CHAPTER 12

MODEL FRAMEWORKS FOR STRATEGIC ECONOMIC MANAGEMENT OF INVASIVE SPECIES

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Abstract. To allocate biosecurity resources efficiently and effectively it is necessary to be able to systematically estimate and describe risks from a wide range of threats and mitigation measures. A common framework for conducting risk assessments is an essential tool for setting national priorities and for making decisions that will justify actions to international trading partners. Two systems, one quantitative and one that combines qualitative and quantitative elements, are presented as examples of such a systematic approach.

Keywords: biosecurity; invasive pests; risk assessment; risk framework; risk profile

INTRODUCTION

Much of the literature on economic aspects of invasive species has focussed on estimates of historical losses, for example the Office of Technology Assessment (OTA 1993) report to the US Congress. Historical losses are useful evidence of the potential and likely scale of analogous new invasions and provide a justification for the continued allocation of resources to quarantine actions against such pests. Quarantine authorities are faced with the constant problem of deciding how to balance their limited efforts to prevent, intercept, detect and/or eradicate specific threats from amongst the thousands of potential pest species that may enter a country through a wide range of pathways. The World Trade Organisation Agreement on the Application of Sanitary and Phytosanitary Measures requires signatories to base their actions on sound scientific evidence and a consistent level of acceptable risk, based on appropriate international standards. The International Plant Protection Convention, for example, offers standards on Pest Risk Analysis methods for quarantine pests (FAO 2003). Stohlgren and Schnase (2006) describe the iterative steps involved in establishing the level of risk from individual species and pathways.

The strategic management of invasive species requires a consistent framework for economic assessment across the wide range of potential species involved.

A.G.J.M. Oude Lansink (ed.), New Approaches to the Economics of Plant Health, 181-190

Without a common method to predict the impacts it would not be possible to establish priorities on risk reduction or make assessments of the share of responsibilities that might be apportioned to the various participants in the system. This applies prior to introductions (Mumford 2002) as well as for decisions on eradication or suppression subsequent to an outbreak or long-term establishment of an exotic pest (Mumford 2005). Decisions concerning invasive species that affect natural environments in particular need to be included in a consistent framework to ensure that environmental impacts are not ignored, although this does not guarantee the priority for such species will be high (Mumford 2001).

Policy makers are faced with major issues at several levels regarding invasive species. The National Audit Office (2003) described the various policy needs for England and Wales, and the needs for many other countries would be similar. There are strategic decisions about the key invasive pest species on which to focus actions, for which preventative actions and pre-planned emergency measures for outbreaks can be budgeted, based on expected probabilities of detection. However, other species will also be detected in the course of routine inspection and surveillance and tactical decisions must be made rapidly on what actions to take and how to fund prevention, containment or control. All of these decisions require common frameworks to ensure that appropriate responses are justified and that the level of risk is consistent.

The following sections illustrate two mechanisms for establishing consistent frameworks for invasive-species assessment. The first involves a stochastic modelling process with generic variables describing invasion and impact, and the second is a more subjective classification scheme for systematically describing risk and impact for either planned or accidental introductions.

GENERAL QUANTITATIVE FRAMEWORK FOR INVASIVE PEST PRIORITIES

The need for a consistent framework for assessing invasive species has been recognized by the Department for Environment, Food and Rural Affairs (DEFRA) in the United Kingdom, in part as a way of managing the changing responses to a constantly evolving problem of invasion (Waage et al. 2004). New challenges arise from invasive species through new pathways, increased volume of trade or climate change, public attitudes put different relative values on environmental conservation, agricultural production or animal welfare, and technological developments create new pest prevention, detection and management opportunities, as well as potential new pathways (Waage et al. 2005). Despite such constantly changing circumstances predictions of impact must still be made, and they must include estimates of the uncertainties that come with that change.

Invasions follow a generic pattern of entry, establishment, spread and growth leading to impact over some proportion of the resource affected. Most do not succeed at some stage in this process (Williamson 1996) and the probability of failure should be accounted for in estimates of impact. A stochastic approach is needed to describe the range of outcomes that are possible over time as repeated invasion opportunities occur.

Waage et al. (2004) presented a demonstration of how a single generic model could include sufficient flexibility and detail to provide a useful estimate of impacts from a wide range of potential invasive species in the United Kingdom (Figure 1). The model consists of ecological modules that lead to estimates of the extent of invasion using common parameters related to success of entry, establishment, spread and growth of populations, taking into account potential control actions. These are coupled to economic modules that put values on the damage and control efforts associated with the added impact of a new pest over a 20-30-year time horizon.

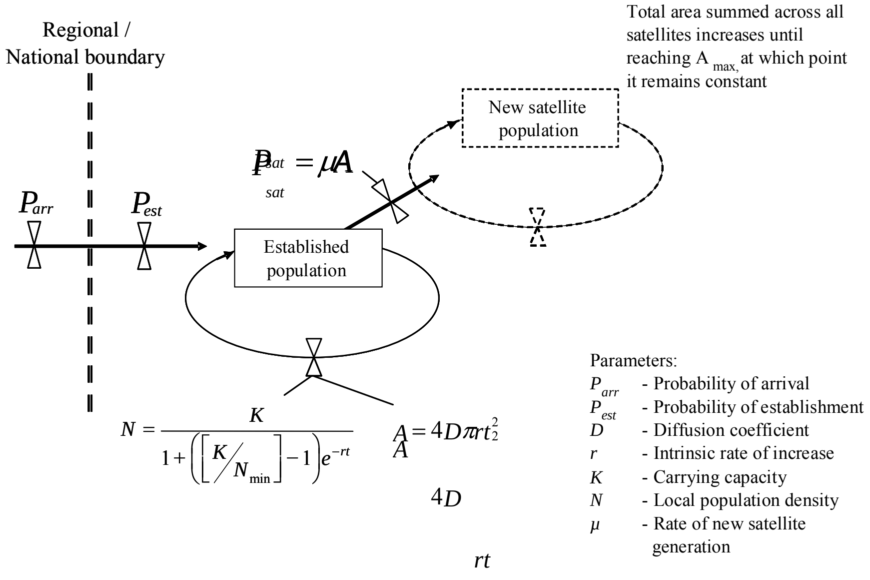


Figure 1*. Schematic representation of a generic entry, establishment, spread and growth model (from Waage et al. 2004)*

Figure 2 demonstrates the typical curves of impact over time for three categories of invasive pests, those that attack crops, livestock and natural environments. The vertical axis represents the total value of a sector that could be affected by an invasive pest, with 100 % being its pre-invasion value, with a subsequent decline in value related to the proportion of the resource that is affected by the new pest (shown on the horizontal axis). Crop pests cause damage that is more or less linearly related to the extent of the crop affected (unless there are significant effects on export potential, which can occur with some major plant quarantine pests). New livestock pests are much more likely to have an impact on export trade or travel, as occurred with the Foot and Mouth epidemic in the United Kingdom in 2001, causing significant immediate economic impact to the industries concerned even with only a limited presence. Pests in the natural environment often cause very little loss of value while they increase, because most of the quality of the environment is retained despite their presence. Eventually, however, as a much larger proportion of the environment is affected its overall value falls sharply as people begin to realize the rarity of the remaining unaffected portion. In each case, the ultimate measure that is used is the proportion of the resource and its value, which allows a common scaling from the model.

The long time delay affecting the impact from pests in the natural environment poses a serious problem in placing priority on such pests, because of the compounding effect of discounting (Mumford 2001). At the extreme, an invasive species may not even be noticed for some time in the natural environment. For example, the modal time lag from first introduction to discovery in the wild for new plant species in the United Kingdom is approximately 100 years (Preston et al. 2002). By contrast, the arrival of a notifiable human or animal disease should be recorded within days. Inevitably, pests of livestock are likely to have higher priority than plants because their impact is more likely to be immediate, and there is an important element of concern for animal welfare in the public, who are now also concerned about the possible crossover of animal diseases to humans (for example, avian influenza). This is reflected in the relative spending on animal and plant quarantine in the United Kingdom, where 90% of the funding supported animal health in 2000, even before the Foot and Mouth epidemic (Mumford 2002).

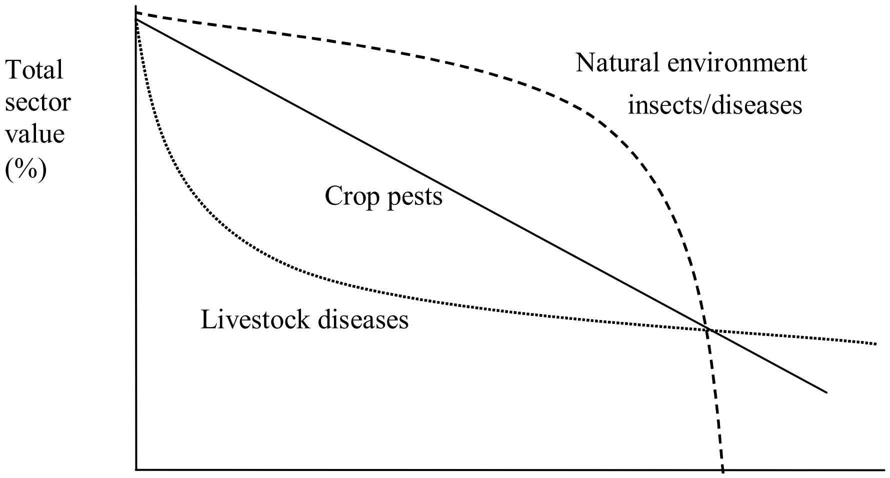


Figure 2. Three general curves depicting the economic relationship between the proportion of resource affected by an invasive pest and the impact on the total value of the sector affected (from Waage et al. 2004)

This approach allows systematic sensitivity analysis of parameter values to determine the effect of their contribution to the overall uncertainty in the estimation of impact. This could be used as the basis for additional research or subjective enquiry to narrow the uncertainty range for particularly variable parameters. Figure 3 illustrates an estimated risk distribution for annual Newcastle Disease loss and control costs in the United Kingdom for a 20-year time horizon. The model in this case is particularly sensitive to estimates of the probability of disease entry and establishment and the proportion of export revenue lost. For crop pests, spread and yield loss estimates are likely to be critical sensitivity parameters.

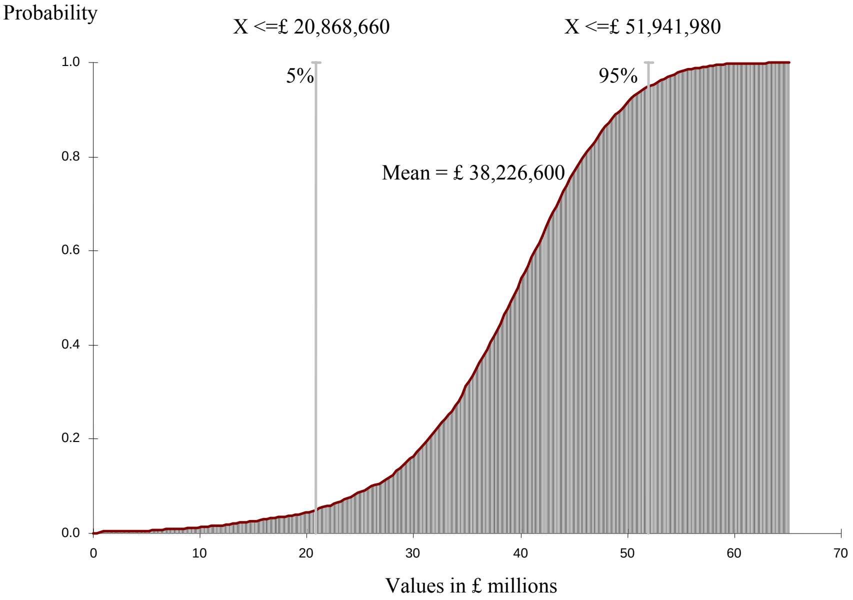


***Figure 3**. Cumulative distribution of the level of expected annual damage over 20 years for Newcastle Disease, a disease of poultry (from Waage et al. 2004)*

A shortcoming with this approach is that the generic format limits inclusion of some detail that might be helpful in specific cases and requires parameter data to be estimated in a form that is not always clearly applicable to a particular species, given the diversity of ways in which pests enter, establish, spread and grow. For instance, the dispersal of plants by seeds, rhizome and transplanting involves a complex of parameter values for spread, while aquatic vertebrates spread linearly in rivers. However, the opportunity to make direct comparisons across a broad range of taxa and resources compensates for the restrictions and simplification imposed by the model structure. This approach is intended for general screening of priorities, which might be followed by more detailed, case-specific analyses of high-priority invasive species.

SUBJECTIVE RISK FRAMEWORKS FOR BOTH BENEFICIAL AND HARMFUL NON-NATIVE INTRODUCTIONS

An attempt has been made by a multidisciplinary group in the United Kingdom to create a common system for assessing the impacts of non-native species that could enter the country, either by accident or design (Defra 2005). Previously, independent assessments using different criteria and scales have been applied to the various taxonomic groups by different responsible technical centres within DEFRA. The proposed new scheme consists of a standard set of questions related to the entry, establishment, spread and impacts of a new organism, which is designed to cover the full range of taxa that could enter, from pathogens to vertebrates. The module on economic impact includes questions to establish the magnitude (Table 1) and likelihood (Table 2) of introductions on common scales that can be combined to form an acceptability matrix (Table 3).

Table 1*. Magnitude values for risks, using four subjectively equivalent dimensions (from Defra 2005; and modified from Standards Australia 2004)*

Scale and score	**Monetary loss and response costs**	**Health impact**	**Environment impact**	**Social impact**
Minimal **1**	Up to £ 10k /yr	Local, mild, short-term, reversible effects to individuals	Local, short-term population loss, no significant ecosystem effect	No social disruption
Minor **2**	£ 10k - £ 100k /yr	Mild short-term reversible effects to identifiable groups, localized	Some ecosystem impact, reversible changes, localized	Significant concern expressed at local level
Moderate **3**	£ 100k - £ 1m /yr	Minor irreversible effects and/or larger numbers covered by reversible effects, localized	Measurable long-term damage to populations and ecosystem, but little spread, no extinction	Temporary changes to normal activities at local level
Major **4**	£ 1m - £ 10m /yr	Significant irreversible effects locally or reversible effects over large area	Long-term irreversible ecosystem change, spreading beyond local area	Some permanent change of activity locally, concern expressed over wider area
Massive **5**	£10m+ /yr	Widespread, severe, long-term, irreversible health effects	Widespread, long-term population loss or extinction, affecting several species with serious ecosystem effects	Long-term social change, significant loss of employment, migration from affected area

Many pest risk assessments must be subjective because of the lack of verified data relevant to the specific issues of introduction and damage in a new environment. The framework shown in Table 1 is an attempt to provide a set of definitions over a range of independent dimensions that might be appropriate to potential invasive species. This system is based on the Australia/New Zealand Risk Management Standard (AS/NZS 4360 Risk Management), but with some modification of the monetary values, and of the wording in the other three dimensions. A logarithmic five-point scale of magnitude of risks can be applied, which allows an approximate translation of impacts to a monetary scale. The five-point range of orders of magnitude covers the main range in which there is a relatively routine decision problem (tens of thousands of £ to tens of millions of £). Where potential impacts are significantly greater than this (as they would be with Foot and Mouth Disease, for example) it is not a routine decision.

Table 2. *Likelihood of impacts with descriptions and frequencies (from Defra 2005; and modified from Standards Australia 2004)*

Likelihood and score	**Description**	**Frequency**
Very unlikely 1	This sort of event is theoretically possible, but is never known to have occurred and is not expected to occur	1 in 10,000 years
Unlikely 2	This sort of event has not occurred anywhere in living memory	1 in 1,000 years
Possible 3	This sort of event has occurred somewhere at least once in recent years, but not locally	1 in 100 years
Likely 4	This sort of event has happened on several occasions elsewhere, or on at least one occasion locally in recent years	1 in 10 years
Very likely 5	This sort of event happens continually and would be expected to occur	Once a year

If a risk is a single one-off loss, or a series of specific incidents, for instance outbreaks of a disease which are quickly eradicated, it should be converted into an annualized average present value using the discount rate over a predetermined time horizon. The time periods and the discount rates selected can have a major effect on the estimated annual loss for single-point events.

Generally a new organism or pest invasion would be expected to cause a continuing loss, and that it could increase in impact over time, as was indicated in Figure 2. If the magnitude is expected to grow then an average annual value based on a net present value of the expected flow of loss/cost could be used as the base value to determine average annual loss over the proposed time period.

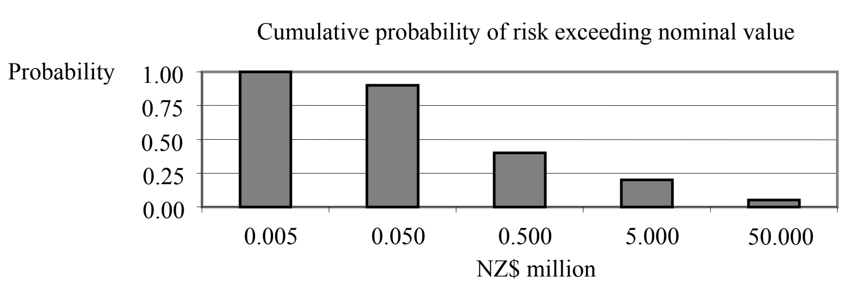
The likelihood values (Table 2) are also on a log scale of frequency and are scored on a five-point scale. This system is also based on the Australia/New Zealand Risk Management Standard with modified wording of definitions, and shifting of the frequencies related to some descriptions to make them less frequent. The Standard uses seven categories, including 1/3-year and 1/30-year frequencies, which would be approximate intermediate values on a log scale between the three relatively frequent categories. Scale scores for magnitude and likelihood can be added to give an overall value of risk, because both are on log scales. Where more specific estimates are available for loss or likelihood, fractional scores could be used to make calculations more precise.

Uncertainty can be expressed by assigning probability values to the likelihood and magnitude scales. The acceptability of risk can be described, as shown in Table 3. ‘Negligible’, ‘Justifiable’ and ‘Unacceptable’ risk would be judged against the benefits or costs of prevention and should be defined in a way that can be applied to any particular taxonomic example.

The uncertainty values for the individual dimensions of likelihood and magnitude can be used to express the uncertainty of the combined risk levels graphically, as seen in three-dimensional form in Figure 4. This shows the extent of the uncertainty in each dimension, while focussing on the most likely outcome expected.

Table 3*. Risk acceptability values, with uncertainty values for the two axes*

		Minimal	Minor	Moderate	Major	Massive
	p =	0.1	0.5	0.2	0.15	0.05
Very unlikely	0.3	**Negligible risk** **0.03**	**0.15**	**0.06**	**0.045**	**0.015**
Unlikely	0.5	**0.05**	**0.25**	**0.10**	**0.075**	**0.025**
Possible	0.2	**Justifiable - Low risk** **0.02**	**0.10**	**0.04**	**0.03**	**0.01**
Likely	0		**Justifiable – High risk**		**Unacceptable risk**	
Very likely	0					



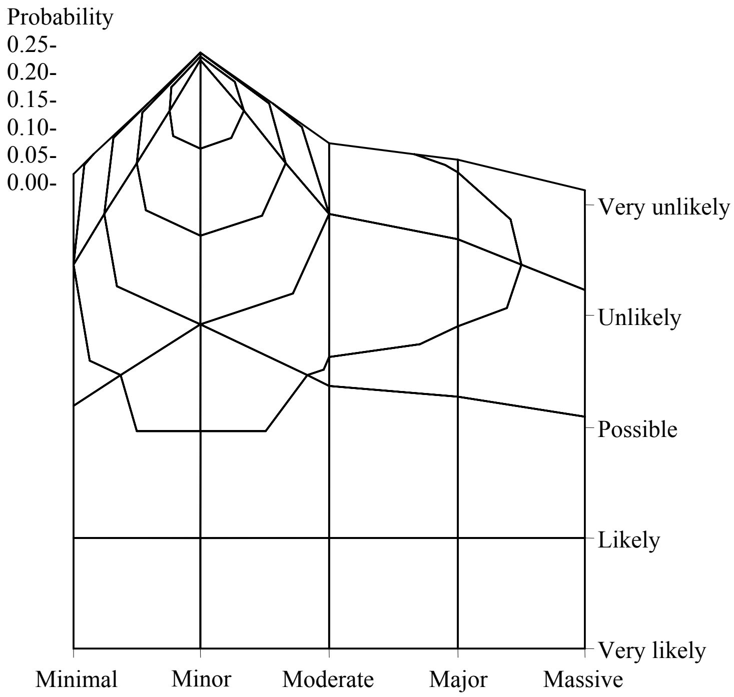


***Figure 4**. An example risk profile, showing the focus of risk from Table 3*

CONCLUSION

These two schemes demonstrate methods for quantitative and qualitative risk assessment and evaluation for introduced species. Both of the examples illustrate how a common system of prediction and common valuation criteria can be applied across the full range of taxa that could be involved in an invasion. They produce as outputs either continuous risk distributions or stepped risk categories and they help policy makers to assess the range of uncertainty involved and the value of obtaining additional information that might reduce the level of uncertainty. In both cases the frameworks are intended as first-level screening tools that allow general comparisons of impact, rather than highly detailed tools for deciding the response to particular priority species. While these generalized approaches have limits, they provide a useful system for ranking risks. The significant advantage of a generic model for predicting impacts is that priorities can be determined by comparing expected impacts in a common monetary unit over similar timeframes. While the feasibility of such models has been demonstrated by the DEFRA research, more effort would be needed to obtain practical parameter estimates for the large number of potential pests that should be evaluated if they were to be used for comprehensive priority setting on a species-by-species basis. It would be most practical to use them in a general form to set priorities, and to limit their use in specific cases to particular invasive species when these have been detected or otherwise under special scrutiny.

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