fever virus introduction into the EU by legal imports of live pigs as a result of variation in the most influential parameters of the model ($\beta \geq 0.1$): Probability of survival to ASF infection (⚹); intraherd prevalence (— · —); undetected outbreaks in Russian Federation (RF) (—); probability of infection in RF in November and Imports from RF to Poland (▲).

Results

Probability of having at least one ASF outbreak in the EU because of import of live pigs

The overall mean (95% PI) annual probability of ASFV introduction into the EU by legal import of live pigs was $5.22*10^{-3}$ ($6.06*10^{-4}$, $1.84*10^{-2}$), which approximately corresponds, if the underlying epidemiological conditions are constant, to one outbreak in 192 years, on average.

The probability of ASFV introduction into the EU was highest for Poland ($3.63*10^{-3}$), followed by the United Kingdom ($6.18*10^{-4}$) and Germany ($3.41*10^{-4}$) (Fig. 2). In fact, Poland represented 69% of the overall annual risk of ASFV introduction into the EU (27 analysed members).

Analysing the monthly distribution of the risk in these three high-risk countries, we observe that most of the risk for Poland and Germany is concentrated in one month. Specifically, the 46% of the annual risk in Poland is concentrated in November, whereas the 42% of the annual risk in Germany is concentrated in December. Conversely, the risk of introduction into United Kingdom is widely distributed in different months (February, October, December, April, August…), without any predominant risky month.

As expected, the country that contributed most to the risk of ASFV introduction into EU was the Russian Federation ($3.53*10^{-3}$), representing 68% of the overall annual risk (Fig. 3). Most part of this risk (47%) is concentrated during the month of November, coinciding with the highest risk of introduction into Poland.

The estimated probability for ASFV introduction into the EU was higher during the months of November ($1.75*10^{-3}$) and December ($7.29*10^{-4}$) (Fig. 4). These two months represented approximately 47% of the annual risk.

Sensitivity analysis

When using EUROSTAT instead of TRACES for input data, the ASFV risk of introduction into the EU through legal imports of live pigs was about two times higher ($1.14*10^{-2}$) than with TRACES ($5.22*10^{-3}$).

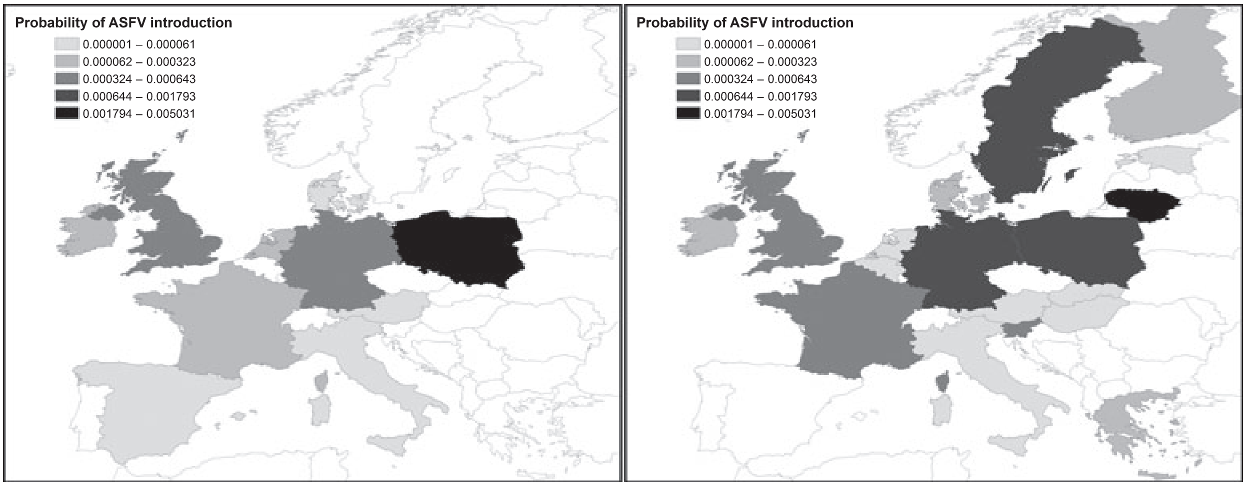


Fig. 2. Probability of African swine fever (ASFV) introduction into the EU by legal trade of live pigs by country of destination using different animal movement databases (TRACES left, EUROSTAT right).

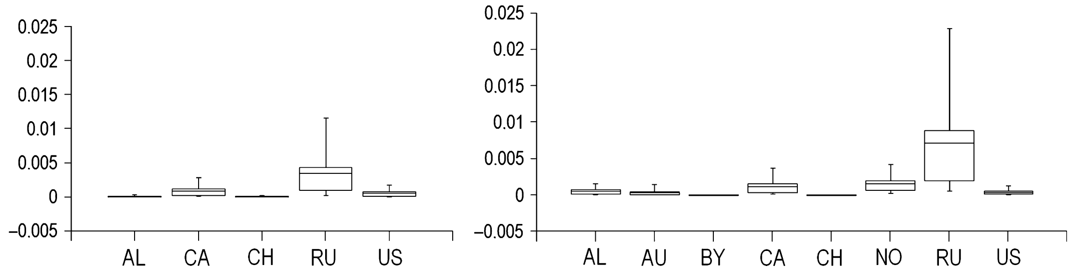


Fig. 3. Probability of African swine fever (ASFV) introduction into the EU by legal trade of live pigs by country of origin using different animal movement databases (TRACES on left side, EUROSTAT on right). AL, Albania; AU, Australia; BY, Belarus; CA, Canada; CH, Switzerland; NO, Norway; RU, Russian Federation; US, United States.

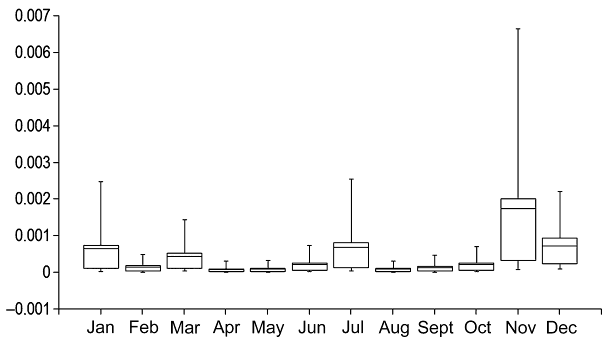


Fig. 4. Monthly probability of African swine fever (ASFV) introduction into the EU by legal trade of live pigs using the TRACES database.

Regarding the countries of origin, EUROSTAT registered eight countries importing pigs into the EU, whereas TRACES registered only five countries. In both cases, the Russian Federation was the country that posed the highest risk for the EU, representing 63% and 68% of the total annual risk based on EUROSTAT and TRACES databases, respectively.

Destination countries within the EU that concentrated the highest risk for ASFV introduction were Lithuania and Poland, based on EUROSTAT data and only Poland when using TRACES data. In both cases, United Kingdom and Germany were included as two of the five countries with highest risk for ASFV introduction (Fig. 2).

With respect to the seasonal variation in the risk of ASFV introduction into the EU, there were important differences when comparing both databases. Only November was considered to be higher risk with both data sets (Fig. 4).

The first step of the sensitivity analysis for input parameters allowed identifying seven parameters with the strongest influence on the model results ($\beta_i \geq 0.1$). However, the one-way sensitivity analysis revealed that model outcomes were only sensitive to changes in three of these parameters, which were the probability of survival of an

ASFV-infected pig, the intraherd ASFV prevalence and the number of outbreaks in the Russian Federation before the detection of the disease (Fig. 1).

Discussion

To the best of our knowledge, this is the first study quantifying the risk of ASFV introduction into the EU by legal import of live pigs. Moreover, this is the first study to specifically address the spatial and temporal variation of such a risk. The identification of geographical areas and time periods at highest risk of ASFV introduction can help update and improve the effectiveness of the surveillance programmes for the prevention and control of potential ASFV incursions into the EU.

Movement of live animals is certainly one of the main routes for disease introduction into free-areas (Ortiz-Pelaez et al., 2006; Zepeda et al., 2001). If we consider how fast and actively infected animals and animal products move in our global world, it is not difficult to imagine how fast an infected but non-detected animal can spread disease to remote regions or countries. In order to minimize risks related with animal trade, OIE and other international organizations are continuously stressing the need to develop risk assessments aimed at preventing and minimizing as much as possible the potential introduction of diseases into free areas.

The risk assessment presented in this study followed the internationally accepted guidelines recommended for the development of quantitative import risk assessments (OIE, 2010b), including the performance of a sensitivity analysis for model validation, and detailed description of the assumptions and parameterization of the inputs. This approach was adopted to enhance the transparency of the model development process in order for the model results to be useful for the decision-making process. A complete and accurate consequence assessment should be further developed in order to complete the risk-assessment process for estimation of the adverse direct and indirect socioeconomic consequences associated with a potential introduction of the disease in the EU.

The incursion of OIE-notifiable diseases into free areas, such as ASF into the EU, which is a large producer and trader of pigs and pig products, would certainly impact the economy of the region. For this reason, the number of studies intended to evaluate and quantify (when possible) the potential risks for disease introduction into free areas has increased in the last years. Recent examples found in literature are the quantitative risk assessment for classical swine fever virus (CSFV) introduction into the Danish pig population (Bronsvoort et al., 2008); the quantitative risk assessment for CSFV introduction by import of live pigs into Spain (Martínez-López et al., 2009); the model presented by de Vos et al. in 2004 to quantify the risk of CSFV introduction into Member States of the EU; and the quantitative assessment for highly pathogenic avian influenza introduction into Spain (Sanchez-Vizcaino et al., 2010), among others. The framework presented here not only quantifies the overall risk of ASFV introduction into the EU but also identifies geographical areas and time periods at increased risk of ASFV introduction, which could be useful to develop targeted risk-based surveillance and control strategies.

Accuracy and quality of the data used to parameterize the model determines the accuracy and quality of the outputs obtained. The stochastic model presented here uses the most recent and detailed information available (i.e TRACES system), but it needs to be acknowledged that it is a dynamic set of information which will change over time and sometimes access to such information is restricted to researchers. The model presented here was structured so that it can be easily updated/adapted to specific conditions/information available in the different EU countries. However, most of the quantitative models developed until now have used EUROSTAT statistics instead of TRACES, which usually is less detailed/disaggregated and less reliable than TRACES information, which is the official system for movement records in the EU. Results obtained from the sensitivity analysis indicate that, at least in this current model, the use of EUROSTAT or TRACES database has no major influence regarding countries of origin and destination (Figs 2 and 3). However, the overall risk estimates (with EUROSTAT data the overall risk was twice as high) and months at higher risk, differed substantially between the two databases. Those differences need to be considered when comparing the outputs of this model with other models. The model presented here specifically addressed the qualitative (i.e. countries and months) and quantitative (amount of risk) variation of risk. This aspect may help policy makers to better interpret and apply models that use EUROSTAT or TRACES as source of information.

The model outputs indicate an annual probability for ASFV introduction by legal imports into EU of $5.21*10^{-3}$, which approximately correspond to one outbreak each 192 years. Legal trade of animals always poses a risk; but in this case, the risk of ASFV introduction associated with live pig imports could be categorized as a low (but not negligible) compared with the risk associated with other pathways. In fact, results of recently published qualitative risk assessments for ASFV introduction into the EU, identified as the most risky pathway for ASFV introduction into EU the illegal imports of pigs and pig products from infected areas (EFSA, 2010; Gale et al., 2010; Wieland et al., 2011). It is important to highlight that other pathways such as illegal import of pigs or pig products, movements of wild boar or introduction of fomites or ticks from infected areas, which may pose greater risks, were not considered in this study, mainly because of the lack of quantitative information. However, work is under way to complement the findings of the model presented here with qualitative or semi-quantitative risk assessments for other routes of ASFV introduction into the EU in order to assess the relative importance of the different risk pathways (under the ASFRISK EU project: EC, FP7-KBBE-2007-1, Project #211691).

In the current analysis, the country with the highest contribution to the risk of ASFV introduction into the EU is the Russian Federation (68% of total risk). This was to be expected, because among the source countries considered here, only Russia had reported recent ASF outbreaks, and furthermore, it had a relatively long period before detection of the first infected pig (29 days based on the WAHID database). Although imports of pigs and pig products are forbidden based on the OIE terrestrial code and EU legislation, since the first notification of the disease in Russian Federation (November 2007), this country was included in the analysis to quantify the risk associated with the HRP.

European countries that had the highest probabilities for ASFV introduction by legal imports of live pigs were Poland, followed by United Kingdom and Germany, mainly during the months of November and December. The higher risk in November and December can be explained by the seasonal high numbers of live pig imports coming from areas/countries with a (relatively) high probability of having an ASFV non-detected epidemic. It should be highlighted that, if geographical and cultural closeness between countries also results in relatively high levels of live pig legal imports, it may also be associated with increased levels of illegal pig and pig product imports or fomite movements, particularly if there are significant differences in pig prices. For example, in the case of Poland, which traditionally imports pigs from Russia, it is also an important exporter of live pigs to the RF (92 289 pigs exported from Poland to RF since 2004) (EUROSTAT database). This may increase the risk for ASFV introduction into EU, not associated with legal import of pigs, but to the vehicles returning from infected areas if they are not properly cleaned and disinfected.

In the potential situation that ASFV enters into one EU country, the potential risk for ASFV spreading to other countries during the high-risk period may be quite high, considering the high frequency of pig movements between EU countries. For example, in the case of a potential introduction into Poland, ASFV may easily spread to Hungary, Lithuania, Latvia and Romania, and from those countries, to other EU countries (EFSA, 2010; EUROSTAT database). This situation would result in severe economic consequences for the EU, because of the cost of control and eradication of the disease, as well as the resulting trade restrictions.

Sensitivity analysis on input parameters reveals that, in general, the model is robust. Changes in input values did not substantially modify the ranking of the countries and months at risk. However, the probability of survival to ASFV infection, the intraherd prevalence and the number of undetected outbreaks in the Russian Federation were the three parameters that had the strongest influence on model results. A 50% of increase in the base value of these three parameters resulted in an increase in the overall probability of ASFV introduction into EU by 51%, 48% and 34%, respectively. These results highlight the importance of using meaningful (i.e. realistic) input values for those three parameters, which could be obtained through good surveillance programmes as well as outbreak follow-up data from the current ASFV epidemic in the Russian Federation.

One of the most critical aspects of any risk assessment model is the capacity to incorporate reliable data and to consider the epidemiological aspects regarding the current situation of the disease under evaluation. In the work presented here, although there is scarce knowledge and literature published about the current situation of the ASF in the Transcaucasus region and Russian Federation, we have produced a flexible and easy to update tool that was illustrated with the best information available to us. For that reason, it would be extremely useful to carry out field studies to improve the knowledge about the epidemiological factors in the current affected areas to better understand the distribution and potential ASF spread to new territories. Such knowledge would allow improving the parameters/assumptions of this and other ASF risk-assessment frameworks, reducing the uncertainty of the results.

The methods and results obtained in this study will be useful for identifying the geographical areas and time periods at increased risk of ASFV introduction. Regular updating and improvement of this risk assessment model for the EU will provide support for the development of more effective risk-based surveillance and contingency plans and, ultimately, will help to reduce the risk of ASFV introduction into the EU.

Conclusion

This study presents the first quantitative risk assessment for ASFV introduction into the European Union for legal import of live pigs. Apart from the results presented here, it is shown that legal trade of live pigs does not pose a high risk for ASFV introduction into the EU, methods and results obtained would help to allocate financial and personnel resources in geographical areas (Poland) and time periods (November) at increased risk, which ultimately will lead to a better prevention and control of potential incursions of ASFV into European Union and other free territories.

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Declaration of interest

None.

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