A Generic Surveillance Framework for Assessing Illegal Meat Introduction Risk

L. Gonzalez Villeta (laura.gonzalezvilleta@apha.gov.uk), R. Davies, R. R.L. Simons

Department of Epidemiological Sciences, Animal and Plant Health Agency, Addlestone, United Kingdom

Summary
Illegal meat introduction poses unrecognised risks of disease introduction, a topic of shared concern among many countries. This work identifies the main pathways of entry of illegal meat and develops a model framework to assess the risk of illegal meat introduction. Air and land passengers were identified as two of the most relevant pathways of illegal meat introduction in the European area. Scenario analysis using synthetic data revealed up to a 2.9-fold variation in risk depending on traveller compliance, regardless of the border inspection sensitivity. Increasing inspection coverage from 0% to 100% produced a moderate reduction in overall risk with a 0.77-fold decrease under an inspection method with average detection sensitivity (Se=0.5), and high traveller non-compliance scenario (p_{carry} =0.5). Surveillance interventions tailored to a given epidemiological and trade reality could substantially reduce the risk of disease introduction from illegal meat. This framework model can be applied to countries where such data are available to help design targeted surveillance programs for specific disease and operational resources. Arrival data of travellers to relevant airports and ports, seizure data from border inspections and expert opinion can be used to parametrize tailored risk levels of illegal meat introduction into a specific area and subsequent disease introduction.

Introduction
The risk of introducing new and emerging diseases through illegal meat smuggling has been a longstanding concern for many countries. African Swine Fever (ASF) is one of these diseases that has increasingly come under the spotlight, as its spread poses significant economic and biosecurity threats to the global swine industry. There have been several instances where long geographic jumps of this disease have been reported in wild boar populations, which cannot be explained by natural animal moves (Dixon et al., 2019). This was the case for Belgium in 2018(Linden et al.), Sweden in 2023 (Chenais et al., 2024), and, most notably, with the introduction into the island of Sardinia (Dei Giudici et al.). The possibility of illegal movement of animals or animal products have been hypothesized as the most plausible cause for the introduction of ASF (Wooldridge et al., 2006). With globalization and the increased movement of people and goods, this concern has only grown in scale.

For the purpose of this work, illegal meat refers to products carried by individuals who have intentionally or unintentionally evaded established entry procedures by not being declared to authorities and that are in contravention of the personal concessions permitted. Illegal meat is considered one of the highest-risk pathways for disease introduction due to its potential to harbour multiple pathogens and the absence of sanitary inspection. Nevertheless, the risks associated with these illicit animal products remain poorly defined, largely because limited data exists on their volume, origin, and pathogen load. Passenger baggage is one of the routes of introduction due to the low frequency of routine inspections conducted at borders. This is of particular concern in areas where freedom-of-movement agreements are in place, such as the Schengen scheme operating across many European countries (Costard et al., 2013).

When considering the risk of introduction of infectious diseases via trade, there is a tendency to focus on legal commercial routes. It is well understood that routes that circumvent legal procedures, such as veterinary inspections and health certificates in the exporting country, pose a risk. However, such routes are inherently hard to quantify to any degree of accuracy due to the lack of concrete available data regarding point of origin, point of entry and volumes of products. In this project we set out to put together a generic framework to illustrate the effects of inspection rates and sensitivity as a key component of surveillance modelling. This sets the path for a subsequent quantitative risk assessment to estimate the risk of illegal meat introduction posed by a specific route of concern and determine the feasibility of parameterising for any geographic area and surveillance setting.

The United Kingdom constitutes an interesting case study in that, despite being an island, it has a major land-based route of entry for both passenger and cargo via the port of Dover. As one of the country's busiest points of entry, Dover handles more than one third of the UK's goods traded with the EU (Port of Dover, 2024), making it a key gateway for international trade and, consequently, an important location for border-control activities. Border control inspections across the UK have reported an upward trend in illegal meat seizures in the recent year. At Dover specifically, the Dover Port Health Authority recorded a notable peak in early September 2025, with 10 tonnes of illegal meat seized in just two weeks (Dover, 2025). While this figure reflects intensified enforcement at that a particular port, it also illustrates the scale of the wider illegal-meat challenge faced across the national

border system. The risk associated with the introduction of illegal meat remains ever present and is influenced by the volume of passenger and consignment movements, which can place considerable pressure on border control resources.

Methods

Model Framework

Through literature review and discussion with experts in the field, we put together a framework consisting of six key routes of introduction of illegal meat (Figure 1, left). These routes covered different modes of transport (air, sea, road, rail) and purpose (commercial and personal). A detailed workflow that combines available data, both public and private, sets a generic framework to estimate the overall risk of disease introduction via illegal meat (Figure 1, right). Entry probability assessment of illegal meat is conducted prior to checks at customs or border inspection posts. Thus, all the confiscated products stopped or seized at border inspections together with the estimated products that have bypassed such controls are considered as an introduction event. The model does not consider the subsequent consequences nor exposure to the product given incursion. The model is coded in the R software package version 4.5.2 (R Core Team, 2025).

Figure 1. Overview of main pathways of introduction for illegal meat (left). To the right, overview of the final risk assessment framework to estimate the risk of disease introduction through illegal meat. Suggested data sources required to parametrize each step are provided in the text next to each blue box, with the equivalent parameter in the model shaded in grey. Highlighted in red is the step related to the work presented.

The number of undetected illegal meat introductions per inspection coverage *c, Undetected*$_{t,c}$, was given by Equation 1,

Undetected$_c$= p_{carry} *(1-c*Se)* [1], where p_{carry} is the probability of illegal meat being carried, and *Se*, the likelihood that illegal meat is detected by a check if it is present. As such, *(1-c*Se)* represents the probability that illegal meat escapes detection. We assumed randomly allocated inspections, as opposed to risk-based. In the estimation of absolute disease introduction via illegal meat applied to a specific case scenario, the proposed Equation 2 can be used: *Undetected*$_{c,r}$=λ*p_{carry}*p_{contam}*(1-c*Se)* [2], where λ corresponds to traffic level, quantified as number of travellers or the volume of traded goods, according to the specific route *r*, and p_{contam} is the probability that carried meat is contaminated with a hazard of interest (*e.g.*, ASFv).

Parameterisation

To ensure the framework is generic and applicable across diverse border-control contexts, we developed a scale-free, dimensionless model where risk depends only on behavioural and inspection parameters rather than absolute traffic volumes. We explored risk across combinations of different inspection coverage rates (0%, 1%, 10%, 15%, 30%, and 100%), detection sensitivities (0.3, 0.5, and 0.7), and the probability that travellers carry illegal meat (0.1, 0.25, and 0.5). This approach avoids dependency on operationally sensitive traffic data while revealing general behavioural and surveillance dynamics relevant to a wide range of ports and jurisdictions.

Seizure data collected by enforcement bodies and port health authorities was used to estimate the quantity of illegal meat that is introduced in the country throughout the year. Data included number of seizures, weight of the seized products, date and seizing port, checks without seizures and total staff time performing inspections, which allowed to parametrize *c, Se* and *pcarry*. Given their sensitive nature, these data are not presented in this work.

The probability of carrying an illegal product, p_{carry}, when set to 0.5, simulates a hypothetical worst-case scenario where compliance with legislation is low and assumes one in two visitors or consignments contain illegal meat. Conversely, a value of 0.1 suggests high compliance with existing restrictions and a lower risk of illicit goods being introduced. Detection sensitivity (*Se*) reflects the fact that detections are imperfect, even at high inspection rates. The chosen values aim to represent different inspection techniques, such as visual inspection, X-ray screening, and sniffing dogs. Operational intelligence from border inspection teams can inform the selection and calibration of these parameters according to higher-risk areas or seasonal risk peaks.

Results

Passenger baggage was highlighted as the biggest contributor to the risk of hazard introduction through illegal imports (expert opinion). The scenario analysis comparing different detection sensitivities and compliance levels reveals that traveller compliance is a key factor to significantly reduce risk. Across inspection sensitivity scenarios, risk decreased non-linearly with inspection coverage.

For the traveller cluster with the poorest compliance with the rules (i.e. p_{carry}=*0.5*) with medium to low detection sensitivity methods, even the highest of inspection rates are insufficient to drop the risk of illegal meat introduction below 20%. This highlights that enforcement of inspections alone is not enough to reduce the risk. A

combination of measures is required to further reduce the risk to low values, i.e. 10% or lower, which includes raising awareness among travellers to increase compliance with law (i.e., reduce p_{carry}), targeting inspections, use of more sensitive inspection methods (increase *Se*), such as detection dogs.

Discussion

Estimating the volume of illegal meat introduction into a country is highly dependent on the resources available for border inspections. By definition, these resources cannot detect all illicit products, and the absence of seizures does not equate to an absence of risk. In this study, we evaluated effect of inspection rates performed at different intensities and using different sensitivity strategies.

This analysis showcases a generalisable, dimensionless model that visualizes the effect of inspection-risk relationships across different surveillance scenarios. Further, the risk function can be tailored to actual arrival values (λ) of an airport or port of interest, risk levels (probability of specific areas where disease is present), and passenger compliance (p_{carry}) to give absolute figures for risk introduction of a disease, such as ASF, via illegal meat. This approach can also be applied to compare risk across different ports of entry, seasons, or transport modalities (e.g. passenger versus cargo).

Illegal meat introduction is shaped by a complex set of behavioural and socioeconomic factors, including lack of awareness of biosecurity risks, cultural food-carrying practices, and demand for traditional or medicinal animal products. A comprehensive analysis integrating social-behavioural components would strengthen risk assessments and support the design of more effective communication and intervention strategies.

Sanitary and phytosanitary (SPS) inspection levels have increased at selected border points in Great Britain in response to elevated risks associated with ongoing disease outbreaks in Europe and beyond. Within the UK's current border biosecurity framework, the Border Target Operating Model (BTOM), the Department for Environment, Food and Rural Affairs (Defra) determines inspection rates based on the risk categorisation assigned to each commodity and country of origin. The BTOM has been operationalised in recent responses to outbreaks of Foot-and-Mouth Disease (FMD) and African Swine Fever (ASF) across the continent (House of Commons, 2026). Identifying high-priority surveillance areas, such as those highlighted in this work, can support the targeted allocation of limited inspection resources toward port practices or characteristics that pose the greatest risk. The traffic volume at the port of entry can also play a decisive role in the overall risk of introduction, especially if effective inspection rates cannot be guaranteed.

Future research

The data currently available will enable to assess the risk of disease introduction into Great Britain via illegal meat carried by air and land travellers, applicable to diseases preset in travellers' countries of origin. In collaboration with other European partner Institutes, future work will apply this model to actual traffic data and incorporate European-wide passenger flows, including major hotspots linked to long-distance land and air travel. This would enable estimation of the risk of ASF entry and spread across the European Union.

Seizure data explored in this work (not shown) reflects resource availability and targeted interventions at the time of collection. A key limitation is that these data represent a temporal snapshot from a specific surveillance operation. Because illegal imports fluctuate throughout the year, the analysis may either overestimate or underestimate annual risk. For example, if the spot checks occurred during a period when visitors were more likely to carry food products, annual extrapolation would lead to overestimation. Conversely, if inspections took place during a low-traffic period, estimates would underestimate the true scale of illegal meat introduction. Without year-round enhanced inspection, it is not possible to determine where within this spectrum the snapshot lies. The analysis further assumes that these trends remain stable across successive years.

Inspection coverage is also partial: only a fraction of entries are inspected, typically at random, and therefore inspections are unable to provide a comprehensive picture of the full range of illegal items crossing the border. We assume the proportion of seized items is representative of the total influx of traffic, although this assumption introduces additional uncertainty. Nevertheless, inspections in this dataset were performed across the entire week, including weekends, meaning the estimates are not affected by weekday bias.

In order to better understand how many illegal meat items pass borders undetected, it would be ideal to introduce a correction factor derived from the identification of illegal meat products already circulating within national food outlets. Such findings could provide an external validation layer for border-seizure-based estimates and help quantify the proportion of items that evade detection. Integrating this type of downstream surveillance, whether through market inspections, retail audits, or targeted sampling, would strengthen the capacity to approximate the true burden of illegal meat introduction and reduce uncertainty in model outputs.

Conclusion

Illegal meat poses a considerable risk of disease introduction, with passenger baggage and traveller compliance to rules as the highest risk contributors to meat smuggling. Despite the inherent challenges and uncertainties associated with estimating illegal meat introduction volumes, the present work provides a general framework to estimate the risk of hazard introduction applicable to different border posts when seizure data is available. Seizure data is often considered a sensitive topic that involves many different actors, which hinders data availability and consistency. Standardizing and centralizing these data would improve estimates and contribute to an improved intelligence, enhanced trust with trading partners and overall health assurance for animal and human populations. Effective inspection planning requires quantifying how different coverage levels translate into probability-based risk bands across port operational practices, as well as by identifying data inputs that have the greatest impact on decision uncertainty.

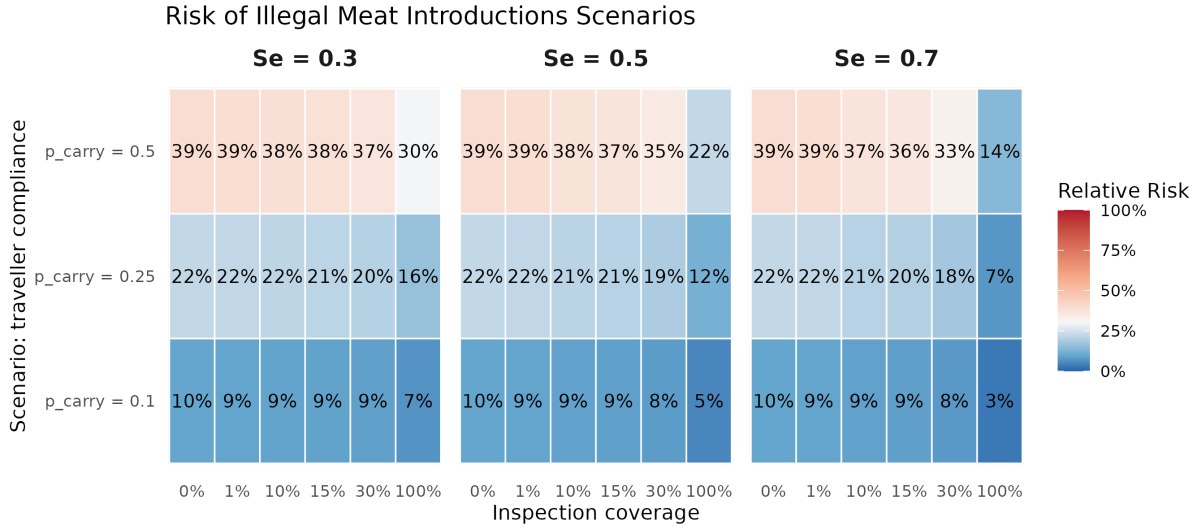


Figure 2. Relative probability of illegal meat introduction for different inspection intensities and traffic level of the port of entry. Se: detection sensitivity; p_carry: probability of carrying illegal meat.

Keywords: surveillance modeling, international trade, illegal meat, Border biosecurity, Inspection strategies.

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