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Putting the quantitative into qualitative Import Risk Assessments

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Report Number: EP/TBC

Australian Centre of Excellence for Risk Analysis (ACERA), Project 0705

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Abstract

This report considers ways of reconciling qualitative and quantitative import risk assessment methods. There is a current view within some quarters that the use of these approaches requires a choice, and that the use of one approach precludes the use of the other. This is explored in this report, and ways of constructing the analysis from a logical foundation is developed.

Both approaches have been used previously in setting biosecurity policy and both have strengths and weaknesses.

Qualitative analysis is by far the predominant technique for performing import risk analysis. What constitutes a qualitative analysis varies widely. The analysis typically breaks up the risk pathway into steps such as entry, establishment and spread and then assesses the likelihood of these steps in some way, consistent with relevant international standards.

The repeatability of qualitative analysis can be debated for a number of reasons. First, its use of loosely defined terms such as Low, Medium and High means that there is ambiguity in their meaning. Second, questions in the analysis are often vaguely defined so there can be significant ambiguity in their definition. Third, techniques to combine the components of the assessment to reach an overall conclusion are typically ad hoc and not based on rigorous analysis.

Quantitative analysis offers the potential for greater transparency and interpretability. Given this, the approach also adds significant technical overheads and challenges when data is sparse or not available. The transparency of the approach invites high degrees of scrutiny which can complicate debate. A simple model can often fail to represent a complicated pattern of trade, leading to significant problems. In responding to this, models can become too complicated. Thus the use of quantitative methods does not, in itself, guarantee an improved analysis.

In this report we develop a quantitative import risk assessment model that is structured equivalently to qualitative import risk assessment models. This means that it will consider the steps of entry, establishment and spread. While the model is quantitative, in the sense that beliefs are expressed numerically, it is anticipated that it will typically be populated by expert-based assessments. We produce clear definitions for the quantities we are eliciting from the experts to ensure that conclusions from the process are logical and well founded. The advantage of the proposed approach is that it will produce an assessment consistent with international standards while clearly communicating its logical basis.

To do this we first describe the risk assessment problem. This highlights the complexity of the task and the diverse range of issues that need to be considered in making an assessment. We then consider the mechanics of probabilistic modelling of this system. While many authors suggest the ad hoc use of probability distributions for dealing with uncertainty, they rarely address the issue holistically, assessing how the results of the analysis map to the real world problem we are considering. With our understanding of the problem and the probabilistic framework we have developed, we consider issues in defining a quantitative analysis. We explore the complications that arise in the context of import risk analysis and show why simple models with strong independence assumptions can fail. Building on this analysis, we consider how an analysis concentrating on entry, establishment and spread could be framed in a quantitative way, and use this to propose a possible set of questions that could form the basis of a compact and rigorous expert-based import risk assessment system. The results are then applied to a simple example.

This is not an academic exercise. Lack of consistency in application of policies because of different interpretations of questions adds an element of randomness to the decision making process. This is because the outcome of the process could depend on the individuals

involved rather than the details of the particular case. Ambiguity in the process also opens up the possibility of manipulation by interested parties. If the meaning of questions is not transparent, parties can make assumptions about the meanings which favour the outcome they want. The ambiguity provides an element of confusion to the debate that can potentially cloud communication. Finally, a clear mathematical framework is the foundation of any logical analysis. By laying this foundation we will be able to successfully and logically integrate appropriate tools for issues such as uncertainty analysis and expert elicitation. Without this, ambiguity could be potentially the biggest source of uncertainty, nullifying any potential benefits of new techniques trying to improve the outcomes of the biosecurity system.

This report is targeted at technical scientists and policy makers within biosecurity agencies. It will hopefully contribute to the debate and thinking about future development of import risk assessment techniques.

1 Introduction

Exotic organisms pose significant threats to agricultural production and the environment world wide. Agricultural pests and diseases can have a range of consequences from imposing additional management costs to making further economic production unviable. Environmental pests can significantly alter ecosystems leading to losses of biodiversity and amenity. Examples abound. Marine pests have had considerable impacts internationally (Bax et al., 2003). Red Imported Fire ants have caused significant damage in a number of countries (McCubbin and Weiner, 2002). Fire Blight (*Erwinia amylovora*) has the potential to have major effects on fruit production in susceptible countries (Biosecurity Australia, 2007). Dutch elm disease has had significant international impacts (Gibbs, 1978).

In addition to these direct effects there are the separate but related impacts on a country's ability to trade. The pest and disease status of a country can lead to trade restrictions on the exports of the nation's industries. Examples include Foot and Mouth disease in cattle (Hartnett et al., 2007), Karnal Bunt in cereals, various species of fruit fly in horticulture and Khapra beetle (*Trogoderma granarium*) in stored grain.

Given the significant implications of bioinvasion by exotic organisms, many countries impose conditions on the importation of live organisms or commodities that may contain harmful agents. These conditions are designed to ensure that the risk to the country is acceptably low. In this report we specifically consider the assessment of risk for the importation of agricultural commodities through managed trade, although the discussion and conclusions are relevant to other potential modes of entry. Import risk assessment is the tool used to assess whether the risk of importing a commodity is acceptable, potentially after mitigation measures are applied. As this assessment can be used as the basis for blocking trade in a particular commodity between two countries there is potential for nations to use the approach to protect domestic industries. This can lead to significant tension between countries.

To resolve these complex issues an international system has developed over time to try and standardise, at some level, the acceptable and unacceptable approaches to import risk assessment. The current international system is administered by the World Trade Organisation (WTO). The WTO currently has 153 countries as members. Within the WTO there is the Agreement on the Application of Sanitary and Phytosanitary Measures - also known as the SPS Agreement. This agreement sets constraints on member-states' policies relating to food safety (bacterial contaminants, pesticides, inspection and labelling) as well as animal and plant health (phytosanitary). This agreement relies heavily on the international guidelines produced by the International Plant Protection Committee (IPPC) for plants (FAO, 1996, 2004) and the International Office of Epizootics (OIE) for animal products (OIE, 2004a,b). These guidelines are high level and provide information about the structure and language of an assessment without mandating the detail. They are the result of long term international cooperation and negotiations.

In addion to these, there are standards developed for treatment of particular pests and packaging developed through the IPPC and the OIE, and there is activity to increase the scope of these standards (Bill Roberts *pers. comm.*). Given this, countries can still apply their own risk assessment applicable to their circumstances and conditions. In this context there has been debate about the role of quantitative and qualitative analysis methods.

Broadly speaking, quantitative analysis involves quantification of probabilities of occurrence of events and a framework for logically and coherently combining them. See for example Vose (2008), Granger et al. (1990), OIE (2004b). Quantification may involve inference from data or direct expert opinion. Qualitative analysis typically involves assigning subjective terms such as high, medium and low to the steps involved in the risk analysis. They are then sometimes combined together using administrative rules. Examples of these approaches in import risk analysis include the Australian, NZ and US systems (Biosecurity Australia, 2001; USDA, 2000; OIE, 2004a).

Qualitative analysis is by far the predominant technique for performing import risk analysis. What constitutes a qualitative analysis varies widely. The analysis typically breaks up the risk pathway into steps, such as entry, establishment, and spread and then assesses the likelihood of these steps in some way. This is consistent with the relevant standards. The Australian system uses qualitative assessments of entry, establishment and spread and combines them through a standard matrix. The United States and Canada use different qualitative systems which map judgements to a scoring system which is then used in decision making (see for example USDA (2000)). European countries use a qualitative system and an expert-based integration (European and Mediterranean Plant Protection Organization, 2009).

As an example, consider the approach described in USDA (2000) for use in decision making in the United States of America. In this system the terms Low, Medium and High are used to describe likelihood. The outcome of the analysis depends on the answers to 11 questions. For each question, answers are mapped to the qualitative descriptors, which are then mapped quantitatively by Low to 1, Medium to 2 and High to 3. The final score is found from summation of the scores. This score is then mapped to a final qualitative descriptor through another rule, which defines the outcome of the assessment. There is ambiguity about the meaning of questions with respect to a complex trade and with the calibration of the scores to the decisions. For example, do two pests with the same score represent the same risk? In discussing this system we do not imply that it is without merit as a decision support tool. While logical anomalies can be found it is important in this analysis to acknowledge the logical structure of these assessments. The questions asked are relevant to the assessment of risk and there can be some confidence that organisms with very high scores represent a higher risk than organisms with very low scores. The question we consider here is how we can better ensure that the results of an approach are transparent, efficient, repeatable and interpretable.

As another example, a different qualitative approach is applied by Biosecurity Australia when assessing the risk of table grapes from Chile (Biosecurity Australia, 2005). In this approach simple descriptors such as Negligible, Very Low and Moderate are used to describe likelihood and these are combined by a matrix. The performance of the matrix is justified administratively as part of the process rather than logically. There is typically no coherent logical framework, in a mathematical sense, involved in the construction of frameworks for combining qualitative descriptors. With the Australian system the assessors rate the likelihood of entry, establishment and spread using qualitative terms. An assessor could rate the probability of entry of a pest as Low if they thought ”the event was unlikely” and the probability of establishment Moderate if they thought ”the event would occur with even probability” (Biosecurity Australia, 2005). These are combined by a matrix of rules (Table 3, (Biosecurity Australia, 2005)) to assess that the probability of entry and establishment is Low. This Table is administrative, in the sense that it is not justified by rigorous analysis. To explore this, consider that the logical process of calculating the probability of two events is:

$$Pr(A \text{ and } B) = Pr(B|A)Pr(A)$$

for events A and B. $Pr(A \text{ and } B)$ is the probability of the events A and B occurring together. In this example A is the event “Entry” and B is the event “Establishment”.

Thus it is only logical to calculate the probability of two events occurring by the products of probabilities if they are correctly conditioned. For example

$$Pr(\text{Entry and Establishment}) = Pr(\text{Establishment}|\text{Entry})Pr(\text{Entry}).$$

Note that

$$Pr(\text{Establishment}|\text{Entry})Pr(\text{Entry}) \neq Pr(\text{Establishment})Pr(\text{Entry}),$$

unless the events “establishment” and “entry” are independent. This is never true, as establishment cannot occur without entry. The process of framing the question to the analyst, for example “What is the probability of entry?”, does not have sufficient detail to ensure appropriate conditioning. This would require consideration of technical issues such as sample spaces and a rigorous definition of probability. It could occur implicitly, but it is not guaranteed by the protocol.

Users can justify the value of qualitative approaches to risk assessment for decision making using a variety of arguments. These include:

- That the risk analysis process is an end in itself. By doing the risk assessment, the analyst has had to think about the problem in greater detail and has thus had an opportunity to reflect on the risks involved. This will add significant value. The decision from the assessment will reflect the analyst’s greater awareness, but is not logically tied directly to it.
- That the risk assessment is an administrative process and is calibrated against the outcomes of the process. For example, an organisation typically applies a risk tool to multiple decisions. In the current context a biosecurity agency will assess a large number of commodities and trade applications. Provided the outcomes of the decisions are consistent with the aims of the process then it can be argued that the tool is well calibrated. The justification of the tool is external to the logic of any one particular assessment. A biosecurity agency might seek to limit the number of damaging incursions to a very low number. If the risk process adopted achieves this in an efficient manner it could be declared successful.
- That a quantitative analysis is not necessarily more objective, nor are the results more precise, than a qualitative analysis. This argument is made in OIE (2004a) but its basis is not transparently explored.
- That a qualitative analysis allows comparative assessment of risk rather than absolute estimation.
- In the absence of data the qualitative approach provides the only reasonable basis for representing views. This relies on arguing as follows. A quantitative analysis constructs a model based on known data and knowledge, and generates an outcome. If the outcome is inconsistent with their views, which may include knowledge not included in the model, they will modify their model, update the outcome of the model and iterate, until the internal beliefs in the model and the external beliefs about the outcome can be reconciled. Thus in the absence of any information/data within the model it is the overall assessment that will prevail and the modelling process provides no additional value.

The qualitative approach can be criticised for not being repeatable. While it is generally agreed that a single individual could use a qualitative risk analysis to perform comparative analysis, difficulties arise as soon as more than one person is involved. If qualitative descriptors are not defined the result is not clearly interpretable. A further challenge to repeatability arises in the questions asked. In many analyses the time period and the volume of the trade are not considered explicitly in framing the questions so ambiguities can arise. Different people applying the same methodology can come up with different outcomes because of the linguistic uncertainties (Regan et al., 2002) inherent in the approaches. Because of this, and the requirements of international agreements, proposals to achieve greater transparency via more explicit quantification appeared in the scientific literature (Miller et al., 1993; Gray et al., 1998; Firko and Podleckis, 2000). This led to a significant literature based on the expression of uncertainty using probability distributions and analysis via Monte Carlo methods (for examples of this approach see Vose (2008); Cox (2009)).

Quantitative approaches to import risk assessment typically construct a model of the expected trade to try and quantify the risk. Approaches for animal products are discussed in OIE (2004a,b). They rely heavily on pathway analysis and the use of statistical calculation based on strong assumptions of independence, at least in their most common form. While dependence is acknowledged and techniques for addressing it, such as conditioning and correlating variables are discussed, the suitability of these for practical implementation is often questionable. Data is limited and scientists not trained in quantitative methods lack experience in manipulating and estimating the likelihood of events.

The application of these quantitative techniques therefore has a number of significant challenges. It can be difficult representing complex trade using simple pathway analysis. There are additional requirements for data, often relating to rare events that have not occurred, typically because there is no history of trade. The approach adds significant technical overheads and challenges when data is sparse or not available. Finally, the transparency of the approach invites high degrees of scrutiny. It is reasonable to suggest that formal quantitative analysis is not widespread in international biosecurity policy and that its use is less than 5 years ago.

Given this background, it is timely to consider how the strengths of quantified approaches can be applied to import risk analysis, without the pitfalls. This report explores the linkages between the approaches and develops a transparent framework for framing questions and ensuring the logical consistency of the results. It is a novel representation and discussion of an old problem and will hopefully add to the debate about ways to improve import risk assessment into the future. It is not an assessment or judgement of any one countries' approach to this problem. Import Risk assessments are administrative procedures and different countries will have different approaches to the issue that are consistent with their international obligations. This report simply seeks to provide the empirical and logical foundations to developing a practical, logically based system.

This is not an academic exercise. Failure of consistency in application of policies because of different interpretations of questions adds an element of randomness to the decision making process. This is because the outcome of the process could depend on the individuals involved rather than the details of the particular case. As an example, Figure 1.1 presents results from an elicitation exercise run by the Australian Centre of Excellence for Risk Analysis on the proportion of farms in India infested by mango weevil (Burgman et al., 2010). Note the considerable variation in beliefs expressed by the different experts. While this cannot be unambiguously attributed to any one source it is not unreasonable to conclude that misunderstandings about the meaning of the questions contributed to this variation. Ambiguity in the process also opens up the possibility of manipulation by interested parties. If the meaning of questions is not transparent, parties can make assumptions about the meanings which favour the outcome they want. The ambiguity provides an element of confusion to the debate that can potentially cloud communication. Finally, a clear mathematical framework is the foundation of any logical analysis. By laying this foundation we will be able to successfully and logically integrate appropriate tools for issues such as uncertainty analysis and expert elicitation. Without this, ambiguity could be potentially the biggest source of uncertainty, nullifying any potential benefits of new techniques trying to improve the outcomes of the biosecurity system.

The report is structured as follows. In Section 2 we will consider how to design a quantitative approach to an assessment based on considering only entry, establishment and spread. In Section 3 we discuss the possible implications of the results for import risk analysis.

2 Designing a quantitative, qualitative import risk assessment system.

2.1 Outline

We seek to define a quantitative import risk assessment model that is structured equivalently to qualitative import risk assessment models. This means that it will consider the compound steps of entry, establishment and spread. While the model is quantitative, in the sense that beliefs are expressed numerically, it is anticipated that it will typically be populated by expert-based assessments. We want to construct clear definitions for the quantities we are eliciting from the experts to ensure that inferences from the process are logical and well founded. The advantage of the proposed approach is that it will produce a compact assessment consistent with international standards while clearly communicating its logical basis.

We will develop this as follows. We will first describe the risk assessment problem. This will highlight the complexity of the task and the diverse range of issues that need to be considered in making an assessment. We will then consider the mechanics of probabilistic modelling of this system. While many authors suggest the use of probability distributions for dealing with uncertainty (see Vose (2008), for example) they often consider only simple models and phenomenon. They rarely address the issue holistically in complex cases, assessing how the results of the analysis map to the real world problem we are considering. With our understanding of the problem and the probabilistic framework we have developed, we consider issues in defining a quantitative analysis. We explore the complications that arise in the context of import risk analysis and show why simple models with strong independence assumptions can fail. Building on the analysis in the previous three sections, we consider how a qualitative analysis concentrating on entry, establishment and spread could be framed in a quantitative way, and use this to propose a possible set of questions that could form the basis of a compact and rigorous expert-based import risk assessment system. We will then demonstrate its application through an example.

We note that we do not consider the issues of consequence assessment in this report. The primary focus is on estimating the probability of entry, establishment and spread. The estimation of consequences is a significant research task. This is considered by Hood (2010) in a companion report.

In the following we will typically use the term infested to describe units that have the biosecurity threat. This does not mean that the analysis is restricted to arthropod pests. The analysis and discussion is equally relevant to other biosecurity threats.

2.2 The Import risk assessment problem

In the following section we discuss the import risk assessment challenge generically. Some terms have very specific meanings under the OIE or IPPC guidelines (OIE, 2004a,b; FAO, 1996, 2004). In this section we argue at a higher level and consider the risk assessment process in a generic way. This allows consideration of the logical issues without becoming bogged down in the administrative detail.

Import risk assessment is about assessing whether a proposed trade represents an unac-

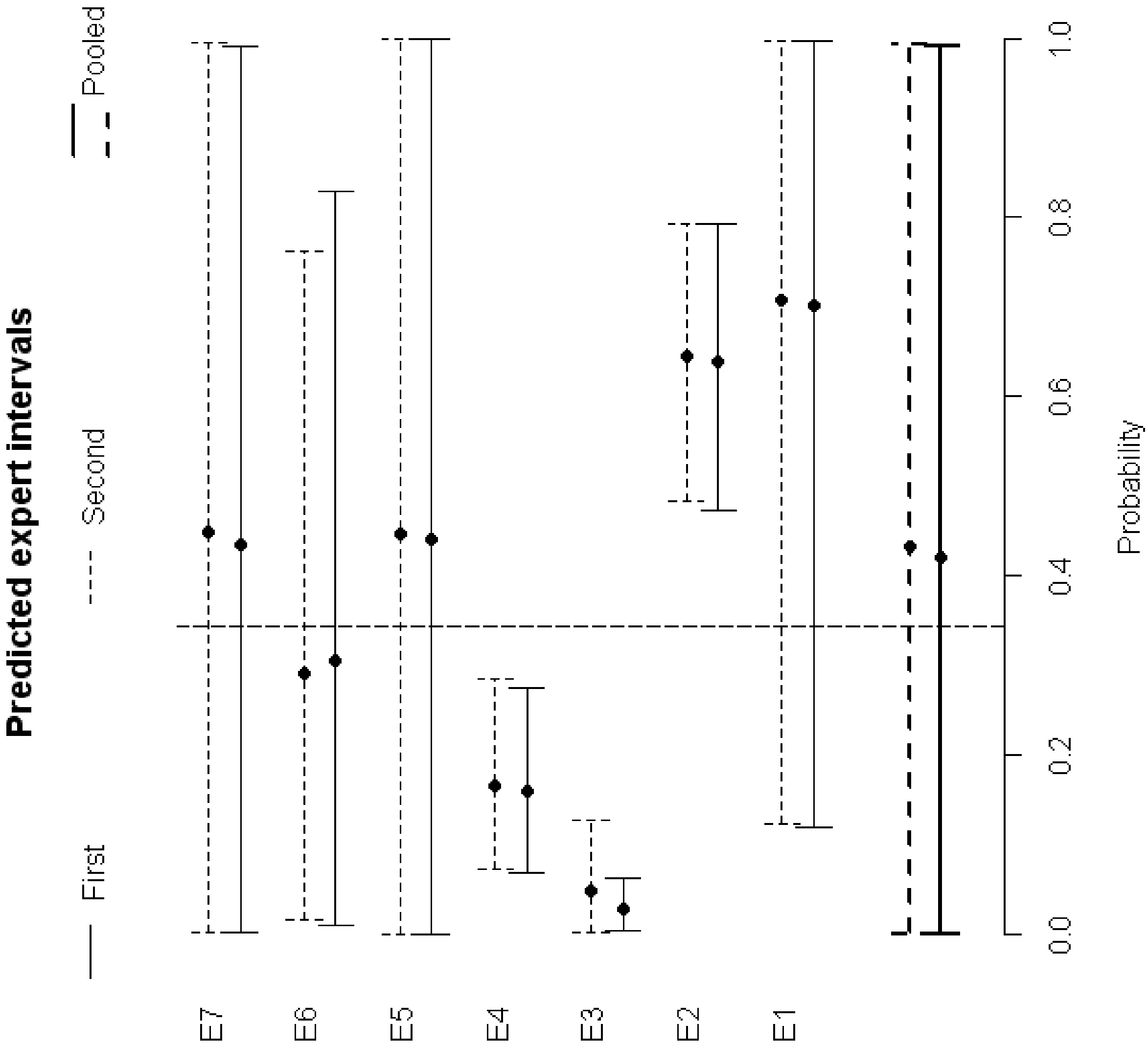

Figure 1.1: Results of elicitation of proportion of orchards infested with Mango Weevil. E refers to the different experts. The x axis shows the different experts and the y axis the probability ranges elicited. (Source: Keith Hayes)

ceptable risk of an adverse outcome. In assessing whether trade in a commodity is dangerous it is necessary to consider the nature of the proposed trade. In the preliminary steps the analyst needs to consider the nature of the pests and diseases in the exporting country and which of these are of sufficient concern to warrant more detailed analysis. The volume of trade, the time scale (one-off or ongoing) and the potential nature of the trade, and use of the material in the recipient country, need to be considered. The biology of the organism has significant impacts. Issues such as its survival during packing and transport, its ability to be detected by inspection and the density dependence of its establishment dynamics will all have bearing on the risk posed by the organism via the trade. All major systems currently in use internationally consider at least some of these factors.

At this point we make a fundamental assertion which is, hopefully, not controversial. We claim that if an individual is doing an objective, science-based assessment of the risk of an organism associated with a particular trade then their beliefs about the nature of the trade and the behavior of the pest should not depend on the type of assessment being performed. The choice of qualitative or quantitative analysis does not change the aims of the analysis and the nature of their understanding of the process. Understanding will surely vary from expert to expert, but within a particular expert it should be consistent. The trade occurs in the physical world. Particular aspects may be uncertain or unknown but we need to accept that they relate to observable and quantifiable processes. In simple terms, we need the way the analyst thinks about the trade to remain the same regardless of the tool used. If this assertion is not true there are significant additional issues that need to be addressed in choosing risk assessment methodologies, and the role of science needs to be considered carefully. This point is important as it means we do not have to consider different physical processes for different risk analysis techniques.

We have produced a number of figures which illustrate some of the main features of commodity based import risk assessment problems. These figures are consistent, in that they represent the same physical process. Where they differ is that they represent different abstractions of the process so the reader should be careful in interpreting them. The key to modelling any system, either qualitatively or quantitatively is to find an abstraction that is consistent with the underlying process and also able to be comprehended by the experts that you intend to elicit information from.

The potentially complicated and complex nature of the trade is shown schematically in Figure 2.1. This figure shows potential interactions between elements in the export pathway. Each line represents a path of material. The key issue to note is the potential mixing and aggregation of material along the pathways. Pests and disease are aggregated on farms. Exporting business can accumulate material from different locations. Inspection is applied to shipments. An early reviewer of this report noted that the figure was too “busy”. This is a key point of the figure. The pattern of trade is potentially very complicated and on a large scale. It is typically more complicated again, than this stylised figure suggests. The dynamics of establishment are density dependent (Hayes and Barry, 2008) and there is potentially considerable heterogeneity in the system. Note we have aligned steps in the process with the concepts of entry, establishment and spread for later discussion.

A more detailed breakdown of a restricted component of the trade is given in Figure 2.2 which considers a small number of farms. In this figure the lines represent individual items of fruit and the figure highlights how fruit from different farms may be packed in different locations. This figure is included to highlight the path of individual fruit. The risk assessor needs to consider the trade at a number of levels and abstractions.

Figure 2.3 represents the trade schematically, based on individual units. The unit could be a range of things such as a fruit, an animal, a bunch, or a box of fruit. In this figure each line represents a unit of trade as it passes along the trade pathway. Marks on the line track the events that occur to the unit as it is infested or disinfested of the organism. We note that for reasons discussed previously, considering the likelihood of infection for one unit can require thinking of interactions with other units, potentially at a range of scales. This figure is useful as it represents the abstraction used in many quantitative assessments.

These three figures give a number of different abstractions. While there are a range of other abstractions that could be represented, those shown reflect the obvious approaches. A fixed unit analysis is reflected in OIE (2004b) and Biosecurity Australia (2007). The full process Figure 2.1 represents the complete case. Summarising the discussion of this section we have argued a number of points:

1. That a person's belief about the nature of a proposed trade is independent of the assessment method used.
2. That the nature of trade in commodities often involves complex interactions and pathways.
3. That there are a number of different abstractions of the trade that can be considered in attempting to model the probability of an adverse event.

2.3 Probabilistic Modelling

An analyst performing a risk assessment needs to have a mental view of this complex trade to perform their analysis. It may be incomplete, based on analogous situations rather than raw data and it may have uncertainties. This is the nature of import risk assessment. The analyst still needs to consider how they can logically perform their assessment and express their views from the available information in a logical and coherent way.

While compiling this information can be an arduous and complicated task, the real challenge arises when trying to integrate this into a logically coherent assessment. Trade is complicated. The epidemiology of many pests and diseases is uncertain. The assessment needs to form inferences that are consistent with any available data and related information, and express the potential uncertainties.

The purpose of an import risk assessment is to make a prediction about the likelihood and consequence of an event in the future. We consider that probability is the most widely accepted technique for modelling uncertainties but recognise there are a range of other approaches that have been proposed (see the companion report Hayes (2010)). There are two main philosophical approaches to specifying probabilities in this context. The frequentist approach would consider defining things in terms of long run frequencies (Welsh, 1996). Mentally, this entails thinking of multiple "worlds" and considering the possibilities in these worlds. These possibilities would incorporate the uncertainty in the analysis that was deemed important. For example natural variation over the scale of the analysis and variations in trade patterns could be potentially incorporated. With this view there are no distributions over the parameters, only long run frequencies. Approaching uncertainty in this framework is somewhat contrived with its use of multiple worlds that could exist and there is not a deductive way of developing the universe of possibilities. The alternative is to consider subjective probability. In this case the analyst needs to consider specifying the range of possibilities for the scenario considered in the risk assessment and the associated plausibilities of these possibilities. The plausibilities are defined in terms of the assessor's beliefs and are defined to be coherent. The plausibilities are represented by probabilities, and we use the terms interchangeably in this report. The subjective approach is a foundation of Bayesian inference (Welsh, 1996). The Bayesian approach is more tractable to discuss in this context and we adopt it here. We note that we have focussed on a "subjectivist" interpretation of Bayesian analysis. We argue that this is appropriate when considering expert beliefs.

In the following discussion, we understand that experts will typically never explicitly

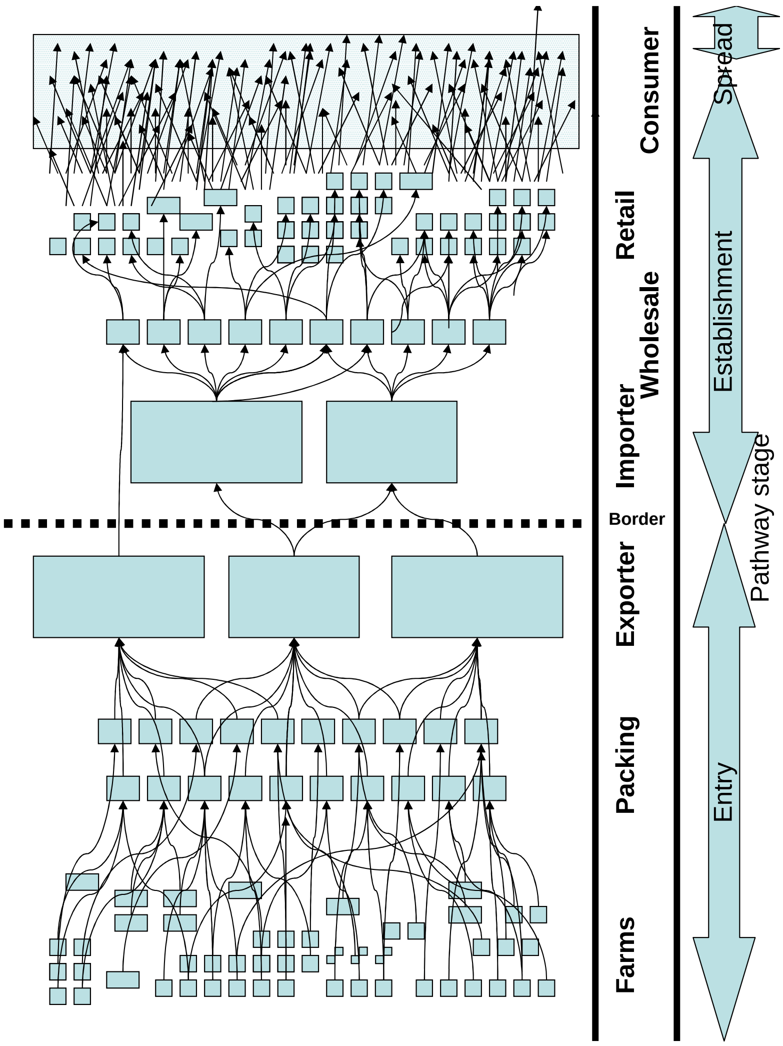

Figure 2.1: Graphical representation of the complex nature of trade in a commodity. Lower bar shows the compound steps typically used in import risk. This figure shows figuratively the potential movement of material between different entities in the importation pathway. Note that different parts of the pathway can expose susceptible hosts to risk.

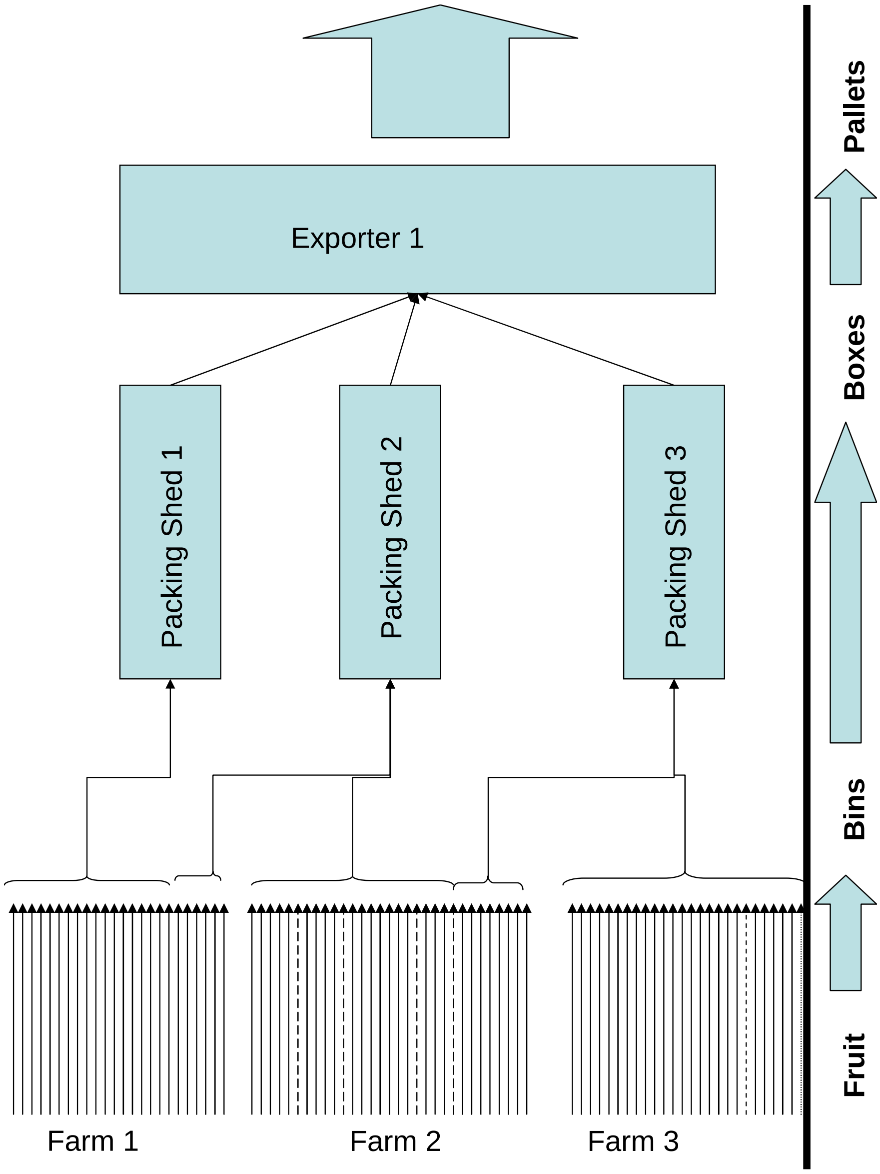

Figure 2.2: Graphical representation of the movement of infested material from farms. Dashed lines represent infested fruit.

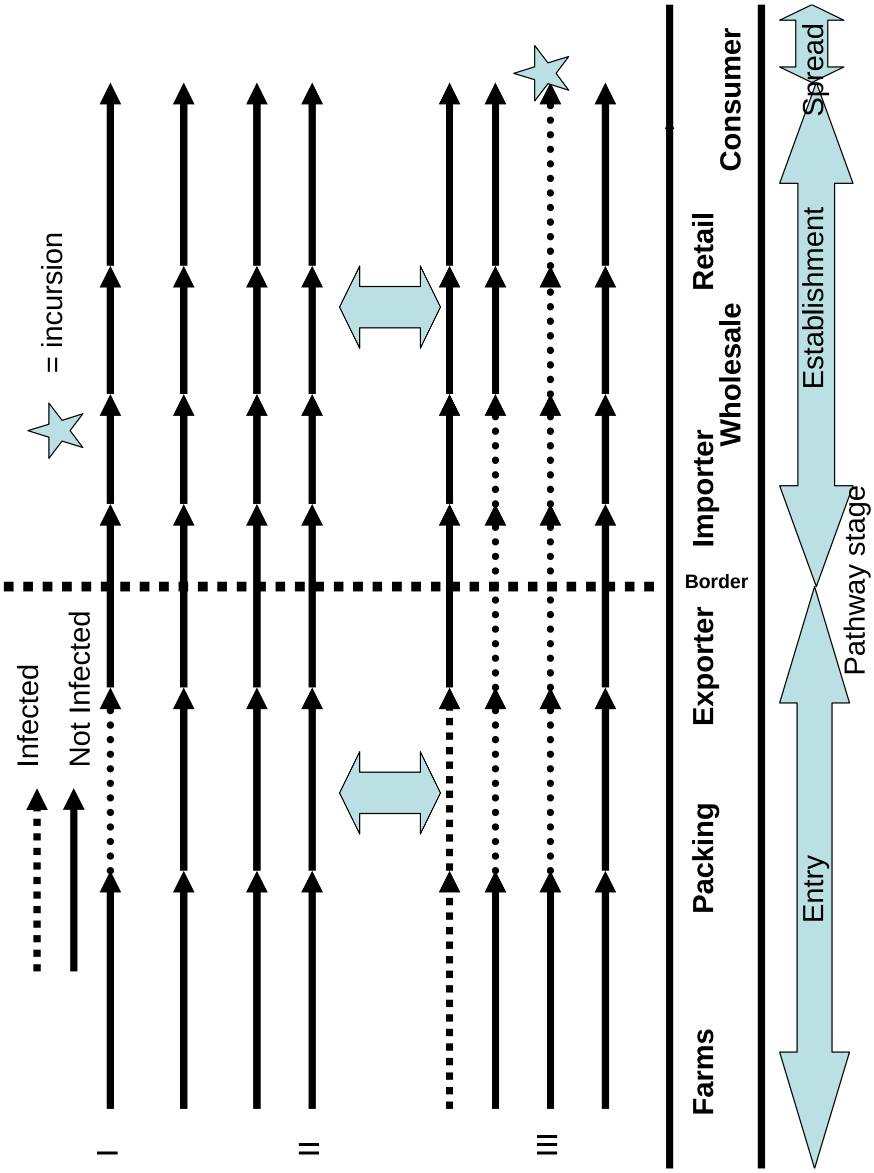

Figure 2.3: Alternative representation of trade as individual fruit, showing schematically how fruit can become infested and uninfested at different stages of the importation pathway and can potentially lead to an incursion, denoted by the star.

perform the process presented here. In most cases it would be too complicated to construct the universe of possibilities and associated plausibilities in this way, and would effectively be a full quantitative analysis. The abstract presentation in this section instead aims to to provide a framework for discussing the relevant issues that the expert needs to consider, and as a framework for answering queries about the correct approach to thinking about uncertainty and variation. This will be considered in more detail later in the report.

The first thing to consider is the range of possibilities. In the abstract, this is the set of all things that could possibly occur. Depending on the definition of the question, they could range over possible processes, environmental conditions and stochastic outcomes. It is helpful to think of this hierarchically. We consider first the set of possible scenarios. As an example, Figure 2.1 represents one possible representation of how the trade may occur. An expert might think there are a range of possibilities for the pattern of trade. The regulator might specifically ask the expert to consider several different scenarios. In addition, the future physical environment is uncertain as there is inherent variability in factors such as the weather, which will have major impacts on many biological phenomenon. Thus the set of possible scenarios can range over both the physical nature of the trade, uncertainties in the biological systems and the associated environmental conditions. We denote that set $\{\omega_i : i = 1, \ldots, K\}$, where K is typically large, and often infinite. For example ω_1 might represent the pattern of trade shown in Figure 2.1 and the same weather as occurred in 1952, say. The element ω_5 could represent the pattern of trade shown in Figure 2.1 and the same weather that occurred in 1976. The element ω_{976} could represent a (defined) different pattern of trade and the weather that is predicted for a particular year under a climate change scenario. We note that this example is heuristic and we ignore the associated technical discussions of countable and uncountable sets required to explore the definition of the ω_i as these do not impact on the point we are trying to make.

The elements ω_i represent particular possible trading structures and environments. In considering the possibilities that could occur from a given pattern of trade and environmental conditions stochastic considerations need to come into play. Incursions are rare events and are typically neither certain nor impossible. The analyst needs to define the possibilities for each element ω_i. Possibilities in this case relate to the physical status of infection, establishment and spread across the trade and associated environment defined by the ω_i. We denote the set of possibilities for a given element ω_i as $\{\omega_{ij} : j = 1, \ldots, M\}$. The possibilities are typically numerous. Imagine all the possible infection states of all the units across the trade, and the associated establishment and spread events. A key point to note is that the ω_{ij} are stochastic outcomes of the given trading structures and environments. Thus for each ω_{ij} we can make statements such as "the proportion of infested units imported was x%"and "The number of establishment events was y". The answers to these questions will typically vary across the ω_{ij}.

Given that we have defined all the possibilities, it is necessary to associate with them plausibilities, typically represented as probabilities. These probabilities represent the relative likelihood of different possibilities and express the expert's beliefs (Cooke, 1991). With each element ω_{ij} there is an associated probability μ_{ij}. We have

$$\sum_j \mu_{ij} = \mu_i$$

with μ_i representing the probability that the ith scenario occurs. We also have

$$\sum_j \sum_i \mu_{ij} = 1$$

as they are probabilities. These are not probabilities of particular parts or aspects of the process but of the overall stochastic outcomes of the given trading structures and environments.

While this description may appear abstract it has a direct linkage to the use of Monte Carlo methods in pathway models. With simple Monte Carlo methods assuming a specified environment we have a fixed scenario ω_i (the "model"). The probability model specified for the pathway implicitly defines the the $\{\omega_{ij}\}$ and $\{\mu_{ij}\}$. The Monte Carlo process lets us draw samples from this distribution and hence estimate the $\{\mu_{ij}\}$ empirically. If the Monte Carlo model includes variation in the scenarios relating to climate or biology it is implicitly defining multiple ω_i. The point to note is that our derivation has started by considering what the individuals beliefs are. How we populate this (via Monte Carlo techniques, perhaps) is a secondary, technical issue. In particular, if the starting point of the analysis is specifying distributions over parameters and using Monte Carlo, we should ensure that the implicitly defined universe of scenarios, possibilities and plausibilities is consistent with our beliefs.

To calculate the probability of an event Q we define the indicator function $I()$ with

$$I(Q) = \begin{cases} 1 & \text{If Q occurs} \\ 0 & \text{otherwise} \end{cases}$$

We note that the expected value of I(Q) is simply the probability of Q. To see this note that

$$E[I(Q)] = \sum_{ij} I(\omega_{ij} \in Q)\mu_{ij} = 1 \times Pr(Q) + 0 \times Pr(\text{not } Q).$$

There is nothing mysterious about the indicator function. It simply allows us to write compactly what the probability of an event is. It simply sums the probabilities over the elements that are in the event Q. In summary this section has:

1. Defined the probability space in a clear and explicit manner.
2. Developed a hierarchial approach that partitions the possibilities into scenarios that may be possible, and the different stochastic outcomes that can occur within a scenario.
3. Discussed how to calculate the probability of particular events.

2.4 Quantitative import risk assessment models

As discussed in the introduction, developments in international trade have required developments in science-based risk assessment to consider threats to a country's biosecurity. Through the 1990's a number of papers (Miller et al., 1993; Gray et al., 1998; Firko and Podleckis, 2000) called for greater quantification of risk as a way of ensuring transparency and scientific rigour. These papers where typically based on considering the pathways that imported material would follow to cause an incursion. An abstract example is shown in Figure 2.4. An example of this approach used by a country is the assessment of risk from NZ apples to Australia developed by Biosecurity Australia (Biosecurity Australia, 2007). The pathway analysis used in the apples analysis is shown in Figure 2.5.

It is reasonable to ask why we don't simply advocate the application of the existing quantitative approaches. This section considers this issue. It looks at the limitations of existing approaches and the logical problems that arise. This analysis will be used in defining an alternative approach in the next section.

Beginning with Miller et al. (1993), most analyses chose a unit of trade and made strong independence assumptions to calculate risk (Gray et al., 1998; Firko and Podleckis, 2000). They assumed each unit acted independently in terms of how it contributed to overall risk. This is typified by the use of calculations based on the binomial distribution. This was a significant simplification of the issue and created a number of difficulties. We accept

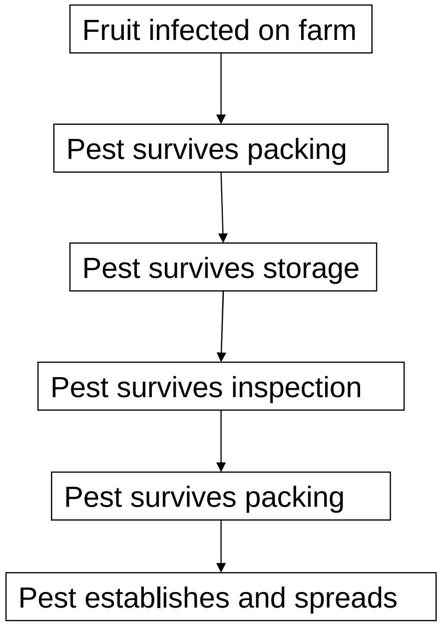

Figure 2.4: Simple pathway describing events that occur for an establishment and spread event to occur.

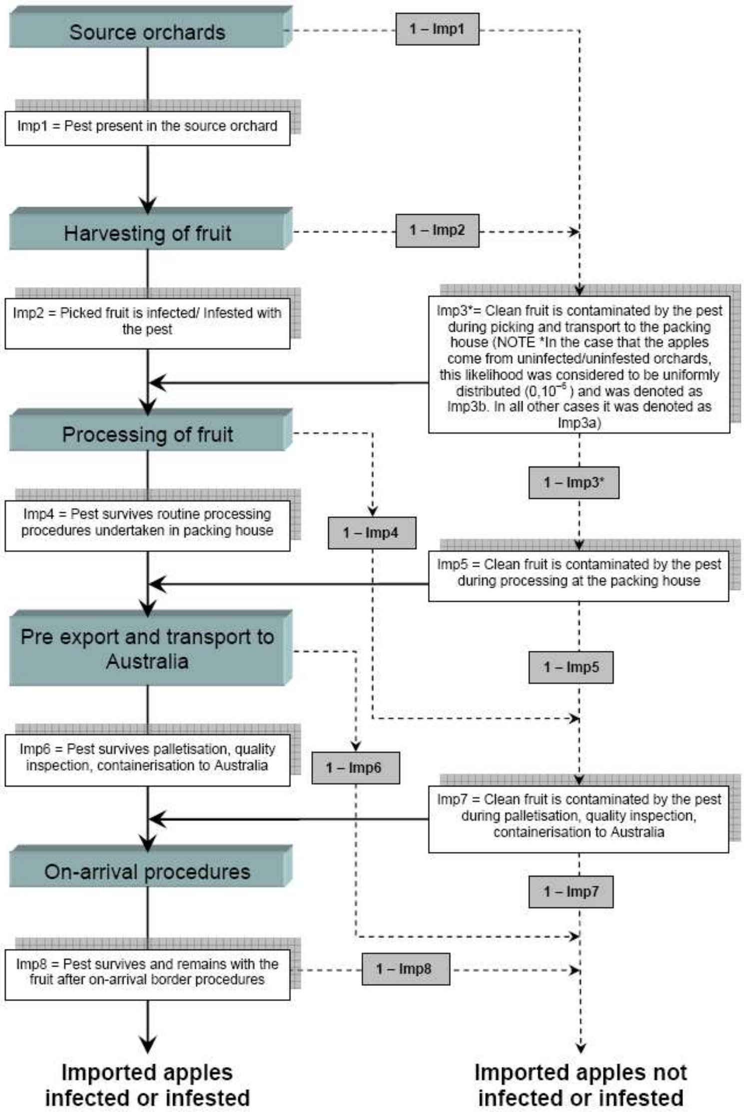

Figure 2.5: Invasion pathway from Biosecurity Australia (2007). In this figure Imp are the parameters associated with each step in the model. See Biosecurity Australia (2007) for details.

that various authors have identified aspects of these difficulties (for example OIE (2004a), Hartnett et al. (2007)) . Issues of dependence are mentioned in most articles but the issue in not considered holistically, i.e. across the whole assessment, and constructively, i.e. laying out a clear methodology that will lead to a defensible answer.

Consider a generic assessment. We have a pathogen/pest and a trade unit such as a piece of fruit or cheese. Except in the simplest cases, there will be a hierarchy of units in the export process, from a piece of fruit, to a box, to a container of boxes, to a ship load. This is represented in Figure 2.1. If we consider a particular occurrence of a pest on a unit of trade in isolation, difficulties will begin to arise very quickly. As an example, cross contamination from one unit (a pallet, say) to another in packing depends on the infection status of other units in the packing house. The probability that inspection will detect an infested unit depends on the prevalence of infested units in the inspected consignment rather than the status of a particular unit. This is discussed in the companion report Barry and Lin (2010b). Thus in many circumstances, assessment of the risk of trade requires thinking about the joint distribution and behavior of trade units at different scales rather than a single unit. This is a fundamental issue. It is analogous to the analysis of clustered data in statistics. If one ignores the structure of the data then typically the inferences produced will be incorrect (Pinheiro and Bates, 2000). Clustering induces covariances in the data that need to be considered in the analysis to ensure correct inference. One might hope that the influences of clustering are small but there are no guarantees.

A simple example will illustrate some of the difficulties.

Assume we have a simple model for a pathway. We will consider a hypothetical assessment for a horticultural product, a fruit. We consider a fruit fly as the hypothetical pest. We will define the unit of assessment to be the fruit, and assume that the trade will be 3 million items. We construct a simple model in the style popular in the late 1990's. Assume that there is a probability of infection for the fruit, p_1, a probability of the pest surviving the shipment, p_2 and the probability that the imported infected fruit leads to an outbreak, p_3. We assume the importation proposal states that N units (3 million) will be traded and we decide administratively to consider a median year based on total rainfall, and assume that production will be the same as the current system in the exporting country. We note that this model is simple but it is purely for explanatory purposes. We assume that each of probabilities $p_1, \ldots, p_3$ is 0.001. Under the assumption of independence, the probability that a randomly chosen piece of fruit leads to an outbreak is

$$p = p_1 \times p_2 \times p_3 = .001 \times .001 \times .001.$$

The probability of an outbreak is

$$Pr(\text{Outbreak}) = 1 - (1-p)^N = 1 - (1-p)^{3,000,000} = .029.$$

As an alternative scenario, consider a trade where there are a thousand orchards in the trade, and each orchard trades a single shipment of 3,000 fruit, such that N is again 3 million. Each year there is a one in a thousand chance that all the fruit in an orchard is infested. If it is infested there is a one in a thousand chance that all the pests survive shipment, otherwise none does. When the shipment arrives there is a one in a thousand chance that an infested shipment causes an outbreak. In this scenario the probability that an outbreak occurs is

$$p = .001 \times .001 \times .001.$$

The probability of an outbreak is

$$Pr(Outbreak) = 1 - (1-p)^{1000} = .000001.$$

Hence there is a 5 orders of magnitude decrease in the probability of an incursion, for the same total quantity of imported fruit. The point to note here is that the marginal probability of infection, survival and establishment are the same in both models but the results are very different. Marginal probability in this context means the proportion of infested fruit in each class surviving each transition on the pathway ignoring its association with other infested fruit. In both cases one in a thousand fruit are infested, one in a thousand infested consignments survive the shipment process and one in a thousand consignments that survive shipment are associated with an incursion event.

Another impact of clustering is the effect of an infestation dependent process such as inspection. Assume that the model is updated and that we now take a random sample of size 600 from the consignments. The consignments contain 3000 fruit. For the independence model assumed in the first scenario the probability an infestation is detected is

$$Pr(\text{Detect}) = 1 - (1 - \text{proportion infested in consignment})^{600}$$

As a worst case analysis assume that the pest survival, with probability .001, occurs before inspection. In this case the proportion infested in a consignment is $.001 \times .001$. Then

$$Pr(\text{Detect}) = 1 - (1 - .001 \times .001)^{600} = 0.0006$$

i.e. 6 in 10,000 containers will be detected. The probability that a consignment of 3,000 fruit is infested is

$$Pr(\text{Consignment infested}) = 1 - (1 - .001 \times .001)^{3000} = .003$$

so the conditional probability that an infested consignment is detected by the sampling is

$$Pr(\text{Detect} \mid \text{infested}) = \frac{Pr(\text{Detect})}{Pr(\text{Consignment infested})} = .2$$

For the alternate clustered model, detection is certain as all fruit in an infested consignment will be infested. Thus there are major differences in the outcomes depending on the assumptions, and an analysis that concentrates on fruit cannot represent this. If an analyst was set on modelling this scenario on a per-fruit basis they could attempt to circumvent these difficulties as follows. We could ask the question "what per fruit risk is consistent with a probability of incursion of .000001, the number found based on the clustered scenario". We then need to solve

$$1 - (1 - p)^{3,000,000} = .000001$$

This leads to a solution of $p = 1 - \exp(3.333332e - 13)$ which is vanishingly close to zero. While this probability can replicate the behaviour of the system it is not clearly interpretable with respect to either of the processes originally considered. In more complex cases this duality might not even exist.

Another way to consider the impact of the independence assumptions in the first scenario is presented in Figure 2.6. This figure represents the process implied by a simple single unit model. The strong independence assumptions lead to effectively parallel lines. The comparison with Figure 2.1 is striking. It is hard to see an expert who is considering what is possible and plausible deciding that Figure 2.6 is an adequate physical or stochastic representation of Figure 2.1.

The obvious response to these points is that the model should be elaborated to reflect the key processes being represented. While this is logically true it can be practically difficult (Bogen, 1983). As Figure 2.1 attempts to demonstrate, clustering can occur at a range of

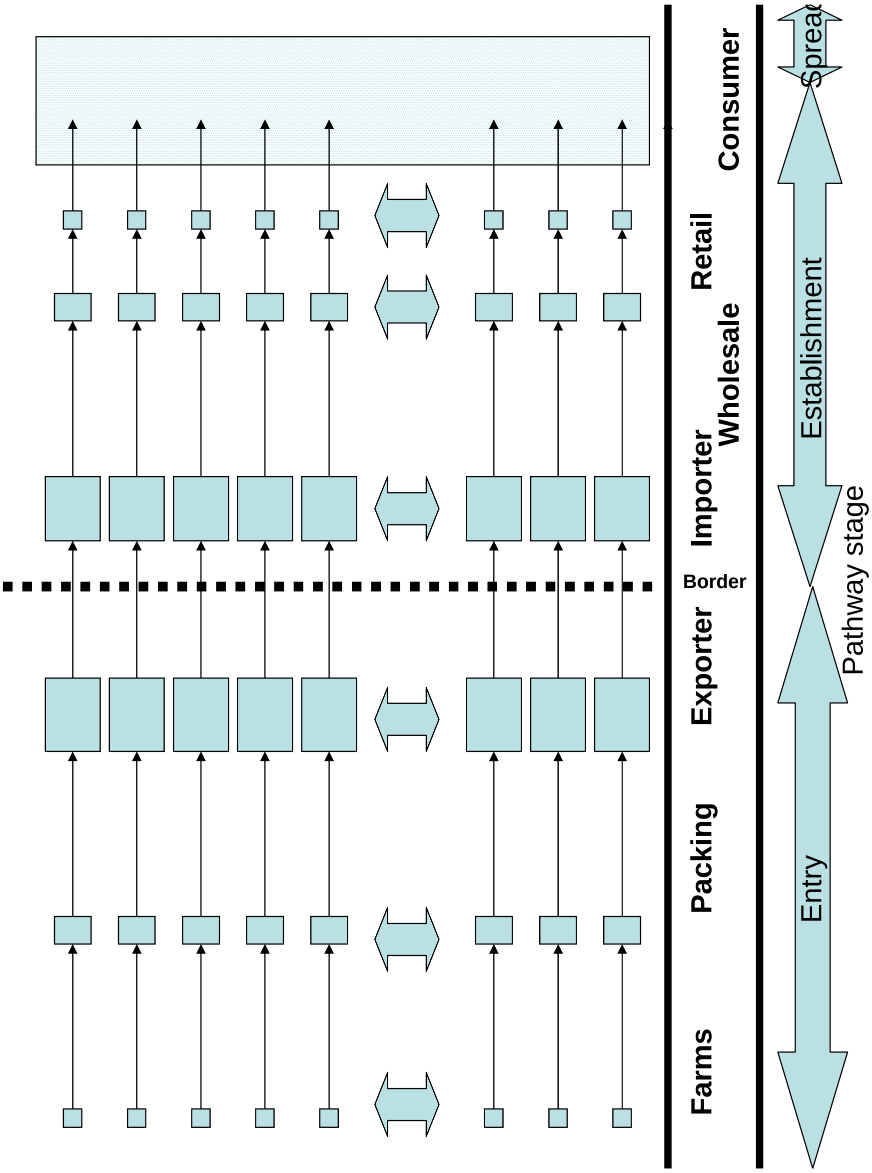

Figure 2.6: Representation of process implied by simple Monte Carlo approaches with simple probabilities at each stage. The extremely strong independence assumptions results in the parallel processes

scales. For example it can occur at farms, packing, exporting, importing and distribution. In addition it will not typically be homogeneous as the pattern of clustering will vary. Another complication is that the analysis of any data used to parametrise the model needs to take into account any clustering, and its representation in the model. As the example here has demonstrated, marginal analysis of data ignoring clustering can have significant impacts.

These issues are exacerbated if we consider that there are a large number of different processes that may be possible and plausible (i.e. the ω_i). Trying to get a simple pathway based model, using a single unit based on marginalising over the ω_i will typically not be feasible. The use of simple probability distributions over the probabilities of a pathway model does not have enough richness to encapsulate the stochastic behaviour of the system. Modelling the entire joint distribution will encapsulate this but it will rarely be possible in practice.

In summary this section has demonstrated the following points

1. That clustering of risk has a significant impact on the overall risk and that care needs to be taken in marginalising over the process.
2. While simple models have obvious appeals, significant difficulties can arise. Simple models based on fixed units using simple probabilities and probability distributions on these parameters will typically not be able to represent complex processes and uncertainties involved in the trade in agricultural commodities.
3. Parameters estimated marginally can be very misleading.

2.5 Qualitative/Quantitative approach

2.5.1 Introduction

A typical import risk assessment is broken into components such as entry, establishment and spread, as this is consistent with the relevant standards of the IPPC and the OIE. In Figure 2.1 to 2.3 we have incorporated these steps on the pathway figures. This provides a useful device to explore linkages between the quantitative and qualitative approaches, by showing the relationship between the process of importation and the compound steps considered in the analysis. In embarking on this journey it is useful to clarify a number of issues. In particular it is important to be clear about the role and expectations of risk assessment in government. The consideration of the science needs to take this context into account.

First, as mentioned in the introduction, risk assessment can be seen as an administrative process rather than a scientific process. The term administrative means that a set of procedures are undertaken that produce an outcome that can be used in decision making. This is an important process in government and the term is not used pejoratively. The aim is to produce an outcome that satisfies the stakeholders or competing interests as far as possible. On the other hand, a scientific process tries to make a calibrated and logically based inference based on available knowledge. It is our belief that real world risk assessments contain elements of each in varying proportions. Governments need processes so that decisions can be made in a timely and orderly way. The views of scientific experts will often be diverse. The distinction between process and science is of interest here because if a qualitative assessment does not need to map to any reality or objective data there is no further point in analysing the scientific basis of its inference. This is because there is no reference point, or inference about the real world that it is trying to achieve.

Within the typical meaning of qualitative assessment, it is usually argued that the assessment allows comparative assessment. This can still be a valid scientific inference. If the outcome of the risk assessment process objectively rates relative risk and its associated uncertainty, it is logically defensible. We do not believe that this is the case with some import risk assessments. The use of subjective terms such as High, Medium and Low will lead to significant linguistic uncertainty Regan et al. (2002). Thus unless the same individual performs all assessments there is significant likelihood of variation due to the assessor's background. The use of heuristic methods of combining the component qualitative assessments to produce an overall conclusion does not ensure the consistent relative rankings. The framing of questions such as "What is the probability of entry" does not refer to any time period or volume of trade so the question itself is not well defined. Thus we argue that a qualitative assessment should frame the questions clearly and precisely so that there is no ambiguity about their definition. Following on from this, the results of the analysis should also be reported in a way that there is no ambiguity about their meaning.

This is a different perspective on qualitative analysis as it applies to import risk assessment. We consider here that a qualitative assessment is trying to reach the same conclusions as a quantitative assessment and have the same logical foundations. It is trying to do this without becoming mired in complex models with limited available data. This view of a qualitative assessment implies that the distinctive feature is the compounding of assessment steps to three fundamental components: the likelihood of entry, establishment and spread. In addition, the assessments of the likelihood of these components are expert-based, with the analyst integrating available data and knowledge. This view of qualitative assessment in import risk assessment is not standard but is implicit in many approaches.

This issue has had some consideration previously. Semi-quantitative approaches have been proposed to link the styles of assessment. For example, semi-quantitative approaches to import risk assessment have been proposed and used by Biosecurity Australia in the past. As noted by OIE (2004b), semi-quantitative approaches can be ad hoc and uncalibrated, and we agree with this criticism. This is discussed by Hood (2010). The approach presented in this report seeks to build the link explicitly. Given this, we are not proposing a new semi-quantitative method. We are trying to find a quantitative analysis with the simplicity of the structure of the qualitative assessments.

2.5.2 Probability based assessment

In considering a compound assessment Figures 2.1 to 2.3 give a basis for framing a series of questions for the analyst to answer that can be logically combined to produce an overall assessment of the probability of an adverse event occurring. From basic probability theory we have

$$\begin{aligned} Pr(\text{Incursion}) &= Pr(\text{Entry})Pr(\text{Establishment}|\text{Entry})Pr(\text{Spread}|\text{Establishment, Entry}) \\ &= Pr(\text{Spread and Establishment and Entry}) \end{aligned} \tag{2.1}$$

The bars in the above equation denote conditioning, which means we assess the probability of an event given that the conditioning event has also occurred.

At the highest level Equation 2.1 is appropriate but as soon as we need to elicit these responses from experts we need to define what we mean by the probability of entry, establishment and spread. These need to be defined with respect to the probabilities μ_{ij} discussed earlier. If these terms are vague there is considerable potential for confusion. Outcomes such as entry will be related to a range of possibilities ω_{ij}. Thus calculation of the probability of these terms is

$$E[I(Q)] = \sum_i \sum_j I(\omega_{ij} \in Q)\mu_{ij}$$

where Q is the required event such as entry. This represents an integration over the set $\{\omega_{ij}\}$, the set of all possibilities defined previously. By integration we mean that we sum the probabilities over each possibility that exhibits the required event.

To perform an actual assessment we need to define the $\{\omega_{ij}\}$, at least implicitly in the expert's mind. To do this we first need to define the period covered by the assessment and nature of the trade that is proposed. For example, we could define this to be a year's trade and that its volume would be 10,000 tonnes with a system of production and distribution the same as that currently employed in the country for export to other markets. The expert would also need to consider the climatic conditions assumed for the analysis as well as the relevant species' biology. For example, the analysis could be defined over the all possible climates, weighted by their occurrence in the climate record. Once this is completed, the nature and likelihood of different possibilities would need to be considered for each scenario ω_i.

Given the belief about the nature of the trade, we now consider defining precise events to associate with the generic terms. Considering Figure 2.3 we could define the event "Entry" as the event that at least one infested unit enters the country during the period covered by the assessment . We can define the event "Establishment" as the probability of at least one establishment event occurring, and the "Spread" event similarly. If we wish to calculate a probability of incursion from Equation 2.1 we need to satisfy ourselves that

$$\begin{aligned} Pr(\text{Incursion}) &= Pr(\text{At least one infested unit enters the country}) \\ &\times Pr(\text{At least one establishment even occurs}|\text{At least one infested unit enters the country}) \\ &\times Pr(\text{At least one spread event}|\text{At least one infested unit enters the country,} \\ &\quad \text{At least one establishment even occurs}) \end{aligned}$$

is logically correct with our newly defined events. This gives

$$\begin{aligned} Pr(\text{Incursion}) &= Pr(\text{At least one infested unit enters the country} \\ &\quad \cap \text{At least one establishment even occurs} \\ &\quad \cap \text{At least one spread event}). \end{aligned}$$

with the symbol $\cap$ denoting the intersection of the events, equivalent to the logical AND operator. The statement is true as the adverse events are all in this intersection and all events in the intersection are adverse. This logic is shown visually in Figure 2.7. In this figure note the nested nature of the events, as each can occur only if the preceding event has occurred. Note also that the probabilities are conditional. If they were calculated marginally (ie without the conditioning) we would have

$$\begin{aligned} Pr(\text{Incursion}) &= Pr(\text{At least one infested unit enters the country}) \\ &\times Pr(\text{At least one establishment even occurs}) \\ &\times Pr(\text{At least one spread event}). \end{aligned}$$

Now if A is nested in B, it follows that $Pr(A) < Pr(A|B)$ so ignoring the conditioning means that the probability of incursion will typically be underestimated, with equality only in the trivial case that all possibilities lead to incursion.

These definitions of the events have some interesting ramifications about performing logically based assessments using entry, establishment and spread. In this case the

$$Pr(\text{at least one infested unit entering})$$

will be one (ie certain) in many cases, as the screening/hazard assessment process would have removed threats with low prevalence. An assessment will usually only be undertaken if there are sufficient pests or pathogens on the pathway. In trade that warrants an

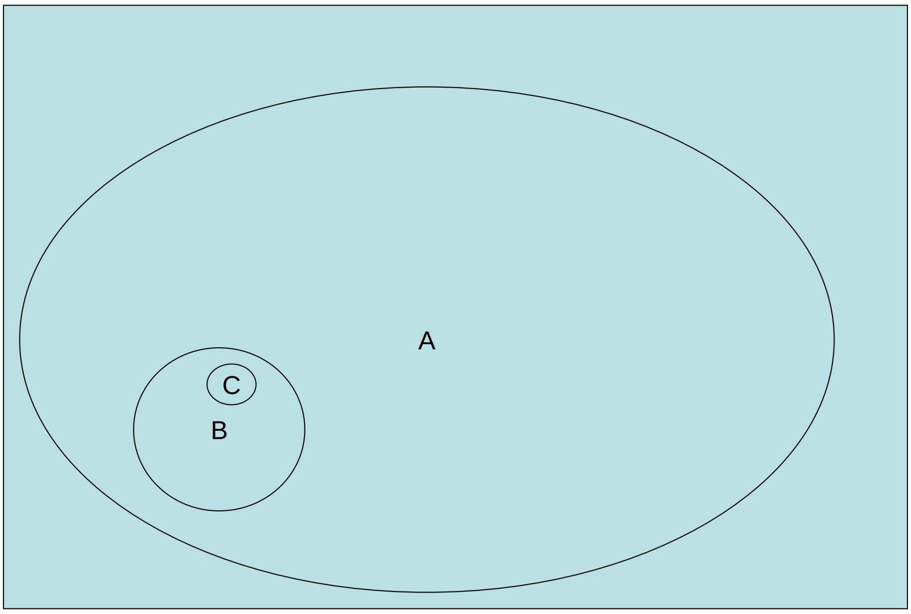

Figure 2.7: Venn diagram showing the different sets involved in calculating the probability of entry, establishment, and spread. The box is the universe of possibilities defined by the scope of the assessment and the beliefs about the uncertainties and stochastic behavior of the assessment. A is the subset of possibilities that result in at least one infested unit entering the country. B is the subset of possibilities that involve an establishment event. C is the subset of possibilities that result in a spread event.

import risk assessment, the volumes would be large with respect to the pest prevalence. Thus this step will typically not impose significant mitigation of biosecurity risks in typical applications. Most resolution of risk will occur in the next two steps. Consideration of $Pr(\text{Establishment}|\text{Entry})$ leads to another insight. In considering the probability of establishment the analyst still needs to consider the pattern and nature of the trade leading to entry. Mathematically, the probability calculation is simply

$$Pr(\text{At least one establishment event occurs}|\text{At least one infested unit enters the country}) = \frac{Pr(\text{At least one establishment event occurs})}{Pr(\text{At least one infested unit enters the country})}$$

which entails only counting the possibilities that involve an establishment event. In words, the chance of establishment depends on the pattern of arrival of infested material. These patterns are formed during the entry phase, as depicted in Figure 2.1 and Figure 2.3. The Spread step is similar in that it needs to consider how the Establishment events occurred. Thus it is not logically possible to partition out the three components and think of them independently. There is a strong element of conditioning in the assessments. The use of the three components is therefore not a natural way of breaking the analysis into components but rather an administrative convenience.

The last point to note is that with three nested events, $C \subseteq B \subseteq A$ that

$$Pr(A \text{ and } B \text{ and } C) = Pr(A)Pr(B|A)Pr(C|A, B) = Pr(A)\frac{Pr(B)}{Pr(A)}\frac{Pr(C)}{Pr(B)} = Pr(C) \tag{2.2}$$

If we associate the events C, B and A with the events "At least one spread event", "At least one establishment even occurs" and "At least one infested unit enters the country" respectively, we have that

$$Pr(\text{Incursion}) = Pr(\text{At least one spread event}).$$

Calculating the conditional probabilities might not represent an easier or more reliable route to $Pr(\text{Incursion})$.

It is reasonable to consider if we can define other events that would make the elicitation of probabilities easier and still lead to a logical inference about the probability of incursion. If we consider specifying more complex events such as at least k occurrences of some phenomenon then the probability of an incursion event is not the product, i.e.

$$\begin{aligned} Pr(\text{Incursion}) \neq\ & Pr(\text{At least k spread events} \cap \text{At least k infested units enter the country} \cap \\ & \text{At least k establishment events occur}), \end{aligned}$$

as we have discounted adverse events with the number of occurrences $< k$. By this we mean that these events are not considered in the calculation of the probability of incursion. It would also not appear to produce a significant simplification in the elicitation, and does not warrant further examination.

In conclusion, the approach discussed in this section represents a traditional probability based analysis of the problem. By defining the probabilities with reasonable rigour we have hopefully demonstrated at least what the experts should be thinking of, and considering, when expressing views about each probability. The analysis presented is the first rigorous consideration of these issues in the literature. Previous discussions have considered simple models and assumed the associated probabilities were well defined. The main purpose of this analysis is to provide a clear view of the import risk analysis challenge. In a practical setting an expert might still find it intimidating to consider the probabilities and expectations involved. This is the author's experience. Experts will typically be untrained in the estimation of probabilities and uncertainties so the communication overheads are high. We will consider an alternative view in the next section.

2.5.3 Bucket Model

Another approach to the problem is to consider the proportion of material that is infested at each step in the pathway. As previously noted, the analyst's beliefs about the nature and risk of the trade should not be affected by the analysis method chosen. Thus the analyst's views are again represented via the probabilistic framework defined previously. This approach is simply a different way of describing the distribution of possibilities. In this approach the analyst begins by considering the total amount of material in the specified trade and period and estimates the proportion of fruit anticipated to be infested at each step of the pathway. The implied proportion of infested material at each step is found by noting that the probability that the proportion of material p is less than a value c can be calculated as follows. Define the event Q as "the proportion of material at a given step is less than c". The probability is then simply the expected value for the indicator function for this event, as described previously. Given we can calculate all quantiles of the distribution we therefore know the entire distribution. This is because the $Pr(a < p \leq b) = Pr(p \leq b) - Pr(p \leq a)$. The expected proportion can be found from the expected value of the distribution for p.

A simple example of these calculations may clarify issues for the reader. Consider an expert's deliberation. The application is a request to import one thousand units of fruit. In this case the set $\{\omega_i\}$ has a single element ω_1 which represents this trade. Assume the expert *believes*, rather than assumes, that there is a probability .01 that each fruit is infested. For this trade there are a 1001 possible outcomes. The trade can lead to $0, 1, 2, \ldots, 1000$ infested fruit entering the country. The associated possibilities are $\{\omega_{1j}; j = 0, \ldots, 1000\}$ with j indexing the number of infested fruit. The associated probabilities μ_{1j} are from the binomial theorem,

$$\mu_{1j} = \left(\begin{array}{c} 1000 \\ j \end{array} \right) .01^j (1 - .01)^{1000-j}.$$

This assumes that each unit of fruit behaves independently. In this case the proportion p of infested fruit in the trade has a discrete distribution. The probability that $p \leq j/1000$ is

$$F(j/1000) = \sum_{i=0}^{j} \mu_{ij}$$

where $F(x)$ is the distribution function, $F(x) = Pr(p \leq x)$. The expected value of this distribution is $1000 \times .01 = 10$ as it is binomially distributed. The distribution of the proportion is given in Figure 2.13.

A graphical representation of this process applied to an abstract assessment is shown in Figure 2.8 to Figure 2.11. In each figure, the overall box represents all the fruit in the trade and each cut gives the proportion infested after each step. This approach moves away from defining probabilities of different events to getting the analyst to describe the nature of the trade via the proportion of infection in the overall population. This has been termed the bucket model in Biosecurity Australia (2007). The bucket refers to the total volume of risk material anticipated to be imported in the given period with the given pattern of trade. The analyst is asked to describe this aggregate trade. The proportion infested is a well defined concept and does not require explicit considerations of more technical devices such as probabilities although this is implicit in enumerating the possibilities. Note that while the proportion infested is a well defined concept it is also necessary to consider the joint

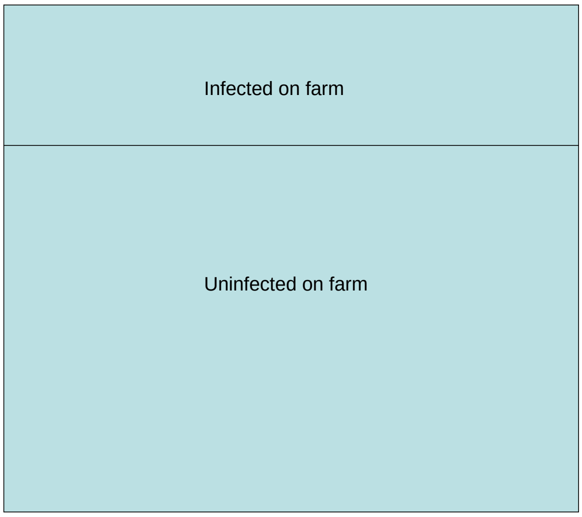

Figure 2.8: Graphical representation of an application of the bucket model. The "bucket" of material is all trade for the specified period. The initial split is between infested/not infested material that was infested on the farm.

Number	Probability
0	0.9990005
1	0.000999
2	.00000001
3+	≈ 0

Table 2.1: Probability distribution for the binomial distribution with n=1000 and p=.000001. See text for details.

distribution with the total volume of trade, ie the size of the bucket. This can vary across the ω_i as the pattern of trade changes so it cannot be assumed constant. This reflects that there may be uncertainty about the nature of the trade in the commodity. The analyst can express uncertainty about the relevant proportions based on their beliefs expressed through the probabilistic framework. An example is shown in Figure 2.12, which overlays these distributions on the cut points in the bucket.

Issues arise as the number of infested/infected units becomes small. For example in the previous simple example with 1000 fruit assume the analyst believes there is a .01 chance that an infested fruit will lead to establishment and a .01 chance that establishment will spread. Thus the proportion of infested units entering the country that will lead to establishment is again shown by Figure 2.13. Similarly, the proportion of establishment events that lead to spread is also given by this figure. Once these proportions have been decided, the number of infested units that result in a spread event (ie an incursion) can be calculated. With 1000 units, this is distributed as $Binomial(1000, .01 \times .01 \times .01)$. This has the distribution shown in Table 2.1 and an expectation of .001. The Probability of an incursion is the Probability that the number of units resulting in a spread event is greater than zero which is 0.0009995, or an approximate one in a thousand chance of a trade in 1000 units causing an incursion.

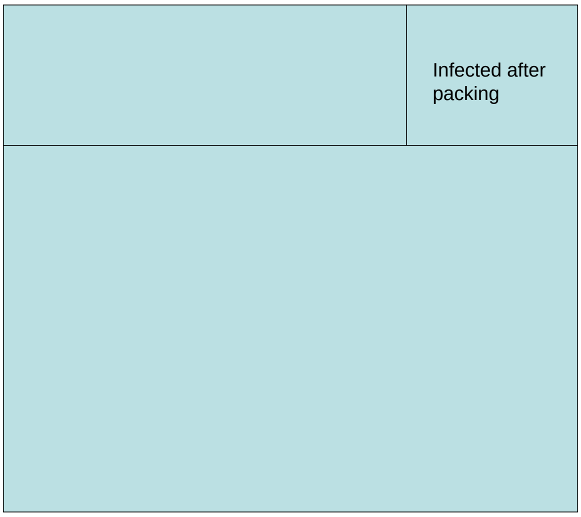

Figure 2.9: Graphical representation of an application of the bucket model. The “bucket” of material is all trade for the specified period. The second split accounts for fate of infested fruit after packing.

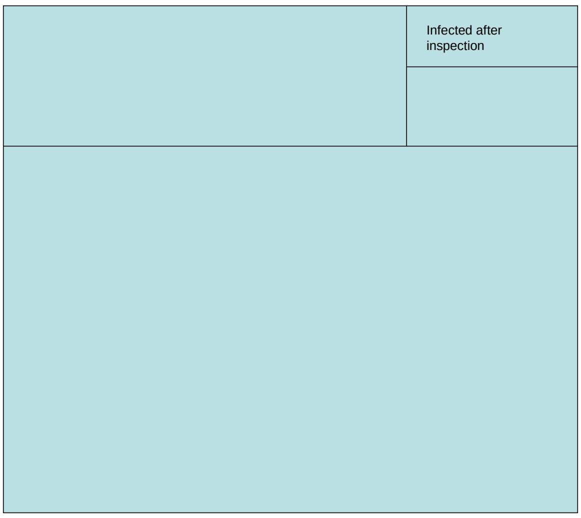

Figure 2.10: Graphical representation of an application of the bucket model. The “bucket” of material is all trade for the specified period. The third split accounts for the impact of inspection on the level of infested fruit.

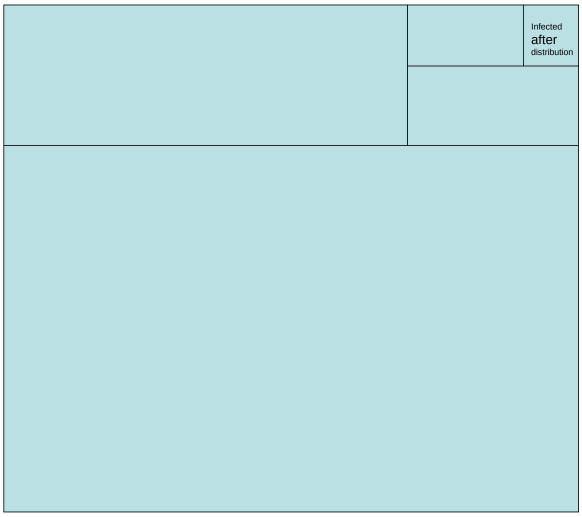

Figure 2.11: Graphical representation of an application of the bucket model. The "bucket" of material is all trade for the specified period. The fourth split accounts for reduction of infection during distribution.

2.6 Recommended approach

The conclusions from this discussion and a recommended approach are as follows. The foundation of successful elicitation is ensuring that experts understand the possibilities they need to consider in the assessment and how they are to logically treat these. They need to come to a view, based on available data and beliefs, about the nature of possible outcomes and their associated plausibilities. The possible outcomes of the trade are considered at two levels. First, the context of the assessment will define what scenarios are considered. For example there may be a range of different production systems that may be put in place. In addition, the risk may vary with environmental conditions and their variation may need to be considered in the analysis. The second level considers the possible outcomes of a particular scenario. For a given production system and environmental condition the stochastic nature of the trade needs to be considered and described. Simple models based on strong independence assumptions could be considered here but they should be used only if they really reflect the expert's view about the system. In considering the probability of all the possibilities, it will typically not be possible to enumerate these explicitly, but the analyst should still strive to consider these. From their beliefs the analyst can express the appropriate probabilities and proportions with reference to the complete set of possibilities.

In summary, the sort of instructions we could provide to an analyst are:

1. Define clearly the scenario(s) that are being assessed. This must be described so that all reasonable questions about the risk of the proposed trade can be answered. For instance a pest may need extreme weather conditions to establish. If the scenario does not define what weather conditions to assume in the analysis, ambiguity is introduced. The description will typically include a productions system, as stylised in Figure 2.1, a time period and volume of trade in this period, and a description of the prevailing climate in this period in both source and destination areas.

   As an example of a description, assume that period of the assessment is one year, and

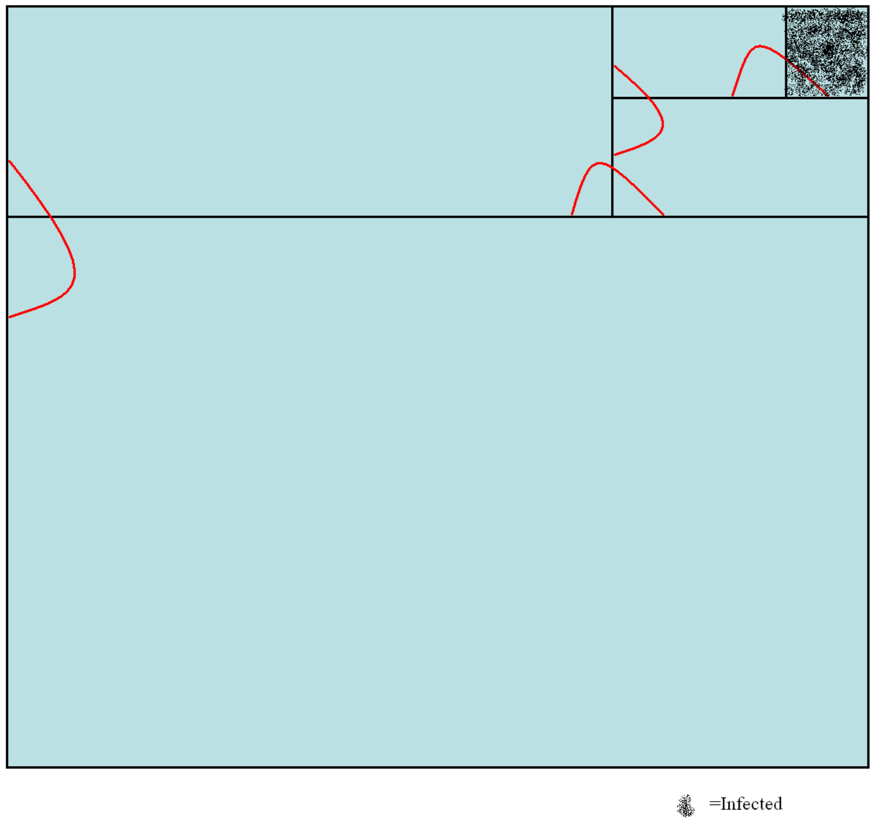

Figure 2.12: Graphical representation of an application of the bucket model. The red curves represent probability distributions that represent the analyst's uncertainty.

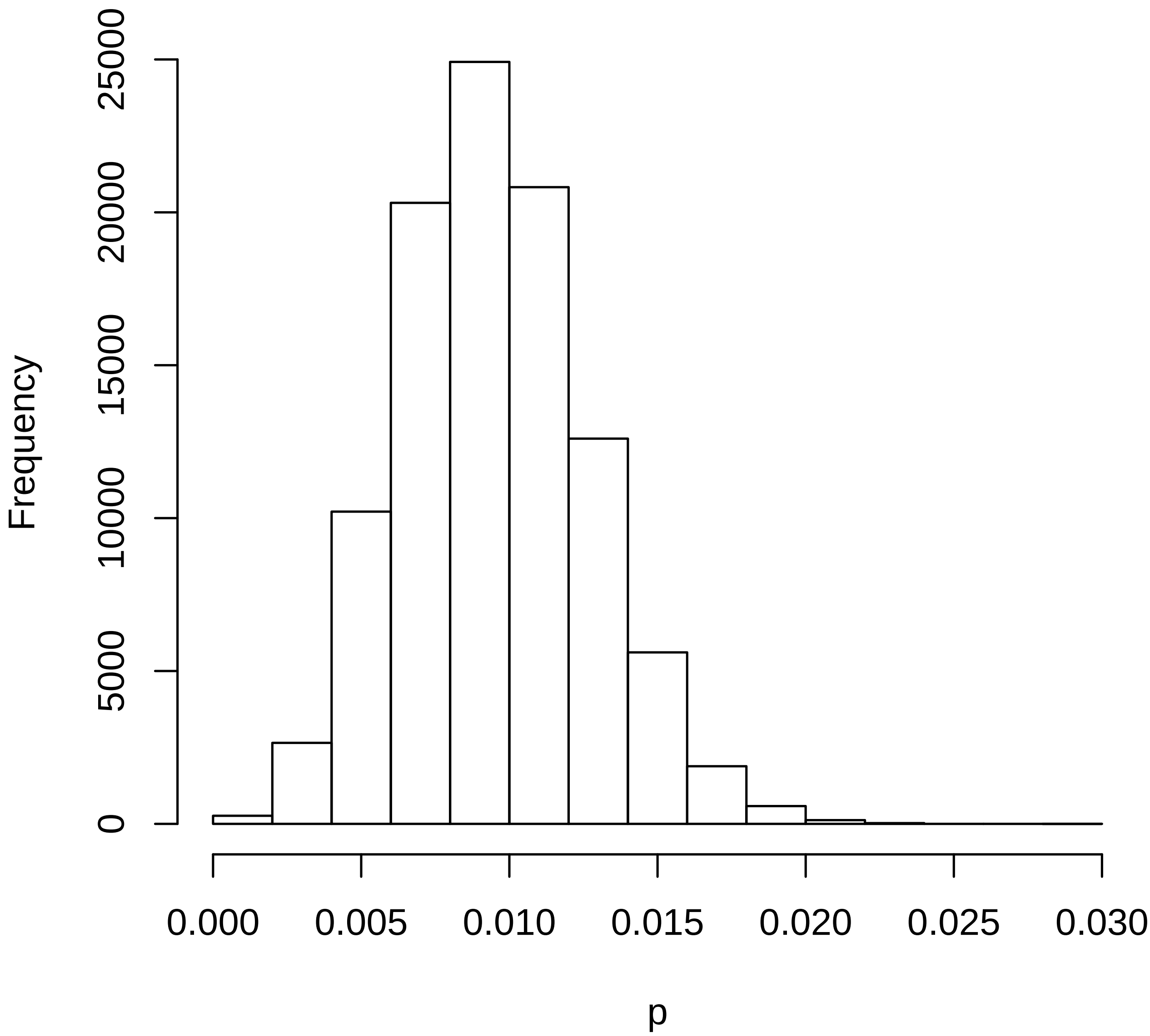

Figure 2.13: The uncertainty in the proportion infested for the simple scenario with 1000 fruit and .01 probability of infection

that the climate for the year is average (that associated with median temperature, say). Assume that the trade is based on the importation of X tonnes of material using the existing processes used by the exporting country to send material to other markets. The different scenarios will need to have associated probabilities. As an example it might be decided that two different production systems are equally likely and are thus given equal weight. An alternative is where the assessment is made over all possible weather patterns. In this case the climatology defines the scenarios. For example, if the period of assessment is a year, all years in the previous 100, say, could be scenarios, each with equal weight.

2. For each given scenario the experts should be asked to consider all the possibilities, in terms of entry, establishment and spread that could occur, and their associated plausibilities. For example if one outcome is unlikely compared to an alternative outcome their results should reflect this. If there are any working models or data analysis that support the analysis they should include this in the report, but the final assessment is their personal integration, as an expert, of all the available information and knowledge. They should not be trapped by simple abstract models. Their assessment should provide a reasoned argument.
3. The experts should be instructed in using the averaging process outlined in this report. This will entail giving an understanding about how all the different possibilities defined by the scenarios and the possible outcomes should be thought of. In particular, the relative probabilities of these need to be in the analyst's mind, and they need to be comfortable in at least implicitly summing over these for defined events.
4. The expert should then consider the following questions, interpreting probability with respect to the probability space previously defined.
    - What is the probability that at least one infested fruit enters the country due to the trade?
    - What is the probability of at least one establishment event occurring given that at least one infested fruit entered the country? Note the conditioning means we are not considering the scenarios where no pests enter the country.
    - What is the probability of at least one spread event occurring given that at least one infested fruit entered the country and at least one establishment event occurred? Note the conditioning means we are not considering the scenarios where no establishment event occurs.

For the bucket model the first three steps are the same, as the definition of the scenarios and the expert's views will not change. What is different is the relevant questions. We would ask:

1. When we ask for proportions of infection or survival we are asking your expert view about the possibilities for the trade, weighted by their different probabilities. You can give an expected value, averaged over all the possibilities, or a distribution which reflects the distribution of the proportion across the different possibilities.
2. What is the proportion of the trade that will be infested when it enters the country due to the trade?
3. What proportion of infested fruit will result in an establishment event.
4. What proportion of the infested fruit that resulted in an establishment event will lead to a spread event (ie incursion).

The discussion in this section has demonstrated that it is possible to construct a compound assessment using the components typically considered in a qualitative assessment that is logically based, interpretable and all components are clearly defined. It needs no more data than a qualitative assessment as it simply requires the analyst to express what they are thinking. It is obvious that to use this approach will require both training in understanding its logical basis, as well as pragmatism in accepting that in complex assessments with little data, no amount of analysis can resolve all uncertainty and ambiguity.

2.7 Example

In this section we consider a more complicated example to fix the ideas presented in the previous section. We stress from the outset that this example is for illustrative purposes to aid understanding of the ideas expressed previously. The aim of this analysis is to give a clear expression of the nature of the problem and the use of probabilities in this context. It does not to lay out a detailed quantitative methodology.

Consider an assessment of an application to import a fruit that is possibly infested by fruit fly. Assume that the application is to import 1,000,000 fruit. It is understood that the fruit will come in shipments from 10 exporting farms. Each shipment will be 1000 fruit, consistent with the existing trade to other countries, and the climatic conditions to be considered are average weather defined to be the median year based on mean temperature in the previous 100 years. Thus there is a single possible trade scenario.

The expert now needs to consider the possibilities for this trade. In this case there is a single scenario and it is well defined. This simplifies the analysis. The expert now has to consider what are the possible outcomes of the scenario in terms of entry, establishment and spread. The expert understands that there is significant variation in the infection rate on farms, dependent on weather. With the specified climate, around 40% of farms will have very low levels of infection, the average infection rate is 1 in a thousand fruit and the maximum could be 8 in 1000, based on limited literature and related species. The expert also has access to literature which shows there is a 10% reduction in the number of infested fruit after washing and packing and that a routine 600 fruit inspection will be applied to the shipments of 1000 fruit at export. Within the importing country there is a 10% chance the shipment will go to a susceptible location and expose susceptible hosts. Infestation rates on individual fruit are low so there is a belief that you would need at least 4 infested fruit in a shipment to cause an incursion. The expert believes that given the nature of establishment there is a 20% chance spread will occur, based on a detailed climatic analysis of long term habitat suitability for this species in Australia.

The expert still needs to convert this information about the behavior of the system into a set of possibilities with associated plausibilities, at least in their mind. As argued previously it is not possible to construct a simple model in this case based on considering individual fruit. While processes such as packing work on individual fruit, inspection and establishment depend on the status of other fruit in the shipment and is driven by the overall prevalence on the individual farms. An expert doing this analysis would need to think of these issues as they consider the possible outcomes based on this pattern of trade.

In this example we will use simulation to populate the possibilities and the associated probabilities associated with a particular model of the trade and disease. This is the standard use of Monte Carlo methods. We stress that we are not advocating that a Monte Carlo model of the process is the best way for an expert to consider these issues. A typical assessment will be more complex and uncertain than this simple example. In many cases the resources available for the assessment are limited. Thus it may be reasonable that the expert do this mentally, provided they are adequately trained and understand the logic of what they are asked to do. Monte Carlo models may be used to illustrate a line of argument but should not be relied upon as the only line of evidence.

The Monte Carlo model in this case is used as a “robot” expert. Its “thoughts” on what is plausible are consistent with the assumptions. The model described was implemented in the R programming language and is included in the Appendix. The distribution of infection was modelled as a Beta distribution with parameters 1 and 1000, which is consistent with

Step	Probability
Entry	1
Establishment	0.26
Spread	.24
Overall	.06

Table 2.2: Summary assessment for example

available information. This distribution is shown in Figure 2.14. Figure 2.15 displays the implications of this model for the number of fruit imported (as some shipments are rejected by the inspection process) and the proportion of fruit infested after inspection. Each plotted symbol is a possibility from the model and the density of points gives the relative plausibility. A knowledgeable, well calibrated and logical expert would hopefully have views which are reasonably aligned with this, given the assumptions.

Continuing to follow the guidelines from Section 2.6 we first need to answer the question "What is the probability that at least one infested fruit enters the country due to the trade?". Given our beliefs about this trade the probability is effectively one. This is a reflection of the mean prevalence of the pest of 0.001, the size of the trade (1,000,000), and the only moderate effectiveness of the mitigation techniques. The next question to answer is "What is the probability of at least one establishment event occurring given that at least one infested fruit entered the country?". The conditioning in this question is simple as the probability of entry is 1. The expert needs to think about all the possibilities that lead to an establishment event and their associated probabilities. Based on this model the probability is 0.264, which is found by summing over all possibilities that had at least one establishment event. The third question to answer is "What is the probability of at least one spread event occurring given that at least one infested fruit entered the country and at least one establishment event occurred?". Based on this scenario this is 0.24. Note that this is larger than the 20% assumed in the scenario because some possibilities have more than one establishment event, and therefore there are additional chances for spread to occur. Thus the overall probability of entry, establishment and spread is $1 \times .264 \times .24 = .062$. Note that the probability of spread, *not* conditional on entry and establishment is also 0.062, consistent with Equation 2.2. This demonstrates the consistency of the analysis. We summarise these results in Table 2.2.

We note the high precision reported in the analysis. While unrealistic for a real analysis, it is reported here to demonstrate that the concepts are well defined and coherent. In a real analysis this would typically not be possible. The definition of the questions and the probability framework would be the same, but an expert could report intervals or classes, like high low and medium, provided they were well defined. Because of the clear definition of the quantities the impact of techniques such as intervals or classes could be transparently integrated into the interpretation of the results.

The alternative approach outlined in Section 2.6 is to consider the proportion of fruit infested. The probability framework and scenario are unchanged. The first question is "What is the proportion of the fruit that will be infested when it enters the country due to the trade?". The expected proportion is 0.00036, i.e. around 36 in 10000 fruit is infested. The second question is "What proportion of infested fruit will result in an establishment event?". There is some ambiguity here because individual fruit do not cause incursions. Instead, there needs to be a number of fruit above the threshold. In this case we count fruit that are associated with an establishment event. In this case the expected proportion of infested fruit that are associated with an establishment event is 0.005. This is much

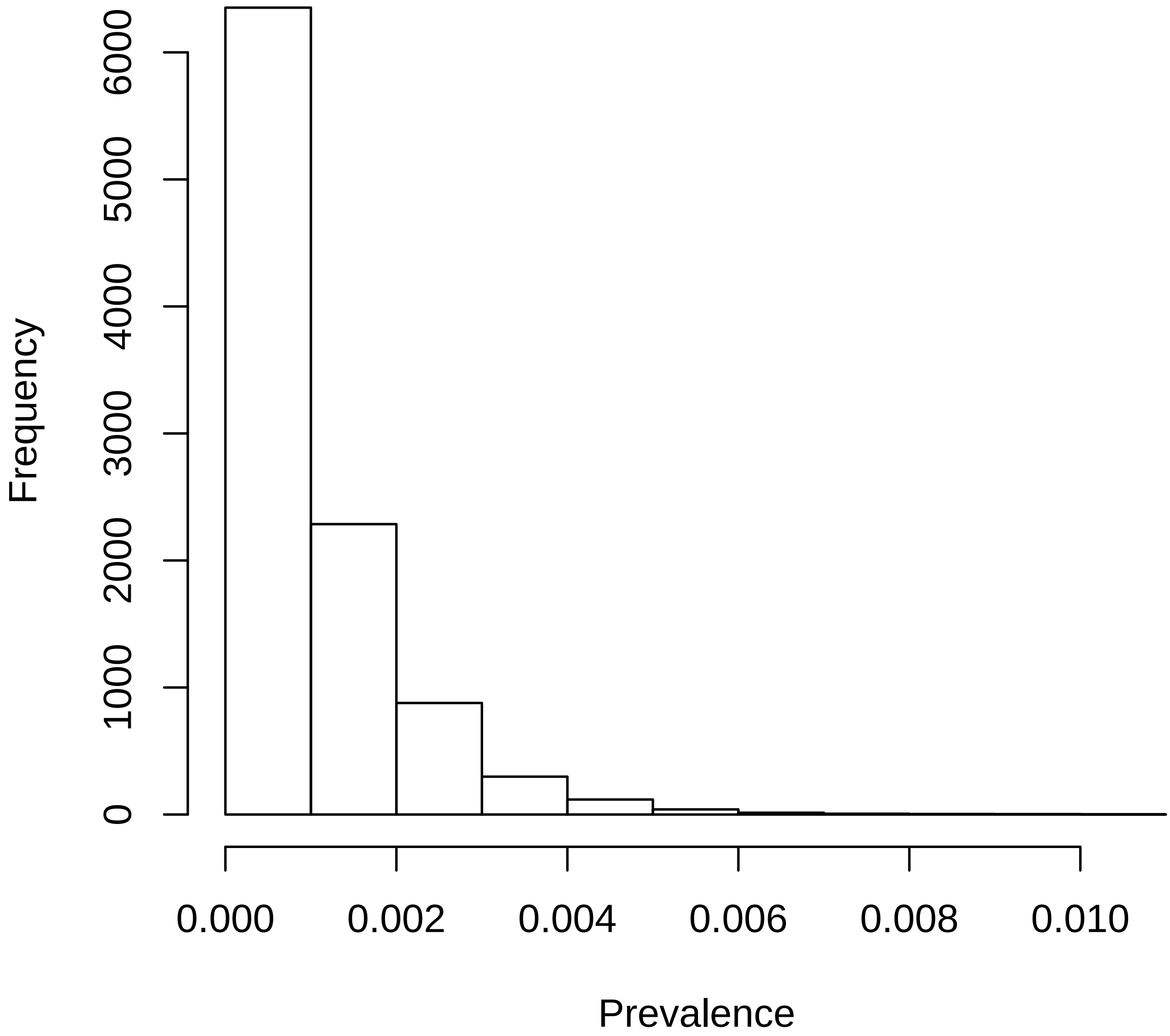

Figure 2.14: Beta distribution for the prevalence of infection on farms for the example. See text for details.

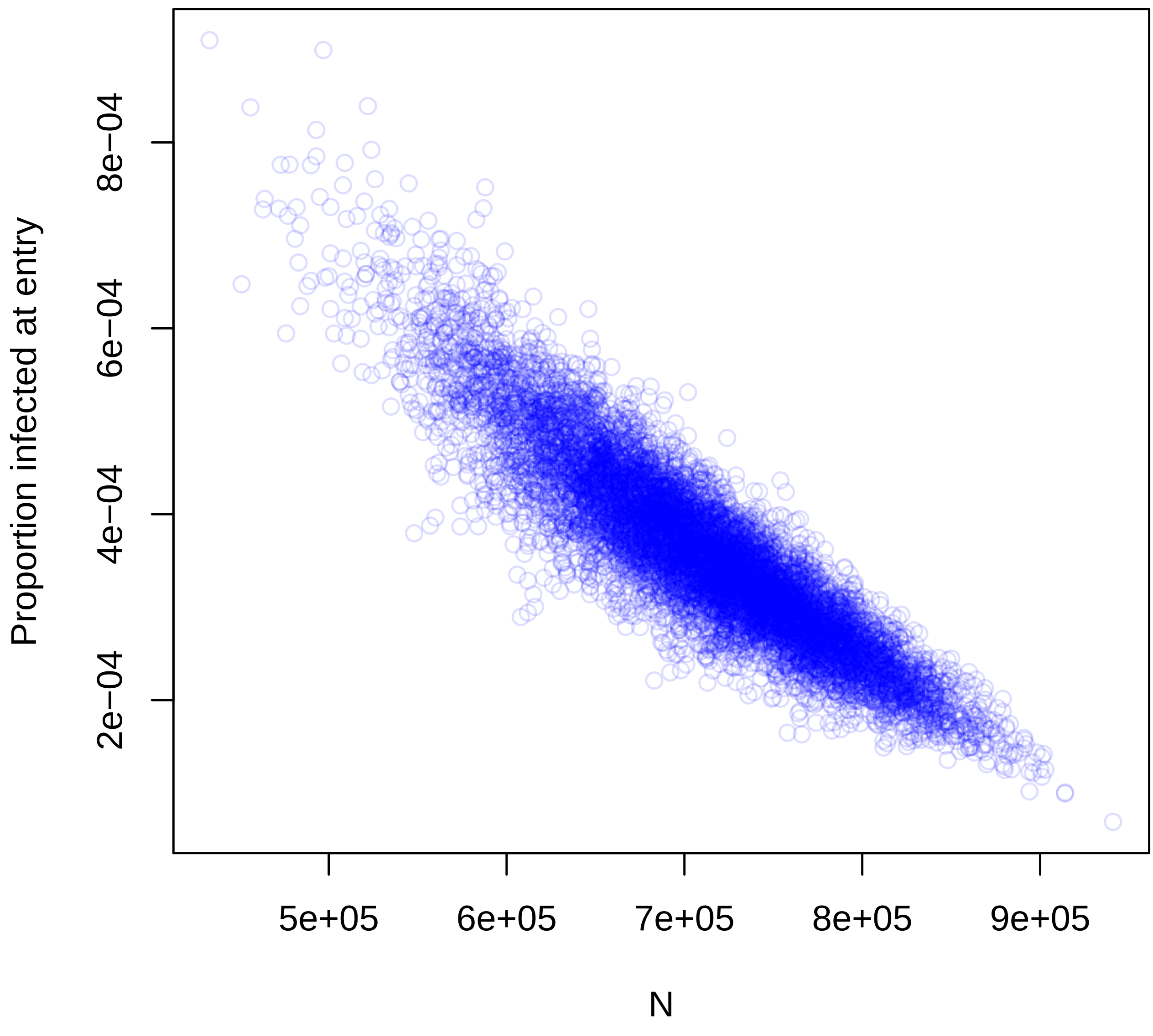

Figure 2.15: Plot of possibilities in the example for the number of fruit imported and the proportion of fruit infested post border. This representation would hopefully reflect the expert's views.

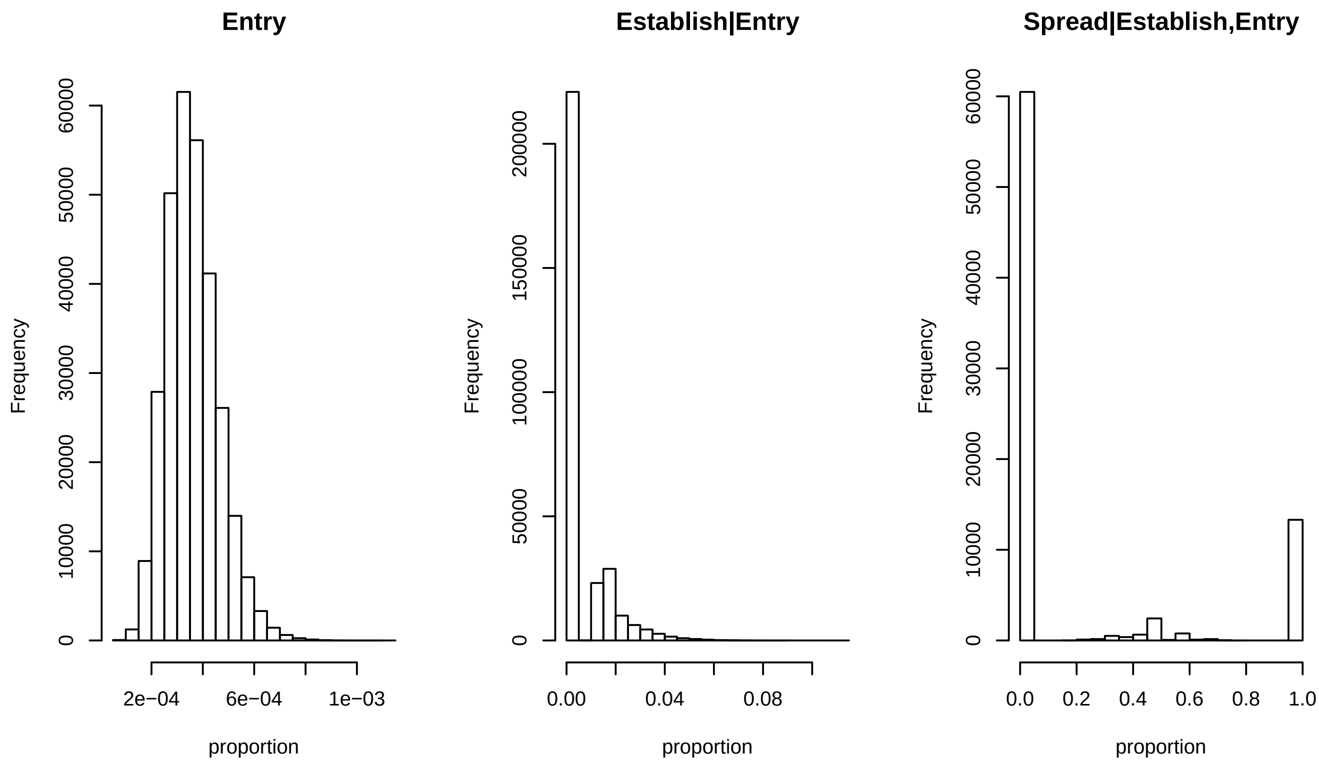

Figure 2.16: Plot of uncertainty around the proportion infested for each transition in the example.

lower than the 10% in the scenario because much of this fruit is in consignments below the threshold. The final question is "What proportion of the infested fruit that resulted in an establishment event will lead to a spread event (ie incursion)?". The expected value is 0.20, as this is now a proportion of the fruit involved in establishment events so it reflects the underlying 20% probability. The distribution of these proportions is given in Figure 2.16. The bimodality and spikes at zero is a reflection of the thresholding.

To see how the two analyses align, we calculate the expected number of fruit that are involved in an incursion. This is found by taking the expectation across all the possibilities. This has expected value 0.282. This is less than one as incursion is far from certain in this example. Heuristically, we understand that we need four fruit to cause an incursion, and that typically the number infested in a consignment will not be much higher given the scenario. If we calculate 4/0.28=14.2, which says that we would accumulate sufficient material over approximately 14 scenario periods. From the probability analysis we have the probability of an incursion to be .06. This implies an incursion once every 1/.06=16.7 scenario periods. The discrepancy here arises from the use of expectations and simplifying assumptions.

In summary we have applied the proposed analysis to an example problem that exhibits significant clustering and thresholding. We have shown that the terms in the analysis are well defined and that they lead to effectively the same conclusions, as they are based on the same scenario and beliefs about the system. We have also shown that the result obtained by separating entry, establishment and spread and combining them by the analysis in the previous section produces the correct result.

3 Discussion

The framework presented here has a key advantage. It defines the scope of the assessment and the way it is to be undertaken. No query can be raised that cannot be resolved by referring to the framework. By covering the trade, period, environment and volume, and explicitly defining how uncertainty in these should be handled, it brings structure to the process. Even if some experts have difficulties in its application in data poor situations, it will still provide some clarity, and serve as a clear expression of the logical basis of the assessments.

The approach is flexible. In the absence of quantitative information, expert-based assessment can be made of the relative possibilities and the associated plausibilities. If more information is available, or the issue is contentious a more detailed mathematical model could be developed to try and capture more of the process and to explore the possibilities and the associated plausibilities. Thus there is considerable flexibility in how the approach is applied. Given this, we recommend that detailed pathway based quantitative model never be used as the sole basis of decision making. No model can capture all features and possibilities in a system. The expert needs to integrate the results of any modelling with their other knowledge and experience to realistically consider the possibilities and plausibilities.

While the approach allows multiple scenarios to be incorporated into the analysis (through defining additional ω_i), caution should be applied to this process. The assessment will average over these components, analogously to Bayesian Model Averaging (Hoeting et al., 1999). Technically, this is an expectation, which will give the expected probability of particular outcomes, which may be appropriate in some circumstances. For weather, or minor variation in production system it could be appropriate. If there are significantly different possibilities for the trade it might be better to do two analyses, and apply the results as needed. For example, if the trade could either be low volume transported by air or high volume sea cargo it would be better to perform separate analyses and apply the results to the particular case that is proposed. While it may be logically feasible to consider a myriad of possible scenarios it will add significant mental complication. This highlights the fact that on some occasions the policy process could mandate the probabilities for different scenarios, while in other cases it will be the expert's view.

We acknowledge that there are significant issues in defining what beliefs are and how they can be elicited (see, for example Cooke (1991) or Hubbard (2009)). Any credible use of experts or opinion will need to structure the elicitation process carefully to ensure reliable and well calibrated responses. This is a diverse area that is beyond the scope of this report and so we do not explore this issue in detail. We note that the main conclusion of this report, that a coherent probability framework exists, is not directly undermined by difficulties in elicitation. The fact that particular experts might find it difficult to express their views in this manner does not invalidate the analysis. Given this, there are obviously legitimate questions about how the results of this project could be used in decision making. The protocols suggested in Section 2.6 would obviously need to be supported by significant training and development of staff. The skill mix of the organisation might also need to be considered to ensure that subject matter expertise is bolstered with staff with professional quantitative skills.

We agree that it could be difficult to train and maintain staff with the requisite inferential skills to support the analyses proposed in this section. But we do not believe it is beyond the skills of many scientists involved in biosecurity assessment. The approach actually seeks to simplify the analyst's work by being more explicit about what the questions are. It will simplify senior managers' jobs by fostering consistency and lowering variation in assessments. It will simplify the agency's approach to risk assessment by having a clear, logic based protocol to justify the decisions taken. The approach is not revolutionary, but rather seeks to evolve the current qualitative approach to foster greater transparency and confidence in the international system.

An argument that could be considered is that the framework suggested here is too technical for experts to use and there is a need to allow the elicited quantities to be more ambiguous. This will introduce another layer of uncertainty into the analysis. This layer is related to the vagueness of the questions to the experts. There has been some discussion recently about the appropriate uncertainty theory to deal with vagueness (Colyvan, 2008; Hubbard, 2009).

The obvious approach to dealing with vagueness is to define as precisely as possible the nature of the question of interest, which is the approach followed in this report. In biosecurity, this approach is manifested in the detailed international agreements setting out the rules and requirements. Where vagueness exists it may be a by-product of the negotiating process involved in setting the international agreement and not a question to be resolved by a science of uncertainty. In particular, in import risk assessment there is no particular vagueness about what constitutes an adverse event. Dispute processes exist to arbitrate disagreements about meanings. Therefore arguments that fuzzy logic or other approximate reasoning (Colyvan, 2008) is useful here should be considered carefully.

The analysis in this report has been firmly based on a coherent, probability based framework. While there are claims that subtle problems exist with the use of probabilistic approaches to uncertainty (see Colyvan (2008)) they still represent the main practical tool in common use for the analysis of uncertainty. The approach presented here might be enhanced by considering alternative uncertainty analysis techniques such as interval arithmetic. The advantage of the approach in this report is that it provides an explicit framework to assess the impact and coherence of any proposed uncertainty technique. Hayes (2010) has reviewed these in a companion report.

There are a range of other approaches which might be considered to bring quantitative structure to qualitative assessments.

As mentioned in the introduction, a risk assessment process need not necessarily be justified on its internal logic. Instead, historical data on its application could be used as an empirical argument to justify its use. For example, a biosecurity agency could record, for each assessment, the outcome from the decision. The obvious information to collate would be if any of the pests and diseases within the assessment was involved in an incursion that could be related to the managed trade. There are a number of difficulties with this approach. First, for assessments that find that there is no cost effective way to mitigate the risk and the only solution is to ban the import, there will be no opportunity to collect data on actual incursions. As these decisions will often be the most contentious this is a serious shortcoming. The second issue is that the rate of incursion is typically very low, by design. Thus, even if the system is not working, the rate of incursion could still be very low and the data not very informative. It would take many years to collect sufficient data. The last issue is that it is typically difficult to unequivocally determine the source of any incursion. Thus it may not be possible to attribute them to a failure in risk assessment. Given these shortcomings it is unlikely to be a viable option. It is still important that there are clear feedbacks between decisions and outcomes.

For qualitative risk analysis techniques that rely on a scoring system (see for example USDA (2000)) a Point of Truth Calibration (PoTCal) analysis could be considered (Barry and Lin, 2010a). In this approach, experts would rate a range of import risk analysis scenarios for their relative risk. In parallel, the scenarios would be assessed by the scoring system. The PoTCal approach would then statistically relate the scores produced to the overall assessments to calibrate. It would provide weightings and the functional form of relationships to build reliable predictors as well as calculating the associated uncertainties.

This style of calibration is under-utilised in biosecurity decision making.

The only other approach that we have considered is the construction of risk systems based on negation. In this system one would consider entry and establishment and spread but would only accept commodities where at least one of the steps had a “negligible” probability of occurring where negligible would be defined by the country to suit its purpose. This is implied in Panel 7 in OIE (2004b). This approach ignores any possibility of joint mitigation (ie that if each step is very low, the overall assessment may be acceptable), and is consistent with a dependency bounds analysis (see Hayes (2010)). Additional work is needed to explore its behaviour with respect to the probability framework developed in this report.

Finally, the pioneering attempts at quantifying risk numerically in biosecurity problems should be acknowledged (Miller et al., 1993; Gray et al., 1998; Firko and Podleckis, 2000). These authors identified the issues in the current practices of the time and proposed a more objective basis. These techniques have been successfully applied in many biosecurity contexts such as sampling and surveillance. For import risk assessment the successes are less clear. As argued in this report these approaches underestimated the difficulty in mapping a complex non-linear process to simple independence based models. We expect the authors were aware of some aspects of this but took pragmatic choices between simplicity and realism. This report has tried to illuminate these issues and to find a way to connect the pioneering work with the qualitative systems in use today.

4 Conclusions

The approach presented here gives a new opportunity for clear and transparent science based import risk assessment. It provides a starting point for defining standard questions in an assessment which will aid interpretability. As there is a continuum between this approach and more quantitative approaches, based on breaking down steps in the pathway, it provides a flexible framework and can potentially unify the approaches to import risk assessment.

In conclusion the key issue to consider is what are the quantities that are being estimated at each step, and how the questions can be framed to aid the assessors in providing a well framed and interpretable response. Perhaps, surprisingly, there are a number of ways of approaching this problem. The discussion in the previous sections has demonstrated that it is possible to construct a compound assessment using the components typically considered in a qualitative assessment that is logically based, interpretable and all components are clearly defined. It needs no more data than a qualitative assessment as it simply requires the analyst to express what they are thinking in a coherent framework.

5 Acknowledgements

This report is the product of the Australian Centre of Excellence for Risk Analysis (ACERA). In preparing this report, the Author acknoweleges the financial and other support provided by the Department Of Agriculture, Fisheries and Forestry(DAFF) and the University of Melbourne.

This report has been improved by discussions with Keith Hayes, Petra Kuhnert, Greg Hood, Mark Burgman, Bill Roberts and Alan Welsh and comments on an earlier draft from Mark Burgman and Mick McCarthy. Two anonymous referees also provided comment. Any remaining errors are my own.

6 Appendix

```
simulate<-function(n=10, packing=.1,
inspect=600, thresh=3, pe=.1, spread=.2){
# this function cvalculates a single possibility,
# that is weighted proportional to the full distribution

#generate farm infection rate
p<-rbeta(10,1,1000)

#generate 1000 shipments of size 1000
ships<-rbinom(1000, rep(1000,n),p)

#reduce the infection rate after washing
after.packing<-rbinom(length(ships), ships, 1-.1)

#identify shipments that are detected as infected
inspection.detect<-rbinom(length(ships),
1, 1-(1-after.packing/1000)^inspect)

#remove detected shipments
post.border<-after.packing[!as.logical(inspection.detect)]

#identify shipments above threshold
establish<-post.border>thresh

#remove those below threshold
post.border.threshold<-post.border[establish]

#does establishment occur?
atom.establish<-rbinom(length(post.border.threshold), 1, pe)

#spread occurs
atom.spread<-rbinom(length(atom.establish), 1, spread)



#summarise
if(length(atom.establish)==0) {
#no shipment above threshold
pact<-0
pest<-0
pspread<-0
spreadact<-0
prop.establish<-0

}  else {
#Theoretical establishment probability
if(sum(atom.establish*atom.spread)>0) {
spreadact<-1
pspread<-sum(post.border.threshold[
```

```
as.logical(atom.establish*atom.spread)])
/sum(post.border.threshold[as.logical(atom.establish)])
} else {
spreadact<-0
pspread<-0
}
pest<-1-(1-pe)^sum(establish)
pact<-sum(atom.establish)>0
prop.establish<-sum(post.border.threshold[
as.logical(atom.establish)])/sum(post.border)
}
entry<-sum(post.border)>0
prop.entry<-sum(post.border)/(length(post.border)*1000)
N<-length(post.border)*1000





#if (sum(atom.establish)>0) k<-post.border[
as.logical(atom.establish)]
#else k<-0
#prob.establish<-k/sum(post.border)


#pact<-sum(atom.establish)>0
unlist(list(pest=pest,pact=pact,entry=entry,
 prop.entry=prop.entry,
prop.establish=prop.establish, N=N,
 spreadact=spreadact, pspread=pspread))


}
```

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