2.6 AGRICULTURAL PESTS AND DISEASES: COMPLEXITY, UNCERTAINTY AND RISK

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Introduction to agricultural risks

Agriculture is an inherently risky activity, undertaken by over 2.6 billion people around the world (FAO, 2005). Risks include production and price fluctuations caused by poor supply control by the large numbers of small producers, by unfavourable short term weather and longer term climatic threats, and by pests, diseases and weeds. The majority of the world's farmers are poor and the uncertainty in production and income contributes to poverty, malnutrition and death. Even in developed countries, agriculture is one of the most dangerous occupations; in the USA (1980–1997) it was second to mining in direct death rate (19/100 000 per year) amongst major occupations (CDC, 2001).

Many of the risks in agriculture are the result of natural events or of unplanned outcomes of markets, while others are the direct or indirect result of human intervention. In this description of risk in agriculture the focus is on the approach to the risks caused by agricultural pests, particularly where these risks are related to human activities, such as trade and travel, or the deliberate movement of organisms around the world.

The impacts of exotic diseases, insects and weeds can be enormous (Waage and Mumford, 2006). The Foot and Mouth Disease (FMD) outbreak in the United Kingdom in 2001 caused an estimated loss of £7 billion (Thompson *et al.*, 2002), the US government has spent £536 million on citrus canker (United States Department of Agriculture (USDA) press release 7 June 2006), Spanish citrus (with annual exports of around 60 000 tonnes to the USA) was banned from the USA for a year at the end of 2001 after Mediterranean fruit flies were intercepted in several US states (USDA, 2002), and in S Africa 7% of the nation's limited water resource is taken up by invasive exotic weed species (Cape Argus, 6 June 2006). Even biological control agents, generally seen as environmentally sound forms of pest control, pose some risks. The S. American *Cactoblastis cactorum* moth that so successfully controlled introduced *Opuntia* cactus in Australia and S Africa now poses a serious threat to endangered N. American cactus species after being introduced into the Caribbean region (Hight *et al.*, 2004).

International standards

Three international bodies provide standards related to risks in the movement of agricultural products, diseases, pests and food contaminants. These are the International Plant Protection Convention (IPPC) (www.ippc.org), the World Animal Health Organisation (OIE) (www.oie.org) and the Codex Alimentarius (www.codexalimentarius.net). The OIE establishes protocols for diagnosis and management of livestock diseases (OIE, 2000), the IPPC has prepared concept standards on pest risk analysis (IPPC, 1995) and is now moving towards more specific standards for diagnosis and management of specific plant pests and diseases (for example, IPPC, 2006b), and the Codex Alimentarius has established maximum levels of a range of specific contaminants in food (see Codex website). These three bodies are recognised by the World Trade Organisation as the standard setters for these areas (WTO, 1994). National authorities have the responsibility to implement systems to meet the standards.

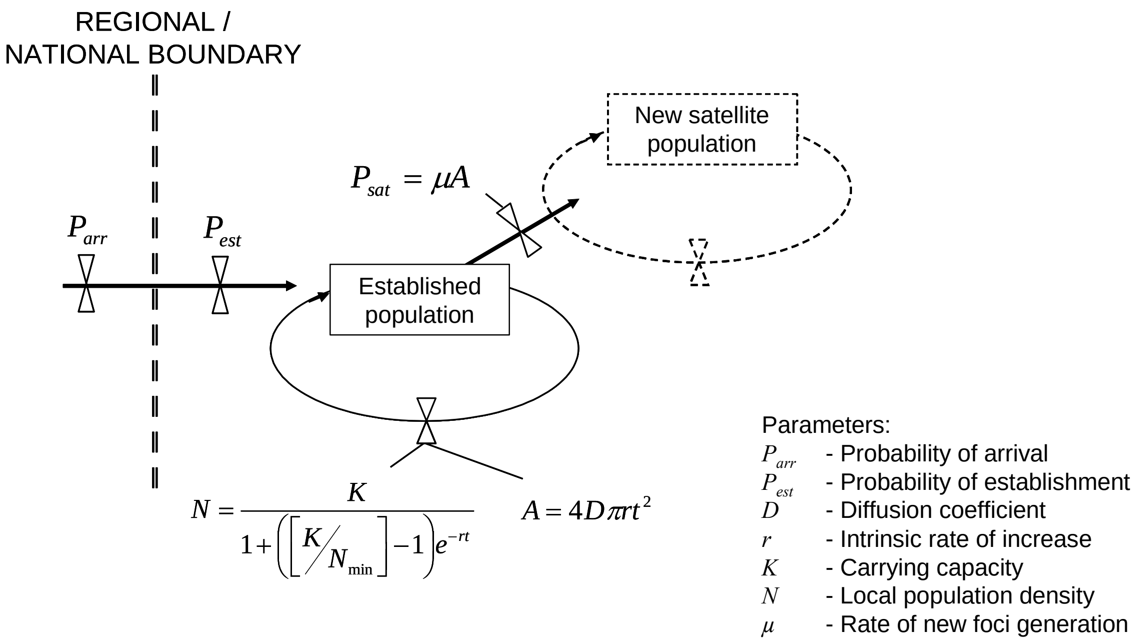
The principal risks involve the movement of animals, plants (including cut flowers and wood) or foods between countries. Animals and animal products must be tested according to OIE and national standards to ensure they are disease free, or be certified to come from disease free areas. Plants and plant material must conform to import rules and have a phytosanitary certificate issued by the exporting country. Foods are tested to Codex and national standards for permitted contaminants. In most cases market standards result in very high quality levels for internationally traded products and while vigilance is important, the threat is relatively low. For example, the USA imports around one million tonnes of citrus per year and intercepts on average around 20 Mediterranean fruit flies in commercial shipments (USDA, unpublished). By contrast, personal imports of fruits, flowers and meat pose quite high risks per item. In New Zealand, one person in 400 arriving by air is fined for failing to observe the well publicised quarantine regulations (Biosecurity New Zealand, unpublished). Smuggling is an important source of risk for animal and human diseases transmitted in meat. In the United Kingdom it is estimated that from 4,000-29,000 tonnes of meat are brought into the country from outside the EU each year (Parliamentary Office of Science and Technology, 2005). Wood packaging and pallets pose a significant risk, since they are incidental to the quality of the products they are associated with. This has caused serious infestations of Asian wood boring beetles in Europe and North America and has led to an international standard on wood packaging materials from the IPPC (IPPC, 2002).

Agricultural pests and diseases

Several reviews have examined the issues of intercontinental movement of agricultural and environmental pests and diseases (Nugent *et al.*, 2001; Mumford, 2002). Specific reviews on the impact of plant pest and disease introductions and the measures taken to prevent this in particular countries have been undertaken: USA (National Plant Board, 1999; Office of Technology Assessment, 1993; Pimentel *et al.*, 2000); UK (Mumford *et al.*, 2000; National Audit Office, 2003; Waage *et al.*, 2005); Australia (Nairn *et al.*, 1996); New Zealand (Parliamentary Commissioner for the Environment, 2000; New Zealand Institute of Economic Research, 2000). The risks are high, for instance it is estimated in the USA that the annual cost of introduced species is around $137 billion per year (Pimentel *et al.*, 2000). However, this comes from approximately 50 000 species introduced since European settlement of the Americas and a wholesale prohibition of trade would not be desirable, Pimentel estimated that benefits from introduced species amount to over $800 billion per year. Americans spend over $4 billion per year on pet food (Pet Food Institute, 2006) for the most damaging single introduced species, the domestic cat ($17 billion per year) (Pimentel *et al.*, 2000). Over $600 billion of agricultural products were exported around the world in 2004 (FAO, 2006) and this trade needs to continue to maintain sufficient food throughout the world and to maintain the international economy. Trade in non-agricultural commodities and travel also pose risks to agriculture as unwanted organisms may be transported in packing material, in personal baggage or on the ship or aircraft itself.

The risks associated with introduced organisms and their pathways are complex and the volume and varied concerns of the trade associated with them means that well-evolved systems of risk analysis have been needed to fairly address the risks and interests involved. Both ecological and economic factors affect the extent of risk that results from a particular pathway. Waage *et al.* (2005) proposed a generalised model of the process from introduction to impact for a new pest species (Figure 1) and illustrated how such a model could be used to produce cumulative risk profiles for a wide range of taxonomic groups.

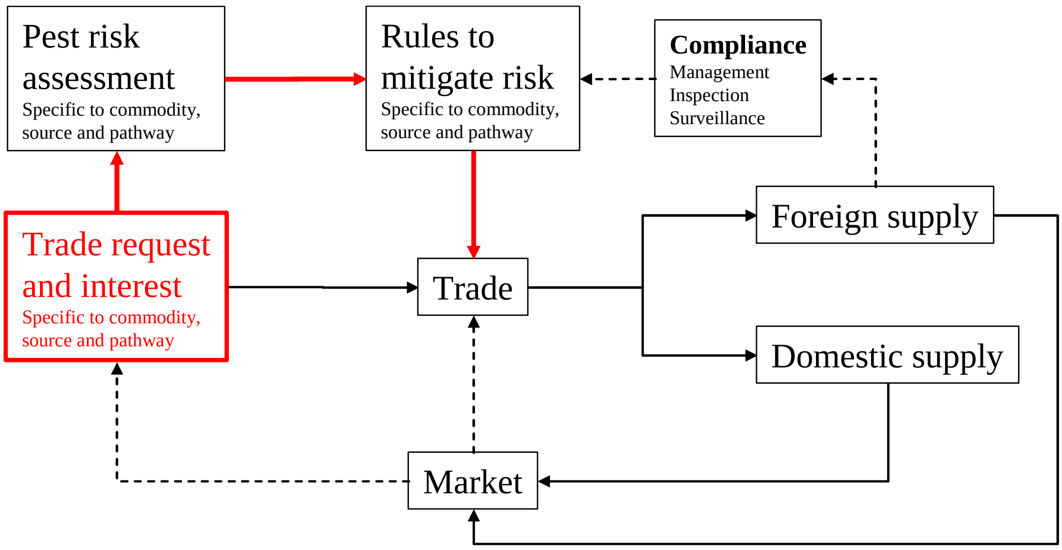
Figure 1: Factors in the introduction, establishment, spread and impact of an introduced pest (after Waage *et al.*, 2005)



The IPPC (1995) established principles for pest risk analysis that cover several stages: risk awareness, risk assessment, risk management and risk communication. The IPPC requires that contracting parties have a national plant protection organisation with a capacity to conduct pest risk analyses (PRA) and to issue phytosanitary certificates that indicate a particular level of quality in exported plant material. In conducting a PRA national authorities should cooperate in the provision of information, refrain from interference, not discriminate between trading partners, adopt harmonised risk mitigation measures and conduct the process transparently. A standard for agricultural pest risk analysis by importing countries (ISPM 11) was adopted by the IPPC (2001) and is the basis for risk analysis for quarantine pests related to plants worldwide. The general pest risk analysis process is shown in Figure 2.

Several features are important to the efficiency and effectiveness of PRAs. It is essentially a reactive process, which is generally initiated by a trade request for a particular commodity from an exporting country to a potential importing country. The importance placed on this request is determined by the potential importer's priorities, so PRAs may take some time to be carried out if this priority is not high. A review of an existing PRA or accepted trading arrangement could also be initiated by a change in circumstances, such as a new pest, a new method of shipping or a new pest control

Figure 2 Pest risk analysis is a responsive process triggered by a trade request



Source: IPPC (2001)

treatment. A typical PRA identifies a list of species known to be pests of the commodity in the exporting country, and often in neighbouring countries, since this could indicate a further risk that a pest has not been recognised in the exporting country, or that it may enter the country and be shipped on. The pests are categorised according to potential for introduction, establishment (based on climate and host suitability), dispersal, and economic and environmental impacts. Estimates are made of the likely quantity of imports and frequency of shipments, which affect the likelihood of introduction. For each significant pest associated with the commodity pathway an assessment is made of its ability to survive available control treatments. The probability of detection at the port of entry is assessed. This leads to a conclusion on the potential risk posed by the set of pests on a scale incorporating a combination of qualitative and quantitative inputs.

Holt (2006) has reviewed some of these scaling processes, typically ranging from three to seven point scales, and demonstrated that combining the scales for the various risk properties associated with introductions can lead to a centring effect that may make it difficult to discriminate amongst risks from different species. He has proposed a method to quantify the scales, which effectively gives greater weight to individual extreme values that affect the overall likelihood and impact of a new pest incursion. This quantification of scales has the merit of being relatively practical to use with limited data.

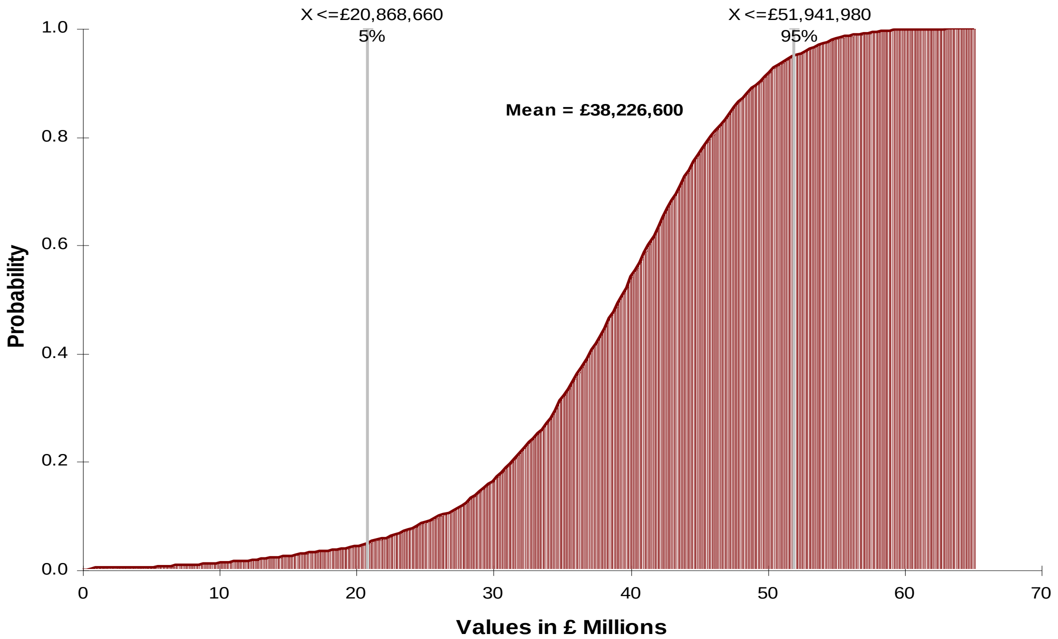
Waage *et al.* (2005) demonstrated a quantitative modelling approach which provides a much more detailed analysis of risk from pest and disease introductions, but is dependent on much more detailed data than would be practical for routine PRAs. They constructed a generic model based on the ecological parameters in Figure 1 coupled with economic estimates of costs and losses. The output of this modelling was in the form of a cumulative probability distribution of annual economic impact (such as illustrated in Figure 3). Sensitivity analysis of the model reveals the parameters for which data is particularly important, and this may allow much reduced data requirements in many cases (Table 1). This modelling approach was used to investigate the long term factors involved in the dynamics of risks from introduced pests and diseases. General rules can be tested through case studies using the model, which can then be applied as qualitative criteria in less intensive routine risk analyses. For example, new pests that are likely to affect subsequent export trade are the most critical; pests with long delayed and dispersed non-tangible environmental impacts are not immediately of high priority. These rules may be intuitive, but can be demonstrated by reference to a range of quantified examples.

By the nature of quarantine pests, they are not present in the potential importing country, so the importer conducting the PRA must rely to a considerable extent on the potential exporter, who generally has experience of the pests, or other importers, for information. This can take time and may not be completely reliable. While an exporter may have an incentive to provide requested information, where it is available, to facilitate the trade, other competing parties may have much less incentive to share information. Real world experimentation to obtain information on establishment or spread is naturally limited, especially with diseases.

The PRA document is the culmination of the risk assessment stage of the analysis and is then used as the basis for creating a set of rules to mitigate the potential risk for the commodity within the specified pathway(s). The rules typically would require management of the pests during production to minimise the density entering the processing chain. Monitoring may be required in the field, according to a specified protocol, to demonstrate the initial density to be expected, on which a statistically based inspection sampling process may be demanded. Physical controls such as washing, heating, cooling, or irradiation or chemical treatments may be proposed. Inspection on arrival is also likely to be included, although some countries prefer to inspect some commodities at the port of embarkation to reduce the risk and cost of unsuitable produce arriving at the destination. These rules are generally open to consultation with importers, exporters and other interested parties and once agreed and published (the risk communication stage) they represent an accepted level of risk on the part of the importer, although they could be reviewed at any time circumstances change.

The range of potential mitigation measures itself poses a problem over the equivalence of different combinations of risk management measures. The IPPC has recently adopted a standard that addresses this issue (IPPC, 2005). In recommending particular risk management measures to prevent pest risks an importer must accept measures or combinations of measures that can be demonstrated to give an equivalent level of protection, so for instance cooling for a week may the same as fumigating for an hour. The choice of measures to take should be left to the exporters, provided they meet the needs of the importer. Two controls that have similar effect, for instance on mortality, such as cooling or fumigating, can be compared directly. It is more difficult to compare methods with different immediate outcomes, such as cooling produce in transport and establishing a low prevalence of pests in the field during production. These can only be compared indirectly, by for example considering market rejections or interceptions at border inspections.

Figure 3: The cumulative distribution of annual losses due to Newcastle Disease, a disease of poultry, in the United Kingdom (from Waage *et al.*, 2005)



The PRA process works best for well known pests and often does not provide any assessment of potential new pests which do not cause problems in their native area and may only become a problem in a new environment. In this regard there is much greater uncertainty associated with plant feeders, such as insects, which number in hundreds of thousands, if not millions, of species, than with animal diseases, which number in scores. The pest risk analysis process is based on an expected likelihood of unwanted organisms entering through a particular commodity pathway for which agreed risk mitigation measures are to be applied and checked. Some element of precautionary bias may enter the process, but the decision to allow trade with prescribed mitigation measures must meet World Trade Organisation rules to have a scientific justification and transparency (WTO, 1994).

So the greatest risks come from personal shipments in airline baggage (an unpublished USDA estimate is that 6% of baggage has potential quarantine material, extrapolating to around 69 million bags per year), smuggled meat, and unexpected pests that survive control measures aimed at species that are expected in commodities.

The PRA process involves risk assessment in anticipation of a trade developing. Once trade is underway and organisms are potentially entering further risk analyses may be applicable in relation to border inspection procedures, surveillance for outbreaks and eradication programmes.

The rules arising from the PRA process prescribe the main mechanisms for preventing the introduction of new pest organisms. In principle any imported commodity that may contain harmful organisms can be inspected on arrival, and in some countries, such as New Zealand, this is routinely carried out. In practice, however, this would be expensive and would not be justified by the risk. The US imports approximately $15 billion of fresh fruits and vegetables annually (FAOStat website, www.fao.org). The rate of interceptions of quarantine pests on these commercial shipments is around 4 per million dollars worth of produce, reflecting a

Table 1: Sensitivity analysis for parameters used in the analysis of Newcastle Disease risk in the United Kingdom (from Waage *et al.*, 2005)

Parameter	Change in Parameter Value (%)	Resultant Change in Expected Damage (%)
Highly sensitive		
Average Total Revenue Loss – Export Losses	–50.0	–46.6
	+50.0	+46.3
Sensitive		
P(Establishment)	–50.0	–23.8
	+50.0**	+17.6
P(Entry)	–50.0	–22.4
	+50.0**	+16.2
Intrinsic Rate of Satellite Generation (□)	–50.0	–11.4
	+50.0	+9.4
Relatively non-sensitive		
Average Total Cost – Vaccination	–50.0	–5.5
	+50.0	+3.9
Intrinsic Rate of Spread (*r*)	–50.0	–4.3
	+50.0	+4.1
Maximum Number of Affected Animals (A_{max})	–50.0	–3.5
	+50.0*	+4.0
Pest Density Immediately Upon Introduction (N_{min})	–50.0	–2.1
	+50.0	+1.5
Very low sensitivity		
Maximum Number of Satellite Infestations (S_{max})	–50.0	–0.9
	+50.0	+1.7
Infection Diffusion Coefficient (*D*)	–50.0	–1.5
	+50.0	+0.6
Animals Infected Upon Introduction (A_{min})	–50.0	–0.8
	+50.0	+1.0
Maximum Attainable Pest Density (K)	–50.0	–0.9
	+50.0	+0.9
Average Total Revenue Loss – Yield Loss	–50.0	–0.1
	+50.0	+0.2

* Sensitivity test value beyond a maximum attainable value, and is therefore purely for illustration.
** Since the parameter is a probability, maximum possible test value used is one.

combination of market driven quality and regulatory vigilance. The EU has recently adopted a reduced inspection scheme for some plant products (Commission Regulation (EC) No 1756/2004 of 11/10/2004). The level of the reduced frequency of inspection is based on the proportion of consignments on which harmful organisms are intercepted, a subjective assessment of the mobility of the most mobile stage of the organisms concerned, the number of consignments on which inspections have been carried out during the previous three years, and 'any other factors relevant to a determination of the phytosanitary risk'. Only products from countries in which less than 1% of consignments have been found to contain harmful organisms can be considered for reduced inspection. Inspections may be reduced to as little as 5% of consignments (for example, citrus from Morocco). While the reduced inspection process results in greater risk, these risks are still very low in absolute terms.

Quarantine inspectors respond to a range of risk indicators at borders. Cut flowers account for 69% of interceptions in commercial air cargo in the USA (Work *et al.*, 2005). Cargo aircraft that depart from their origin during the night account for 66% of aircraft that are found to contain insects in their holds at Miami (Caton *et al.*, 2006). USDA analysis (Meissner *et al*, 2003) of quarantine risks from road traffic on the US-Mexican border shows that trucks pose less of a risk than cars, because they are carrying commercial quality produce. Higher risks are found for: returning citizens/residents, vehicles with a distant starting point, 5+ passengers, recreational vehicle, and vehicles crossing the border on Sundays as all of these factors favour personal transport of food provisions. Focussing inspections on higher risk categories such as these can increase interception rates by 4–10x compared with results from random searching.

Despite preventive measures and border inspections pest outbreaks still occur. Surveillance to detect outbreaks is directed at early identification of small populations which would allow containment and eradication. However, the range of potential species that might occur and be harmful to crops and other plants is very great and surveillance methods are often specific to particular organisms, and all surveillance has a cost and may be intrusive to the public. Surveillance is therefore often conducted on the basis of some form of risk analysis. This is more difficult to do quantitatively than for specific commodity/pathway based PRAs because so many parameters are unknown, since post entry surveillance does not necessarily arise from known and controlled supply chain conditions. The USDA Animal and Plant Health Inspection Service (APHIS) has used an analytic hierarchy process (AHP) to prioritise 141 exotic plant pest organisms (Schwartzburg *et al.*, 2005). Expert opinion from those with experience in biology, economics and quarantine procedures was canvassed in several workshop sessions to establish a set of important criteria and to evaluate a list of pest according to the criteria selected by the group as whole. The major criteria in order of importance and weight were: economic impact (0.413), potential for post-establishment increase and spread (0.234), establishment potential (0.179), entry potential (0.108) and non-economic (social and environmental) impact (0.066). These criteria are similar to those used by Waage *et al.* (2005) and others to model the impact of potential pests, but with the added value for risk analysis of specific weightings for the various contributing criteria.

Eradication may be achieved if unwanted organisms are found early enough to be contained and there are effective control measures available at relatively low cost. The Mediterranean fruit fly (Medfly) has been eradicated on many occasions in Florida and California at a cumulative costs of $328 million, but in recent years outbreaks have been reduced by preventative control practices even when the pest is not recorded to be present (Waage and Mumford, 2006). Carey (1991) caused considerable controversy by raising the issue of the statistical basis of eradication in relation to Medfly. In effect, eradication is defined statistically as the inability to find individuals of a population at a particular agreed level of intensity of sampling. This leaves open the small risk that the pest may still be present at densities too low to be detected by that level of sampling, compounded by the problem that the a very low density population may have an highly heterogeneous spatial distribution. The level of sampling is determined in part by the cost and efficiency of sampling large areas for very low populations of pests and by the willingness of trading partners to accept the sampling intensity as representative of the risk they may face by importing produce from the eradication area. Standards covering the principles for sampling intensity following eradication have been agreed for some pests, such as fruit flies (IPPC, 2006a).

Bioterrorism

Schaad *et al.* (2006) present a model for subjective, expert assessment of crop pathogens that may be deliberately introduced and spread in the United States as agents of bioterrorism directed at the agricultural industry. This would be a more subtle form of economic warfare than the release of human pathogens, such as anthrax, and attacking crops would probably have less immediate psychological impact than attacking livestock. However, opportunity may be a prime consideration and all potential threats need to be considered. This sort of assessment is rather different from normal pest risk analysis, which focuses on the most likely pathways and impacts under normal, managed practices, which are generally unfavourable to the accidental introduction of exotic organisms because market conditions promote clean produce in controlled conditions. In the case of bioterrorism a risk analysis focuses on the most favourable circumstances, since the introduction could in theory be managed so that it could occur in such a situation. Schaad *et al.* established a set of 17 criteria relevant to the crop pathogen, its dissemination, detection, control and impact (Table 2). A series of workshops with groups of experts were held to establish these criteria, to determine the relative weighting of each of the criteria and to assign scores for the specific pathogens being considered. Demonstration scores were presented for some potato pathogens, highlighting the significance of Potato Ring Rot, a disease with serious implications for trade.

Table 2: Groups of criteria developed for rating threats from deliberate plant pathogen introductions (Schaad *et al.*, 2006)

Pathogen properties

1. Pathogen survives easily for long periods under field conditions
2. Organism produces toxin or other compound in plants toxic to animals/humans
3. Organism is easily manipulated genetically
4. Organism targets multiple hosts
5. Organism is easily disseminated or transmitted in nature
6. Affects yield
7. Virulence of pathogen is high

Production and dissemination

8. Pathogen is easily fermented or grown
9. Organisms is easily introduced and not dependent upon weather conditions
10. Organisms is seed transmitted and breeder seed is often produced abroad

Detection

11. Organism is difficult to detect, often latent, escaping detection
12. Attributes of organism make it difficult to trace

Controls

13. No chemical controls available
14. No resistance available

Impact

15. Presence of organism would result in negative psychological impact
16. Pathogen is of quarantine significance and affects trade
17. Presence of organism or product could greatly affect economics

The first outbreak of this disease in the United Kingdom occurred in 2003 in Wales (DEFRA, 2005b), caused by an accidental introduction of infected planting material from the Netherlands. This has led to consideration by DEFRA of how such risks can be reduced, which highlight some of the criteria determined by Schaad *et al.* (2006). Routine sampling as required by EC Directive 93/85/EEC would only have an 18% chance of detecting a 0.1% infection level; the testing method has a 6-8 week development time; potato varieties of differing susceptibility and provenance may be mixed at harvesting, affecting dissemination, detection and interpretation; control involves disposal of all potentially infected tubers and disposal of large amounts of potentially infected material can be difficult, particularly given conflicting regulations on waste disposal; there was considerable media interest, since the spread and disposal process was in some ways similar to Foot and Mouth Disease and there was concern of a potato shortage which would affect the public; notification requirements are different for different potato diseases within the EU, so further spread could occur for some diseases before other states are notified.

Beneficial species introductions

The New Zealand Environmental Risk Management Agency (ERMA NZ) (www.ermanz.govt.nz) operates a system to approve introductions of beneficial organisms into New Zealand, under the Hazardous Substances and New Organisms Act 1996. Applicants wishing to introduce an organism must provide documentation on the species to be imported, the purpose, the manner of collection, shipment and release, a description of risks to commercial or environmental interests and proposed mitigation measures. A review process is undertaken with the applicant and ERMA NZ technical staff to ensure that sufficient evidence is available for a public enquiry. Explicit stakeholders and the public are notified, and once this is complete an enquiry with a panel of three lay assessors is convened, in which evidence to support the introduction is presented and any objections are heard. The assessors work within a framework of risk assessment in which likelihoods and consequences of introduction are expressed in a standard format and predetermined levels of acceptability are applied. The process allows risks to be taken, but ensures that a consistent upper limit of risk is achieved. Individual component risks, for instance for impacts of a new organism on several different potential host species, and overall risks are considered. Efforts are made to quantify the likelihood and monetary consequences of negative impacts and the variability of the estimates. A degree of conservatism is applied to uncertain estimates, of either likelihood or magnitude, to reflect the uncertainty of dealing with natural ecological processes.

A format similar to that used by ERMA NZ has been proposed in the United Kingdom for assessing the impacts of non-native species that could enter the country, either by accident or design (DEFRA, 2005a). The module on economic impact in this proposed scheme includes questions to establish the magnitude (Table 3) and likelihood (Table 4) of introductions on common scales that can be combined to form an acceptability matrix (Table 5).

Many pest and beneficial organism 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. Table 2 defines the magnitude of risk in several dimensions that might be relevant to invasive species. These various descriptions are related to each other and to a monetary scale that allows for conversion to a common unit, if needed. This system is based on the Australia/New Zealand Risk Management

Standard AS/NZS 4360 Risk Management (Standards Australia, 2004). 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 £), but in cases involving magnitudes of risks much greater or less than this range the decision process is likely to be more clear cut, to either accept or reject the risk.

The likelihood values (Table 4) can also be expressed on a log scale of frequency and scored on a five point scale. This system is also based on the Australia/New Zealand Risk Management Standard with modified wording of definitions. Two intermediate categories in the Australia/New Zealand system are deleted because the log scale can essentially be treated as continuous if it is used quantitatively. 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.

Table 3: Magnitude values for risks, using four subjectively equivalent dimensions (from DEFRA, 2005a, 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, localised	Some ecosystem impact, reversible changes, localised	Significant concern expressed at local level
Moderate **3**	£100k–£1m /yr	Minor irreversible effects and/or larger numbers covered by reversible effects, localised	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

Table 4: Likelihood of impacts with descriptions and frequencies (from DEFRA, 2005a, 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 1000 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

The acceptability of risk can be described and set in advance, as shown in Table 5. '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. In the example given in Table 4, assessors would initially focus on the modal point (unlikely-minor) and consider that it is justifiable (assuming sufficient benefits are expected) and of relatively low risk. The weighted values of the cases that are worse than this modal cell, in the row to the right and the column below fall in the two adjacent cells that are lightly shade in Table 4. These also fall in justifiable, low risk categories and so a decision to accept the risk of such an introduction would be considered robust, despite the possibility of a massive consequence with probability of 0.002. A beneficial organism introduction scheme, such as applied in New Zealand, while conservative, would be unlikely to take a completely precautionary approach in a case laid out like this.

Conclusion

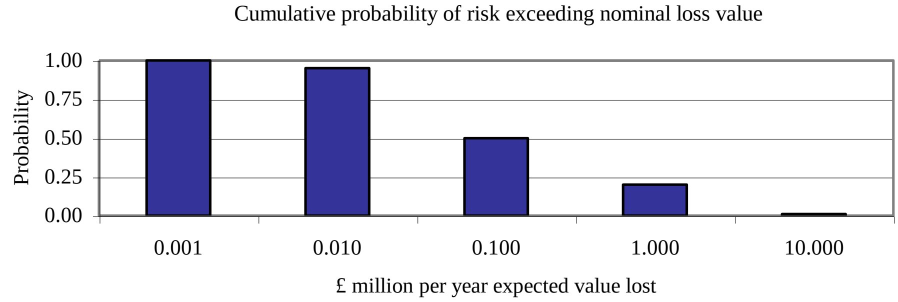
Risks from unwanted exotic organisms are a significant issue in agriculture and the environment and international efforts have been made to establish systems to assess and manage these risks. The approach that has resulted has been qualitative or semi-quantitative so far, although there are continuing efforts to make it more directly quantitative. A fundamental limitation to strict quantification is the lack of hard data on probabilities and consequences of introductions because each set of conditions is unique and there are few well documented cases of analogous situations.

There are important implications for trade involved in the process of pest risk analysis that require approaches to be based on commonly agreed standards and scientific justification. While these standards are helpful in establishing a basis for accepting trade, they must be fairly general for plant health in agriculture because of the very large number of potential pest species to consider, while animal diseases can be covered more specifically. The generality of standards can be a limiting factor in their usefulness for consistent risk assessment across a wide range of circumstances.

Several generic lessons are evident from this discussion of an important set of risks facing agriculture. The risks described are mainly unique cases, albeit within an overall framework of intentional or accidental movement due to trade. They involve

Table 5: Risk acceptability values, with likelihood and magnitude uncertainty on the two axes (after DEFRA, 2005a)

	p =	Minimal 0.05	Minor 0.45	Moderate 0.3	Major 0.19	Massive 0.01
Very unlikely	0.2	Negligible risk 0.01	0.09	Justifiable - Lower risk 0.06	0.038	0.002
Unlikely	0.6	0.03	**0.27**	**0.18**	0.114	0.006
Possible	0.2	0.01	**0.09**	0.06	0.038	0.002
Likely	0					
Very likely	0	Justifiable - Higher risk			Unacceptable risk	



Modal annual loss (£ mn) 0.003 Mean annual loss (£ mn) 0.325

thousands of species potentially entering new environments in which their performance can not be completely known in advance. In this way, these risks are very different from those in engineering applications where operating conditions, performance and outcomes are likely to be more predictable. Much of the effort in dealing with these agricultural risks has therefore been placed in securing expert subjective opinions and in trying to establish consistent frameworks for risk analysis into which this expert opinion can be channelled and interpreted. The lack of shared access to these risk analyses, and to performance measures such as subsequent pest interceptions, around the world has limited the development of stronger quantitative approaches to risk analysis related to exotic agricultural pests.

Much of the complexity related to exotic agricultural pest risks stems from the huge range of simultaneous risks faced due to the large scale of agricultural and other trade internationally. One common approach has been to focus on key pathways for introduction, and to develop mitigation rules based on that pathway, with the expectation that this would at least address the most likely risk components, or that the mitigation efforts may have some effect beyond the pathway addressed. Many pest risk analyses cover a large assortment of potential pests that may enter with a specific commodity, and where possible mitigation measures that control more than one pest would be prescribed. However, often the only connection between two pests may be that they are associated with a common commodity, such as oranges – their lives and options for control may be quite unique. It is common in pest risk analyses to list all pests in the complex that may occur with a commodity and to rate each according to likelihood and impact, but then to focus only the few that have the highest levels of likelihood weighted impact. This is an implicit recognition that priorities must be set in a process that can only reduce, no eliminate risk, given the resources available to it.

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