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Summary		
<p>The aim of this project was to review literature on the way in which risk is integrated over time and over volume of trade in Import Risk Assessments in Australia, to evaluate the implications of the approach, to compare it to the approaches used in other places and in other technical areas, and to evaluate potential avenues to improve application or communication. The report provides examples that illustrate assumptions of the current approach, and makes suggestions regarding the future use of tools for integrating and communicating probabilities.</p>		
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Review of the use of period of trade and trade volume in import risk analysis

Final Report
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1. Executive Summary

Import risk analyses (IRAs) provide estimates of the risk — in terms of likelihood and consequences — of the entry, establishment and spread of pests and diseases associated with commodities imported in varying volumes and over varying periods. This report deals with the likelihood component of risk and does not consider how consequences are assessed.

A one-day workshop was held to identify the primary concerns of a sample of stakeholders regarding how the duration and volume of trade are treated in IRAs. The results of the workshop were combined with reviews of IRAs, guidelines from Australia and several other countries, and analogous risk analysis procedures from other professional areas, to provide an assessment of Australian procedures.

The report concludes that a case-by-case assessment for each pest or disease in each IRA is needed to determine whether greater than one year's worth of trade should be included in the analysis. The decisions and justification regarding time and other assumptions should be transparent within the IRA. If probabilities are derived from considering more than one year, they need to be standardised to one year (or some other consistent probability framework) to ensure consistent comparisons and decisions.

2. Background

Import risk analyses (IRAs) provide estimates of the risk — in terms of likelihood and consequences — of entry, establishment and spread of pests and diseases of concern associated with commodities that are imported in varying volumes and over varying periods. This report deals with the likelihood component of risk and does not consider how consequences are assessed. Currently, Biosecurity Australia (BA)'s IRA method uses the volume of trade in one year to estimate the likelihood of entry, establishment and spread, while consequences are usually assessed over a longer period. Note that BA refers to the probability of an event as the likelihood — we use the terms "probability" and "likelihood" interchangeably in this report. One year is used in part because it allows the evaluation to account for seasonal variation in probabilities.

People respond differently to risks depending on the timeframes in which probabilities are specified, and their reactions may differ when their concerns are viewed over longer or shorter timeframes. The pattern of events can be expressed in different ways, including:

- the likelihood of an event occurring at the end of a specific period;
- the likelihood of an event occurring at least once during a specific period;
- the total number of events expected, on average, during a specific period; or
- the average time until the occurrence of the first event.

Some stakeholders have expressed concern about the how the volume of trade is considered in Australia's IRA process. Some stakeholders recalculate the probability estimates by factoring in additional years of trade and claim that the resulting risk estimates exceed Australia's appropriate level of protection (ALOP). In brief, the claim is that the method used by BA provides only one year's quarantine protection and that this is not compatible with Australia's conservative quarantine policy. Others claim that this approach is an incorrect interpretation of the method. BA states (see p. 17 of Part B of the *Revised Draft Import Risk Analysis Report for Apples from New Zealand*, December 2005) that if the method is followed, then the risk estimates reflect Australia's policy for ongoing quarantine protection, not just for one year.

This project aims to explore different approaches to incorporating the volume and duration of trade in IRAs. The project focuses on methods for analysis of probability and does not address Australia's policy on ALOP.

3. Approach

A one-day workshop was held to identify the primary concerns of a sample of stakeholders regarding how volume and duration of trade are treated in IRAs. Stakeholders were identified, beginning with a list provided by BA of relevant groups and individuals. The facilitator (Mark Burgman) asked each group to nominate additional potential participants and continued the process until there was substantial overlap in recommendations. The resulting list was too long for an effective workshop. Our collaborator (Dr Jane Gilmour) mapped the stakeholders onto axes representing sector (five: local, State Government, Australian Government, industry, and other) and trade position (three: import, export, both). Representatives from each of the sectors were invited, resulting in a total of about 20 participants.

The meeting agreed a process to complete the project (outlined below). There was broad agreement at the workshop on the following issues:

- Risk analysis is subject to the disciplines and methods in the Sanitary and Phytosanitary Agreement, the OIE and the IPPC.
- Volume of trade is a fundamental consideration in an IRA.
- Language-based interpretation of likelihood provides an alternative approach to the use of ‘semi-quantitative’ numerical thresholds.
- Although the equation, $\text{likelihood} = 1 - (1 - p)^t$, where p is the likelihood of entry, establishment and spread per year and t is the number of years, has been used to estimate likelihood over time, it is not the only way to represent the issue or to estimate likelihood in this context.

The following issues were identified as needing more detailed consideration in this project:

- Do changes in the volume or duration of trade influence the consequence component of risk? In its IRA process, BA uses a structured set of questions to determine the consequence of a pest or disease becoming established and spreading in Australia. Volume of trade could have implications for consequences. For example, a larger volume of trade could lead to a wider geographical distribution of the pest or disease across Australia, and this might make control or eradication more expensive. Possible influences of volume of trade on the consequence component of IRAs are not considered by BA; these are a subset of the issues and we do not focus on them in this review.
- Is a longer period (e.g. 5 to 10 years) preferable to 1 year for estimation of likelihoods (considering numerical thresholds in the risk matrix and how recalibration might affect decision-making)?
- Is it appropriate and feasible to use different timeframes for different commodities (considering pest and disease biology, management timescales, and related issues)?

The procedures for assessing probabilities are integral to how volume and duration of trade are used to estimate the likelihood of entry, establishment and spread. Successful risk management recommendations are defined in policy as those that meet Australia’s ALOP. The risk matrix and quantitative and qualitative nomenclature are considered to the extent that they are directly relevant to the techniques used to deal with the volume and duration of trade, but a full review of them is outside the limits of this project.

The project aims to explore relevant issues by reviewing:

- 1) Published Australian IRAs and other relevant documents to determine how they address the volume and duration of trade.
- 2) Methods used to address the volume and duration of trade in published IRAs in other countries (particularly Canada, the European Union, New Zealand, and the United States, taking into account differences that relate to different countries’ ALOP); and
- 3) Methods used to address volume and duration in risk analyses used in a range of other disciplines (including ecology, engineering and public health) to determine whether any of the approaches used in other disciplines might be useful for biosecurity risk analysis.

Based on this review, this project provides a basis for considering methods used to address the volume and duration of trade in IRAs.

4. Process

1. BA proposed an examination of the issue of volume of trade and time in IRAs and asked ACERA to undertake a review and assessment.
2. ACERA's Scientific Advisory Committee approved the proposal.
3. ACERA facilitated a stakeholder workshop on 22 November to identify the primary concerns of stakeholders regarding how time and volume of trade are treated in IRAs.
4. A 'project steering committee' was formed from workshop participants who volunteered to read and provide feedback on progress reports and draft documents. The composition of the steering committee is shown in Appendix 1.
5. ACERA prepared and circulated a report of the stakeholder workshop held on 22 November and a detailed draft project proposal in December 2006.
6. ACERA wrote a final project proposal, based on comments received, and distributed it to the project steering committee before the end of December.
7. ACERA conducted the review and prepared a draft report for distribution to the project steering committee before the end of February 2007.
8. The project steering committee and ACERA's Scientific Advisory Committee had a month to consider the report, discuss options and their implications. They provided feedback to ACERA by the end of March.
9. ACERA received and assessed the comments and provided a final report to DAFF, for its consideration, by the end of April.
10. ACERA sought a second round of comments on the draft final report in May and sought responses by May 18, aiming to submit the final report by the end of May.
11. When finalised, the report will be posted on ACERA's website.

5. Review

This review considers only the likelihood of entry, establishment and spread. It is beyond the scope of this work to evaluate methods for assessing consequences. In evaluating published Australian IRAs, it examines whether the current system provides an overall assessment of risk in which decisions are consistent with ongoing quarantine protection. That is, this report evaluates whether BA's method for undertaking IRAs implicitly considers the volume and duration of trade, and whether it provides a basis for decisions that are consistent with those taken previously for other commodities and at other times.

BA stated in its recent IRAs that, *'The estimate of the likelihood of entry, establishment and spread is combined with the estimate of the consequences according to the matrix The reference to 'annual' indicates that the likelihood estimate is based on one year of trade. One year of trade is a convenient timescale to estimate the likely volume of trade and the risk analysis system is based on using this volume. However, it does not mean that the quarantine protection only applies to one year. Clearly the consequences of pest entry, establishment and spread will normally extend beyond a year, and the assessment of consequences is not restricted to a particular time period. Estimates of 'very low' or 'negligible' are considered to be acceptable'* (Commonwealth of Australia 2006a, page 7, Commonwealth of Australia 2006b, Page 9).

The risk assessment uses a risk matrix that was developed as part of the BA method and was agreed by all State/Territory governments and the Australian Government (Commonwealth of Australia 2006a). BA uses the matrix to combine the estimates of likelihood and consequence. BA states that this provides a risk assessment that reflects the risk (and level of protection) for periods much longer than a year, accounting for conservative estimates of likelihood and consequence that emerge from the method. This report will not examine the construction of the matrix. This report will examine more explicit approaches to dealing with volume of trade and duration in risk assessments.

5.1 Volume and duration of trade in Australian IRAs

BA's approach to IRAs considers the pathways by which pests and diseases can affect Australian industry, expressing assessments in stages of entry, establishment and spread. The IRAs estimate the various components of the potential incursion pathways, leading to an estimate of the probability of entry, establishment and spread (PEES, which we also call the probability of incursion). When the various pathways are combined, the complete IRA model can be detailed, with a large number of variables. For example, the recent NZ apple IRA used approximately 40 parameters to estimate the probability of entry, establishment and spread of fireblight, one of 16 pest species considered in detail (Commonwealth of Australia 2005).

The PEES is assessed on a per-year basis by BA. Over a longer timeframe, the volume of trade would be greater, so the likelihood of entry and establishment would also be greater.

If the PEES of an organism resulting from an annual volume of trade is equal to p , then the probability that the organism will not invade, given a year of trade, is equal to $1 - p$. If the annual PEES is the same from one year until the next, and each year represents an independent chance of incursion, then the probability that the organism will not invade in t years is $(1 - p)^t$. 'Independent' means that if a pest or disease appears in one year, it implies nothing about its chances of appearing the following year. This leads to the likelihood or probability of entry, establishment and spread over t years being

$$l = 1 - (1 - p)^t. \text{ (eqn 1)}$$

The term t could equally refer to volume (see below). This is a well-established result that is presented in the IRA Guidelines for converting the likelihood of entry, establishment and spread based on one unit of trade (such as a single shipment) to the likelihood when importing a year's worth of trade (Commonwealth of Australia 2001). The equation for the likelihood of incursion is numerically identical to that used by Wallace (2006) to estimate the probability of incursion by at least one of many species (see below).

In equation 1, time is used as a surrogate for volume, so when importing a total volume of v units of the product, the likelihood of incursion is $1 - (1 - p)^v$, where p is the probability of incursion when importing one unit of volume of the product (Commonwealth of Australia 2001). In this case, the discreteness and independence of the units needs to be considered carefully. For example, if one unit of volume is a single shipment, then the underlying assumptions may be reasonable provided the conditions are the same, so that the PEES for each shipment is identical. However, if one unit of volume is simply a standard volume unit (e.g. a single piece of fruit or one animal) applied in the context of a large volume of material, then the units would not be discrete or independent, and the equation may not be applicable.

Under this model (equation 1), the number of years until incursion occurs follows a geometric distribution (e.g. Balakrishnan and Nevzorov 2003), so we will refer to it as the geometric model. Providing conditions remain the same, the probability of one or more incursions within a period (the cumulative probability) approaches certainty as time increases. The probability of incursion within different periods for different annual probabilities of incursion is shown in Figure 1.

Note that if the chance of incursion in any single year is small (e.g., $p = 0.01$ or less), the probability of incursion increases in an approximately linear fashion for an extended period. If the annual probability is not very small (e.g., $p = 0.3$) the probability of incursion increases rapidly and is effectively equal to one (certainty) after a relatively short time. Further, for the geometric model, the average time until incursion is $(1/p)$ years; thus if $p = 0.1$, the average time until incursion is 10 years.

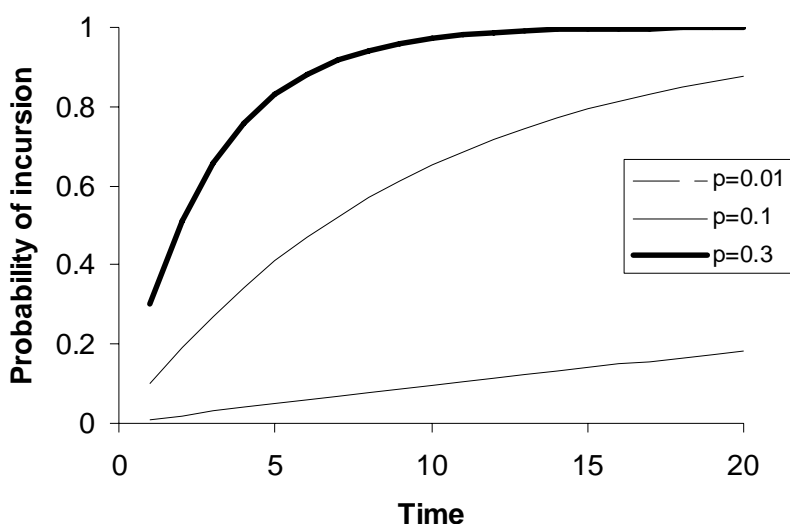


Figure 1. Probability that an incursion will have occurred within a specified time for three annual probabilities of entry, establishment and spread (based on equation 1).

Each line in Figure 1 may represent the cumulative probability of incursion by, for instance, a different organism. Under the geometric model, if one organism has a higher probability of invasion than another over one particular period, it will also have a higher probability over another period (i.e. the lines in Figure 1 do not cross).

Because the lines in Figure 1 do not cross, the choice of period does not influence the relative ranking of probabilities. The Australian Government aims to make risk-based import decisions that are consistent from one decision to the next (Commonwealth of Australia 2001). This is achieved by Australia setting an ALOP against which risk (combining the likelihood and consequence) is compared. Once the ALOP is defined, so too implicitly is the PEES that is acceptable for a particular consequence. Thus, if the risk of importing a disease under one proposed import permit is assessed at a particular level and the import is permitted, then a second import must also be permitted if the risk associated with it is assessed to be the same as or lower than the first. To make the IRAs more useful to industries sensitive to estimated probabilities, it may help to make explicit the probabilities over longer time horizons.

Import decisions that are inconsistent can be appealed against successfully to the WTO Appellate Body (e.g. Atik 2004). Given the assumptions of the model outlined above, the logic employed by BA to rank relative probabilities implies that a commodity with lower probabilities in the short term (one year) will have lower cumulative probabilities over all timeframes.

It is worth re-stating some assumptions of the geometric model:

- 1) The volume of trade is the same from year to year, or (for the formulation of the model in terms of volume) the probability of incursion is the same for each unit of volume; and
- 2) The chance of incursion is independent from year to year.

Violation of these assumptions might make the geometric model overestimate or underestimate the cumulative probability of an incursion. In a subsequent section of this report (see Section 6.2), an alternative model demonstrates that cumulative probabilities of incursion might increase with time or volume at a rate that is different from the geometric model. This report outlines some conditions under which the assumptions of the geometric model may be violated in routine assessments.

Australian IRAs are based on defining the components of the pathways by which a pest or disease might enter. For example, a pest or disease might enter on a commodity if it is present in the source country, infects the commodity, and survives processing, transport, treatment and storage. The likelihood of entry can be obtained by multiplying the probability that the agent is in or on the commodity by the probabilities of the subsequent events. Probabilities at each step are conditional on the agent surviving the previous steps.

When assessing different components of likelihood using semi-quantitative methods, the IRA Guidelines define language-based likelihoods by probability intervals. For example, a 'low' likelihood of an event is defined as having a probability between 0.05 and 0.3 (Commonwealth of Australia 2001). The full range of definitions is given in Table 1.

Table 1. Relations between language-based descriptions and probabilities as used by BA for semi-quantitative risk assessments (Commonwealth of Australia 2001).

Language-based description of likelihood	Probability Interval
High	0.7 – 1.0
Moderate	0.3 – 0.7
Low	0.05 – 0.3
Very Low	0.001 – 0.05
Extremely low	10^{-6} – 0.001
Negligible	0 – 10^{-6}

The different components of the probability of entry, establishment and spread (PEES) are combined to estimate the overall PEES. The resulting probability can then be expressed either in terms of probability (e.g. a range of 0.001 – 0.05) or a language-based description (e.g. very low). Thus, the terms used to describe probability intervals (very low, low, moderate, etc.) have the same meaning whether they occur on the left- or right-hand side of the equations that are used to combine the different components of the PEES. This is a sensible approach for the sake of internal consistency.

The PEES is then combined with the consequence to calculate the risk, which is compared to Australia's ALOP. The import would not be permitted if the consequence is sufficiently large for a particular likelihood (or, equivalently, if the likelihood is sufficiently large for a particular consequence) such that the risk exceeds the ALOP. However, the language in the IRAs might provide a misleading assessment for some stakeholders. If an IRA report states that there is a low risk of an

industry being affected, unless the context was fully understood, a stakeholder might scale the probabilities assessed for a year of trade to probabilities over longer periods and then be surprised to learn that it would almost certainly be affected within, for example, 10 years.

5.2 Relevant methods used in IRAs in other jurisdictions

5.1.1. United States

Import risk assessments in the US do not explicitly consider the volume or duration of trade. For example, wood import risk assessments do not mention the period over which probabilities are assessed (e.g., Kliejunas et al. 2003). Instead, the number of interceptions of pests or diseases at ports guides subjective judgements of the likelihood of introduction. The period over which these interceptions are observed is not considered. Although 20 interceptions in one year should represent a different risk from 20 interceptions in 50 years, this is not explicitly addressed in the US's wood IRAs. In practice, it is likely that the rate of interceptions (e.g. number of interceptions per year or per volume of wood) is considered in these subjective assessments of risk. However, the risk analysis process is incomplete because the time period and the volume of trade are not stated explicitly.

USDA uses qualitative risk assessments to evaluate the likelihood that a disease exists in a region, or might be introduced into a region in the near future. It equates qualitative expressions of probability (negligible, moderate, high and so on) with quantitative probabilities (Table 2). The definitions used by the USDA (Table 2) are sometimes identical to those used by BA (Table 1), such as 'negligible', but can be very different, such as the definition of 'high'. The differences between the USDA and Australian definitions are not important provided that all stakeholders have a common understanding of the meanings, because in both cases the probabilities are on an ordinal scale, which permits consistent decisions.

Table 2. Regional risk classifications (after Rickansrud et al. 2001).

Unknown/Unclassified	$> 10^{-2}$ or unknown
High	$10^{-3} - 10^{-2}$
Moderate	$10^{-4} - 10^{-3}$
Low	$10^{-5} - 10^{-4}$
Slight	$10^{-6} - 10^{-5}$
Negligible	$0 - 10^{-6}$

¹ Rickansrud (et al. 2000) nest the categories, so that in their publication low is <1 per 10^4 and 'moderate' is <1 per 10^3 (thus, 'moderate' includes 'low'). The categories are rearranged here to be exclusive rather than nested, consistent with Table 1.

5.1.2. New Zealand

The *draft* Risk Analysis Procedures (see IPPC 2006) of the New Zealand Ministry of Agriculture and Forestry (MAFF) state that IRAs estimate the combination of entry, establishment and spread. These likelihoods are combined with a consequence assessment to assess risk. The standard protocol employs binary qualitative assessments of each step, based on judgement of whether the likelihoods and consequences are 'negligible' or 'non-negligible'.

The procedures indicate that it will not normally be necessary to undertake formal external consultation. However targeted peer review (internal and/or external) may be helpful when the potential mitigation measures are likely to be contentious and/or costly, or when there is a high level of uncertainty associated with any of the assessment stages. Where there is significant uncertainty in the estimated risk, 'a precautionary approach' to managing risk may be adopted (IPPC 2006). If the risk estimate is non-negligible, sanitary measures can be justified.

The guidelines provide no explicit consideration of duration or volume of trade in estimating probabilities or specifying monitoring conditions. For example, to manage effectively the risks of *Aspidiotus destructor* (coconut scale), phytosanitary measure(s) would need to ensure with 95% confidence that not more than 0.5% of the units in any given consignment of a commodity are infested with the scale when given a biosecurity clearance into New Zealand. A contamination level of less than 0.5% of the units in any given consignment will be achieved with 95% confidence if a sample of 600 fruit randomly collected from a homogenous lot is visually inspected and no live *Aspidiotus destructor* life stages are found (IPPC 2006). Analyses make many assumptions (such as independence of samples) and the reliability of this approach depends on whether the assumptions are reasonable. Heavy clustering of a pest or disease agent among consignments or other units of trade might make the assumptions problematic.

In New Zealand, quantitative IRAs have been employed for some import access requests. For example, New Zealand's Animal Biosecurity (Biosecurity Authority 2000) estimated probabilities on an annual basis and assumed a fixed import volume of the commodity. They found that, even with a consumption of US chicken equivalent to 0.1% of current New Zealand consumption, the upper 95th percentile of the estimated probability of disease being introduced was 0.03 per year (that is, a probability of three introductions per 100 importation years). MAFF considered this to be an unacceptably high risk. The analysis was based on Monte Carlo simulation to propagate uncertainties through the chains of probabilities in the exposure pathway.

5.1.3. Europe

Plant quarantine protocols in Europe follow European (European and Mediterranean Plant Protection Organisation) and international standards (IPPC 1996). They employ standardised questions that reflect pathway analysis, requiring qualitative judgements in one of several categories (very unlikely, likely, very likely, etc.). These questions give some consideration of volume of trade, albeit qualitatively. For instance, they ask how large is the volume of the movement along the pathway (minimal, minor, moderate, major, massive) (Schrader 2005)? The answer to this question contributes to the overall assessment of risk.

The Animal Health and Welfare Risk Assessment Team of the UK's Department for Environment, Food and Rural Affairs noted that its IRAs estimate the probability of experiencing an outbreak in any one year (Adkin et al. 2004). Adkin et al.'s (2004) view is that if this is thought of as a true probability, it could be interpreted as the probability of exactly one outbreak in a year, or the probability of one or more infections in a year. For low probability situations, the probability of having two or more events in the same year is low, so the distinction between 'exactly' one or 'one or more' is of little practical interest. Their paper points out that the situation would be different if the period were extended, say to 10 or 100 years, in which case the mathematics of these probabilities would become complex.

5.1.4. Canada

In Canadian plant IRAs, likelihoods of introduction, establishment potential and consequences are assessed qualitatively using subjective language-based scales. For example, PHRAU (2004) outlines guidelines for rating the likelihood of introduction of a pest or disease. Negligible (score =0) implies the likelihood of introduction is extremely low given the distribution of the pest or disease at the source, management practices, commodity volume, probability of survival in transit, probability of contact with susceptible hosts in the area (given the intended use), or unsuitable climate. Low (score=1) implies that the likelihood of introduction is low but clearly possible given the expected combination of factors necessary for introduction. High (score=3) implies that introduction is very likely or certain. Consequences are similarly scored subjectively. The product of these scores is used to provide an assessment of the risk. For example, European stone fruit yellows were estimated to have a low likelihood of entry and a medium impact (= Low (1) x Medium (2)), giving an overall risk rating of Low (2). The Canadian procedure provides for a subjective judgement of the degree of uncertainty associated with each assessment. For instance, the uncertainty in the assessment of European stone fruit yellows was considered to be 'generally low' (PHRAU 2004).

The Canadian guidelines for IRAs for plants and animals consider both qualitative and quantitative methods (Moreau and Jordan 2005, CFIA 2007). For example, a risk assessment of

Bovine Spongiform Encephalopathy (BSE) in cattle (Animal Health Risk Assessment Group 2002) used second-order Monte Carlo methods to estimate probabilities of exposure to BSE in Canada. The number of animals imported to Canada over particular periods was considered explicitly in the risk assessment. The risk assessment considered the possible pathways of infection, and then estimated the relevant probabilities of the steps on that pathway. The method CFIA used for risk assessment of BSE in Canadian cattle is similar to the method used in risk assessments undertaken in IRAs conducted by BA such as the New Zealand apple IRA (Commonwealth of Australia 2005).

5.3 Discussion

Volume of trade is an important consideration, but it is treated differently by different jurisdictions. Volume is not considered explicitly in some IRAs (e.g. US, see Kliejunas et al. 2003), but is used explicitly in others (e.g. the Canadian BSE risk assessment, see Animal Health Risk Assessment Group 2002). All approaches to import risk assessments examined in this project consider using qualitative categories to estimate probabilities. Sometimes the categories are linked to explicit numerical thresholds; more often they are not.

All examples of quantitative risk assessment in IRAs we have seen rely on Monte Carlo simulation of uncertainties to estimate a distribution for the probabilities of entry, establishment and spread, and for the consequences of the pest or pathogen. All analyses in other countries either do not specify a model for aggregating probabilities over volume or duration of trade, or they use the geometric model implicitly.

6. Relevant methods used to deal with volume and time in other disciplines

When predicting the probability of an event, it is usual to specify explicitly the period and quantity for which the probability is assessed. For example, probabilities of extinction in conservation biology can be assessed over decades (Mace and Lande 1991), risks from exposure to chemicals are assessed over lifetimes (Suter 1993), risks associated with food additives are based on daily intake rates (WHO 1995), and financial risks are assessed over investment time horizons (Kritzman and Rich 2002). For IRAs, BA uses an annual volume of trade to assess the probability of entry and establishment of pests and diseases.

6.1 Food additives and ecotoxicology

The assessment of chronic health risks associated with food (WHO 1995) demonstrates that short-term risks are extrapolated to longer timeframes in other disciplines. For example, the Joint FAO/WHO Expert Committee on Food Additives evaluates toxicological effects of food additives, and calculates an acceptable daily intake that estimates the amount of the additive, expressed on a body weight basis, that can be ingested daily over a lifetime without appreciable health risk. That is, acceptable risk is calculated over a person's lifetime and acceptable daily exposures are back-calculated from this dose.

One protocol in ecotoxicology operates in the opposite manner, determining acceptable concentrations based on lethal acute (short-term) effects, and recalibrating these to estimate acceptable rates of chronic (long-term) exposure. For example, organisms are assessed in laboratories to determine the concentration of a chemical that causes 50% of individuals to die within 96 hours of exposure (Suter 1995). This concentration is known as the LC_{50} . In the environment, organisms are exposed for extended periods, and it is necessary to estimate the long-term responses based on the short-term (96-hour) results. The concentration that leads to no observable effect in the long term is known as the chronic No Observed Effect Concentration (NOEC).

In ecotoxicology and food safety, relatively simple relationships between long-term and short-term risks have sometimes been employed. These simple relationships can lead to incorrect assessments of risk. For example, because the chronic NOEC has been evaluated for few species, it has been assumed that the chronic NOEC is a fixed proportion of the LC_{50} . The ratio of the two is sometimes assumed to be 100. Thus,

$$\text{chronic NOEC} = LC_{50} / 100.$$

However, in the few instances where the ratio has been assessed directly, it is commonly very different from 100, varying over a range of three orders of magnitude (Calow and Forbes 2003, Burgman 2005). This simple re-scaling of probability over time leads to underestimation or overestimation of risk, depending on the organism being assessed. The possible magnitude of error should be assessed before using similarly simple rescaling of probabilities over time or volume in IRAs.

6.2 Conservation biology

Other fields of risk assessment routinely assess probabilities over a number of different timeframes, typically including timeframes that suit management considerations. For example, critically endangered species have been defined in the field of conservation biology as those that have at least a 50% probability of extinction within 5 years. Endangered species are those that are not critically endangered but have a 20% probability of extinction within 20 years (Mace and Lande 1991). Note that different periods are employed for the different levels of endangerment. Akçakaya (1992) recognised that classification of risk had three dimensions, namely, level of decline (the consequence), time, and probability of decline (the likelihood). He generalised the approach of Mace and Lande (1991) to represent conservation status using these three dimensions (Figure 2). For example, a species is regarded as critically endangered if the probability of extinction is greater than

0.5 within 5 years or 0.7 within 50 years. The exact shape of the curves that separate the different categories of threat (Figure 2) depends on the model used to extrapolate risks over time.

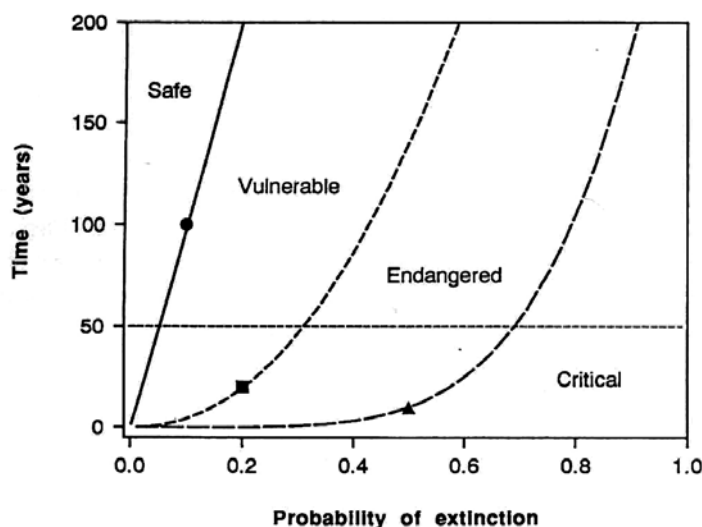


Figure 2. Levels of threat faced by species as a function of time and the probability of extinction (reproduced from Akçakaya 1992).

Spatially and structurally explicit population models are used to integrate annual changes, to predict the probability of extinction within a particular time frame (Shaffer 1981), probabilities that the abundance will become unacceptably small (termed quasi-extinction by Ginzburg et al. 1982), the average time to (quasi-)extinction, and the smallest abundance that is expected within a particular timeframe (McCarthy and Thompson 2001).

6.3 Investments

Models of investment performance, and calculations of investment risk operate in a similar manner to those in conservation biology (Jorion 2001). In fact, some of the models of population change that are used in ecology (Ginzburg et al. 1982) are mathematically identical to those used for predicting changes in the value of investments (Kritzman and Rich 2002). Methods for quantifying probability over longer timeframes are also similar, with the probability of the value of the investment becoming unacceptably small within a particular timeframe (Kritzman and Rich 2002) being equivalent to the probability of quasi-extinction (Ginzburg et al. 1982). Some of these tools are reviewed in detail by Franklin et al. (2007), in ACERA project 0602.

Explicit process-based models of how probabilities accumulate over time are used in conservation biology and the management of investments. Similar process-based models could be employed in IRAs. The value of doing this depends in part on how much the details of the models will deviate from the assumptions of the geometric model, which includes constant per unit probabilities and independence.

6.4 Engineering and manufacturing

Reliability analysis (alternatively known as failure analysis) is a general mathematical approach to analysing how probabilities (typically of failure) accumulate over time (Zacks 1992). It is applied in engineering and manufacturing industries, but can also be applied to biological problems (Johnson and Gutsell 1994, McCarthy et al. 2001).

The concept of hazard is central to reliability analysis. Note that its definition is different from that used by BA. In reliability analysis, hazard is the instantaneous probability of an event (failure) occurring. A hazard function defines how the hazard changes with time. Once the hazard function is defined, mathematical relationships provide the probability of failure within a particular time period and the probability distribution of the time until failure (Zacks 1992).

The simplest model is that the hazard is constant, which leads to an exponential distribution of time until failure. This distribution is the continuous time equivalent of the geometric distribution that forms the basis for how BA assesses the likelihood of entry, establishment and spread for a particular volume of trade (Commonwealth of Australia 2001).

Other models can be characterised on the basis of whether the hazard increases or decreases with time (Zacks 1992). Models in which the hazard function increases over some periods of time and decreases over others can also be considered (e.g., McCarthy et al. 2001). Examples of two hazard functions are shown in Figure 3a, with the resulting probability of failure versus time given in Figure 3b. These illustrate that the timeframe of analysis can interact with assumptions about the underlying hazard rate to influence the ranking of the probability of failure.

In biosecurity risk assessment, a realistic example of such a case is represented by a pest or disease that is known to have become established in an exporting country and is still spreading, compared to one that is established and has reached equilibrium in terms of spread and the frequency of occurrence in orchards or on farms. The former case would be reflected in a hazard function that increased through time and slowly levelled off as it reached equilibrium. In the latter case, where the pest or disease is already at equilibrium and is expected to occur with a particular probability on farms or in produce, the hazard function would be constant.

These observations have implications for IRA. Different commodities are likely to have different hazard functions. Diseases that have a relatively constant infection intensity in source areas and for which there are stable and tested control measures may be reasonably well described by a constant hazard function. Other pests and diseases that are, for example, changing their virulence, pathogenicity, response to treatment, or host or geographical range and have a variable incidence (increasing, decreasing or fluctuating from year to year) may be better represented by alternative hazard functions. The ranks for different commodities (hazards) will then depend on the timeframe of the analysis.

It is not always known whether or how the distribution and frequency of a pest or disease is changing over time in response to processes such as pathogen evolution, global warming or disease control strategies. If there are substantial shifts in the distribution or prevalence of a pest or disease, the deliberations in a risk assessment in an IRA should change. A biosecurity risk analysis system can cope with such dynamics by providing for re-analysis whenever there is a prospect that conditions have changed. This is the approach taken by BA.

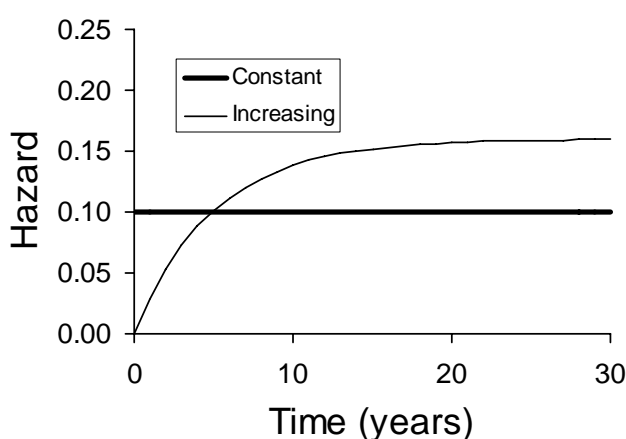


Figure 3a. Hazard functions for the constant hazard model ($h(t) = 0.1$), and a model in which the hazard increases with time ($h(t) = 0.16(1 - e^{-0.2t})$). The mean time to failure is 10 years for both of these models.

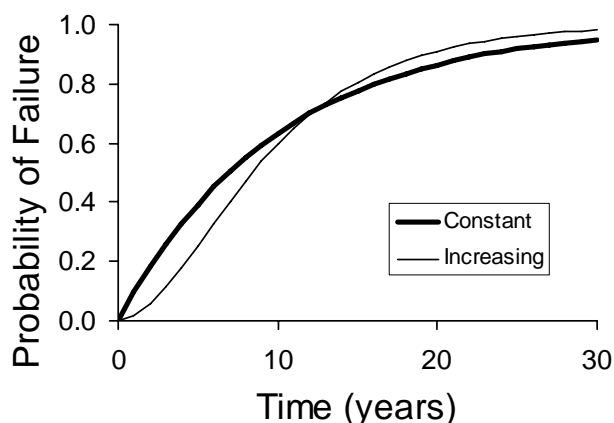


Figure 3b. Cumulative probability of failure versus the time for the constant hazard model and the model in which the hazard increases with time (from Figure 3a). The mean time to failure is the same for both of these models (10 years), but the ranking of the probability of failure depends on the time horizon chosen.

Prevalence in areas from which there are no data may be inferred from frequencies in other jurisdictions, or from knowledge of the basic biology of the species. If the knowledge base is uncertain and a pest or disease may not yet have reached the full extent of its eventual distribution, or may increase its range or pathogenicity as it adapts to a new environment, or if experts are unsure of the ultimate distribution of the species, a conservative (bounding, risk-averse) approach would assume the pest or disease is everywhere in the environment being assessed. It would be possible to assume the asymptotic rate and then use the constant hazard model to place an upper bound on the PEES. This would be equivalent to assuming the hazard is constant, rather than increasing, and equal to the asymptotic probability in Figure 3a that the increasing curve approaches.

6.5 Nomograms and graphs

Nomograms are graphical devices for calibrating one set of numbers or outcomes with another. Nomograms are tools that aim to assist in calculation and communication. They have been used in a variety of applications, including risk analysis and risk management (Kinney and Wiruth 1976). For example, the Department of Primary Industries in Victoria recommends the use of a risk nomogram as one way of considering likelihood, frequency and consequence when evaluating the risk of mining operations (State of Victoria 2002). The purpose of introducing nomograms and some related graphs here is that they represent a simple way of communicating probability that may overcome some of the problems encountered with more quantitative approaches such as the presentation of mathematical equations.

Nomograms work by tracing the intersection of lines. For example, the nomogram in the risk assessment guidelines for the Victorian mining industry demonstrates the calculation of an event that has a remote possibility of happening in any one instance, people are exposed to the possibility of this risky event once per month and extensive injuries would occur if the event occurred (Figure 4). The risk score in this case is evaluated by first drawing a line between the likelihood 'Remotely possible' and exposure 'Unusual Once per month'. This first line is extended to the middle 'tie line'. Then a second line is drawn from the point at which the first line intersects the tie line through the relevant severity score ('Extensive injuries' in this example). The resulting risk is read from the risk score axis, which in this example leads to 'A substantial risk – correction required'.

This is a relatively straightforward way of integrating the likelihood of an event (e.g. an accident) from a single exposure (e.g. a visit to the mine), the frequency of exposures, and the consequence of an event occurring. These measures are analogous to the likelihood of an outbreak for a particular volume of trade over which the risk is being assessed, and the consequence of an outbreak. Note that nomograms are graphical devices for doing calculations, removing the need for stakeholders to use the detailed model or formulae on which the nomogram is based.

Simple graphical devices other than nomograms can be used to communicate the results of analyses without having to use the underlying details or mathematics involved. For example, C. Thompson (pers. comm.) developed a graphical translation of the likelihood from a unit volume of trade (e.g. volume of trade over one year) to a different volume of trade using the geometric model. It works by identifying the likelihood arising from a unit volume of trade on the x-axis. A line is traced vertically until the appropriate curve is reached for the smaller or larger volume of trade. Then a line is traced horizontally to arrive at the likelihood for this different volume. In the example below, a likelihood of 0.2 from a unit volume of trade is translated to that for 5 units (vt = 5), leading to a likelihood of 0.67 (Figure 5; but see below for possible problems with the assumptions for this situation).

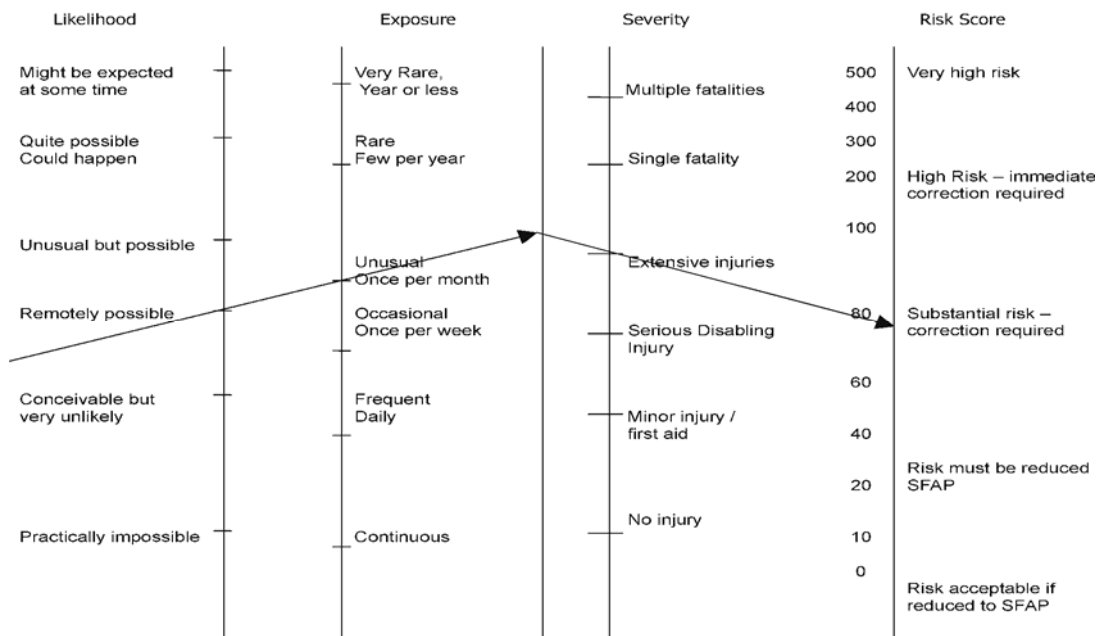


Figure 4. Nomogram recommended for risk assessment of mining operations in Victoria to integrate likelihood, frequency of exposure and severity. Reproduced from the Mining Health and Safety Guidance Note No. 3 (State of Victoria 2002).

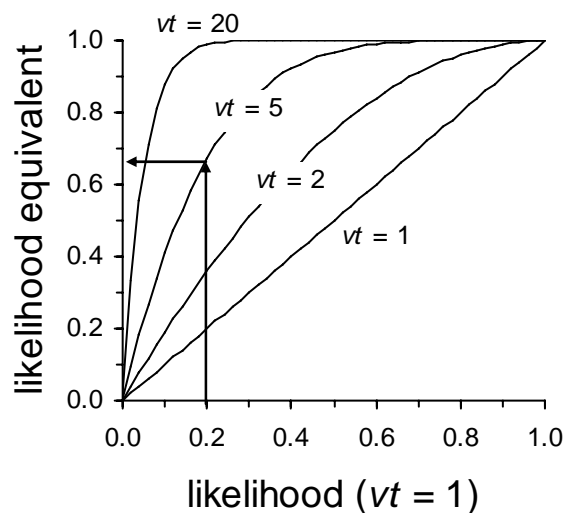


Figure 5. Chart for translating the likelihood from a unit volume of trade (e.g., volume of trade over one year) to a different volume of trade using the geometric model (from C. Thompson, pers. comm.).

The primary difficulty in applying nomograms and other graphs to biosecurity risk contexts is that many of the critical risks have very low likelihoods. Many assessments would result in likelihood estimates on the extreme left of Figure 5, with values much less than one in a thousand.

To deal with situations where most likelihoods are small, it is possible to re-scale the two axes of the nomogram. For example, the axes can be re-scaled to reflect the six language-based probability classes used in Australian IRAs (Table 1). Figure 6 illustrates that a likelihood that is ‘Low’ over a unit volume of trade (e.g. one year), will be ‘Low’, ‘Moderate’ or ‘High’ over 5 units of trade. This interval analysis is analogous to using the limits of the probabilities for ‘Low’ (0.05 and 0.3), and using the probabilistic diagram (Figure 5), or the geometric model $(1 - (1-p)^{vt})$ to convert the probabilities. In this example, the limits for the ‘Low’ category (0.05 and 0.3) translate to the limits 0.23 and 0.83, which are classified as ‘Low’ and ‘High’, respectively, on the language-based scale.

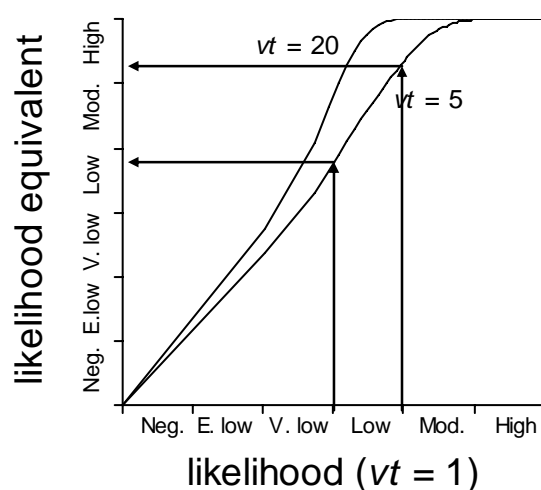


Figure 6. Chart for translating the likelihood from a unit volume of trade (e.g., volume of trade over one year) to a different volume of trade, expressed in terms of the subjective risk scale used in IRAs. The subjective scale was derived by re-scaling the probabilistic scale in Figure 5.

Re-scaling can alleviate the problem of dealing with many low-likelihood events but the straight lines typical of nomograms can become convoluted and more difficult to interpret. There is potential to use them in various parts of the IRA process (e.g. to summarise calculation of probability over volume and time). The utility of nomograms, and the degree to which they contribute to improved understanding and decision-making, would have to be tested before they could be adopted.

In presenting these nomograms and graphs, it is important to emphasise the two assumptions of the geometric model: that the probability of the event occurring is the same for all units; and that the units are independent. These two assumptions might be met if each unit of trade is imported under the same conditions, is of similar size, and if it is sufficiently large (e.g. a shipment or series of shipments of a commodity) but would be unlikely to be met if, for example, the unit of trade was a single piece of fruit. Violations of these assumptions may be taken into account in decision-making by defining units appropriately, or by making a range of different assumptions and evaluating their importance (i.e., doing sensitivity analyses). For example, the importance of violations of the assumption of independence depends on the degree of clustering of pests or diseases (see, for example, Section 6.2).

7. Issues arising

7.1 Language based interpretation of likelihood may be preferable to 'semi-quantitative' numerical thresholds.

One option for estimating parameters in explicit probability trees is for experts to judge the probabilities subjectively, by providing either a quantitative estimate (e.g. a number such as 0.1 per year) or a language-based assessment such as 'low', 'medium' or 'high'. These subjective assessments may be supported by a range of sub-modules, as they are in some BA IRAs. These sub-modules might use rule sets (e.g. Kliejunas et al. 2003), quantitative models, or peer-review processes. We outline some details and issues arising from the use of language-based likelihoods in Appendix 2.

7.2 Dependencies

BA's IRA process assesses the probability of entry, establishment and spread for a unit volume of trade, and assesses the annual probability by using the geometric model (Commonwealth of Australia 2001). An example of this is the Pig Meat IRA (Commonwealth of Australia 2004), in which the basic unit is termed a waste unit. A waste unit is a particular quantity of waste from imported pig meat that is discarded and, if infected, could lead to exposure of pigs in Australia. The annual probability of entry and exposure (for a particular scenario) was calculated as (e.g. Commonwealth of Australia 2004, p. 56):

$$\text{Annual Likelihood of Entry and Exposure} = 1 - (1 - p)^N, \quad (\text{equation 2})$$

where p is the probability that each unit of waste will result in exposure, N is the number of waste units generated by one year of trade, and p is the product of individual probabilities that describe the chain of events that would lead to exposure. The chain of events includes the probabilities that an individual waste unit is infected, the pathogen remains viable, and a sufficient quantity is consumed by another pig to cause infection.

We will demonstrate why dependencies matter, using as an example the within-year geometric model presented in the IRA guidelines. Similar dependencies would also matter when using the geometric model to extrapolate beyond one year. When using the geometric model to calculate the annual probability, it is assumed that these events are independent among waste units. For the sake of illustration, we will ignore the subsequent steps in the exposure pathway.

Assume there is an overall infection probability of 0.00001 for each waste unit. If 1000 waste units are discarded in a year, then the geometric model predicts that the probability of at least one infected waste unit being discarded is $1 - (1 - 0.00001)^{1000} = 0.01$. However, there may be dependencies. For example, consider the situation where there is a small chance that numerous imports from a single source in a year will be infected, but in other years no infected waste is expected from that source. For instance, there is a 0.001 probability that 0.01 of waste units will be infected in a year, and a 0.999 chance that no waste units will be infected. The overall risk per waste unit is the same as used in the geometric model above (0.00001), but the probability of at least one waste unit being infected is now $0.001 \times [1 - (1 - 0.01)^{1000}] = 0.001$. This is an order of magnitude smaller than the estimate obtained with the geometric model.

The purpose of these calculations is to demonstrate that dependencies can lead to large differences in the calculated probabilities of exposure. The nature of the dependencies will influence whether the geometric model will over-estimate or under-estimate the probability of entry, establishment and spread. Currently, BA accounts for dependencies where they are known to exist (e.g. Commonwealth of Australia 2007). We suggest that the risk analyst has a responsibility to substantiate assumptions of independence, wherever they are made, or to bound probabilities appropriately. Otherwise, there will be the possibility that risks will be poorly estimated or misunderstood. There are methods for placing bounds on probability estimates as a function of the assumptions the analyst is willing to make about dependencies (e.g. Ferson 2005).

7.3 How to communicate the temporal dimension of probability

The temporal dimension of probability in the models considered in the preceding Section is expressed as the probability of entry, establishment and spread within a particular period. BA uses a period of one year for import risk assessments. This provides a benchmark for comparing different import risk assessments. The choice of a single year for likelihood estimates allows assessments to rely on relatively reliable trade estimates, but it concerns some Australian stakeholders because what may appear to be a low probability event over one year (e.g. 0.2), can become a much higher probability event when extended to, for example, 10 years ($0.89 = 1 - (1-0.2)^{10}$ from the geometric model). However, this increase in the probability with time is not necessarily transparent to stakeholders.

Alternative frameworks for considering the temporal dimension of probability include the average time to entry, establishment and spread, or the time at which the probability of entry, establishment and spread is equal to a particular value. These alternatives have different implications for communication and implementation.

Expressing the pattern of entry, establishment and spread in terms of the average time removes the need to choose an arbitrary period. The trade-off in using this approach is that the actual time of entry, establishment and spread will almost certainly be different from the average, and given the typically right-skewed nature of arrival distributions (e.g., Balakrishnan and Nevzorov 2003), the actual time of entry is more likely to be before the average time than after it.

Another approach is to determine the time (t) at which the likelihood of entry and establishment reaches a particular value (l). Under the geometric model with annual probability p , this is given by

$$t = \ln(1 - l) / \ln(1 - p) \quad (\text{equation 3})$$

This equation illustrates that, for example, for $l = 0.95$, the critical time is less than 100 years when the annual probability of entry, establishment and spread is greater than 0.03 (Figure 7).

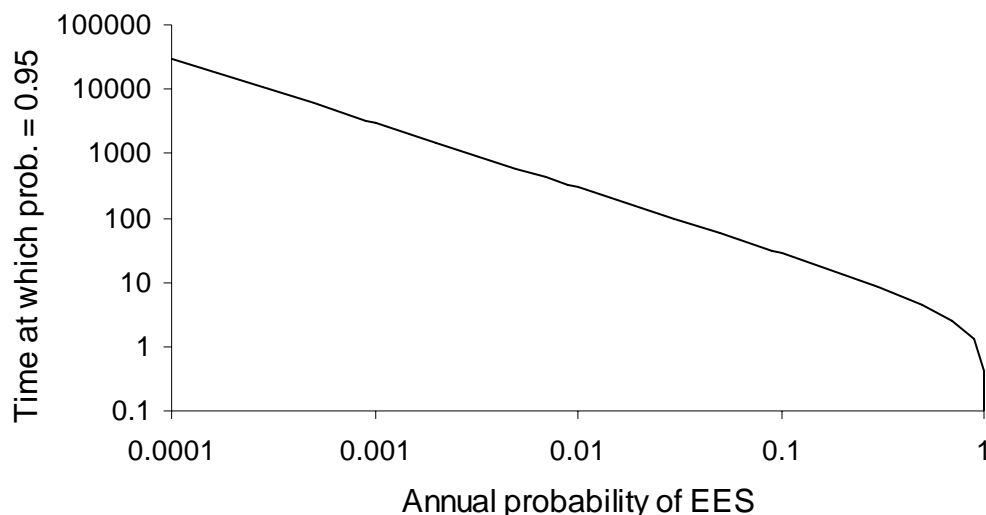


Figure 7. The time at which the cumulative probability of entry, establishment and spread is equal to 0.95 versus the annual probability of entry and establishment, assuming the geometric model. Note that both axes are on a logarithmic scale.

If a method such as estimating the time to reach some probability were used in IRAs, the IRA procedure would need to change to accommodate it. We do not suggest such whole-scale change; rather we suggest that IRAs might be more informative to some stakeholders if other metrics were calculated in addition to the analyses conducted at present.

7.4 Decisions may be sensitive to timeframes: longer horizons may be preferable

BA assesses the likelihood of entry, establishment and spread using the volume of trade over a one year period. Some stakeholders assert that if probabilities were estimated over a different period of trade, recommendations with regard to risk management would not change because likelihoods would need to be scaled to a common standard. Implicit in this argument is that the rank ordering of probabilities over different commodities, pests and diseases would remain unchanged when the period changed (e.g. Figure 1).

If an organism is assessed as higher probability than another for one period, and the assumptions of the geometric model are met, the rank order of the probabilities will be insensitive to the choice of the period over which probabilities are assessed. Import decisions would then remain consistent with the ALOP regardless of the time period chosen.

However, under different assumptions the rank order of probabilities of entry, establishment and spread can change when different periods are chosen (Fig. 3b). This means that if import probabilities are assessed over a one-year period, there might be a decision to not permit one import because the risk exceeds the ALOP assessed over one year, but to allow another because the risk is less than the ALOP. However, the rank order of these probabilities could be reversed if the likelihood of entry, establishment and spread were assessed over a longer period (e.g. 10 years: Figure 8), so the import decision would also change (assuming the same low consequence impact).

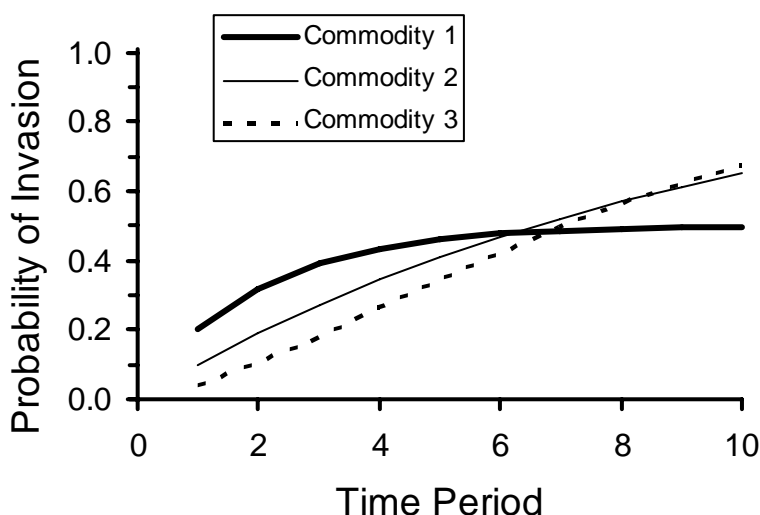


Figure 8. Probability of entry, establishment and spread versus time for three different organisms that have a low consequence impact, summarizing the implications of probabilities changing at different rates over time.

The line labelled 'Commodity 2' in Figure 8 represents a situation where Australia's ALOP is met, as assessed over one year for a low consequence event. The probability of at least one event that causes entry, establishment and spread increases over time according to the geometric model. The underlying hazard rate is fixed. The situation labelled 'Commodity 3' has a probability of entry, establishment and spread that is less than "Commodity 2" at year 1. However, the probability of at least one event increases more rapidly because, for example, the hazard rate is increasing (as in Figure 3). The situation labelled 'Commodity 1' has a greater probability at year 1. However, dependencies such as numerous infected commodities from a single source in a single year and none in other years (Section 7.2) result in smaller chances of at least one event over longer time horizons. The ranking of these three situations is the same at year 5, but is reversed at year 10. This example illustrates the kind of circumstances in which the choice of timeframe may matter.

It may be preferable to use different periods to estimate probabilities for different commodities. BA uses one year of trade to estimate the likelihood of entry, establishment and spread but consequences may be assessed over longer periods. As the period of trade increases, it becomes more difficult to predict the volume of trade reliably, leading to greater uncertainty about the probability of entry, establishment and spread. Although uncertainty about future volume of trade can be accommodated in risk analysis procedures, it is generally true that probabilities are more predictable over shorter periods than over longer ones, a result found in range of disciplines (e.g. McCarthy et al. 1996). Thus, short-term estimates may be preferable.

However, the period used should also be matched to management and investment timeframes (e.g. decision-making timeframes of regulators and of investment decisions by producers) and the biology of the pest or disease (e.g. to account for incubation periods, and likely times until detection). It is unlikely that a period of one year will be the most appropriate choice in all these circumstances.

It is worth noting here that the probability of spread as used by BA, is not the probability of spread within a particular year but is the probability of spread at some stage given that the disease has established in Australia and is assessed to reflect the biology of the disease. Spread is accounted for by extrapolating the outcome of one year of trade to whatever period is necessary for the pest or disease to reach equilibrium. However, this is not explicitly stated in the IRA Guidelines (Commonwealth of Australia 2001) and could be more explicitly stated in these and in individual IRAs. For example, individual IRAs define the annual probability of entry, establishment and spread as the probability of entry, establishment and spread if one year of trade is conducted. The actual spread may occur a considerable time later.

Analyses of probability over more than a single period may be informative, but protocols for how to weigh probabilities that are assessed over different periods would be required if the assumptions of the geometric model were not met. It may be effective to assess and rank risks using the time at which the likelihood of entry, establishment and spread reaches a particular value (as outlined in Figure 7). Decision-makers would need to convert assessments to a common period or time or other probability frame to ensure consistency between decisions. The tools for these innovations would need to be developed and tested for a range of circumstances.

8. Discussion and conclusions

The following points summarise the issues that arose during the development of this report.

1. Currently, IRAs estimate probabilities of entry, establishment and spread based on an annual volume of trade to assess relative risks for a range of commodities.
2. Consequences are assessed using unlimited periods.
3. Communication of probability can be obscured by inconsistent or unspecified timeframes. The occurrence of at least one event (of entry, establishment and spread) that is virtually impossible for a small volume of trade (e.g. of one year) may become much more certain when risks are assessed for larger volumes of trade (e.g. of 50 or 100 years). Volume of trade and associated risks should be assessed over periods that are relevant to decision-making, but also reflect the biology of the organism and other relevant aspects. The periods over which probabilities and consequences are assessed should be stated explicitly.
4. The risk matrix was developed as part of the BA method and BA's position is that it was agreed by all State/Territory governments and the Australian Government. BA uses the matrix to combine the estimates of likelihood and consequence, stating that this provides a level of protection for periods much longer than a year. This report did not evaluate the matrix. Rather, it evaluated more explicit ways of examining risk as a function of volume or duration of trade. Monitoring 'systems failures' can be used to assess how well this risk matrix is functioning in practice.
5. Commodities that trade for more (or less) than a year should be judged in context. The duration or volume of trade may need to be assessed explicitly but there is still a need to convert assessments to a common timeframe or other consistent probability frame, to support consistent decision-making.
6. IRAs account for many commodities and an enormous number of potential pests and diseases. For each, there are usually significant deficiencies in data needed to estimate the likelihoods of various steps in the pathways leading to entry, establishment and spread (and sometimes in understanding of exposure pathways themselves).
7. The equations explored in this report illustrate that it is possible to produce qualitatively different estimates with plausible changes in model structures and assumptions. The geometric model may provide a reasonable approximation but IRAs should include an assessment of the potential for, and consequences of, violations of assumptions.
8. Analysts sometimes overlook the importance of indicating the uncertainty embodied in numerical estimates of probabilities. They are a guide to the relative ranks of the probabilities. Quantitative estimates of absolute probability are rarely reliable when considering extreme values in data-poor and novel circumstances. Models can generate an appearance of false precision, especially when sensitivity analyses are incomplete or are not communicated clearly. The precise results of such quantitative models assist thinking but are not appropriate for decision-making *per se*. There was broad consensus on this point among stakeholders and it was not considered explicitly in this report.
9. The task of BA is to consider the potential ramifications of alternatives. BA's advice needs to account for the ideas that result from models, violations of model assumptions, and the possibilities that modellers have not (yet) thought of, and to deal with the deficiencies in data that are used in them.
10. There are many potential approaches to assessing and ranking probabilities resulting from propositions to import commodities. The product of the probabilities of entry, establishment and spread provides a reasonable template around which to structure assessments. However, human judgement informed by models should continue to have the last say in IRA decisions, combining precedents, accumulated evidence of past successes and failures, and structured expert advice.

11. Few, if any, other countries appear to have explored comprehensively the range of quantitative alternatives to qualitative and subjective risk assessment systems. Where quantitative analyses have been used, they rely almost exclusively on Monte Carlo simulation.
12. A range of methods is available to account for the imprecision of probability estimates. The potential utility of such models to IRAs should be explored.
13. Several ways of communicating probabilities were outlined in the report. These include specifying the probability of entry, establishment and spread for longer periods and specifying the time at which the PEES is equal to some value. Including these metrics in IRAs should be considered.

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10. Appendix 1. The Steering Committee

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11. Appendix 2. Language-based likelihoods

A range of methods could be used to analyse how cumulative probabilities of entry, establishment and spread increase with the volumes of trade. One possibility is to use a language-based assessment for translating likelihoods for one volume of trade to another. This appendix discusses the use of language-based likelihoods.

IRAs conducted by BA use a range of sub-modules to help estimate the likelihood of each step of the potential pathway. When the sub-modules are combined, the complete IRA model can be quite detailed, with a large number of parameters. In many cases there are few data for estimating parameters. A basic principle of modelling is that the complexity of the model should reflect the available information, and a simple model is preferable when data are scarce (Burnham and Anderson 2002). One consequence of using a model with a large number of parameters but few data is that estimates or assessments tend to be imprecise, and precision deteriorates as complexity increases.

A language-based assessment of probability, rather than the use of actual probability values, avoids the requirement to estimate parameters formally. It may be easier for experts to make subjective judgements of probabilities by specifying ordinal values of ‘low’, ‘medium’ and ‘high’ rather than attempting to assign numbers.

However, there are well-documented difficulties of using language-based risk assessments. One obvious problem is that what constitutes a low probability for one person may seem like a high probability to another, particularly if cast in another light. This was seen in the workshop that was conducted for this project, where a stakeholder noted that a 30% probability of a ‘low’ impact hazard seemed like a ‘high’ risk, even though this is regarded as ‘low’ risk in the method used by BA.

A common understanding of language-based risk assessments can be established by defining the terms such as ‘low’, ‘medium’ and ‘high’ in terms of actual probabilities. The consequence is that numerical probabilities are simply re-introduced to the process. Further, different scales may be employed in different jurisdictions, limiting communication. For example, the meaning of a ‘moderate’ probability has very different meanings from risk assessments conducted in Australia and the United States (see Tables 1 and 2).

It is difficult to combine probabilities consistently when using language-based assessments. For example, the IRA guidelines (Commonwealth of Australia 2001, p.41) describe how different likelihoods can be combined, with an example of combining likelihoods in the pathway of entry of a pathogenic agent. The rules state that two ‘low’ likelihoods are equivalent to a ‘very low’ likelihood when multiplied, and two ‘very low’ likelihoods are equivalent to an ‘extremely low’ likelihood. In contrast, a ‘low’ likelihood and a ‘very low’ likelihood combine to form a ‘very low’ likelihood.

There are two possible outcomes of these rules when multiplying two ‘low’ likelihoods and one ‘very low’ likelihood. If first combining the two ‘low’ likelihoods, and then the ‘very low’ likelihood, we have:

$$(\text{low} \times \text{low}) \times \text{very low} = \text{very low} \times \text{very low} = \text{extremely low}.$$

However, if we first combine the very low and one of the low likelihoods, we have:

$$\text{low} \times (\text{low} \times \text{very low}) = \text{low} \times \text{very low} = \text{very low}.$$

This example shows that language-based methods can be sensitive to the order in which operations are performed, making it possible for them to be used improperly or to be misunderstood.

Numerical approaches to multiplying probabilities, including the semi-quantitative and quantitative methods used by BA, are not subject to these inconsistencies. This does not suggest that all IRAs should be based on numerical methods. We do not intend to imply that Monte Carlo and related techniques are a panacea — they are not. Rather, when combining language-base estimates, the results will be more consistent if the methods for combining categories reflect an underlying numerical

logic. There are several quantitative tools that could be used to ensure that language-based methods operate consistently.

For example, when multiplying two 'low' probabilities (defined as the interval 0.05 – 0.3, Commonwealth of Australia 2001, p. 43), the result must be in the range 0.0025 – 0.09 (assuming independence of events), which spans the language-based intervals 'very low' (0.001 – 0.05) and part of the range of 'low'. In contrast, the language-based rules in the IRA Guidelines do not include the possibility that the result of multiplying two 'low' probabilities is 'low', thereby providing an unrealistically precise representation of the likelihood.

An additional issue in using language-based descriptions of probability is that subjective judgements are conditioned by the scale employed (Slovic et al. 2000). For example, if an expert is asked to provide a probability, the results are likely to differ depending on whether the expert is provided with a three point scale 'low', 'medium' and 'high', or a five-point scale 'negligible', 'very low', 'low', 'medium' and 'high'. Therefore, considerable care is required in framing the questions to elicit subjective judgements of probabilities.

We have highlighted difficulties of using language-based assessments in IRAs because similar difficulties would arise when determining how the cumulative probability of entry, establishment and spread would increase with greater volumes of trade. A number of quantitative and qualitative techniques may be useful in supporting language-based methods. They include fuzzy arithmetic (Kaufmann and Gupta 1985), second-order Monte Carlo analysis (Biosecurity Authority 2000), interval bounds of various types (Alefeld and Herzberger 1983, Ferson 2002), and decision theory methods (e.g. Ben-Haim 2006). For example, treating each probability as a bounded interval and specifying the nature of any correlation among variables permits calculation of bounds of estimates (Ferson 2002). The multiplication of two 'low' likelihoods (an interval of 0.05 – 0.3) to produce an interval of 0.0025 – 0.09, is an example of interval analysis. However, there is no broad scientific consensus on appropriate numerical strategies in circumstances such as those encountered in most IRAs. The methods have different strengths and weaknesses in these contexts and they should be explored and evaluated before adoption.

12. Appendix 3. List of acronyms

ACERA: Australian Centre of Excellence for Risk Analysis

ALOP: Acceptable Level Of Protection

BA: Biosecurity Australia

DAFF: the Australian Department of Agriculture, Fisheries and Forestry

IRA: Import Risk Assessment

NOEC: No Observed Effect Concentration

PEES: Probability of Entry, Establishment and Spread

SAC: Scientific Advisory Committee

USDA: US Department of Agriculture