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Risk of African swine fever incursion into the Netherlands by wild boar carcasses and meat carried by Dutch hunters from hunting trips abroad

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A B S T R A C T

After the first introduction of African swine fever (ASF) in the European Union in 2014, the ASF virus (ASFV) has steadily spread in the European Union. The virus has occasionally been transmitted over unexpectedly large distances that are believed to be related to human-mediated spread. Hunting tourism has been mentioned as a potential contributor to these long-distance jumps, although evidence is lacking. In this study, the possible role of hunters carrying ASFV-contaminated wild boar products (WBP) from hunting trips in affected countries was evaluated. A quantitative risk model was developed to estimate the expected annual number of ASF exposures of wild boar and domestic pigs in the Netherlands via this introduction route. Main input data into the model were the ASF prevalence in hunted wild boar, the number and destination of hunting trips of Dutch hunters, and the probabilities that hunters take WBP home and dispose leftovers such that wild boar or domestic pigs have access. The model indicated that the total expected annual number of exposures (wild boar and domestic pigs together) in the Netherlands is 0.048 (95% uncertainty interval 7.5×10^{-3} – 0.15). Model results were most sensitive to uncertainty on leftovers fed to domestic pigs (swill feeding), which is an illegal practice. Uncertainties on the ASF prevalence of hunted wild boar and the probabilities that hunters take WBP home also impacted model results. Default model results were based on the 2019 situation. Alternative scenarios were run with the model to account for the change of ASF status of Belgium (recovery of ASF-free status) and Germany (ASF-infected) in 2020. Results indicated that especially the presence of ASF in Germany increased the incursion risk. However, this increase might be counteracted by a change in travel behavior of hunters.

1. Introduction

African swine fever (ASF) is a viral hemorrhagic disease, causing high morbidity and mortality in both domestic pigs and wild boar (Blome et al., 2020). The causative agent of ASF is the ASF virus (AFSV), a large double-stranded DNA virus and the only member of the Asfarviridae family (Dixon et al., 2019; Penrith et al., 2019; Blome et al., 2020). ASF is endemic in sub-Saharan Africa where it is maintained in a sylvatic cycle between warthogs and soft ticks (Dixon et al., 2019; Penrith et al., 2019). Its first escape from the African continent resulted in long-lasting circulation of the virus in the Iberian Peninsula and subsequent outbreaks in other western European countries (including the Netherlands), the Caribbean and Brazil (Cwynar et al., 2019; Penrith and Kivaria, 2022). In the 1990s, ASF was eradicated from the Iberian peninsula and again confined to the African continent, with the exception of the island of Sardinia, Italy, where the virus persisted in free-ranging pigs (Mur et al., 2016; Jurado et al., 2018; Laddomada et al., 2019). The introduction of ASF into Georgia in 2007 resulted in an unprecedented spread of ASF on the European and Asian continent, and in 2021 ASF was also introduced into the Caribbean (Penrith and Kivaria, 2022). Control and eradication of ASF is based on biosecurity, movement bans and culling of infected and contact animals (Dixon et al., 2019; Blome et al., 2020). The disease continuous to spread by various pathways, including movement of infected animals, feeding of contaminated meat, and other human-mediated routes (Dixon et al., 2019; Blome et al., 2020).

After its introduction in the Baltic states in 2014, ASF has steadily spread westwards in the European Union (EU) and outbreaks in both wild boar and domestic pigs have been reported in Germany, a neighboring country of The Netherlands, since 2020 (Sauter-Louis et al., 2021a). Spread to new areas or countries can occur over short distances, e.g. by migrating wild boar or human actions, but transmission of the virus has also occurred over large distances that cannot be explained from wild boar movements only. Examples include the introductions of

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the virus in the Czech Republic in 2017, in Belgium in 2018, and in Italy in 2022 (Linden et al., 2019; Šatrán, 2019; WOAH, 2022a). Although the transmission routes involved in these 'long-distance jumps' have not been elucidated, these transmission events are likely to be related to human-mediated spread, e.g. the movement of contaminated meat or materials into naive areas (Chenais et al., 2019; EFSA, 2020; Mauroy et al., 2021; Sauter-Louis et al., 2021b). The increasing geographic expansion of ASF in Europe presents a serious risk to the Dutch wild boar and domestic pig population. Furthermore, an incursion of ASF is likely to result in severe economic consequences for the export-oriented Dutch pig production sector. The ASF incursion risk into the Netherlands via legal trade in pigs and meat products has been estimated as very low, because legal trade is banned from infected areas (De Vos et al., 2022). The virus can, however, enter the Dutch territory via multiple introduction routes including illegal trade of animals or meat, transportation vehicles, and wild boar and human movements (Sánchez-Vizcaíno et al., 2015; Beltran-Alcrudo et al., 2019; Chenais et al., 2019; Dixon et al., 2019). The latter could, e.g., be tourists carrying contaminated meat products, hunters bringing infected wild boar carcasses or contaminated vehicles or equipment, and professionals working in the pig industry (Bellini et al., 2021). ASFV can survive for long periods in meat and other contaminated materials, especially at low temperatures (Mebus et al., 1993, 1997; Farez and Morley, 1997; Fischer et al., 2020), and transmission by animal products has historically been an important transmission route of ASFV (Sánchez-Vizcaíno et al., 2015; Beltran-Alcrudo et al., 2019). While the incursion risk via tourists carrying contaminated meat products has been estimated in previous studies (Wooldridge et al., 2006; Jurado et al., 2019a, 2019b; Ito et al., 2020a, 2020b; De Vos et al., 2022), the potential role of hunters in transmission of ASFV has not been estimated in a systematic way (EFSA, 2019).

Roelandt et al. (2017) indicated "hunting tourism" as a risk factor for ASF introduction into Belgium (this was before ASF was introduced into the country) and pointed out the importance of information campaigns and hunting biosecurity to mitigate this risk. Hunters travelling back from ASF-infected areas could accidentally carry the virus on their boots, clothes, hunting equipment, etc., or bring carcasses of hunted animals that have not undergone proper control (Beltran-Alcrudo et al., 2019). Although, to our knowledge, no outbreaks of ASF have been directly linked to hunting activities, hunting activities are perceived a risk factor for ASF incursion into the Netherlands. To elucidate the importance of recreational hunting to the incursion risk of ASF for the Netherlands, a quantitative risk assessment was performed to estimate the incursion risk via wild boar carcasses and meat carried by Dutch hunters from a hunting trip abroad. In this paper, the risk model for hunters is described and results are presented and discussed.

2. Materials and methods

2.1. Model outline

A quantitative risk model was developed to estimate the expected annual number of ASF exposures of wild boar and domestic pigs in the Netherlands from contaminated wild boar products (WBP), brought into the Netherlands by Dutch hunters after hunting abroad. The model calculates the expected annual number of entries of ASFV-contaminated WBP into the Netherlands and the subsequent number of exposures of wild boar and domestic pigs arising from these entries.

Because the project started in 2019, the reference year for the model was 2019: input data and other information needed for the model are from 2019 (if available). The number of entries into the Netherlands was defined as: the number of WBP contaminated with ASFV crossing the Dutch border. A WBP could be a whole carcass, parts thereof, or a portion of meat derived from a single hunted wild boar (see Section 2.3). The number of exposures was defined as the number of occasions in which domestic pigs or wild boar had direct access to a contaminated WBP resulting in consumption (oral intake). It was assumed that a single entry would result in a single exposure, or no exposure at all, i.e. the number of exposures can never exceed the number of entries. The probability of infection upon exposure was not included in the model given the huge uncertainty on the viral load of the contaminated WBP.

The model was developed in Microsoft Excel (Office 365) and @Risk 8.2 (Palisade, 2022). The model was run with 10,000 iterations (Latin hypercube sampling).

The main parameters assessed by the model are the annual number of entries of ASFV-contaminated WBP and the annual number of exposures of wild boar and domestic pigs to these WBP. The entries and exposures result from a chain of "events", which is schematically presented in Fig. 1. The figure also provides an overview of the numbers (N_i), probabilities (P_i) and fractions (F_i) used in the model calculations. A list of all parameters used in the model is given in Table 1.

Model calculations were performed on country level, i.e., we assumed that ASF infection prevalence in wild boar is homogeneously distributed across infected countries, and that hunters can freely hunt in infected countries without any restrictions or control measures in infected regions, as no data were available on a higher spatial resolution. In reality, in most countries ASF-infected wild boar are only present in specific regions, and taking wild boar carcasses from infected regions is only allowed if tested negative for ASF (Regulation EU 2023/594, EU, 2023). The model is thus a simplified version of a more complex reality and is likely to result in a worst case estimate of the ASF incursion risk for the Netherlands due to hunters taking WBP home.

2.2. Entry

The expected number of entries (N_{en_c}), i.e. the expected number of ASFV-contaminated WBP, that Dutch hunters bring to the Netherlands per year from source country c, was calculated as:

$$N_{en_c} = N_{ht} \times F_{ht_c} \times P_{wb\_carried_c} \times P_{wb\_inf_c} \times \left(1 - P_{wb\_det}\right) \quad (1)$$

where N_{ht} is the total number of hunting trips from the Netherlands to foreign countries per year, F_{ht_c} is the fraction of hunting trips to country c, $P_{wb\_carried_c}$ is the probability that a hunter takes a WBP home from country c, $P_{wb\_inf_c}$ is the probability that a shot wild boar is infected with ASFV in country c, and P_{wb_det} is the probability that ASF infection in a shot wild boar is detected.

The total number of entries was calculated as the sum of entries of a total of i individual source countries:

$$N_{en} = \sum_{c=1}^{i} N_{en_c} \quad (2)$$

The total number of hunting trips from the Netherlands to foreign countries per year (N_{ht}) was estimated by multiplying the number of Dutch wild boar hunters hunting abroad (N_h) with the average number of hunting trips per hunter per year (n_{ht}).

$$N_{ht} = N_h \times n_{ht} \quad (3)$$

N_h and n_{ht} were estimated using information obtained from interviews with representatives of two Dutch hunting associations and a survey that was distributed among members of these hunting associations (Suppl. material 1). The interviews and survey were conducted in 2020 (after the start of the COVID-19 pandemic), but we asked explicitly for answers representative for "normal" circumstances. The survey was held exclusively under wild boar hunters. The survey was returned by 648 persons, from which 570 indicated to hunt abroad, with on average 6.7 hunting trips per hunter per year (Suppl. Table 1). Pert distributions were used to model uncertainty for N_h and n_{ht} (Table 1). In the Supplementary material more details about the survey are given, as well as the results that were used to estimate the values of model input parameters.

The fraction of hunting trips with destination country c (F_{ht_c}) was

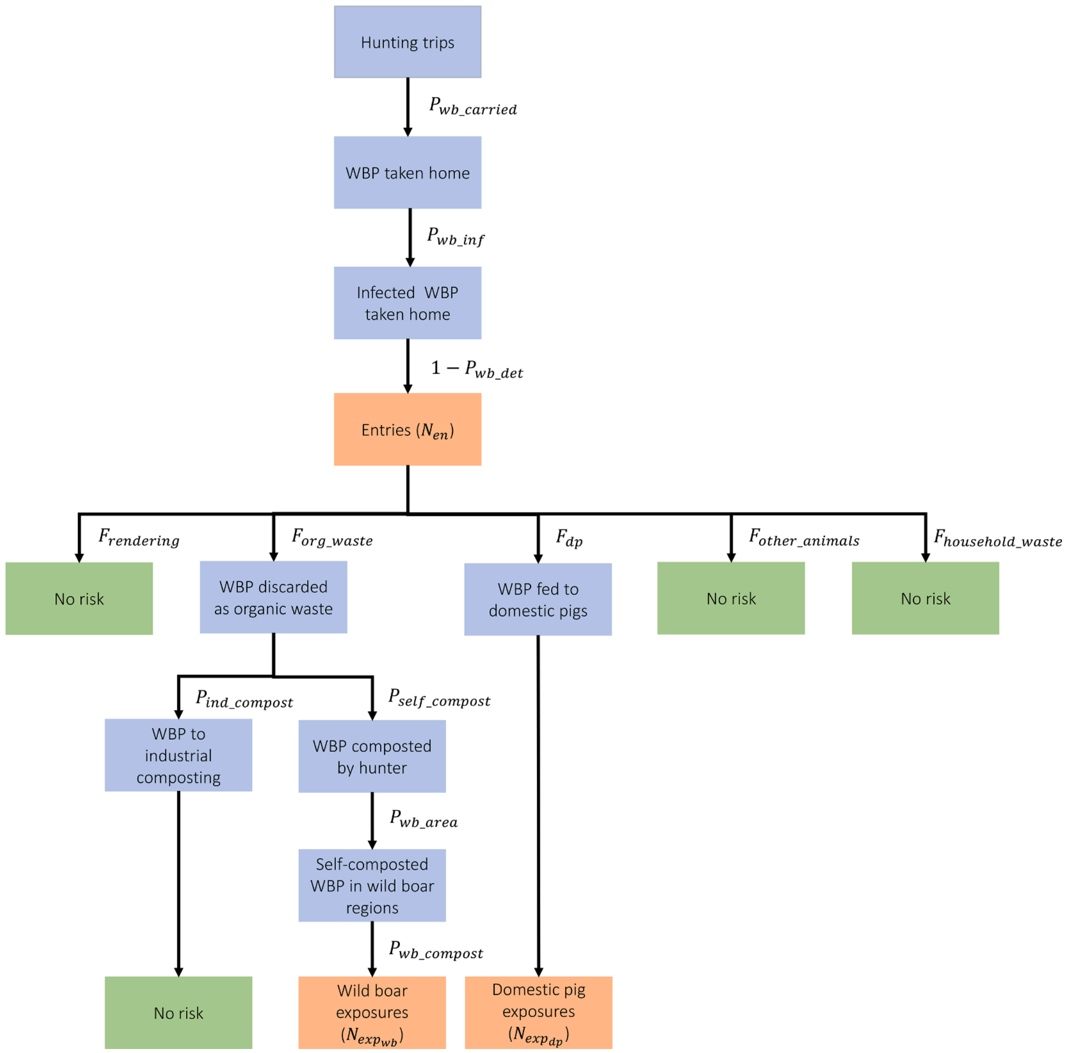

Fig. 1. Model outline, showing all events possibly leading to entry of ASFV-contaminated wild boar products (WBP) into the Netherlands by carcasses and meat brought by Dutch hunters from a hunting trip abroad and subsequent exposure of wild boar or domestic pigs to ASFV. Blue boxes in the scenario tree represent a number. Output parameters of the model are given in the orange boxes.

also estimated using results of the survey. Hunters were asked to list all countries they had ever travelled to for hunting and to provide the destination of their most recent hunting trip. Both were used to calculate F_{ht_c}, resulting in two different parameterizations of F_{ht_c} (Suppl. Tables 2 and 3). The values of F_{ht_c} based on the destinations of the most recent trip were used in the default calculations, as these were assumed to be most representative. Values of F_{ht_c} based on all countries hunters ever travelled to resulted in a longer list of countries and were used in an alternative scenario (Section 2.5).

The probability that a hunter takes WBP home ($P_{wb\_carried_c}$) was based on the survey results. Approximately 27% of the respondents brought WBP after their last hunting trip abroad. Because this probability differed between countries, a country-dependent probability was used. Beta distributions were used to model uncertainty for $P_{wb\_carried_c}$ (Suppl. Tables 4 and 5). $P_{wb\_carried_c}$ was zero for non-European countries, as no meat or carcasses can be carried legally from these countries.

Although hunters can shoot multiple wild boar abroad, it was assumed that, if they would take WBP home, this would be only from a single boar, because hunters legally can only take one wild boar home from foreign countries (pers. comm. hunters associations).

The probability that an ASF infection in a shot wild boar is detected (P_{wb_det}) was modelled as the probability that a hunter will recognize ASF symptoms. This probability was also based on the survey results (Suppl. Table 6). Approximately 55% of the respondents indicated to recognize ASF symptoms in dead wild boar. In the model calculations, it was assumed that no WBP were taken home if ASF signs were suspected by the hunter, reducing the probability of entry into the Netherlands. A beta distribution was used to model uncertainty for P_{wb_det} (Table 1).

$P_{wb\_inf_c}$ is the probability that a wild boar in country c is infected with ASFV when it is shot by a hunter. The apparent prevalence of ASF in wild boar based on positive blood samples (PCR or virus isolation) from hunted wild boar was used to estimate this probability. Data to estimate the apparent prevalence for individual countries was limited. EFSA (2017), EFSA (2018b) and Śmietanka et al. (2016) reported ASF prevalence in hunted wild boar in the Baltic states and Poland for the period 2014–2017. The apparent prevalence in hunted wild boar varied by year and country, from 0.0% to 0.1% in Poland to 3.9% in Estonia. In addition, for some countries data were available on the number of ASFV-positive hunted wild boar from the EU CSF/ASF wild boar surveillance database for the years 2019 and 2020 (EU, 2021) (Suppl. Material, Section 3). Apparent prevalences estimated from these data varied from 0.1% to 3.0%, when excluding countries that submitted only negative or only positive samples. These values were used to set an uncertainty distribution for $P_{wb\_inf_c}$ that was used for all European countries that reported ASF in wild boar to the World organisation for Animal Health (WOAH) in 2019 (OIE, 2021) (hereafter referred to as

Table 1
Model parameters to estimate the annual number of entries of ASF-contaminated wild boar products and subsequent exposures of wild boar and domestic pigs. 1a. Parameters for introduction, 1b: Parameters for exposure.

Table 1a Parameters for introduction

Introduction

Parameter	Description	Value	Source/Reference
N_h	Number of Dutch wild boar hunters hunting abroad	Pert(8000,8800,9600)[c]	Interviews and survey (Suppl.)
n_{ht}	Number of hunting trips to foreign countries per hunter per year	Pert(5.4,6.7,10.1) Suppl. Table 1	Survey
N_{ht}	Total number of hunting trips abroad per year	Eq. 3	
F_{ht_c}	Fraction of hunting trips with country *c* as destination	Suppl. Table 2	Survey
$P_{wb\_carried_c}$	Probability that a hunter takes WBP[a] home, if a wild boar was shot in country *c*	Suppl. Table 4 and 5	Survey
$P_{wb\_inf_c}$	Probability that a hunted wild boar is infected with ASFV in country *c*[b]	Uniform(0.001,0.01)	EFSA, 2017; EU, 2021 Suppl. section 3
P_{wb_det}	Probability that ASF infection in a shot wild boar is detected	Beta(359,291)[d] Suppl. Table 6	Survey
N_{en_c}	Number of ASFV-contaminated WBP brought by hunters from country *c* into The Netherlands per year	Eq. 1	
N_{en}	Total number of ASFV-contaminated WBP brought by hunters into the Netherlands per year	Eq. 2	

Table 1b Parameters for exposure

Exposure

Parameter	Description	Value	Source/Reference
$P_{carcass}$	Probability that WBP taken home is a whole carcass (eviscerated)	Beta(62, 54) Suppl. Table 7)	Survey
P_{meat}	Probability that a WBP taken home is (a portion of) meat	MINIMUM (Beta(48,68), $(0.94 - P_{carcass})$[e] Suppl. Table 7	Survey
F_{raw_i}	Fraction of WBP discarded raw	Meat: Pert(0.6,0.8,0.95) Whole carcass: 1	Survey (Suppl.)
$F_{dp_{carcass}}$	Fraction of rest material of ASFV-contaminated carcasses fed to domestic pigs	Beta(3,58) Suppl. Table 8	Survey
$F_{dp_{meat}}$	Fraction of rest material of ASFV-contaminated meat fed to domestic pigs	Beta(1,144)	Survey (Suppl. Table 9)
$F_{org\_waste_{carcass}}$	Fraction of rest material of ASFV-contaminated carcasses discarded as organic waste	Beta(13,48) Suppl. Table 8	Survey
$F_{org\_waste_{meat}}$	Fraction of rest material of ASFV-contaminated meat discarded as organic waste	Beta(25,120)	Survey (Suppl. Table 9)
$P_{self\_compost}$	Probability that hunter composts his own organic waste (self-compost)	Pert(0.03,0.05,0.13)	Van Soest and Schwenke, 2009; A. Brinkmann, Branche Vereniging Organische Reststoffen, pers. comm.
P_{wb_area}	Probability that hunter lives in a region where wild boar are present	0.2	Suppl. section 2: Fig. 1
$P_{wb\_compost}$	Probability that a wild boar has direct access to the compost pile	Pert(0.05,0.15,0.25)	Authors' estimate
$N_{exp\ wb}$	Number of exposures of wild boar to ASFV-contaminated WBP brought into The Netherlands by hunters per year	Eq. 5	
$N_{exp_{dp}}$	Number of exposures of domestic pigs to ASFV-contaminated WBP brought into The Netherlands by hunters per year	Eq. 6	
N_{exp}	Total number of exposures of wild boar and domestic pigs to ASFV-contaminated WBP, brought into The Netherlands by hunters per year	Eq. 4	

[a] WBP: wild boar products.
[b] ASF-infected country: a country where ASF was present in wild boar in the reference year 2019, based on disease timelines per country in 2019 as given by the World Animal Health Information System (OIE, 2021).
[c] Parameters of the Pert distribution are the minimum, most likely, and maximum value.
[d] Beta distributions were defined as ($s + 1$,n-$s + 1$), where s is the number of "successes" and n is the total number of observations.
[e] 94% of WBP carried by hunters are whole carcasses or meat; therefore the sum of the sampled values of $P_{carcass}$ and P_{meat} should not exceed 94% in the model calculations.

ASF-infected countries). A Uniform distribution was used with 0.1% as minimum and 1% as maximum value (Table 1), taking into account that the higher apparent prevalence values were based on heavily infected wild boar populations, and that in most countries not all wild boar territories are affected by ASF. There was no need to estimate $P_{wb\_inf_c}$ for non-European countries, because hunters did not carry any WBP from these countries ($P_{wb\_carried_c} = 0$). In an alternative scenario, ASF cases in wild boar reported by EMPRES-i (FAO, 2020) were used to estimate country-specific values for $P_{wb\_inf_c}$ (Section 2.5) (Suppl. Table 12).

2.3. Exposure

Hunters can bring different types of WBP after a hunting trip. For the risk assessment, we assumed the whole (eviscerated) carcass and meat to be risk materials, because they can contain ASFV and might end up with domestic pigs or wild boar. Hunters also sometimes carry the teeth or the head of wild boar. We didn't expect these to come into contact with domestic pigs or wild boar, as these are considered "trophies", and will be used for collection or decoration purposes. The probabilities of a hunter bringing a whole carcass ($P_{carcass}$) or meat (P_{meat}) were estimated from the survey and Beta distributions were used to model uncertainty for these input parameters (Table 1; Suppl. Table 7). We assumed that both carcasses and meat were primarily intended for human consumption, but that leftovers could end up with wild boar or domestic pigs in the Netherlands, resulting in exposure. We assumed that rest material of the whole carcass (offal) would always be raw ($F_{raw_{carcass}} = 1$), whereas meat could be either raw or cooked when discarded. We assumed that only raw meat would pose a risk of infection, as ASFV does not survive proper cooking (McKercher et al., 1978; Farez and Morley, 1997). The fraction of meat discarded raw ($F_{raw_{meat}}$) was estimated from the survey results (Suppl information). A Pert distribution was used to model uncertainty for $F_{raw_{meat}}$ (Table 1).

Fig. 1 shows five possible pathways for discarding the leftovers of WBP. Only two pathways are assumed to result in potential exposure of domestic pigs or wild boar in the Netherlands, i.e. disposing WBP as organic waste and feeding WBP to domestic pigs. Most people will have their organic waste collected by the municipal garbage collection service. However, some people will compost the organic waste in their garden. The risk of exposure via the municipal organic waste collection was considered negligible, because the industrial composting facilities in the Netherlands are all Keurcompost (www.keurcompost.nl) certified. All material is stored indoors and processed for a minimum period of 3 days at a minimum temperature of 55 °C (A. Brinkmann, BVOR, pers. comm.), which will inactivate ASFV (WOAH, 2022c). Feeding WBP to other animals, rendering WBP and discarding WBP as normal household waste were assumed not to result in potential exposure of domestic pigs or wild boar. When fed to other animals, the virus will not result in infection as only members of the pig family (Suidae) are susceptible to ASFV (CFSPH, 2019). Rendering (133 °C and 3 bar for 20 min) will rapidly inactivate ASFV (WOAH, 2022c). Normal household waste is incinerated at temperatures between 800 °C and 1000 °C (https://www.wastenet.nl/afvalverbranding/), which will also inactivate ASFV.

The expected number of exposures (N_{exp}), i.e. "the expected number of exposures of wild boar and domestic pigs to ASFV-contaminated WBP brought by Dutch hunters from a hunting trip abroad per year", was calculated as:

$$N_{exp} = N_{exp_{dp}} + N_{exp_{wb}} \tag{4}$$

where $N_{exp_{dp}}$ is the expected number of exposures of domestic pigs and $N_{exp_{wb}}$ is the expected number of exposures of wild boar. The number of exposures of domestic pigs was calculated as:

$$N_{exp_{dp}} = \sum_i N_{en_i} \times F_{dp_i} \times F_{raw_i} \tag{5}$$

where N_{en_i} is the number of ASF entries for WBP i (i = whole carcass or meat), F_{dp_i} is the fraction of leftovers of WBP i fed to domestic pigs and F_{raw_i} is the fraction of WBP i discarded raw. N_{en_i} was calculated by multiplying the expected number of entries (N_{en}) with the probability of a hunter bringing a WBP of type i (i.e. $P_{carcass}$ or P_{meat}).

The number of exposures of wild boar was calculated as:

$$N_{exp_{wb}} = \sum_i N_{en_i} \times F_{org\_waste_i} \times F_{raw_i} \times P_{self\_compost} \times P_{wb\_area} \times P_{wb\_compost} \tag{6}$$

where N_{en_i} is the number of ASF entries for WBP i (i = whole carcass or meat), $F_{org\_waste_i}$ is the fraction of leftovers of WBP i discarded as organic waste, F_{raw_i} is the fraction of WBP i discarded raw, $P_{self\_compost}$ is the probability that a hunter composts organic waste himself, P_{wb_area} is the probability that a hunter lives in a region where wild boar are present, and $P_{wb\_compost}$ is the probability that wild boar can access the compost pile.

The fraction of WBP fed to domestic pigs (F_{dp_i}) and the fraction of WBP discarded as organic waste ($F_{org\_waste_i}$) were estimated from the survey results (Suppl. Tables 8 and 9). Beta distributions were used to model uncertainty.

Little data was available to estimate the probability that a hunter composts organic waste himself ($P_{self\_compost}$) rather than having it collected for industrial composting. Van Soest and Schwenke (2009) estimated that in 2001/2002 approximately 10 to 13% of Dutch households composted organic waste at home. The major part of organic waste composted at home is, however, garden waste rather than kitchen waste (A. Brinkmann, BVOR (bvor.nl), pers. comm.). Therefore, ($P_{self\_compost}$) was modeled by a Pert distribution with 0.05 as the most likely value, and 0.03 and 0.13 as minimum and maximum value, respectively.

To estimate the probability that a hunter lives in a region where wild boar are present (P_{wb_area}), the areal fraction of the Netherlands with wild boar present was used as a proxy value. This fraction was estimated from a map showing regions with wild boar (Suppl. Fig. 1), and was set at 0.2 (Table 1).

The probability that a wild boar has direct access to the compost pile ($P_{wb\_compost}$) depends on various factors, such as the possibilities for wild boar to reach the compost pile (fencing yes/no), the way the pile is constructed and covered, the density of wild boar in the region, and the attractiveness of the pile for wild boar (e.g. by smell). Experts estimated this probability as low, because garden owners are likely to abandon the practice of composting when the compost pile is regularly ruined by wild boar. However, because of high uncertainty, $P_{wb\_compost}$ was modeled as a Pert distribution (0.05, 0.15, 0.25) (Table 1).

2.4. Sensitivity analysis

Sensitivity analysis was carried out to evaluate how the uncertainty of input parameters affected the expected number of entries (N_{en}) and exposures (N_{exp}). To this end, Spearman rank correlation coefficients were estimated in @Risk for all input parameters that were modelled by an uncertainty distribution.

2.5. Scenario analysis

To evaluate the effect of model assumptions on the estimated annual number of exposures (N_{exp}), some alternative scenarios were modeled, the results of which were compared to the results of the default scenario (S0). Four scenarios (S1-S4) were evaluated to assess the impact of the estimated apparent ASF prevalence in wild boar populations in affected countries, whereas S5 and S6 evaluated the effect of changes in hunters' behavior. In the first scenario (S1), presence of ASF in wild boar in Germany was simulated, accounting for the presence of ASF in wild boar in Germany since September 2020 (Sauter-Louis et al., 2021a). In the second scenario (S2), absence of ASF in wild boar in Belgium was simulated, accounting for the recovery of the ASF free status of Belgium in October 2020 (FASFC, 2020). In the third scenario (S3), ASF prevalence in wild boar was estimated based on the number of ASF cases in wild boar reported to EMPRES-i (FAO, 2020) in each country in 2019, the estimated wild boar population in the affected countries (Pittiglio et al., 2018), and the average infectious period of ASF in wild boar (14 days, based on Pietschmann et al., 2015) (Suppl. Table 12). If no cases were reported by EMPRES-i for an ASF-infected country, outbreaks reported by the Animal Disease Information System (ADIS) (EU, 2022) were used. The fourth scenario (S4) combined scenario S3 with scenarios S1, using 2020 data for Germany. In the fifth scenario (S5) the probability that ASF infection in a shot wild boar is detected (P_{wb_det}) was set at 0, considering it is very unlikely that hunters will recognize symptoms of ASF in a shot wild boar, as most infected wild boar shot will still be in the incubation period or have only mild clinical symptoms. In the sixth scenario (S6), the probability of hunters travelling to each country c (F_{ht_c}) was based on all countries hunters ever travelled to, rather than the country of their most recent hunting trip (Suppl. Table 3). A summary of all scenarios is given in Table 2.

Table 2
Alternative scenarios evaluated in the scenario analysis.

Scenario[a]	Parameter changed	Value in default scenario (S0)	Value in this scenario
S1: Germany 2020	$P_{wb\_inf_c}$ (Germany only)	0	Uniform(0.001,0.01)
S2: Belgium ASF free	$P_{wb\_inf_c}$ (Belgium only)	Uniform(0.001,0.01)	0
S3: Prevalence wild boar	$P_{wb\_inf_c}$	Uniform(0.001,0.01)	ASF prevalence in wild boar based on 2019 cases reported by EMPRES-i (Suppl. Table 12)
S4: Prevalence wild boar, combined with Germany 2020	$P_{wb\_inf_c}$	Uniform(0.001,0.01) for ASF-infected countries; 0 for Germany	ASF prevalence in wild boar based on 2019 cases reported by EMPRES-i; for Germany 2020 data were used; (Suppl. Table 12)
S5: Detection of ASF in wild boar	P_{wb_det}	Beta(359,291)	0
S6: Travel destination of hunters	F_{ht_c}	Based on country visited during most recent hunting trip (Suppl. Table 2)	Based on all countries visited for hunting trips (Suppl. Table 3)

[a] Scenarios are explained in more detail in Section 2.5.

2.6. Evaluation of preventive measures

The model can be used to evaluate the effectiveness of measures aimed at reducing the risk of hunters bringing ASFV to the Netherlands. Three possible measures were evaluated: (1) discouraging or prohibiting hunting trips to ASF-infected countries, (2) banning the carriage of WBP from hunting trips in ASF-infected countries, and (3) an information campaign to raise higher awareness among hunters on the ASF risk. The first two measures would eliminate the ASF risk via WBP carried by hunters if compliance would be 100%. These measures were evaluated in a single scenario (P1) in which 90% compliance was assumed (N_{ht_c} to ASF infected countries reduced by 90%). An information campaign could reduce the ASF incursion risk via various routes, e.g., hunters deciding to go hunting in ASF-free countries rather than ASF-infected countries, or hunters staying away from regions where ASF is present; hunters taking fewer WBP home from ASF-infected countries; a better recognition of ASF signs by hunters resulting in a lower probability of ASFV-contaminated products carried home; no feeding of WBP to domestic pigs in the Netherlands; discarding WBP as normal household waste rather than composting. In the second scenario (P2), a combined effect of the information campaign was assumed, with a 30% reduction of the number of hunting trips to ASF-infected countries (N_{ht_c}), a 30% reduction of the probability that WBP are taken home from ASF-infected countries ($P_{wb\_\_carried_c}$), and a 50% reduction of the probability that WBP are fed to domestic pigs or discarded as organic waste (F_{dp_i} and $F_{org\_waste_i}$).

3. Results

3.1. Default scenario

The expected mean number of entries of ASFV-contaminated wild boar products carried by hunters into the Netherlands per year (N_{en}) with the default settings of the model was 1.7 (95% uncertainty interval (UCI) 0.52 – 3.7). The expected number of subsequent exposures of wild boar and domestic pigs in the Netherlands (N_{exp}) was 0.048 (95% UCI 7.5×10^{-3} – 0.15) per year, from which 0.048 (95% UCI 7.2×10^{-3} – 0.14) in domestic pigs (99%) and 5.0×10^{-4} (95% UCI 1.2×10^{-4} – 1.3×10^{-3}) in wild boar (1%). Most entries were expected to originate from Belgium (47%) and Poland (32%). Only few countries contributed to the incursion risk, as the most recent trip of hunters was mostly to ASF-free countries in Europe, the exceptions being Belgium, Poland, Hungary and Italy. It should be noted that in Italy, ASF was only present at the island of Sardinia in 2019 (Dixon et al., 2019; WOAH, 2022a). Some hunters reported a hunting trip to African countries where ASF is present. However, the incursion risk from these trips was not considered in the calculations, because meat and carcasses cannot be carried legally from African countries.

3.2. Sensitivity analysis

Fig. 2 shows the results of the sensitivity analysis using Pearson rank correlation coefficients. Results are only shown for input parameters that had a correlation coefficient > 0.1 with either the number of entries, the number of exposures or both. Model results were most sensitive to the uncertainty on the fraction of remnants of ASFV-contaminated carcasses fed to domestic pigs ($F_{dp_{carcass}}$) (Fig. 2). This parameter only affected the estimated number of exposures, not the estimated number of entries, similar to the fraction of leftovers of ASFV-contaminated meat fed to domestic pigs ($F_{dp_{meat}}$). The impact of $F_{dp_{meat}}$ on model results was, however, smaller, which reflects the smaller uncertainty interval modelled for $F_{dp_{meat}}$ (Table 1), as more hunters had reported on disposal of meat leftovers than on disposure of remnants of carcasses. The number of entries, and subsequently also the number of exposures, was highly sensitive to uncertainty on the ASF prevalence in wild boar in ASF-infected countries ($P_{wb\_inf_c}$) and the probability that a hunter takes WBP home from these countries ($P_{wb\_carried_c}$). Another important parameter was the number of hunting trips per hunter per year (n_{ht}).

3.3. Scenario analysis

Table 3 shows the results of the alternative scenarios that were simulated. It is very clear that the ASF prevalence in wild boar is an important input parameter. Assuming presence of ASF in Germany at the same prevalence level as for all other infected countries (S1) resulted in a huge increase of the estimated number of entries and exposures. This is explained by the large number of hunting trips to Germany in the model. An ASF-free status for Belgium (S2), on the other hand, resulted in a 53% reduction of the incursion risk. Estimating the prevalence of wild boar from reported ASF cases in wild boar (EMPRES-i; FAO, 2020) (S3) rather than from sampling of hunted wild boar resulted in a much lower estimate for the probabilities of entries and exposures. Adding Germany as an infected country to this scenario (S4) increased the risk by 56%, but the risk was still far lower than estimated in the default scenario. Also, the relative increase of the incursion risk due to presence of ASF in German wild boar was much lower when comparing scenario S4 to S3 than when comparing scenario S1 to S0. This is explained by the relatively low number of ASF cases reported in wild boar in Germany in 2020, while the country has a huge wild boar population, resulting in a very low apparent prevalence (Suppl. Table 12).

Assuming that hunters would not recognize ASF symptoms (S5) increased the risk by 130%, compared to the default scenario. The estimated risk also increased substantially when the travel destination of hunters was based on all countries hunters ever travelled to rather than the destination of their last hunting trip (S6) (Suppl. Table 3). This scenario accounted for hunting trips to many ASF-infected East-European countries, that were not included in the default scenario.

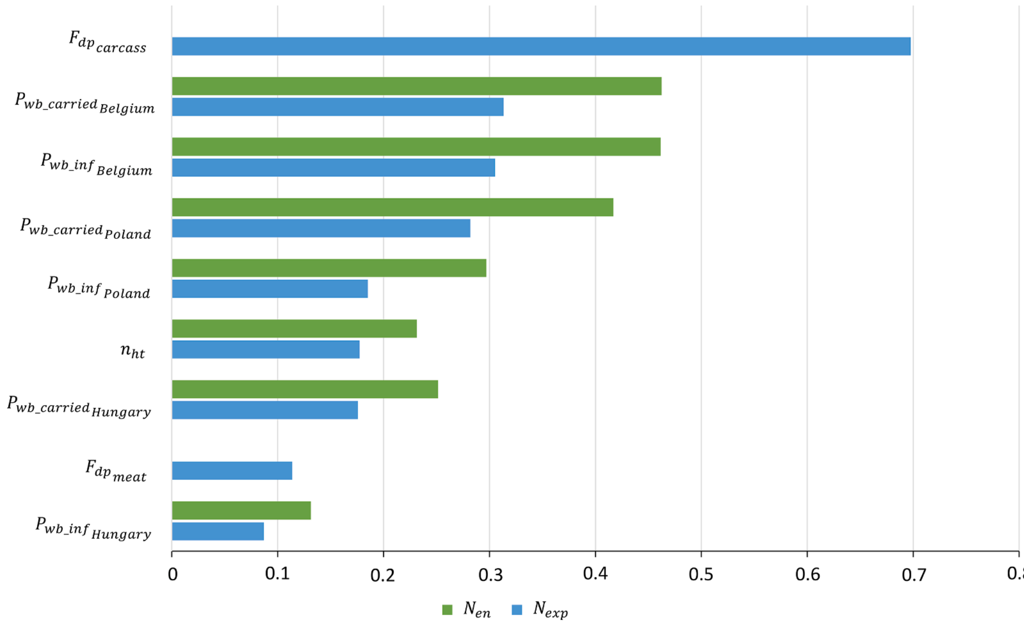

Fig. 2. Tornado chart showing the correlation coefficients of uncertain model input parameters with the estimated number of entries of ASFV-contaminated wild boar products carried by hunters into the Netherlands per year (N_{en}, green) and the estimated annual number of exposures of wild boar and domestic pigs resulting from these entries (N_{exp},blue). Only input parameters with a correlation coefficient > 0.1 are shown.

Table 3
Expected mean number (and 95% uncertainty interval) of entries and exposures per year in the alternative scenarios.

Scenario	Description	Estimated number per year (95% UCI)		Relative risk compared to default scenario[a]	
		Entries	Exposures	Entries	Exposures
S0	Default scenario	1.7 (0.52 – 3.7)	0.048 (7.5×10^{-3} – 0.15)	1	1
Alternative scenarios					
S1	Germany 2020	41 (10 – 80)	1.2 (0.17 – 3.5)	24	24
S2	Belgium ASF free	0.88 (0.19 – 2.3)	0.025 (3.1×10^{-3} – 0.085)	0.53	0.52
S3	Prevalence wild boar	0.22 (0.082 – 0.42)	6.3×10^{-3} (1.1×10^{-3} – 0.018)	0.13	0.13
S4	Prevalence wild boar and Germany 2020	0.34 (0.19 – 0.56)	9.8×10^{-3} (2.2×10^{-3} – 0.025)	0.20	0.20
S5	Detection of ASF in wild boar	3.8 (1.12 – 8.27)	0.108 (0.017 – 0.327)	2.3	2.3
S6	Travel destination of hunters	4.7 (1.4 – 10)	0.13 (0.021 – 0.40)	2.8	2.8
Preventive measures					
P1	Hunting ban for ASF-infected countries	0.17 (0.052 – 0.37)	4.8×10^{-3} (7.5×10^{-4} – 0.015)	0.1	0.1
P2	Information campaign	0.82 (0.25 – 1.81)	0.012 (1.8×10^{-3} – 0.036)	0.49	0.25

[a] Relative risk expressed as x times the risk in the default scenario.

3.4. Evaluation of preventive measures

The effect of preventive measures is shown in Table 3. The proposed preventive measures both resulted in a lower expected number of entries and exposures, with a hunting ban for ASF-infected countries being most effective with a 90% reduction of both the number of entries and exposures. The information campaign reduced the expected number of entries by approximately 50%, and the number of exposures by approximately 75%.

4. Discussion

Although the route of most long-distance jumps of ASF in Europe has not been elucidated, it is commonly believed that these transmission events are somehow related to human behavior (Chenais et al., 2019; EFSA, 2020; Mauroy et al., 2021; Sauter-Louis et al., 2021b). Trade in contaminated pork products and swill feeding are often indicated as risk factors (Sánchez-Vizcaíno et al., 2015; Dixon et al., 2019) and several studies have evaluated the contribution of travelers (tourists and/or farm workers) to the ASF incursion risk (Wooldridge et al., 2006; Jurado et al., 2019a, 2019b; Ito et al., 2020a, 2020b; De Vos et al., 2022). To our knowledge, there is no evidence published on the role of hunters in spreading ASF over longer distances, although hunting tourism has been mentioned as a risk factor, especially related to contaminated clothes and materials (Roelandt et al., 2017; Beltran-Alcrudo et al., 2019; EFSA, 2019). Hunting in a region with ASF-infected wild boar can result in an increased transmission risk if hunters leave the carcasses or offal in the hunting area, or if they do not take proper biosecurity measures when dressing the carcass (Bellini et al., 2016; Guinat et al., 2016a; Podgórski and Śmietanka, 2018; Chenais et al., 2019; Guberti et al., 2019; EFSA, 2021). Hunting can, however, also be used as a control measure in an outbreak situation to reduce the susceptible wild boar population, although hunting activities in the infected areas themselves are discommended because they can have an adverse effect on disease control when resulting in increased movement of infected wild boar spreading ASF to naive populations (Brown and Bevins, 2018; Guberti et al., 2019; EFSA AHAW Panel, 2018; Taylor et al., 2021).

In this study, the possible role of hunters carrying ASFV-contaminated WBP from hunting trips abroad was evaluated. To this end, data on hunting practices of Dutch wild boar hunters was collected via an extensive survey that was returned by a large number of respondents. Nevertheless, uncertainty on some model input parameters was high, which is also reflected by the large uncertainty intervals for the expected number of entries (N_{en}) of ASFV-contaminated WBP into the Netherlands due to recreational hunting trips abroad, and the subsequent number of exposures (N_{exp}) of domestic pigs or wild boar to these products.

The alternative scenarios run with the model also illustrated the uncertainty on the expected number of entries and exposures, especially when accounting for changes in ASF occurrence in wild boar in Europe (scenarios S1-S4, Table 3). The intended use of the model was therefore not to predict if, when and where recreational hunting would result in an ASF incursion in the Netherlands, but rather to raise awareness on the potential contribution of hunters to the ASF incursion risk, to evaluate the effectiveness of preventive measures, and to identify existing knowledge gaps.

The default scenario indicated an average of 1.7 entries of ASF into the Netherlands per year by hunters bringing ASFV-contaminated WBP from hunting trips abroad. The subsequent number of exposures of wild boar and domestic pigs to ASFV-contaminated WBP in the Netherlands was much lower with an average of 0.048 per year (i.e. one expected exposure every 21 years). The majority of exposures (99%) were expected in domestic pigs due to feeding of remnants of carcasses or meat leftovers. The sensitivity analysis indicated that model results were highly sensitive to uncertainty on the fractions of remnants of carcasses ($F_{dp_{carcass}}$) or meat leftovers ($F_{dp_{meat}}$) that would be fed to domestic pigs (Fig. 2). Uncertainty distributions for these parameters were based on survey results. Surprisingly, a few hunters indicated to feed remnants of carcasses to domestic pigs (Suppl. Table 8). This is an illegal practice, given the European ban on swill feeding (EU, 2009). If none of the rest materials of WBP were fed to domestic pigs, only wild boar would be exposed to ASFV-contaminated WBP in the model. Discarding ASFV-contaminated WBP as organic waste only results in an exposure risk if the hunter composts the material himself (i.e. no industrial composting), lives in a region where wild boar are present, and if wild boar have access to the compost pile (Fig. 1). This cascade of events reduces the probability of an exposure event. Therefore, the estimated annual number of exposures via this route is extremely low with an average value of 5.0×10^{-4} (i.e. one expected exposure every 2000 years).

The expected number of entries, and consequently also the expected number of exposures, was sensitive to uncertainty on the estimated ASF prevalence in hunted wild boar ($P_{wb\_inf_c}$), the number of wild boar carried from ASF-infected countries ($P_{wb\_carried_c}$), and the number of hunting trips per hunter per year (n_{ht}) (Fig. 2). In the default scenario, $P_{wb\_inf_c}$ was estimated using test results from shot wild boar in a limited number of ASF-infected countries (Śmietanka et al., 2016; EFSA, 2017, 2018b; EU, 2021) (Suppl. Material, Section 3) and used for all ASF-infected countries in the model. It is unclear how representative these data are for the probability that a hunted wild boar is ASF-infected. Sampling of hunted wild boar populations is usually not random, with most likely the majority of samples having been collected in at-risk or infected regions, or, alternatively, in regions declared free-of-disease. This will lead to a biased estimate of ASF prevalence in wild boar, in which the bias can thus lead to overestimation as well as underestimation. Moreover, in most infected countries, ASF infections in wild boar are limited to specific regions, rendering the probability of ASF-infected wild boar shot in non-infected regions negligible. This was not accounted for in the model, as no data were available on the specific regions that Dutch hunters visited when hunting abroad. It is, however, likely that hunters do not travel to regions where ASF is present in wild boar. Hunting in the core and buffer areas of infected regions is advised against in guidelines for ASF control in wild boar (Guberti et al., 2019). Furthermore, wild boar hunted in ASF restriction zones of the EU can only be carried for human consumption when tested negative for ASF, and movement of WBP to other EU member states is not allowed (Regulation EU 2023/594, EU, 2023). The values used for $P_{wb\_inf_c}$ in the model are thus likely to result in an overestimate of the incursion risk for the Netherlands. In the alternative scenarios S3 and S4, ASF prevalence in wild boar was estimated for each country individually using the number of ASF cases reported in wild boar (FAO, 2020) and the estimated wild boar population (Pittiglio et al., 2018). This resulted in far lower estimates of $P_{wb\_inf_c}$ (Suppl. Table 12) and thus also a lower expected number of entries of ASFV-contaminated WBP carried by hunters (Table 3). In these scenarios, the value of $P_{wb\_inf_c}$ is, however, most likely an underestimate of the true ASF prevalence in wild boar, as only part of the ASF-infected wild boar in the field will be found, tested and reported. On the other hand, the infectious period of 14 days used to estimate the incidence of disease from reported cases was a conservative estimate and is likely to be shorter in most infected animals (Gabriel et al., 2011; Guinat et al., 2014, 2016b, 2018). Furthermore, we had uncertainty on the true size of wild boar populations. The numbers given by Pittiglio et al. (2018) are from 2011 or before. Wild boar populations in Europe have increased over the last decade (Massei et al., 2015; EFSA, 2018); however, in ASF-infected areas wild boar populations have been reduced due to disease-induced mortality (ENETWILD-consortium et al., 2022).

All in all, we think that the alternative estimate of $P_{wb\_inf_c}$ accounts better for the presence of infected and non-infected regions in a country, averaging out the prevalence for the whole country. This scenario might therefore be more representative for the ASF prevalence in regions that hunters travel to than the default scenario.

Default model calculations were based on 2019 data, when ASF was still present in Belgium and not yet in Germany, which are both neighboring countries of The Netherlands. Alternative scenarios S1 and S2 account for the changes in ASF status of these countries in 2020 (FASFC, 2020; Sauter-Louis et al., 2021a) and illustrate that especially the status of Germany has a high impact on model results, given the large number of hunting trips to this country (86% of respondents to the survey reported Germany as the most recent country travelled to) (Suppl. Table 2). Since 2019, ASF has spread to more countries and regions in Europe and worldwide (WOAH, 2022b), which will also affect the incursion risk posed by WBP carried by hunters. However, another important parameter in the model is the number of wild boar carried from ASF-infected countries ($P_{wb\_carried_c}$), which is directly linked to the number of hunters travelling to ASF-infected countries. Based on survey results, we conclude that relatively few hunting trips (9.2%) were made to ASF-infected countries when considering the most recent country travelled to. We deduce that hunters consider the ASF situation when choosing a destination for hunting. This will not only apply for the country visited, but also for the region within the country. ASF-infected regions will less likely be the destination of hunting trips, as control measures are in place, and carrying WBP from infected regions is subjected to testing. Since the model evaluated the incursion risk on country level, not accounting for specific regions visited in affected countries, results probably are an overestimate of the incursion risk, especially from countries where the ASF infection in wild boar was limited to specific zones, such as Belgium and Germany. When accounting for all countries ever travelled to (scenario S6), 28% of hunting trips were to ASF-infected countries and the ASF incursion risk was almost three times higher than in the default scenario (Table 3). It should be noted that the number and destination of hunting trips might have changed quite a lot since 2019 due to the COVID-19 pandemic and the changing ASF situation in Europe. Although model calculations can easily be updated when new data become available on e.g. ASF cases in wild boar, updated data on the number and destination of hunting trips is not available.

The model was used to evaluate the effectiveness of measures aimed at reducing the risk of hunters bringing ASFV-contaminated WBP to the Netherlands. Discouraging or prohibiting hunting trips to ASF-infected countries is very effective, where the incursion risk is reduced linearly with the decrease in hunting trips (Table 3). Banning the carriage of WBP from hunting trips in ASF-infected countries had equal results in the model calculations. The model does, however, not account for the risk of contaminated fomites carried by hunters, such as infected clothing and footwear, equipment or vehicles (Costard et al., 2013;

Chenais et al., 2019; Dixon et al., 2019). Therefore, a ban on carrying WBP is expected to be less effective than a ban on hunting trips. An information campaign to raise awareness on ASF among hunters (EFSA, 2019) was also evaluated by assuming a reduction in hunting trips to ASF-infected countries and WBP taken home, as well as the fraction of leftovers fed to domestic pigs or discarded as organic waste. These are indeed behavioral elements that can be influenced by education, but it is difficult to predict and quantify the magnitude of changes in behavior achieved by such an information campaign. The assumptions for scenario P2 might have been too optimistic, considering that Dutch hunters seem to be very much aware already of the ASF infection risk in wild boar. Seventy-five percent of the respondents to the survey indicated that they had a training on hygiene practices during hunting, in which they were also trained to recognize infectious diseases in living and shot wild boar (Suppl. Table 10). Furthermore, almost 78% of respondents (Suppl. Table 11) indicated that they will take additional measures if they know that ASF is present in the country where they are hunting, such as applying extra hygiene measures, disinfecting materials, not hunting in an ASF-infected region, not taking WBP home, and sampling shot wild boar for testing. Both Dutch hunting associations regularly disseminate information on ASF to their members and inform them on preventive measures. Respondents to the survey were optimistic on their capabilities to recognize ASF-infected wild boar in the field, resulting in a 55% probability of detection in the model (P_{wb_det}). Modelled uncertainty on the detection rate did not have much impact on model results. It is, however, likely that the detection rate is much lower, when accounting for infected wild boar incubating the disease or not showing clear visible signs (mild and/or atypical symptoms). Furthermore, the probability that ASF-infected wild boar with clear clinical signs are shot is very low, as most animals will become deadly sick and will no longer move around. A zero detection rate was therefore evaluated in alternative scenario S5, resulting in a 130% higher incursion risk.

Exposure to ASFV-contaminated WBP does not by definition result in infection of exposed pigs or wild boar, i.e. the expected number of new infections in the Netherlands resulting from this introduction route is likely to be lower than the expected number of exposures. The probability of infection upon exposure depends on the amount of virus that the animal ingests and the dose-response relationship. The expected number of new infections was not accounted for in the model due to high uncertainty on the amount of ASFV-contaminated WBP ingested by exposed domestic pigs or wild boar and the concentration of ASFV in these products. In experimental studies, ASFV concentrations in muscle tissue of infected pigs at slaughter varied from 3.7 to 5.5 $\log_{10}$ HAD_{50}/g (HAD=hemadsorption dose) (McKercher et al., 1987; Petrini et al., 2019), although Mebus et al. (1993) reported higher infectivity levels up to 7.7 $\log_{10}$ HAD_{50}/g. ASFV survived up to three months in chilled carcasses and frozen or chilled meat (Farez and Morley, 1997; Fischer et al., 2020), although virus titers decreased over time (Fischer et al., 2020). However, in carcasses kept at room temperature, no viable ASFV was detected after storage (Fischer et al., 2020). The viral load in ASFV-contaminated WBP ingested by domestic pigs or wild boar will thus be highly variable, depending on the initial virus concentration in muscles, the amount of product ingested, the time elapsed before ingestion and the conditions at which the WBP have been stored in the meantime. It is likely that ASFV will be rapidly inactivated if WBP end up in a compost pile, with inner temperatures exceeding room temperature, therewith reducing the infection risk of exposed wild boar. Experimental studies in which pigs were fed with feed that contained ASFV estimated a minimum infectious dose of 4 to 5 $\log_{10}$ $TCID_{50}$ (TCID=tissue culture infectious dose); (Niederwerder et al., 2019; Blázquez et al., 2020). That implies that ingestion of larger volumes of ASFV-contaminated WBP by domestic pigs or wild boar could indeed result in infection. The estimated minimum infectious dose of ASFV via liquid consumption is much lower than via feed consumption; this might be due to direct virus exposure of the tonsils, when the virus is ingested in a liquid medium (Niederwerder et al., 2019). Similarly, ingestion of virus in solid feed could result in infection at lower doses if virus exposure would be in the pig's mouth rather than the acid gastric environment due to e.g. small wounds in the mouth. There is ample evidence of ASFV-contaminated meat contributing to transmission of ASF in the field (Guinat et al., 2016a; Chenais et al., 2019; Olesen et al., 2020). It is therefore not unlikely that exposure of domestic pigs or wild boar to ASFV-contaminated WBP results in infection. The expected number of exposures can thus be considered a worst-case estimate for the expected number of ASF infections induced by WBP carried by hunters.

Based on the results of this study, we conclude that the risk of an ASF infection in the Netherlands due to hunters carrying WBP is low with one expected exposure every 21 years. This can be explained from the low number of hunters travelling abroad, the continuous education of hunters on the risk of ASF, and the fact that most hunters did not visit ASF-infected countries for recreational hunting. The latter could have changed though, now that ASF is present in wild boar in Germany, although only at the eastern border, so most Dutch hunters will still hunt in ASF free areas. Moreover, obligatory testing of wild boar hunted in ASF restriction zones will also further diminish the risk. Other measures, such as a prohibiting hunting trips to ASF-infected countries or an information campaign to make hunters more aware of the risks of ASF, could also have a preventive effect.

It should be stressed that the model only assessed the ASF incursion risk due to WBP taken home after hunting abroad, and that it did not account for the risk of contaminated fomites, such as footwear, clothes and equipment. The overall ASF incursion risk due to hunting abroad might thus be slightly higher. Long-distance jumps of ASFV to free territories might also be induced by other human-mediated routes, such as tourists carrying contaminated meat products, professionals working in the pig industry, or truck drivers discarding meat products carried from their home country. To effectively deploy resources for prevention, it would be helpful to also assess the ASF incursion risk of these routes and to elucidate the relative importance of each route, including WBP carried by hunters.

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Data availability

The data that were used in the model for generating the results are available in the supplementary material of this article.

CRediT authorship contribution statement

Manon Swanenburg: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing. **Tosca Ploegaert:** Project administration, Conceptualization, Writing – review & editing, Funding acquisition. **Michiel Kroese:** Project administration, Investigation, Writing – review & editing. **Clazien J. de Vos:** Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare no conflict of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.mran.2023.100276.

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