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Short communication

Qualitative import risk assessment: A proposed method for estimating the aggregated probability of entry of infection

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ABSTRACT

In the absence of sufficient numerical data, qualitative risk assessment is recognised as an important tool for providing risk managers with evidence-based predictions on which to formulate their decisions. Such approaches have been used in the area of animal health for import risk assessment for both livestock and zoonotic pathogens. Very few qualitative import risk assessments have, however, considered the aggregated probability of introduction, that is, the probability of at least one infected/contaminated entry per group of import units. Those that have are generally based on specific cases and do not follow a generic approach. In this paper, we consider whether or not it is feasible to develop a generic method and under what circumstances such an approach could be applied in practice. Our conclusion is that it would be difficult to specify a generic method because any such approach would rely on specifying numerical bounds for qualitative categories of probability as well as an idea of the number of imports and would thus be case-specific. As an alternative we propose a way of using case by case information to create a simple graphical reference tool which removes some of the subjectivity that is often associated with deriving qualitative risk. The reference tool considers various qualitative categories of individual probability and determines the relationship between this probability, the number of imports and the aggregated probability of entry. Applying the reference tool to a previously published case-study demonstrated some differences in conclusions and suggests that more subjective approaches can under-estimate probability and thus risk. It is concluded that this approach may be useful for future qualitative assessments of aggregated probability, provided that bounds for qualitative probabilities can be defined for the specific case situation.

1. Introduction

In the absence of sufficient numerical data, qualitative risk assessment is an important tool for providing risk managers with evidence-based predictions on which to formulate their decisions. Qualitative risk assessment is also widely accepted as a mechanism for rapid, reactive risk assessment, for example, during outbreaks of a notifiable exotic disease. Such assessments can enable policy-makers to formulate and compare disease control and prevention strategies. Central to each risk assessment is the risk question which is specific to the proposed disease control or prevention policy. The subsequent risk assessment may include all steps from entry assessment to risk estimation, as set out in the OIE Animal Health Code framework for risk assessment (OIE, 2013). In certain circumstances, the policy question may only concern entry assessment and the resulting estimate of risk would typically be the probability of disease/infection entry. This probability may be defined at an individual or aggregated level. At the individual level, the risk question will typically be of the form, *what is the probability that an individual imported animal/product (unit) is infected*. The units for the individual probability are thus "per product" or "per animal" as in the case of capripoxviruses on imported ruminant skins and hides (Gale et al., 2016). When data are available on the number of units imported per year or per batch, the individual probability may be scaled up to give the aggregated probability, for example the risk question may be, *what is the probability of one or more infected units being introduced per year* as in the case of avian influenza virus in migratory wild birds (Gale et al., 2014). Implicit in the aggregated probability is the number of units per batch or imported over a given time period.

In quantitative assessment, estimation of the individual probability of entry is usually based on a linear, conditional probability model; each probability on the risk pathway is associated with a step which is assumed to be conditional on the previous step and the probabilities are multiplied together to give a joint probability of all steps occurring. If imports are assumed to follow a binomial process, where each import is independent and has the same probability of being infected, the aggregated output can also be derived. In such cases, as mentioned

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previously, the aggregated probability is estimated as the probability of one or more infected import events occurring per specified time period or per batch. This estimation is based on a non-linear model. In qualitative assessment, there is no such set of probabilistic and distributional rules that allow for the derivation of either the individual or aggregated probabilities. There have been some attempts to define rules for estimation of the individual probability (Gale et al., 2010), however, the same is not true for the aggregated probability and any published assessments have been subjective in their estimation.

In this paper, we consider what has been done for qualitative estimation of the individual probability and extend this to propose a general procedure for estimating the aggregated probability of disease entry for animal import risk assessments. We investigate the usefulness of the procedure by applying it to a previously published case study. Although the subject of the case study was risk prioritisation, we here compare our results on a case-by -case basis and draw conclusions on how general the procedure can be made. We also consider limitations of the approach.

2. Methods

2.1. Derivation of a general equation

Many quantitative import risk assessments for the entry of infected/contaminated animals/products assume that the individual units are independent and have the same probability of being infected (Goddard et al., 2012). Thus, entry of infected/contaminated units can be assumed to follow a binomial process with p being the probability of infection/contamination of an individual unit and n being the number of individual units imported (over the given time period or per batch). The aggregated probability, P say, is normally defined quantitatively as:-

$$P = 1 - (1 - p)^n \quad (1)$$

The animal health risk assessment literature provides a number of qualitative definitions of probability. These are generally based on expert consultations or definitions used in other areas of risk assessment application, for example, chemical risk assessment. Table 1 presents the definitions provided by EFSA (2006). These definitions consider the likelihood of events occurring in an ordinal manner without giving quantitative comparisons or bounds. In contrast, EFSA (2012) describes qualitative probabilities in terms of numerical bounds (see Table 2). There are a limited number of studies that have considered qualitative evaluation of the aggregated probability given in Eq. (1) (Snary et al., 2012; Gale et al., 2014). In the examples which do exist, the estimate of probability has been undertaken subjectively, with assumptions being made on how to combine, for example a low p with a high n or a high p with a low n. To determine the most appropriate way to formalise this estimation, we break down Eq. (1) into separate components.

We first consider the term $(1 - p)^n$ and determine how this can be derived qualitatively. Literature searches (based on searching for animal health qualitative import assessments) have not identified any published papers that have formally considered this step. However, the evaluation of the product of two qualitative probabilities has been tackled. Several matrices for this product have been published (Gale et al., 2009, 2010, 2014; Wieland et al., 2011). Of these, the matrix of Gale et al. (2010) is considered most appropriate from a mathematical point of view because it is based on the premise that probabilities can only take values between 0 and 1 and that the product of two probabilities is at most, the minimum of the two values (see Table 3). Wieland et al. (2011) present a matrix which follows the same approach, discussing the idea of conditional dependence between the two probabilities. The other papers have presented modifications to the matrix of Gale et al. (2010), at the lower end of the ordinal scale (Gale et al., 2009, 2014). These modifications are, to some extent, subjective and arise because of assumed quantitative ranges for the lower end qualitative probabilities in an attempt to account for the problem that, for example, the product of two *low* probabilities may be lower than *low*. They are thus case-specific rather than general as per the case for the matrix in Table 3. Matrices also exist in other areas of application, for example, antimicrobial resistance (CVM, 2003), however they do not give justification for how probabilities are combined.

Table 1
Qualitative definitions of probability from EFSA (2006).

Probability category	Interpretation
Very high	Event occurs almost certainly
High	Event occurs very often
Medium	Event occurs regularly
Low	Event is rare but does occur
Very Low	Event is rare but cannot be excluded
Negligible	Event is so rare that it does not merit to be considered

Table 2
Quantitative bounds corresponding to qualitative categories from FAO/WHO reported by EFSA (2012).

Qualitative level	Quantitative bounds
Negligible (N): $j = 1$	Indistinguishable from 0
Very Low (VL): $j = 2$	$<10^{-4}$, except 0
Low (L): $j = 3$	10^{-3}–10^{-4}
Medium (M): $j = 4$	10^{-2}–10^{-3}
High (H): $j = 5$	10^{-1}–10^{-2}
Very High (VH): $j = 6$	$>10^{-1}$, not 1
Certain: $j = 7$	1

The evaluation defined in Table 3 for two qualitative probabilities could, in theory, be repeated n times to evaluate the term $(1 - p)^n$. Because this matrix assumes that the product of two probabilities is at most the minimum of the two, the end result of the multiplication of n probabilities is the minimum of all n probabilities. In our case, because all n probabilities have the same value, that is, $(1 - p)$, then the end result is $(1 - p)$ and thus independent of n. Using this leads to a worst-case assumption; in reality the result may be a probability of a lower qualitative category and this effect will be amplified as n becomes larger.

Now that we have evaluated the component $(1 - p)^n$ as $(1 - p)$, we can substitute this result into Eq. (1) and evaluate the remaining component. Substitution gives

$$P = p \quad (2)$$

and thus the aggregated probability is independent of n. For the higher levels of p (e.g. Very High, High, Medium) this makes sense because if an individual unit is likely to be infected/contaminated then for a batch of units there will be a high chance of it containing at least one infected/contaminated unit. For the lower levels of p, the aggregated risk could, however, be under-estimated, that is, assessed as being of a lower qualitative category than is probably realistic, if n is high enough. This results because of the potential over-estimation of the product $(1 - p)^n$ as discussed previously; if we over-estimate $(1 - p)^n$ then we under-estimate $P = 1 - (1 - p)^n$, that is P (Eq. (1)).

Under-estimating risk is not desirable and thus it would not be appropriate to use Eq. (2) as a general rule. The degree of under-estimation will depend on the value of n, that is, the number of times that the term $(1 - p)$ is multiplied together. As an alternative approach, we consider the qualitative value of n at which Eq. (2) underestimates P. To investigate this, a semi-quantitative approach has been adopted. This approach creates a reference tool which can be shown in a graphical form.