A quantitative interpretation of the Entry Section of the EPPO Decision Support Scheme for Pest Risk Analysis

Holt J[1,2], van der Gaag DJ[3], Leach AW[2], MacLeod A[4], Baker RHA[4], Mumford JD[2]

[1]*Natural Resources Institute, University of Greenwich, Chatham Maritime, Kent, ME4 4TB, UK. e-mail: j.holt@gre.ac.uk*
[2]*Centre for Environmental Policy, Imperial College London, Silwood Park, Ascot SL5 7PY, UK. e-mail: j.holt@imperial.ac.uk; a.w.leach@imperial.ac.uk; j.mumford@imperial.ac.uk;*
[3]*Office for Risk Assessment and Research, Netherlands Food and Consumer Product Safety Authority, Utrecht, the Netherlands. e-mail: d.j.van.der.gaag@minlnv.nl*
[4]*The Food and Environment Research Agency, Sand Hutton, York, YO41 1LZ, UK. e-mail: alan.macLeod@fera.gsi.gov.uk;richard.baker@fera.gsi.gov.uk*

Abstract
The development of methods to combine components of risk and their associated uncertainty in Pest Risk Analysis (PRA) has received attention in a number of recent European projects. Many of the risk components distinguished in the EPPO Decision support scheme (DSS) for PRA are usually difficult to quantify but when there is detailed knowledge of the pest and pathway, quantification may be possible to a limited extent for the pest entry section of the scheme. The European Food Safety Authority has recently commissioned a project to investigate approaches to quantitative pathway analysis for pests of commodities entering and moving within the EU (QPA-Food); a sister project concerns non-food commodities. This paper illustrates the potential for a quantitative pathway model based closely on the Entry Section of the EPPO DSS for PRA, where existing quantitative definitions of rating categories have been used as a basis to estimate the proportion and number of infested lots on a pathway. Such quantification may provide additional insights without requiring substantial changes to the information elicited via the DSS.

Introduction
The primary international standard for pest risk analysis (PRA), ISPM No. 11 (FAO, 2004), indicates the elements to be included in a PRA but does not state how the analysis should be undertaken or provide a mechanism for combining risk and uncertainty. Recent work to improve European decision support schemes for pest risk assessment, 'Prima phacie' (MacLeod *et al*., 2010, 2012) and for PRA, 'PRATIQUE' (Baker *et al*., 2009; Baker, 2012), have used models with utility functions in the form of risk matrices to integrate components of risk (Holt *et al*., 2012; Holt *et al.,* 2013). This approach is consistent with the existing risk-rating systems and accommodates the difficulties of estimating quantitative values or probabilities in the majority of cases.

The European Food Safety Authority (EFSA) has commissioned two projects to explore methodologies for quantitative pathway analysis applied to movement of pest infested commodities into and around the EU; one concerns food (QPA-Food) and the other non-food commodities. This paper illustrates a simple quantitative pathway model related to QPA-Food[1] based on part of the EPPO Standard PM 5/3

[1] QPA-Food concerns food commodities (a stone fruit, a pome, a citrus and a cereal) rather than as here, seed potato, an agricultural commodity.

Decision Support Scheme (DSS) for PRA (EPPO, 2011). In order to enhance consistency in PRAs, Prima phacie and PRATIQUE explored and tested the use of quantitative definitions to describe and rank categories within risk elements, and showed how these can be used as guidance when responding to questions posed within the DSS. This was carried out as part of a broader consideration of consistency issues (Schrader *et al*., 2012). Here these ideas are extended further to use the quantitative definitions of the ratings to calculate the number of units of a commodity contaminated with a pest that is likely to travel from one country to another on a particular pathway. Biosecurity Australia (2001) described a similar potential approach in their draft guidelines in the context of risks to animal health. In this paper one of the case studies from Prima phacie, *Meloidogyne fallax*, a root-knot nematode pest of potato and many other crops (Van der Gaag *et al*., 2012), is used as an illustration of a possible framework for a quantitative pathway model for plant pests.

Method

Model

The EPPO DSS for PRA employs a model based on utility functions which mimic assessor logic to combine the components of risk, not only for the entry section, but also for the whole assessment (Holt *et al*. 2012, Holt *et al*., 2013; Schrader *et al*., 2012, Kenis *et al*., 2012). Here a quantitative model of the entry section was developed which included the same set of risk components as the EPPO DSS but for the purposes of this study, reduced the number of questions. There are two questions which relate to the association of the pest with the pathway, the first concerning biological factors, such as the occurrence of suitable life stages of the pest and the period of the year and the second, management conditions. Only the second question was used since, to be effective, management measures will also need to take biological factors into account. The question about possible increase in prevalence of the pest during transport was also omitted since this was not relevant in the case examined because *M. fallax* has a long life cycle. Lastly there are two questions concerning the frequency and volume of commodity movement and these were combined by expressing commodity movement in terms of the number of lots per year, referred to this in the paper as 'volume'.

All the questions in the Entry Section have the same five rating categories: very unlikely, unlikely, moderately likely, likely or very likely, and as part of the scheme, the assessors are provided with an explanatory note to assist with their response and help enhance consistency. Of the five questions in the simplified scheme used here, quantitative interpretations of the ratings of four of these were obtained from MacLeod *et al*. (2012). They are expressed as intervals and all use the same logarithmic scale (Tables 1 and 2) so that each rating corresponds to a specified range of percentages. Each interval corresponds to one order of magnitude, so the scales (Table 2) provide a range encompassing five orders of magnitude. This wide range ensures that the frequencies corresponding to the lowest rating, 'very unlikely', are appropriate for situations that are highly improbable.

The consequence of such a scale is that each category is itself very wide, so for example if ‘very likely’ is selected this represents a value somewhere in the range 10% to 100%. When a rating is defined explicitly as an interval it therefore carries built-in uncertainty which, depending on the size of the interval, may be quite large. In the EPPO DSS model (Holt *et al*., 2012), low, medium and high uncertainties correspond to the likelihood that the selected rating is correct: 90, 50 and 35% respectively; these values were adapted from IPCC definitions (IPCC, 2005). A different way to express differences in uncertainty is therefore needed and a possible approach is to allow some greater control of interval width, whilst still retaining a limited set of discrete choices.

Table 1 Quantitative interpretations of questions

Question	Quantitative interpretation
2.04 How likely is the pest to be associated with the pathway at the point(s) of origin taking into account *current management* conditions?	Percentage of lots likely to be contaminated or infested
2.05 Consider the volume of movement along the pathway (for periods when the pest is likely to be associated with it): how likely is it that this volume will support entry?	The number of lots of commodity per unit time (e.g. per year)
2.07 How likely is the pest to survive during transport or storage?	Percentage of lots on which the pest is likely to survive
2.09 Under current inspection procedures how likely is the pest to enter the risk assessment area undetected?	Percentage of infested lots that are likely to be undetected
2.10 How likely is the pest to be able to transfer from the pathway to a suitable host or habitat?	Percentage of infested lots that will provide transfer opportunities

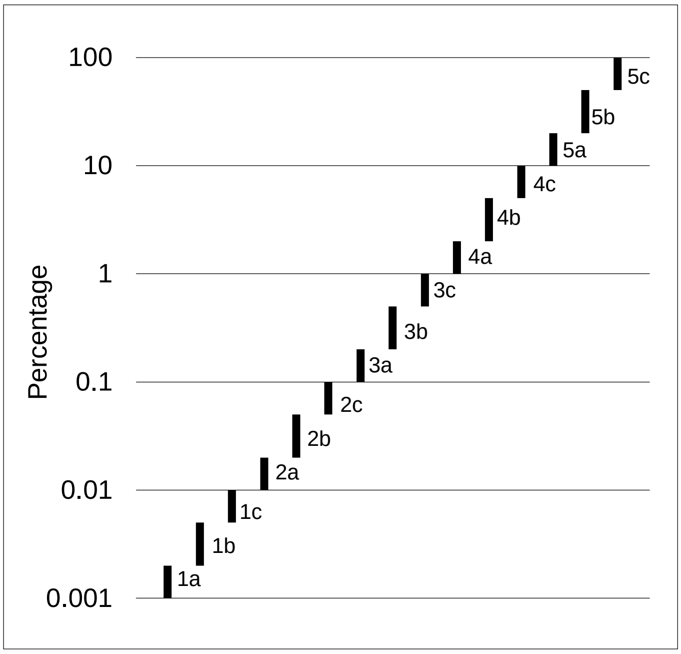
Table 2 The percentage ranges of values corresponding to each rating category of the questions listed in Table 1, defining the interval represented by each category MacLeod *et al*. (2012)

Rating	Percentage range
very unlikely	< 0.01%
unlikely	Between 0.01% and 0.1%
moderately likely	Between 0.1% and 1%
likely	Between 1% and 10%
very likely	Between 10% and 100%

To help illustrate the quantitative approach discussed here, sub-divisions were introduced to allow a lesser (or greater) degree of uncertainty to be expressed than is already implicit in the original intervals. Each interval was divided into three approximately equal sub-intervals, so, for example, for the original interval 10% to 100%, the sub-intervals are (a) 10-20%, (b) 20-50% and (c) 50-100%, corresponding approximately to thirds on a logarithmic scale. The intervals and sub-intervals are shown in Fig. 1; the 1-5 rating scale is retained but sub-intervals allow assessors to express differences in the uncertainty of the variables by specifying a wider or narrower range of sub-intervals.

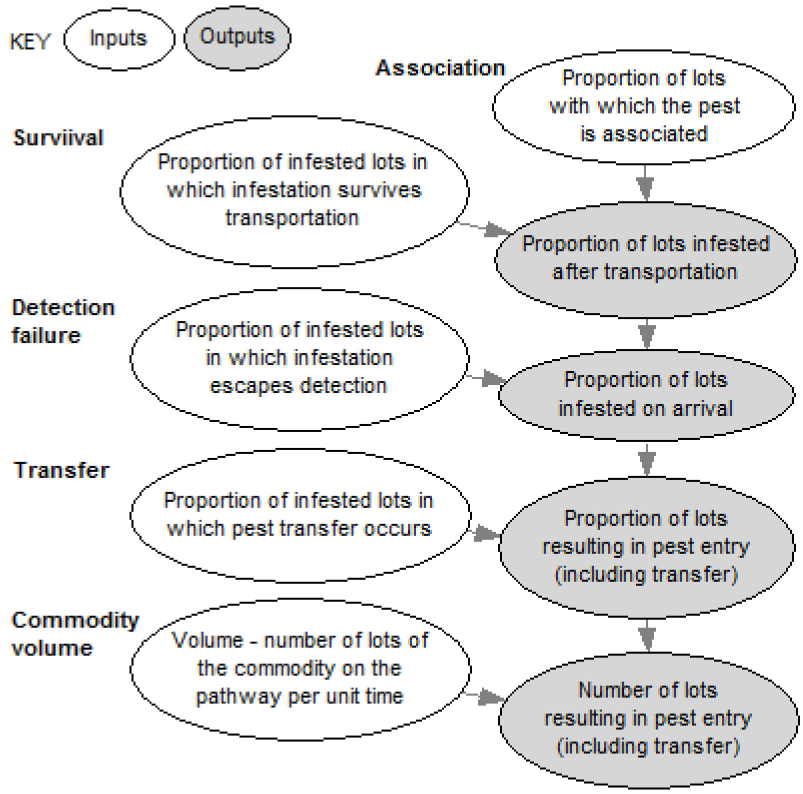
The model is stochastic and all of the variables are expressed not as single values but as uniform distributions with the minimum and maximum corresponding to the limits of the interval selected. The choice of a uniform distribution implies an equal probability across the interval. The model is implemented using @RISK software, a commercial Monte Carlo simulation package designed to work in conjunction with Excel spreadsheets (Palisade Corporation, 2012); the model is set out as a table in an Excel spreadsheet. In the simulation, the calculation is repeated many times, each time sampling the input distributions to gradually build up a picture of the outcome probability distribution.

Fig. 1 Chart by which assessors may select a range of sub-intervals judged appropriate for each variable. To recover the original rating system the range of sub-intervals corresponding to the original rating is selected, e.g. 5a-5c inclusive corresponds to a rating of 5. The sub-intervals equate approximately to thirds of the original interval when considered on a logarithmic scale.



The model represents a single pathway and the calculation is therefore straightforward: the result is the product of the five variables. In order to allow a more detailed consideration of the change in infestation along the pathway, intermediate results are calculated at each step. In the final step the volume is taken into account to calculate the number rather than the proportion of lots resulting in pest transfer. A diagram of the topology of the model (Fig. 2) shows the sequence in which the calculation is performed. The variables were described in percentage terms as this may make it easier to conceptualise smaller values; the model itself works with proportions rather than percentages. To consider multiple pathways the final numbers would need to be summed across all pathways with appropriate volumes attributed to each.

Fig. 2 Topology of the model based on a modified version of the entry section of the EPPO DSS for PRA showing the calculation sequence and the output at each step



Case study

To illustrate the calculation the assessment carried out for *M. fallax* for the pathway associated with the trade of seed potato from the Netherlands within the EU was used. Full details of this assessment are provided in Van der Gaag *et al*. (2012). Two scenarios were used here: that without any risk-reduction options and that with current phytosanitary measures.

In the absence of risk-reduction options, survival, detection failure and transfer were all rated 'very high' with low uncertainty. Association was rated 'unlikely' with medium uncertainty. With current phytosanitary measures, both association and detection failure were reduced, to 'very low' and 'moderate', respectively (Van der Gaag *et al*., 2012). In the Netherlands, which is a major trader of seed potatoes, *M. fallax* has a more limited distribution than *M. chitwoodi*. The NPPO of the Netherlands has not found *M. fallax* on seed potatoes since 2008 despite annual surveys and inspections including testing of seed potatoes (Plant Protection Service, 2011). In Belgium *M. fallax* has, thus far, not been found in seed potatoes despite inspections and testing. In the two other countries where *M. fallax* is present, Germany and France, *M. fallax* is only known from a few locations. The likelihood of association could be expected to increase if the current phytosanitary measures were lifted. Growers may currently avoid infested fields for the production of seed potatoes to prevent their crop being rejected after testing[2].

Four simulations with different assumptions were compared. Assessments for each scenario were performed firstly by using the intervals as defined by the 5-point scale (Table 2) and secondly by using more precisely-defined intervals (Fig. 1) to reflect differences in the uncertainty of ratings. In some cases the more precisely defined intervals were smaller (e.g. 5c instead of 5) and in two cases, larger (1b – 2b instead of 2, and 3a – 4c instead of 3). These larger intervals reflected a medium uncertainty attributed to pest association and a high uncertainty attributed to detection failure in the original assessment (Table 3).

The ratings given in Table 3 correspond to intervals shown in Table 4. In the case of commodity volume, the number of seed potato lots produced in the Netherlands every year is estimated to be about 35 000 – 40 000. Because about 50% of seed potatoes produced are exported to non-EU countries and the risk assessment concerned the probability of spread from infested areas in the EU to other areas in the EU, 17 500 – 20 000 seeds lots were used for the assessment in the present study.

Table 3 Entry to other EU countries of *Meloidogyne fallax* via seed potatoes exported from the Netherlands. Four components of the assessment were rated under two scenarios: with current phytosanitary measures and without measures. The original 5-point rating and the more precise definitions reflecting the level of uncertainty are shown

Scenario	Current phytosanitary measures		Absence of current phytosanitary measures	
Assessment resolution	5-point rating	More precise definitions	5-point rating	More precise definitions
Association	1	1a	2	1b-2b
Survival	5	5c	5	5c
Non-detection	3	3a-4c	5	5c
Transfer	5	5b-5c	5	5b-5c

Volume was 17.5 - 20 thousand lots and this interval has been used throughout

Table 4 The intervals defining the minimum and maximum of uniform distributions corresponding to the ratings in Table 3

Scenario	Current phytosanitary measures		Absence of current phytosanitary measures	
Assessment resolution	5-point rating	More precise definitions	5-point rating	More precise definitions
Association	0.001-0.01%	0.001-0.002%	0.01-0.1%	0.002-0.05%
Survival	10-100%	50 -100%	10-100%	50 -100%
Non-detection	0.1-1%	0.1 -10%	10-100%	50 -100%
Transfer	10-100%	20 -100%	10-100%	20 -100%

[2] Testing is one of the current options in the EU-regulation when seed potatoes originate from areas where *M. fallax* is known to occur (Annex IV of Directive 2000/29/EC),

Lots (thousands)	17.5 -20	17.5 -20	17.5 -20	17.5 -20

Results

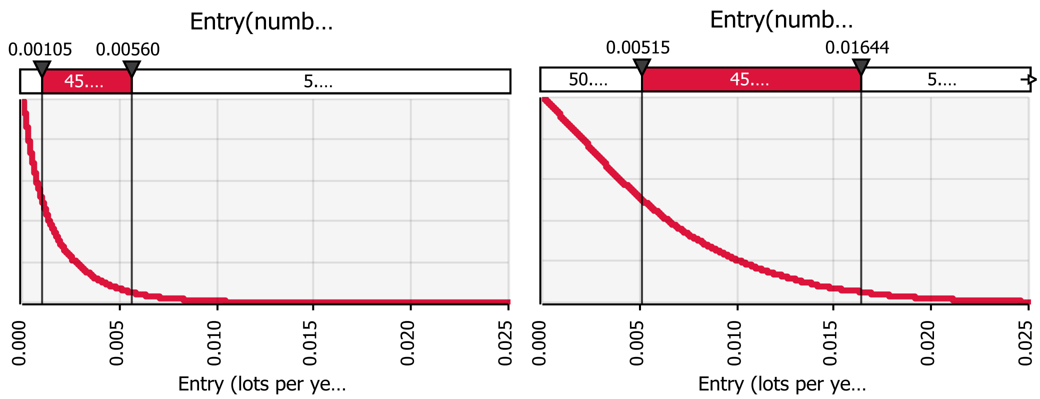
In the simulations the uniform distributions were sampled 10,000 times and this gave good consistency between repeat runs of the model. The distributions of the predicted numbers of entry events are shown in Fig 3 with summary statistics provided in Table 5. These figures show the distribution of possible outcomes resulting from the variation expressed when estimating the inputs. For example, in Fig. 3b, the median of the distribution is approximately 0.005 so there is a 50% chance that the actual number would be less than this value and a 50% chance that it would be greater than this value. All the distributions were highly skewed with a high probability of a low number and progressively lower probabilities of higher numbers. The mean and median (50th percentile) summarise the central tendency and the 95th percentile, the length of the tail of the distribution. Arguably the 95th percentile is most informative because it describes the situations of most concern; it indicates the value that has a 5% chance of being exceeded.

Table 5 Summary statistics of the probability distributions of the number of *Meloidogyne fallax* entries per year to other EU-countries linked to Netherlands seed potato exports. Results are shown for the four simulations described above.

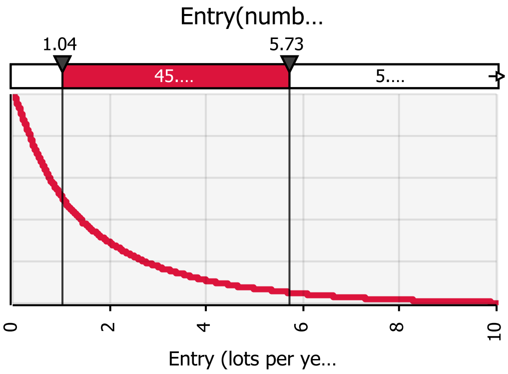
	Current phytosanitary measures		Absence of current phytosanitary measures	
	5-point rating	More precise definitions	5-point rating	More precise definitions
Mean	0.0017	0.0064	1.7	1.7
50th Percentile (Median)	0.0011	0.0052	1.1	1.3
95th Percentile	0.0056	0.016	5.7	4.2

Fig. 3 Probability distributions of the number of *Meloidogyne fallax* entries per year. The left and right vertical lines on each figure indicate the median and 95th percentile, respectively. With current phytosanitary measures using: a) original ratings and b) more precise estimates. Without current phytosanitary measures using: c) original ratings and d) more precise estimates

a) b)



c)



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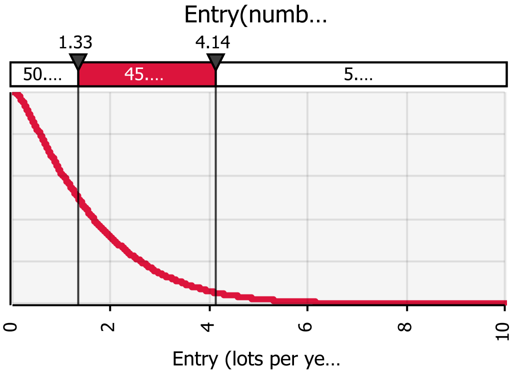

The four simulations allowed two useful comparisons to be made, firstly between the scenarios with and without current phytosanitary measures and secondly, between the situations with more and less detailed specification of the parameter values.

There were large differences between the situations with and without current phytosanitary measures. Without the current measures the predicted number of new infested fields increased 250 to 1000 – fold, from a mean of far less than one field per year to approximately 2 fields per year (Table 5). Without current measures, the model calculated a mean number of infested lots moving in trade of approximately 3. Depending on the probability of transfer, 0 - 2 fields would be expected to become infested every year. The median values (Table 5) indicate that there is a 50% chance that the number will exceed 1.1 to 1.3 lots in any year. There was a 5% chance that the numbers could be as high as 4 to 6 lots in any year. If lots of seed potatoes are divided and planted in more than one field then the number of fields becoming infested may of course be greater than the number of infested lots.

The original assessment was based on five rating categories, very low to very high, and the likelihood of entry (in this case spread to other countries within the risk assessment area) was characterized as ‘high’ (Van der Gaag *et al*., 2012). Based on the simulations, there is a greater than 50% chance that the pest would enter at least once per year and risk managers may describe such a number as ‘very high’ rather than ‘high’.

The current phytosanitary measures are predicted to be extremely effective in reducing the likelihood of entry of infested lots to considerably less than one in ten years so risk assessors might describe this frequency as ‘very low’. In the original assessment the likelihood of entry was characterised as ‘medium’ to ‘low’, so the quantitative approach suggests a much larger difference between the situations with and without current phytosanitary measures than the original assessment. When estimating values for the model variables, the assessors judged the current measures to reduce association by approximately 10-fold and detection failure by approximately 100-fold (Tables 3 and 4), hence a large differences between the results for the scenarios is to be expected. In the original evaluation of risk reduction using current phytosanitary measures detection failure was rated as moderately likely with a high uncertainty because testing would in most cases probably prevent growers from using fields known to be infested, so positive detections become less likely.

The two approaches to model parameterisation were also compared. One used the rating from the original assessment along with the uncertainty already included in the definition of the rating categories (Table 2). This did not take into account differences in uncertainty expressed in the original assessment, so by sub-dividing the intervals the more precise parameterisation enabled these differences to be expressed by using a range of sub-intervals of varying width.

In the situation with current phytosanitary measures there was a three to five-fold difference in the likelihood of entry between the two parameterisations. The more precise definitions better-reflected the high uncertainty associated with detection of the pathogen. This was counter-balanced to some extent by an expression of greater certainty in the association and transfer of the pathogen. A five-fold difference in result could be important in some circumstances but not pivotal to decision-making in this case because the likelihood was extremely low in both simulations.

In the situation without current measures, the results from the two parameterisations were more similar. In this case the means were similar but the variance was reduced slightly using the more precise parameterisation. The association was originally rated '2', but a more precise estimate placed it between 1b and 2b; a larger interval but straddling ratings 1 and 2. The increase in uncertainty concerning association was balanced by the estimates of the other variables that where considered to be near the top of their original ratings. The net outcome was a similar mean for the two parameterisations.

Discussion

The limitations of qualitative or linguistic definitions of ratings in PRA schemes are widely recognised and major steps to rectify these have been made (Schrader *et al.,* 2012). The definition of rating levels of individual questions using quantitative ranges represents a step towards closer to quantification (MacLeod *et al*., 2012) but the models remain semi-quantitative because within a modelling framework of ordinal variables integrated by expert judgement, the quantitative meaning is still lost in the calculation itself; 'low' and 'high' do not have the same meaning in quantitative terms in the final result as they do in the individual questions. As a consequence, the rating for entry, for example, could still be interpreted differently by different risk assessors and managers.

In the semi-quantitative models with ordinal categories of risk, the rating 'high' for example, can be interpreted as meaning that the risk is similar to other cases that are also rated as high (Holt *et al*., 2012; Holt *et al*., 2013). A rating of 'very high' can be said to express greater risk than 'high' but not the degree to which the risk is greater, except in comparative terms with other examples. Here the underlying quantitative meaning given to the ratings was used directly in the calculation but despite this, the actual choice of ratings remained to some extent judgement-based. The key difference then is that the factors are treated as numeric rather than categorical or ordinal variables, so the extent of the differences between cases is meaningful rather than just their ranking; not just that 'very high' is greater than 'high' but by how large a factor.

Stochastic models require a selection to be made both of the type of distribution and of the parameters for each of the variables in the model. There is a wealth of approaches and techniques to elicit the information required to make these decisions (O'Hagan *et al*., 2006) but here a level of information is used that is not much more than currently elicited through the EPPO DSS. To illustrate a quantitative pathway modelling approach with limited data, the variables were represented by intervals or uniform distributions because the ratings had previously been given such an interpretation.

Heterogeneity in the size of lots has not been incorporated and to do so would require a significant increase in model complexity and data requirements. For consistency in estimating the values of the different variables, assessors should have a particular lot size in mind. For a given volume of commodity, it may be reasonable to assume that the total number of the pest entering is not greatly affected by lot size unless detection of the rate per unit volume is affected. Other things being equal, larger lots would be expected to have a greater probability of infestation but the greater probability of an infestation is counterbalanced by there being fewer lots.

In the EPPO scheme each risk factor is given a rating and a separate score which expresses the level of uncertainty. Here the risk factors are numeric variables in which the rating and its uncertainty are treated as a single concept of an interval of varying width. In the EPPO scheme, to help improve consistency, the choice of rating and uncertainty was restricted to a limited set of options (Schrader *et al* 2012; Holt *et al*., 2013). Similarly, here, the choice of interval width was restricted to incremental steps. The step size was a compromise allowing discrimination between different degrees of uncertainty but not so detailed that the resolution exceeded the ability of the assessors to make a reasoned choice, at least in the cases considered here. In the divisions of the rating scale indicated in Fig. 1, the horizontal lines provide reference points to the original 5-point rating system. Where little or no information is available to specify the interval, the original 5-point system can be represented by selecting the range of three sub-intervals *a* – *c*, corresponding to the original rating. The objective was to illustrate the potential for a quantitative approach whilst as far as possible retaining compatibility with information already available from the current DSS for PRA.

It was necessary to elicit a small amount of further information from the assessors to allow reinterpretation of the uncertainty scores from the EPPO DSS as intervals of varying widths. At the same time this allowed the assessors to provide a little more discrimination in the uncertainty associated with the variables. The information available for our case study offered a reasonable basis for the estimation of these intervals but even in this case there was considerable uncertainty especially concerning association and transfer. Some interception information, mainly a lack of interceptions, was also available to provide a degree of validation of the results.

The number of other situations where sufficiently accurate data exists to specify a range of sub-intervals is likely to be quite limited. This may even be the case for the basic 5-point scale with its very broad, order of magnitude (factor of 10), categories. In such cases, it is not feasible to go beyond a semi-quantitative description of the pathway in terms of ordinal risk categories and so provide a relative likelihood of entry.

The model gave an indication of the value of, and indeed the need for, more precise information. The use of more precisely-defined intervals for the variables led to changes in the results. These were very minor in one scenario and larger in the other. The model may be useful to indicate whether more precise information may be likely to effect the conclusion and in this case it probably did not. Primary statistics such as the mean give a summary of the likelihood of entry but because the model calculates a simple product of the variables, the mean values would be readily calculated without recourse to Monte Carlo simulation. The value of the stochastic approach lies in the shape of the probability distribution rather than the central tendency. Of particular interest, the results indicate the likelihood and magnitude of the worst situations that might reasonably be expected.

In the Biosecurity Australia (2001) guidelines, uncertainty in category selection was recognised as a particular problem with the principal constraint being seen as the need to place likelihoods confidently in one or other category. Here category uncertainty was expressed using intervals which can span more than one category. The value of this simple quantitative pathway-modelling framework for plant health has been explored by considering a real PRA example for the entry section of the scheme. The model offered complementary insights to the semi-quantitative approaches that mimic assessor logic (Holt *et al*., 2013). Despite working with very broad estimates of model parameters, an indication of the real magnitude of differences between scenarios or cases was possible.

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