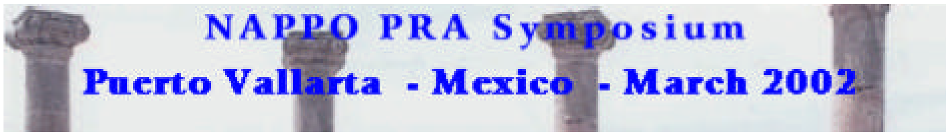

Review of Methodologies for Environmental Risk Assessments

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I. Introduction

We were asked to review methodologies used for environmental risk assessments that might be applied to the situation of plant health. There is no internationally recognized definition of "environmental risk assessment". Although similar approaches to risk assessment exist in various fields, there is disagreement among the leading developers of risk assessment theory regarding the treatment of uncertainty (Griffin 2000, EC 2000; Smithson 1989, Freudenberg 1988, Kappeli and Auberson 1997, Anderson 1998). The differences in treatment of uncertainty arise partly from contrasts between the philosophy that emphasizes expected net benefits (discounted by risk), and a philosophy that places a burden on assuring safety. Statisticians and philosophers of science have pointed out that sometimes it comes down to whether one assumes the null hypothesis is "safety" and risk has to be proved, or the null hypothesis is "risk" and safety has to be proved (Shrader-Frechette and McCoy 1993). Other concerns frequently expressed by environmental protection groups include the lack of information about which species will be invasive when introduced to a new set of conditions and even more uncertainty about their ultimate impacts on entire ecosystems.

Invasive species are widely discussed as a global environmental scourge, both in the popular press and in scientific journals (Vitousek et al. 1996, Myers et al. 2000). Estimates of the damage caused by exotic species vary widely, but even the lowest estimates are on the order of several billion US dollars annually (Pimentel et al. 2000, 2001). In addition, most accounting of damages due to invasive species does not reflect the hard-to-quantify impacts of invasives on biodiversity. Part of the challenge is that the regulatory community has only recently come to appreciate that invasives represent a risk not just in agriculture (as weeds or pests that attack crops), but also as disrupters of unmanaged ecosystems, and even as factors contributing to the extinction of native species. Because environmental risks outside of agricultural systems are a new concern, it is not surprising that regulatory approaches are still nascent. By the same token, ecologists and those who developed the language for the Convention on Biological Diversity are just waking up to the role of plant health regulators and inspection services in keeping out unwanted species. The key point is that the international community and governments throughout the world recognize invasive species as an environmental hazard warranting regulation and mitigation. The question is what form of regulatory approaches might be both practical and effective.

In this chapter we review existing approaches to plant pest risk assessment, paying particular attention to the extent to which risk assessment has considered impacts outside of agricultural systems. We then survey several examples of environmental damage caused by invasive plants and pests in natural systems. Here our purpose is to make clear that indirect effects frequently arise, and that such effects would be difficult to anticipate simply by considering each invasive species as an entity unto itself. Then we review what approaches in the war against invasive species have worked and what approaches have not. We tread lightly on the question of whether it might be a hopeless war, and whether the planet is doomed to be overrun with exotic species to such an extent that native versus non-native loses any meaning. We synthesize all of these threads in a conclusion that recommends a broadened approach for pest risk analysis that includes difficulty of control and likelihood of damaging impacts to native ecosystems as weighting factors.

II. Pest Risk Assessment and How Regulatory Policy Deals With Hazards Outside of Agriculture

Although no one claims to have found the perfect risk analysis procedure, achieving consistency and predictability in any risk assessment is an important first step. A return to the days when trade decisions were strictly bilateral and often tainted with politics is of interest to no one. Notably, it is only in the past decade that a harmonized Pest Risk Analysis methodology was defined. The North American Plant Protection Organization (NAPPO) helped to start that process of harmonization by holding its meeting in 1991 on international approaches to plant pest risk analysis (NAPPO, 1993). The first international standard on this methodology was presented in the original International Standard for Phytosanitary Measures (ISPM) No. 2 *Guidelines for Pest Risk Analysis* (IPPC, 1996). The process of defining and giving guidance to methodologies for risk analysis is ongoing, as shown by the latest International Standard on Phytosanitary Measures (ISPM) no. 11, *Pest Risk Analysis for Quarantine Pests* (IPPC, 2001), which was approved only last year. Obviously, pest risk analysis is not limited to the justification of trade measures but is used to assist many national decisions about the relative merits of exclusion, eradication, or containment as options for mitigating pest problems. Moreover, risk assessment is used in other fields to make decisions about hazards other than plant pests.

Provision for environmental aspects of risk was made under the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS) of the World Trade Organization (WTO, 1994). That agreement requires trade-related phytosanitary measures to be based directly on either an international standard of a recognized reference setting organization (for plant health, this is the IPPC) or on a risk assessment. At the time, there were no standards set on the issue and methods for factoring in environmental risk when conducting an overall risk assessment. The contracting parties to the International Plant Protection Convention have been grappling with the challenge of getting environmental criteria into the risk assessment of plant pests (ICPM Working Group, 2001, as has the North American Plant Protection Organization (NAPPO). A recent European Directive defines environmental risk assessment as “the evaluation of risks to human health and the environment, whether direct or indirect, immediate or delayed”…(European Directive 2001/18/EC). This Directive, which applies only to genetically modified organisms, indicates that more detailed guidance on how to do an environmental risk assessment will be forthcoming. It will be interesting to see exactly what guidance is provided, since, as we discuss below, once one considers indirect and possibly delayed ecological effects any possibility of simple prediction is lost.

There is no question that national plant protection authorities have focused their efforts in the past on protection of agricultural resources. Of course, this is not uniformly true, since some countries have considered the protection of wild flora to fall within the scope of the International Plant Protection Convention (IPPC). New Zealand, for example, has taken a more holistic approach through its biosecurity program for several years (New Zealand, 1993). The USA is among the growing number of countries that examine risks to forests (both managed and unmanaged) before allowing entry of timber from a new source (USDA, 1991). However, for most countries, concern for wild flora has only evolved over the past decade in conjunction with the rising awareness of environmental impacts from exotic species. The international community took a bold step this year in requiring risk management of wood packaging and dunnage on a routine basis (ICPM4 2002).

This same international plant health regulatory community (ICPM3, 2001) clarified the scope of work for National Plant Protection Organizations with words that clearly embrace a broad definition of invasive risks, *"plant pests includes weeds and other species that have indirect effects on plants.*" In order to offer more guidance, this group of governments requested some additional guidance on environmental risks in particular. The supplement to the international standard on Pest Risk Assessment (ISPM 11), now in draft form, specifies the scope of the convention to include *"organisms which are pests because they:*

- *directly affect uncultivated/unmanaged plants*
- *affect plants indirectly (weeds)*
- *Affect plants indirectly through effects on other organisms."*

This suggests that for a risk analysis of any pathway, commodity or organism in question, the factors to be examined will broaden considerably. For example, the initiation of a Pest Risk Analysis is likely to expand simply because we will need to consider a larger number of species (native wildflowers as well as crop plants) as being possibly harmed by an invasive organism. It may expand because the size of the area potentially impacted increases due to the inclusion of unmanaged lands. Finally the scope for initiating a risk analysis is likely to expand because a wider variety of negative impacts (such as threats to biodiversity) are under consideration.

Although today there is increasing interest in methods for assessing "relevant ecological and environmental conditions" or "potential biological consequences" (WTO 1994), tangible products from this interest are scarce. In particular, text supporting inclusion of environmental factors has been part of the plant health dialogue for years, yet few examples of "environmental" pest risk analysis are on record. One important question regarding possible changes implied by the draft supplement for environmental risks will be, *"how can we effectively implement this broader mandate?"* This is particularly worrisome because ecological systems are more complicated than agricultural systems and expertise regarding these systems has not been included in the traditional Ministry of Agriculture staff. We focus here on what it means to extend pest risk analysis to broader environmental impacts, and how the challenge of meeting this daunting task might be met.

III. Impacts of Invasive Species on Native Ecosystems and Biodiversity

Invasive species are a dominant factor contributing to the extinction risk for over 40% of the threatened and endangered species in the USA (Wilcove et al. 1998), and this pattern is thought to hold worldwide. For example, the introduction of Nile perch into Lake Victoria is responsible for the extinction of over 200 species of cichlids that were endemic in the lake (Kaufman 1992). Ecologists feel the impact of invasive organisms on native flora and fauna is generally underestimated because no one has regularly searched for these sorts of impacts (as is done in agricultural systems): in other words, the absence of evidence is not evidence for no effect due to invasive species. The threat due to non-native plants is so large, that The Nature Conservancy, which is the world's largest conservation NGO and largest nonprofit owner of conservation lands, considers invasive plant species their number one management problem. The US National Park System similarly considers invasive plants to be their number one environmental problem. In many cases invasive plants have become the dominant species in native landscapes. Examples include scotch broom and purple loosestrife in many areas of western North America, or *Spartina* cordgrass as it spreads along the Pacific coast of USA.

Although a small percentage of invasive species cause dramatic change to native communities, most invasive species cause little, if any, notable impact (Williamson and Fitter 1996). Williamson (1996) has argued that in general only about 10% of all introduced species ever establish self-sustaining invasions (i.e. invade successfully), and that of those species that are successful invaders, only about 10% ever cause noticeable damage to natural communities. This bit of good news is complicated, however, by two problems: first, the relatively few species that are harmful can cause enormous harms, both ecologically and economically, and second, ecologists, weed scientists, and biocontrol experts share a dismally poor track record at making a priori predictions about which potential introductions will cause harm. In fact, of the species intentionally introduced to Australia for some purported benefit, more species are viewed as weedy than as useful (Lonsdale 1994). In other words, more than half on the plant species purposely introduced to Australia because they were thought to be beneficial, have turned out to be considered weeds. In the arena of biological control, introductions are typically preceded (at least in recent years) by detailed studies of life history, diet breadth, and potential for interactions with non-target species. Yet, even following such detailed studies, mistakes are commonly made. In North America, a flower-feeding weevil, *Rhinocyllus conicus* was introduced to control non-native thistles of the genus *Carduus*. Although laboratory studies demonstrated the ability of this weevil to feed and grow on native thistles, the threat to native species was considered negligible due to the weevil's preference for the problematic weedy thistle . Unfortunately, recent surveys have documented that the introduced weevil is now heavily attacking certain populations of native thistle that have been previously demonstrated to be seed limited (Louda et al. 1997).

Despite the many horror stories regarding species introductions gone awry, there is some irony associated with the remarkable success of invasive species – namely that, at a local scale, invasive species are typically producing dramatic increases in biodiversity. For example, the species richness of California has been increased by over 20% thanks to invasive plants – with an addition of 1023 non-native species to a baseline native flora of 4839 species, and only 26 documented extinctions (Hickson 1993). In some cases invasive species have become such an accepted component of local ecosystems, that money is expended to protect the invasive species from future invaders. Thus *Eucalyptus* trees are so well established in California that California is actively engaged in a program aimed at controlling herbivorous insects that attack *Eucalyptus* (Hanks et al.2000; Luhring et al. 2000). In fact, exotic insect species are being imported to California to control populations of herbivores that feed on *Eucalyptus* (Hanks et al. 1995; Hanks et al 2000; Paine et al. 2000). Thus, California is actively working to protect an abundant exotic species by importing yet more exotic species to help in this mission. California's affection for *Eucalyptus* is not easily justified on biological grounds, since the allelopathic effects of these trees on native annual grasses is well documented, and the extreme flammability of *Eucalyptus* has substantially contributed to property loss due to wildfires in California.

One might think that the impact of an invasive organism on endangered species should be easily predicted, such that in any case where a species fed directly on or competed directly with endangered species, that species would be strictly quarantined. Unfortunately, indirect effects on endangered species can be so hard to predict that we should expect to be surprised by impacts due to invaders. For example, several non-native fish have been introduced to the Columbia River system, which also harbors a number of salmon that are endangered species. These non-native fish (small-mouth bass, walleye, channel catfish) do not directly consume salmon. However, they do consume crayfish and sculpins, which are the preferred prey of a native fish called the pike minnow. In the presence of these invasive species, the pike minnow switches its diet away from crayfish to focus on salmon. Consequently, native pike minnow now consume over 16 million salmon each year in the Columbia River basin, primarily because of the indirect effects of a suite of non-native fish introductions (Ruckelshaus et al, in press). It would have been extremely hard to predict this effect, no matter how thorough a risk assessment had been done on the bass, walleye, and catfish.

A second example of surprising indirect effects on endangered species involves feral pigs, an abundant, non-native resident of the California Channel Islands. Ecologists initially viewed feral pigs as environmental threats because they dug up and destroyed native vegetation. And pigs do indeed have this harmful direct effect. But they do more. Pigs have been so successful that abundant piglets have provided a bountiful new food source for golden eagles. Then, as golden eagle numbers have increased over recent years, populations of the endemic island fox have declined dramatically, and three subspecies of island fox are now on the brink of extirpation (Roemer et al 2002). It is hard to imagine one easily predicting that feral pigs would have anything to do with foxes on the brink of extinction.

Over 100 species of parasitic flies and wasps have been introduced to Hawaii to control moths that feed on crops. It would not be terribly surprising to find that some of these parasitoid species occasionally attack native moth species, in addition to the crop pests. It was surprising, however, when a recent survey found that the vast majority (83%) of parasitoids emerging from native Hawaiian moth larvae were species that had been intentionally introduced for biological control (Henneman and Memmott 2001). This finding is particularly striking given that the surveys took place in a wilderness preserve, maximally isolated from agricultural areas. Admittedly, many of the parasitoids were introduced some 50-100 years ago, before much care was taken to study the host range of parasitoids prior to their introduction. Still, the extent to which the parasitoids are utilizing native host species in a fairly remote area, highlights the point that species do not only interact with their intended targets, nor do they remain confined to their intended ecosystems. In an examination of 2754 records of established non-indigenous plants in the USA (Lockwood et al 2001), 245 (~9%) of the species had invaded valuable natural areas ("native ecosystems including national, state and local parks, ecological reserves, wildlife areas, national forests, etc").

The surprises due to invasive species are not always negative. *Phragmites australis* is a highly invasive wetland species along much of the North American Atlantic coast (Chambers et al. 1999). Although a lot of money has been spent trying to control the *Phragmites* invasion, several biologists have recently wondered if the benefits of Phragmites might outweigh the costs of control. *Phragmites* marshes are every bit as productive as native marshes, and support equivalent fish and macroinvertebrate communities to native wetlands (Meyer et al. 2000). *Phragmites* marshes can provide important habitat for birds, with over thirty avian species recorded from New Jersey *Phragmites* marshes, including four threatened or endangered species of birds (Kane 2000). Most surprising is the finding that unlike native plants, *Phragmites* sequesters heavy metals from the water below the ground where it does not enter the fish food-chain, and may thus provide an important water-purification service that native plants do not provide (Windham et al., in press).

A final generic impact of invasive species is homogenization. Even though invasive species may not deplete biodiversity locally, they certainly reduce the local uniqueness of each and every landscape and make it so that places on the planet which once had unique collections of plants and animals, now share similar fauna and flora and look more and more alike (Rahel 2000). Ecologists are not sure what will be the consequences of such homogenization. Many people value "local uniqueness" and feel that the loss of local uniqueness undermines their sense of a "home" and of "natural legacies".

In summary, invasive species are everywhere, often representing 10-40% of the species in any ecosystem. Their impacts range from horribly destructive, to negligible, to perhaps beneficial. It is often not a simple matter to distinguish a "good invasion" from a "bad invasion". Once we leave the arena of agriculture and the convenient currency of reductions in crop yield, it is nearly impossible to catalogue the many possible risks due to invasive species, much less estimate quantitative hazard functions. But throughout the globe, the steady influx of local species is eroding local uniqueness and spatial heterogeneity.

IV. But Haven't Several Statistical Analyses Suggested Indicated Some Measure of Predictability?

Although the ecological literature surrounding invasions is replete with examples of intentional invasions that went awry, and of surprises, a recent spate of studies indicates some clear statistical proclivities.

1. Expert system questionnaire

The expert system questionnaire approach used by Australia to screen invasive plants has been shown to be remarkably effective when applied independently to an entirely different arena (Daehler and Carino 2000). In particular, when the Australian system was applied to Hawaiian plants (after their fate was known), 90% of the species that we now know are invasive would have been outright rejected by the Australian risk analysis. Moreover, the remaining 10% that we now know are invasive would have been flagged by the Australian system for "further study". Clearly, there is a methodology available that has great promise. The Australian system uses 49 questions, whose responses (not all questions have to be answered) are used to calculate a composite risk score (http://www.aqis.gov/au/docs/plpolicy/wrmanu.htm). The Australian system does appear to be cautious in the fact it scored roughly 14% of the Hawaiian plants that cause no problems in natural systems to be a serious risk. But this modest rate of "erring on the safe side" is not especially egregious.

2. Survival factors

Several studies indicate that species with broad physiological tolerances or large geographic ranges are especially likely to be highly invasive (Marvier et al, in press; Goodwin et al 1999; Scott and Panetta 1993). Most of these studies considered plants, although geographic range is widely recognized as a contributing trait to insect species' propensity to outbreaks (Nugent et al 2001). Yamamura and Katsumata (1999) discuss how spatial and mating behavior impact the probability of successful introduction by way of agricultural commodity trade.

3. Level of endemism

An analysis by Ruesink (2003) in which the impact of 1408 cases of introduced fish were examined reports one predictor of the "impact of invasions". Introduced fish species were most likely to have a marked ecological effect where the recipient community was characterized by high rates of endemism. The impact of co-evolution of the host and predator or pest may also play a role in predicting responses (as discussed in Quinlan 2001). Protecting areas of endemism from introductions is a high priority for regulation of living modified organisms (Thwaite and Seal 2001).

4. Taxonomic trouble makers

Taxonomic identity and previous history are also good predictors of invasiveness. For example, woody plants that have become invaders in one place are highly likely to be an invader in another place (Reichert and Hamilton 1997). The principle of taxonomic affinity as a basis for regulatory restrictions has already been suggested in Hawaii, where a broad coalition of state and federal agencies argue that any shipment found containing an ant species not already established in Hawaii requires quarantine action if the shipment includes ant lifestages with the ability to reproduce (Hawaiian Ant group 2001). There is also some statistical evidence that if a plant species comes from a genera that is novel to an area, that species is more likely to end up invading natural areas than representatives of genera already present (Lonsdale et al 2001, but data only for Florida and California).

5. Frequency of introductions

Lastly, the more frequently a species is introduced, the more likely it is to establish a population (Bierne 1975). In particular, the more times a ladybird species had been released for biocontrol purposes, the more likely was that species to establish a population, even though all of the releases were placed in favorable conditions. This empirical result should not be surprising, since it follows from the simplest proababilistic arguments (Kareiva 1989). This result emphasizes that simply reducing the propagule pressure or number of introductions can represent effective management without requiring 100% success. A more interesting question is whether the addition of non-native species in an ecosystem has a simple additive effect (e.g., six non-native species cause twice as much damage on average than do three non-native species), or whether there are non-linear interactions and "invasion meltdowns" (Simberloff & Von Holle 1999). If non-indigenous species facilitate one another, there will be an opportunity for ever-increasing numbers of exotic species to eventually lead to greatly exacerbated ecosystem changes beyond any expected additive effect.

This final point may seem obvious and is, in fact, noted as a contributing factor to probability of an introduction in guidance on Pest Risk Analysis. Adjustments to import decisions over time because of a marked increase in the number of shipments, for example, have been rare and only followed repeated detections that showed treatment failure. The idea that probability is largely affected by not only frequency of shipments of particular commodity but the level of infestation of each consignment has occurred to US Port Directors, but sampling methods do not reflect that idea in even the best resourced inspection situations. The work under coordination of the International Plant Protection Convention regarding efficacy of measures that is to take place later this year may begin to better incorporate this final point in decision making and for feedback and review of decisions.

V. After Invasions Are Underway, Can they Be Controlled?

Even more than with agricultural pests, it is hard to document when prevention of an ecologically significant invasion is achieved. First, one must show that the species would have caused a significant impact, and then demonstrate that the introduction was a possible event. Preventive measures are especially important for protecting unmanaged areas (Murphy et al 2001) due to:

- the limited surveillance programs aimed at such areas,
- lack of detection tools for some of the key environmental pests,
- our nascent understanding of which species are of priority concern, and
- the lack of environmentally acceptable treatment options once an invasion has occurred.

Unfortunately, it is hard to gain support for taking such preventive measures for environmental pests that in many cases are not even listed, let alone fully understood in terms of the impact if establishment were to occur.

The range of available control measures in natural areas are also somewhat limited in comparison with those developed over the years for agricultural or managed lands (see Table 1). For agricultural lands, for example, the possibility exists to adapt to an introduction by planting disease resistant varieties over time, thereby reducing the impact (consequences). This is not an option in a native prairie or wetland. The question of what can be done after an invasion is underway is a traditional element of the Pest Risk Analysis, although for agricultural systems the question has often focused on availability of registered pesticides that are efficacious in killing the new introduction. The lack of environmentally benign control measures for containing or eradicating an invasive alien species once it is in a sensitive natural area should be an important consideration for Pest Risk Analysis. The difficulty of control measures for natural areas may be the basis for choosing prevention measures (quarantines) when calculating risks and identifying mitigation options. But, before specifically considering such a risk analysis, we need to ask if there are examples of invasive species being controlled after they have already arrived?

Usually we hear about biological invasions that swept over a country regardless of all control efforts. It is worth noting that many control efforts have succeeded. For example in 1969 the state of Florida discovered 42-block infestation of giant African snails in Miami, and a second infestation 40 km away (Simberloff, in press). By quickly mounting an eradication campaign that included hand-picking, poison baits, quarantines and publicity, Florida eradicate this snail by 1975 at a cost of $1 million. New Zealand has been successful at eradicating many notorious weeds by mounting aggressive campaigns immediately after discovery (e.g., against pampas grass, ragwort and prickly hakea, see Simberloff, in press). Australians have also had great success eliminating some legendary weeds – karoo thorn in Western Australia and Taurian thistle in Victoria (Weiss 1999). Even the highly mobile pest insect, white-spotted tussock moth was eradicated in Auckland at a cost of $5 million, using *Bacillus thuringiensis* sprays. Key to all of these successful controls was relatively early detection, and a policy of immediate action ("shoot first and ask questions later"). However, there are also instances in which longstanding invasions have been controlled or eradicated, just as has occurred with some agricultural pests (e.g. cotton boll weevil from the United States, Cunningham and Grefenstate 2000). For example, there have been a number of successful eradication programs targeting non-native vertebrates (such as mice and rats) on islands (Myers et al. 2000). The Norway rat was eliminated from Langara Island in a single year, although this highly organized and well funded poisoning effort also killed a large number of ravens and eagles (refs in Myers et al. 2000).

Although preventive measures are preferred, there are instances in which invasions can be controlled after they start. Chances for success are generally enhanced by rapid action, which may require an existing funding mechanism and contingency plan (Meyers et al 2000). The systems approach using integrated measures, as described in the international standard approved only very recently (IPPC, 2002), should be examined in relation to the pathways of entry of environmental pests when post-entry control is impossible.

VI. Confronting The Ecological Realities of Invasive Species With Pest Risk Analysis

International agreements (WTO 1994; IPPC 1997) indicate that, in order to avoid the abuse of phytosanitary measures, countries must state which species or biotypes they consider to be threats to their natural and agricultural resources. Unfortunately, experience indicates that predicting the environmental risks associated with particular species, one at a time, is limited. The task is especially daunting when one considers the traffic in biologically significant products; for example, in just one year over 300 million plants were brought into Florida (Lockwood et al 2001).

The environmental community responds to this enormous flow of potentially invasive species and uncertainty about their likely impacts by invoking a precautionary principle. The precautionary approach would suggest that all introduced species should be treated as "guilty until proven innocent" and hence excluded (Ruesink et al 1995). It is worth noting that the precautionary approach was embraced at the Earth Summit of the United Nations in Rio de Janiero in 1992 (UNCED 1992). Specifically it was agreed in Principle 15 of *the Rio Declaration on Environment and Development* that: "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities" (UNCED 1992). But the precautionary principle does not factor in the possibility of benefits outweighing costs, nor admit the fact that many invasive species end up being valued components of ecosystems. It also does not address the risk of illegal trade replacing sanctioned trade channels if a country's measures become too restrictive. Clearly, there may be a need for a delicate balancing act between a "precautionary principle" and trade realities.

We suggest that in Pest Risk Analysis, plant health officials should recognize the possibility of serious consequences although the probability is low. In particular, even if there is no experience indicating that a particular species will cause damage, we ask that governments find the resources to consider the risk in more depth. The actual risk calculation should include three dimensions:

- likelihood of invasiveness given all relevant statistical generalizations,
- possibility of great damage if the invasive species thrived,
- cost and difficulty of control should the species become a pest.

Although these dimensions are listed in international guidance on Pest Risk Analysis, the second point is usually limited to evaluating a species' capacity to survive and spread. One novel aspect of our recommended approach is an emphasis on the vulnerability/value of the recipient region when deciding whether to aim for prevention rather than accepted risk. The concept of vulnerability, which is a common element in environmental impact assessment, is usually limited in Pest Risk Analysis to a review of the climatic conditions and the presence of known hosts or susceptible agricultural systems. Issues such as the impact of drought, pollution, introduction of other species, isolation of an ecosystem or other disrupting forces that make a plant community more vulnerable to invasion are not discussed (Quinlan 2001). This is where ecologists should be consulted, so that the latest thinking about concepts such as ecosystem resilience, species clusters and population persistence can be interpreted into regulatory approaches (Liebhold 2001). Special protection for more vulnerable plants or plant communities is very analogous to a general principle of medical risk analysis in which children are afforded an extra degree of precaution.

Similarly, including a dimension about "great damage" also suggests that one knows the value of the endangered area. There are a number of approaches to valuation that can be applied to environmental factors for this purpose (Mumford 2000). Minor impacts to plants may result in large consequences if the plants are highly valued or if the indirect effects caused by the initial minor impact are serious ones. While evidence must be collected to support such decisions, or trade would come to a screeching halt, ecologists have been addressing the question of what to protect in the rubric of conservation biology for a number of years.

When data are available, an approach along the lines of the Australian weed risk assessment is recommended. In the absence of such information, a potential invader's risk could be assembled by an "experts score sheet" that tabulated the invasiveness, impact, and difficulty of control factors mentioned above. For example, invasiveness should be scored as high if the species being evaluated has a broad geographic range, has broad physiological tolerances, or is closely related taxonomically to destructive invaders elsewhere. All three of those attributes are relatively easy to ascertain. Impact risk should be considered high if the recipient region is rich in endemic species or includes lands of great conservation value. Lastly, difficulty of control should be considered high if dispersal capacity is high, if there is a resistant life stage (e.g. dormant seeds), or if reproductive rates are high. Even if a species offers little indication of an invasion risk, the mere fact the species could be difficult to control should elevate its risk score. The use of "expert judgement" in risk analysis in the absence of data needs to be conducted with special care, since experts sometimes just support conventional wisdom. Fortunately, there are well-developed methods for the implementation of expert evaluations (Meyer and Booker 1991). While there is frequently pressure to pursue mathematical models of risk as the preferable "quantitative" option, these approaches cannot make up for an absence of data. The main criteria for successful risk analysis are that it is consistent, transparent, tested and testable, easily modified as new information is obtained, and adaptive. If an approach is quantitative yet falls short in these criteria, it will fail as risk analysis.

A sample "expert questionnaire" that tallies these queries is given in Table 2. As a practical example, it is worth noting that although the Hawaiian Ant Group mentioned above does not use the framework described in Table 2, all of the ingredients in Table 2 figure prominently in their analysis. Specifically, the major reasons for such a strict quarantine policy are the numerous cases where ants have been both successful invaders, destructive invaders, and notoriously difficult to control. Ideally the synthesis of the three axes of risk (invasiveness, impact, and difficulty of control) should be a product, rather than an average. This is because high risk on any one axis or dimension poses the threat of overcoming low risks on all other dimensions. For example, if a species is highly invasive, even though it is easy to control and enters regions with few endemics or less native conservation value, that species will spread so widely and have so many opportunities that some sort of damage is likely.

Given the relentless flux on non-native species at every country's borders, and the absence of detailed species information, these sorts of expert system evaluations will be fraught with errors. This means that it is critical that each risk evaluation, no matter how data poor, be entered into a global database on invasive risk analyses. In this way, although errors will be made, the global community will be able to benefit from experiences throughout the world, and resource-poor countries will be able to draw on the more detailed risk analyses carried out by resource-rich countries. Risk analysis done under the guise of plant safety regulations must contribute to a global database.

One of the statements by the Conference of Parties to the Convention on Biological Diversity (Decision V/6, C.3.) expresses it in this way:

> *Ecosystem management should be envisaged as a long-term experiment that builds on its results as it progresses. This 'learning by doing' will also serve as an important source*

of information to gain knowledge of how best to monitor the results of management and whether the established goals are being attained.

Additional capacity is needed to be able to approach Pest Risk Analysis in this spirit. The key point is that indirect effects and surprises become more likely and more difficult to predict when broad environmental concerns such as biodiversity and stability in unmanaged ecosystems are considered. The regulatory response to this uncertainty cannot be paralysis – but it has to include some expansion of environmental protection thinking and an expert system approach that factors in invasiveness, impact, and difficulty of control.

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Table 2. Expert Score Sheet. In the absence of extensive data, a score sheet similar to this might be used to assess a species potential for invasiveness, impact, and difficulty of control. High = 1, Medium (denoted Med below) = 2, Low=3.

Species Name ___________; Expert Evaluator _____________

Invasiveness	Low	Med	High
Geographic range in native sites			X
Breadth of physiological tolerances	X		
Taxonomic relatedness to destructive invaders	X		
Degree of Phenotypic Plasticity	X		

Impact	Low	Med	High
Richness of Endemics in recipient region			X
Conservation Value of recipient region		X	

Difficulty to control	Low	Med	High
Dispersal Capacity			X
Presence of resistant life stage			X
Reproductive rates			X

Invasiveness Score = $(3 + 3 + 3 + 1)/4 = 2.5$

Impact Score = $(2 + 1)/2 = 1.5$

Control Difficulty = $(1 + 1 + 1)/ 3 = .33$

Overall Risk is the geometric mean, or the cube root of $2.5 \times 1.5 \times .33 = (1.25)^{1/3} \sim 1.1$

Where the range is 1 = highest possible risk, and 3 = lowest possible risk. Alternatively, one could use geometric means, as opposed to arithmetic means for the component scores (invasiveness, impact, control). The species would be entered into a global data base, as would written records indicating the reason (or source if data or previous documentation is available) for each entry in the above table.

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The authors wish to thank the Rockefeller Brothers Fund for their support through the grant to CABI Bioscience, UK Centre, entitled “Increased participation in a WTO standard setting process regarding assessment of risks from invasive alien species”. CABI is one of the lead organizations for the Global Invasive Species Programme (GISP).

Table 1. Phytosanitary Measures for Managing Regulated Plant Pests

Timing of measure in relation to the entry and establishment of an unwanted non-indigenous insect disease, weed, or vector:	**Reducing risk of entry** of a given pest through man-made pathways. Takes place prior to arrival to the country or area.	**Verification of compliance at the time of possible entry** to the country or area.	**Control or mitigation after introduction** to the country or area.	**Adaptation to the introduction**.
Trigger to carry out these measures:	• Request for permission to import new commodity, or from new country. • New information on risk from a pest or a pathway. • Policy review on existing pathways or pest status. • IDENTIFICATION OF A PLANT SPECIES OR COMMUNITIES IN UNMANAGED SYSTEMS THAT A COUNTRY CHOSES TO PROTECT BASED ON SOME CONSISTENT AND DEMONSTRABLE CRITERIA	• Arrival of cargo, passenger or vehicles that may pose risk. • Arrival through mail. • Arrival at distribution point, nursery, packing site, etc when border inspection is not done.	• Outbreak or incursion detected and control options exist. • Initial outbreak observed to spread or become established. • Natural pathway led to introduction and control deemed appropriate. • CLARIFICATION OF POLICY TO PROTECT PARTICULAR PLANTS OR PLANT COMMUNITIES • IMPLEMENTATION OF CONTROL MEASURES ON AN ALREADY ESTABLISHED POPULATION TO ALLOW FOR TRADE RESTRICTIONS	• Impact found to be less than predicted. • New ability to adapt becomes available. • Decision to end control due to continuing spread or ineffective control measures. • Belated discovery of an introduction that has spread. • Cost of control exceeds benefits. • EXISTING PLANT COMMUNITY FOUND TO OVERCOME THE IMPACT OF THE INVADER
Examples of measures and tools:	• Training, technical assistance, surveys and research in country of origin of a shipment. • Literature reviews. • On-going contact with officials, experts, universities, etc in areas of origin of shipment. • Review of interception lists. • Development of restricted lists and quarantine pest lists in accordance with SPS guidelines. • Inspection in country of origin. • Restricting imports to a designated free area in a country with pest. • Requiring treatment for high- risk items. • Pathway analysis using above tools and statistics on pathway. • Genetic fingerprinting on historic introductions to find pathways. • Environmental modeling for predicting potential range of organism, survival parameters. • Probabilistic calculations from range of survival parameters. • Indices of invasiveness. • Pest Risk Assessment using all of the above tools. • CONSIDERATION OF WHICH TAXA HAVE BEEN INVASIVE TO SIMILAR PROTECTED SYSTEMS IN OTHER LOCATIONS • CONSIDERATION OF THE STABILITY OF THE PLANT COMMUNITY IN QUESTION AND FACTORS THAT WILL ALTER THIS STATUS.	• Inspection ➢ visual ➢ random sampling ➢ targeted by risk ➢ x-ray, sound equipment, other ➢ detector dogs • Review of permits, phytosanitary certificates, bills of lading. • Isolation for set period to watch for disease or pests. • Treatment, re-export or destruction in response to interception. • Limited ports of entry according to type of cargo and/or risk. • Limited market destination (e.g. portions of Europe) • Containerization for transit through vulnerable zone. • Public education and “amnesty” bins at site of entry. • Identification of all suspect organisms. • Policy for unlisted/unknown organisms. • Other decision guides and headquarters support for inspectors. • Working relationship with other branches of government such as Customs to receive data. • Market checks for prohibited materials. • SURVEILLANCE NEAR SITES OF PROBABLE ENTRY	• Detection and delineation of infested zone. • Monitoring of surrounding zone. • Suppression, containment or eradication using: ➢ pesticide applications ➢ baits and attractants ➢ sterile insect release ➢ quarantine stations ➢ biological control agents • Systems approach using a combination of measures (at this stage as well as for prevention of original entry). • Treatment of crop leaving the area to avoid spread of pest. • Emergency reporting systems to inform of movement to new areas (leads back to risk reduction measures as well).	• Research new control options for producers. • Registration of new pesticide that is effective in control. • Advancement of new resistant varieties of the crop. • Create disease-free nursery stock certification and supply. • Biological control program keeps population down to a level of minor damage (and cannot be paired with pesticide control). • Change in cultivation practices. • Addition of water treatment for water-borne diseases. • MANAGE SOURCES OF STRESS (E.G. POLLUTION, LOSS OF BUFFER AREAS, CHANGE IN WATERSHED DUE TO CONSTRUCTION, ETC) TO THE PLANT COMMUNITY THAT IMPACT ITS ABILITY TO “LIVE WITH” THE INVADER • TRANSPLANT TO A NEW AREA OR REINTRODUCE TO IMPACTED AREA NATIVE SPECIES UNDER CONDITIONS THAT WILL SUPPORT THEIR ESTABLISHMENT – I.E. MANAGE THE FORMERLY UNMANAGED SYSTEM

Some reasons for failure of these measures: All measures may fail with inadequate funding or political will to carry them out.	• Information not published. • Intentionally misleading information regarding the presence/absence of a pest. • Brain drain (experts leaving position for better opportunities) causes loss of contacts/institutional memory. • Treatment options limited. • Pathway not yet recognized. • Host not yet recognized (for example with a pest to natural environments rather than to agricultural systems). • Parameters entered into models are not accurate or the right ones to consider. • LACK OF COMPETENCY ON ECOLOGICAL ISSUES AND LACK OF ACCESS TO THIS SUPPORT FROM OUTSIDE THE REGULAR RISK ASSESSMENT UNIT	• Inspection fails due to volume of entry, poor sampling, etc. • Cryptic life stage at time of entry or difficult to identify or diagnose. • Parallel system not monitored (e.g. research permits) • Natural pathway not regulated. • Smuggling of high-risk items. • Treatment options limited. • Transshipment obscures country of origin. • Hitchhiker pests from transport vehicle or stopover sites not anticipated based on documentation.	• Detection techniques not successful (i.e. pest not detected) • Insufficient numbers of traps or monitoring insufficient area. • Low population continues below level that can be detected. • Pesticide applications not accepted by public in area. • Environmental concerns arise over control options available. • Pesticides or baits not registered for this use; tools not available. • Sterile insect production not adequate for the needs of all programs requesting them. • Biological control agents not researched sufficiently before program begins.	• Control methods used by some producers but not by all. • Pest may become resistant to the adaptation measures (the crop resistance or a pesticide). Pest may cause greater damage even years after establishment; for example it may be a vector for a non-indigenous disease so that further damage comes with the introduction of new populations that are no longer controlled.
Danger of reliance on these measures:	• Requirements to reduce risk become onerous. • Trade dispute results from imbalance between risk reduction and free trade values. • Consumers in importing country lose benefit of new supply. • RELIES ON IDENFICATION OF (ECONOMIC) VALUE FOR UNMANAGED SYSTEMS	• Delays in release of cargo and passenger delays. • Civil rights could be violated. • Avoidance of system, for example, cargo may be redirected to points of entry that are not well monitored. • Smuggling may increase. • EFFECTIVE MONITORING TOOLS (E.G. ATTRACTANTS) MAY NOT EXIST	• More severe environmental impact from control versus prevention. • Control measures may not be completely effective. • Repeated introductions lead to high costs when the original pathway is not closed.	• Secondary impacts from the pest may not be recognized initially. • Pest is no longer quarantine, therefore statutory control and government support will generally end. • MEASURES TAKEN TO ADAPT IN MANAGED SYSTEMS MAY RESULT IN THE INVADER DAMAGING UNMANAGED SYSTEMS EVEN MORE (E.G. PLANATION TREES WITH RESISTANCE TO A PEST OR DISEASE MAY LEAVE UNMANAGED TREES MORE VULNERABLE)

Based on a table in Quinlan, MM. 2000. Phytosanitary Measures for Managing Regulated Plant Pests. An invited paper on pages 165-170, in *Proceedings of the Indian Ocean Commission Regional Fruit Fly Symposium.* June 2000 in Flic en Flac, Mauritius. 232 pp. (CHANGES APPEAR IN CAPITAL LETTERS.)