PRATIQUE

ENHANCEMENTS OF PEST RISK ANALYSIS TECHNIQUES

Review of impact assessment methods for pest risk analysis

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PROJECT OVERVIEW: PRATIQUE is an EC-funded 7th Framework research project designed to address the major challenges for pest risk analysis (PRA) in Europe. It has three principal objectives: (i) to assemble the datasets required to construct PRAs valid for the whole of the EU, (ii) to conduct multi-disciplinary research that enhances the techniques used in PRA and (iii) to provide a decision support scheme for PRA that is efficient and user-friendly. For further information please visit the project website or e-mail the project office using the details provided below:

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1 Introduction

1.1 Background

Pest risk analysis (PRA) procedures are used to investigate the consequences of the entry, establishment and spread of potential quarantine pests. A PRA is necessary to determine whether a pest should be regulated or not. International conventions like the International Plant Protection Convention (IPPC) and the World Trade Organization (WTO) Agreement on the Application of Sanitary and Phytosanitary measures (SPS) require phytosanitary measures to be based on scientific principles. In European and Mediterranean countries, the PRA scheme developed by The European and Mediterranean Plant Protection Organization (EPPO) is used. A PRA consists of three main stages. In the first stage, pest initiation, the pest pathways and PRA area are defined. In the second stage, pest risk assessment, the introduction and the spread of the pest are evaluated in addition to its economic, social and environmental impacts. In the third stage, possible management strategies to control the pest are evaluated.

However, significant improvements to the methodologies to perform PRAs are required and this is the fundamental objective of PRATIQUE. Enhancing the development of methods to assess the economic, environmental and social impacts of alien pests (including pathogens) are a key component of the project, and the subject of work package 2. In particular, task 2.4 concerns the development of those modules. Components of this work package are an analysis of species traits, which can serve as indicators for potential impacts. The development of indicators and scoring systems to assist with the application of assessment modules and the development of an integrated framework is being undertaken to embed the PRATIQUE deliverables in the EPPO PRA scheme. In order to determine which methods should be applied and developed further, a review of existing techniques has been undertaken.

1.2 Objective

The objective of this paper is to review the methods that can be used for assessing impacts in PRAs. Recommendations of the most appropriate methods, based on the review of impact assessment methods used in PRA and in comparable policy areas, are given. Particular attention is paid to methods for assessing long-term impacts and scaling-up impacts.

1.3 Structure of the paper

This paper is structured as follows. In chapter 2, definitions for economic, social and environmental impacts are described. In chapter 3, the analytical framework is explained. Recommendations based on annexes in which the methods are discussed in greater detail are presented in chapter 4. The paper concludes with chapter 5, in which some topics are discussed.

2 Definitions

In PRAs, all impacts, whether economic, environmental or social need to be assessed. The different impacts often overlap, causing difficulties in distinguishing their content. Moreover, environmental and social impacts can both be assessed in economic terms. Supplement 2 to the IPPC glossary FAO (2007) states that pests can be deemed to have potential economic importance if they have:

- *a potential for introduction in the PRA area;*
- *the potential to spread after establishment; and*
- *a potential harmful impact on plants, for example:*
- *crops (for example loss of yield or quality); or*
- *the environment, for example damage to ecosystems, habitats, or species; or*
- *some other specified value, for example recreation, tourism, aesthetics.*"

However, FAO (2007) also states that although "*economic analysis uses a monetary value as a measure to allow policy makers to compare costs and benefits from different types of goods and services. This does not preclude the use of other tools such as qualitative and environmental analyses that may not use monetary terms.*"

PRATIQUE follows in principle the definitions in the IPPC glossary and recognises that:

Economic impacts

Economic impacts cover both commercial and non-commercial (social and environmental) consequences of pest introduction. However, in the context of the EPPO PRA scheme and thus in PRATIQUE we do not follow the broad IPPC definition of economic impact in ISPM5 and separate impacts into economic, environmental and social even though all types of impacts can be analyzed economically. Therefore in the context of this review, economic impacts are limited to those effects that have monetary consequences to affected private and public bodies.

Environmental impacts

According to the IPPC glossary, environmental impacts of plant pests refer to:

- *reduction or elimination of endangered (or threatened) native plant species;*
- *reduction or elimination of a keystone plant species (a species which plays a major role in the maintenance of an ecosystem);*
- *reduction or elimination of plant species which is a major component of a native ecosystem;*
- *causing a change to plant biological diversity in such a way as to result in ecosystem destabilization;*

- *resulting in control, eradication or management programs that would be needed if a quarantine pest were introduced, and impacts of such programs (e.g. pesticides or the release of non-indigenous predators or parasites) on biological diversity.*

If at least one of these effects occurs, other environmental impacts not resulting directly or indirectly from effects on plants such as impacts on animal biodiversity may also occur; these need to be communicated to the appropriate authorities.

Social impacts

Social impacts are not defined in the IPPC glossary. Therefore, the following description of social impacts provided in the EPPO PRA scheme (EPPO, 2007) is used. "*Social effects may arise as a result of impacts to commercial or recreational values, life support/human health, biodiversity, aesthetics or beneficial uses. Social effects could be, for example, changing the habits of a proportion of the population (e.g. limiting the supply of a socially important food), damaging the livelihood of a proportion of the human population, affecting human use (e.g. water quality, recreational uses, tourism, animal grazing, hunting, fishing). Effects on human or animal health, the water table and tourism could also be considered, as appropriate, by other agencies/authorities*".

3 Analytical framework

In the appendices, methods for assessing economic, environmental, social and integrated impacts are presented. In this section an analytical framework to assess the applicability of the methods is presented. This framework can be applied both to assess which methods should be investigated further by PRATIQUE, and to assess the best methods that can be applied by pest risk analysts using the EPPO PRA scheme.

The ultimate objective is to apply impact assessment methods in PRA so as to accurately characterise risk while minimising uncertainty whatever the pest and the problems it may cause. The biological and epidemiological characteristics of the pest determine what climatic conditions are suitable and which hosts or habitats are required for the pest to survive, reproduce and spread. The endangered area is initially determined by identifying where in the PRA area such ecological factors are favourable for the pest to establish. According to ISPM 11 (FAO, 2004), these characteristics are identified and assessed before assessing potential impacts.

Impacts can be represented in a three-dimension graph. Choices on each of the three dimensions have to be made in order to demarcate the analysis. The three axes are 1) Impact scale, referring to the geographical dimension from farm to sector or region to national level, 2) Impact scope (direct and/or indirect impacts) and 3) Impact time line, from short to intermediate to long term. Direct impacts include losses in yield and quality of plant products and negative reductions in biodiversity, while indirect impacts are consequences of direct impacts. Examples of indirect economic impacts include changes in consumer demand and prices, access to export markets, changes in producer costs or input demands, changes in social welfare and impacts on other related markets, sectors and economic entities, e.g. government (FAO, 2004). Loss of tourism is an example of an indirect social impact. Similarly, the direct impact of a plant pest on a native plant may indirectly affect ecosystem services or native species communities at higher trophic levels.

Each method for assessing impacts is designed to capture particular types of impact and also requires specific inputs and resources to conduct the assessment. The pest risk analyst needs to select not only the most appropriate method for the type of impact assessed but also one which has the least complexity, is simplest to use, is relevant to the data available and takes the shortest amount of time to apply. A good understanding of the characteristics of the different methods is required to select that which is most appropriate for the PRA being studied. Figure 1 outlines some key considerations that need to be taken into account when selecting the least complex method to conduct an impact assessment. It consists of three stages: 1) understanding the characteristics of the pest and receptor environments (hosts, habitats, industries, tourism etc.), 2) defining the selection criteria and 3) choosing the proper method, taking available resources into account. If the selection criteria do not match with the available impact assessment methods, the selection criteria have to be adjusted. Table 1 contains an overview of all possible economic, environmental and social methods that can be applied, and how they score for each criterion.

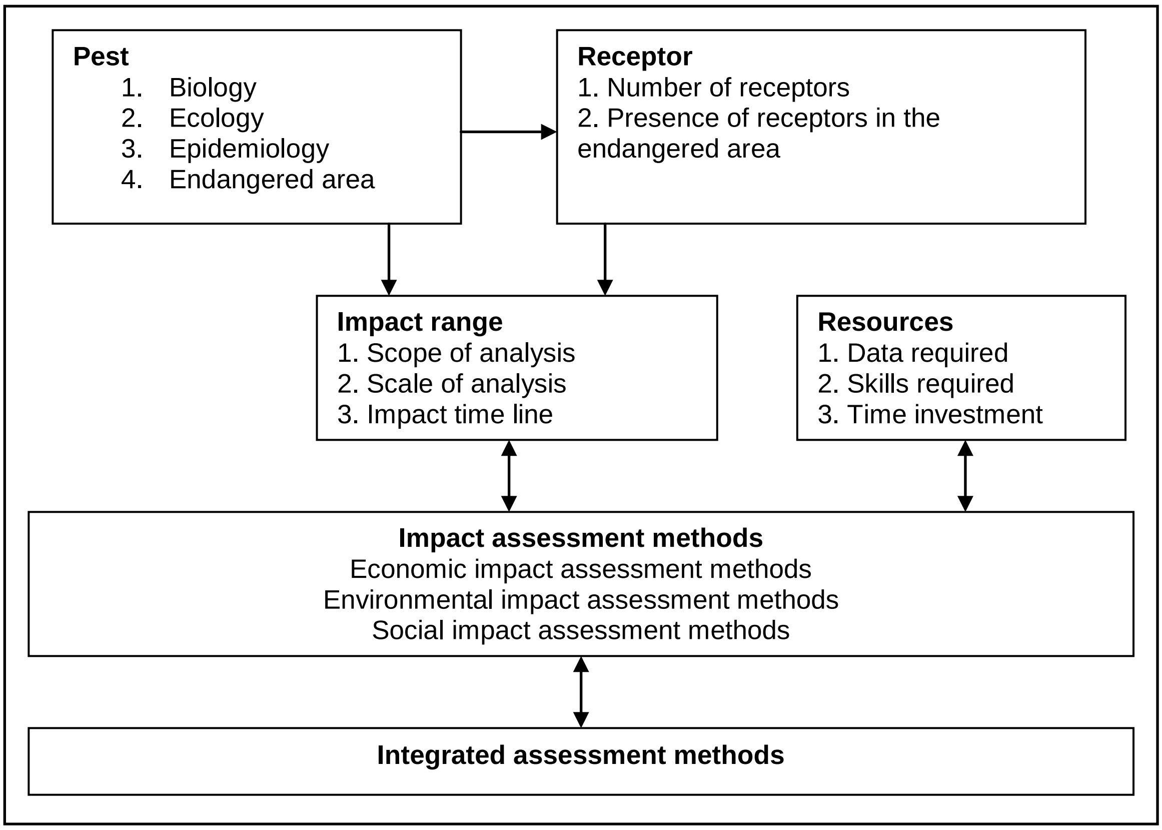

Figure 1: Selection scheme for the optimal impact assessment method

4 Recommendations

The application of this scheme to the impact assessment methods that are discussed in Appendix 1 (economic impacts), Appendix 2 (environmental impacts), Appendix 3 (social impacts) and Appendix 4 (integrated impacts) produces the following choices of methods to be investigated in detail by PRATIQUE. The pest on the qualitative and quantitative evaluation of the impacts causes the emphasis of economic impact assessment methods, whereas, because of difficulties in quantifying the scale of the damage, environmental and social impact assessment methods primarily focus on identifying the types of impacts that may occur and their scale using expert opinion. The application of integrated methods is necessary to evaluate environmental and social impacts and compare them with economic impacts.

Economic impact assessment methods

In annex 1, the following six potential methods for quantitative economic impact assessment are discussed:

1. Partial Budgeting (PB)
2. Linear Programming (LP)
3. Partial Equilibrium (PE)
4. Dynamic Programming (DP)
5. Input-Output Analysis (I-O)
6. Computable General Equilibrium (CGE)

In Table 1, these methods have been rated according to the range of impacts they cover and the resources required. In addition to the information presented in Table 1, some extra information is needed to understand how the different methods have been selected. Some techniques, such as dynamic programming, have an important role in comparing pest management strategies but are less useful in assessing impacts to justify regulatory decisions. To determine which methods will be recommended for further study, the three dimensions as presented above are compared with experiences based on actual PRAs. In general, although risk analysts have little time to perform a PRA and have little data, they still want to assess impacts in as much detail as possible. From this perspective the methods selected for further study will be those that perform well in the majority of cases, and have as little requirements for data etc as possible.

To fulfil the need to address both direct and indirect impacts, partial budgeting and partial equilibrium models require the lowest resources and are particularly recommended for use in PRA.

Environmental impact assessment methods

In Annex 2, the methods for assessing environmental impacts are discussed. Standardized ecological methods for quantifying the potential environmental impact in the framework of a PRA are lacking. The main reasons are the limited knowledge of the mechanisms underlying environmental impacts and the fact that modelling the effects of invasive alien species on native communities and ecosystems is very difficult due to the complexities and uncertainties involved. There are several methods for assessing environmental impacts in economic terms but they are difficult to apply and are not commonly used. Furthermore, application of those methods presupposes that environmental effects are known (see annex 4). Therefore, for the time being, expert judgment is the principal method for assessing environmental impacts.

Based on this review, the following recommendations are made to improve qualitative environmental impact assessments:

1. When possible, base the prediction of potential environmental impact on current impacts in areas where the pest is already present in addition to considering the suitability of the PRA area for colonization and the vulnerability of the receptors. Examples of closely related species should also be taken into account. Empirical studies have shown that this is one of the few indicators that can be used to predict environmental impacts (Williamson, 1996).
2. Provide pest risk analysts with examples of environmental impacts of alien pests, e.g. by facilitating access to, or developing databases of studies that have investigated such impacts.
3. Provide clear guidelines for scoring impacts in order to enhance consistency.
4. Combine the predicted amount of impact and the geographic scale to obtain an impact score.
5. Make use of the species traits analysis being studied by PRATIQUE. In this study, relationships between characteristics of invasive plant pests and impacts have been investigated.
6. Identify and incorporate best practice from weed risk assessment (WRA) schemes into the EPPO PRA scheme.

Table 1. Summary of the characteristics of impact assessment methods.

	Impact range			**Resources**		
	Scope	**Scale**	**Time line**	**Data**	**Skills**	**Time investment**
Economic methods						
PB/CBA	Direct	Farm, Sector, regional, national	Short term	Low	Low	Low
LP	Direct	Sector, regional, national	Short term	Low	Low/medium	Low
PE	Direct and Indirect	Sector, regional, national	Long term	Medium	Medium	Medium
DP	Direct	Farm, Sector, regional national	Short term	Medium	Medium/high	Medium
I-O	Direct	Regional,	Mid	High	Low	High

	and indirect	national	term			
CGE	Indirect	Economy wide	Long term	High	High	High
Environmental methods						
Expert judgment	Direct and indirect	Regional, national	Long term	Low	High	Low
Social methods						
Diverse	Indirect	Regional, national	Diverse	Diverse	Diverse	Diverse
Integrated methods						
Monetizing methods	Direct and indirect	Regional	Long term	High	High	High
MCA	Direct and indirect	Regional, national or international	Long term	Medium/ High	Low	Medium

<u>Social impact assessment methods</u>

As explained in Annex 3, social impacts receive less attention than economic and environmental impacts in impact assessment. The reason is that social impacts are essentially indirect impacts caused by economic and environmental impacts. If economic and environmental impacts provide substantial evidence for regulation, there is rarely any need to assess social impacts. Furthermore, if economic or environmental impacts are uncertain, social impacts are by consequence even more uncertain. Existing PRA schemes do not provide guidelines for impact assessment. Furthermore, social impact assessment lacks generic methods because of the diversity of the effects, such as on employment, livelihood and tourism.

The recommendation is to develop guidelines for social impact assessment elaborating further from existing concepts or concepts in development focused on separate social effects.

<u>Integrated impact assessment methods</u>

In Annex 4, integrated impact assessment methods are discussed. These methods are intended to compare economic, environmental and social impacts in order to integrate the results in one final conclusion regarding the impact of the invasion of a foreign plant pest in the PRA area. To compare these impacts, the following methods are discussed:

- Monetizing methods (Contingent Valuation Method or Conjoint Analysis)
- Multi Criteria Analysis (MCA)

In Table 1, the integrated impact assessment methods have been rated according to the range of impact and resources they cover. Based on this overview, Multi Criteria Analysis is recommended for further investigation. The main advantage of this method compared with monetizing methods is that it is able to calculate impacts at a larger scale. Furthermore, when the risk analyst has little time, MCA allows the risk analyst to derive weight factors by himself. The application of MCA requires fewer specialist skills, and less data.

5 Discussion

Differences between impact categories

The principle objective of PRA is to characterize the risks posed by a pest as accurately as possible in order to justify any measures taken. The objective of PRATIQUE is to enhance the methods and data employed by the pest risk analyst and provide more effective communication of the risk to decision makers. The development of tools, which help to reduce uncertainty effectively and efficiently, is therefore a high priority. The recommended methods for economic, environmental and social impact assessment vary widely in nature. Economic methods focus on the evaluation of impacts. Those impacts have the advantage that the affected products are often included in commercial transactions, and thus have a price to valuate them. Environmental and social impacts are not part of the commercial traffic, and generally lack simple indicators that express their value. Furthermore, the underlying mechanisms causing environmental impacts are more complex than the mechanisms causing economic impacts. Therefore, the development of impact modules should ideally contribute to bringing those impacts more into balance. However, bridging this gap is far beyond the scope of PRATIQUE. Cooperation between partners developing economic, environmental and social impact assessment methods is highly recommended to reduce this gap. This is of great importance when both economic and environmental methods have to be applied to assess the consequences of the same organism. This means that it is important to assess when damage threshold values are exceeded based on knowledge of the biological and ecological characteristics of pests and the receptor environment.

The risk assessor must not make the mistake of focusing only on direct impacts, since indirect impacts may compensate for direct impacts, reducing the total impact.

Expert Judgment

Expert judgment can also be used to assess impacts. Expert judgment is used in the EPPO PRA scheme and other schemes worldwide. In the EPPO scheme impacts are assessed on a five-point scale (minimal, minor, moderate, major or massive) based on the evidence and expert's experience. These qualitative assessments are justified by detailed text with or without quantitative analysis. Quantitative assessments may be based on methods such as Partial Budgeting for the estimation of direct economic impacts or even Partial Equilibrium for the estimation of indirect economic impacts. Expert judgment is particularly useful when there is insufficient data or time to conduct a detailed quantitative assessment. However, the application of quantitative assessment methods does not replace expert judgment. Expertise in both the pest and the host environment is a prerequisite to apply these methods successfully.

Risk assessment and risk management

This paper recommends methods for assessing the consequences of the introduction, establishment and spread of a pest in the pest risk assessment stage of PRA. In the next stage of PRA, potential management measures are evaluated. Since ISPM 11 (FAO, 2004) states that management measures must not only be feasible but also cost-effective and with minimal impact on trade, some of the techniques described in this paper for impact risk assessment can also be applied for analyzing management options. When analyzing the benefits of a measure, these are normally taken to be equal to the costs of the impacts avoided if such a measure is implemented.

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Annex 1: Quantitative Economic Impact Assessment in Pest Risk Analysis

1 Introduction

The worldwide increase of trade in plant material, the introduction of new crops, the continued expansion of the EU and the impact of climate change have lead to increased threats posed by new plant pests. According to the International Plant Protection Convention and the WTO-SPS agreement, any emergency measure against the introduction and spread of new pests must be justified by a science-based pest risk analysis (PRA). As a result, PRAs are an essential component of plant health policy, while allowing trade to flow as freely as possible.

A PRA is "*the process of evaluating biological or other scientific and economic evidence to determine whether an organism is a pest, whether it should be regulated, and the strength of any phytosanitary measures to be taken against it*" (FAO, 2007a). In the pest risk assessment stage of PRA, the "*evaluation of the probability of the introduction and spread of a pest and the magnitude of the associated potential economic consequences*" (FAO, 2007a) is conducted, making the estimation of the potential economic consequences a fundamental component of every PRA. If the risk of introduction and spread is assessed to be unacceptable, phytosanitary measures can be imposed to reduce the risk to an acceptable level (FAO, 2004).

The International Plant Protection Convention is responsible for the development and adaptation of the International Standards on Phytosanitary Measures (ISPMs) to prevent introduction and spread of plant pests and to promote appropriate measures for their control. Two ISPMs, ISPM2 (FAO, 2007b) and ISPM11 (FAO, 2004), set out the procedures for conducting PRAs for quarantine pests. In ISPM11, two types of economic analysis are available using a qualitative or a quantitative approach. In the quantitative approach, three economic techniques, viz. partial budgeting, partial equilibrium and general equilibrium, are listed as the methods that may be used for the evaluation of economic impacts. However, no guidance is given, first, on which approach to choose and second, if quantitative approach has been chosen, it is not clear which method to apply in a particular case. In practice, the economic assessment within most PRAs, including those undertaken in Europe following the EPPO[1] PRA scheme, are based mostly on the qualitative approach (i.e. expert judgment) and rarely on simplified quantitative evaluations. Accordingly, the level of quantitative economic assessment of plant health risks worldwide is rather limited. The reasons for the limited application of these quantitative methods could be multiple, but one paramount problem is lack of insight concerning the resources required in terms of data, skills and time and the added value that the method will provide to the PRA results.

The main objective of this annex is to identify the most appropriate method for economic impact assessment for a given situation. To achieve this goal we

[1] European and Mediterranean Plant Protection Organization

will: (1) review the literature on methods used for estimating the economic impact of pest invasions, (2) define the main selection criteria to determine the relevance of each method given a particular case study and (3) construct a guidance scheme to support the selection of the optimal method.

This annex is organized as follows. It starts with a review of existing risk assessment schemes. The next chapter describes the methodology for crop loss assessment. An evaluation and description of the main criteria to determine the relevance of each method to assess economic impacts follows. Subsequently, a description of the economic impact assessment methods applicable in pest risk assessment together with their strengths and weaknesses is given. Selected applications from the plant health economics literature are reviewed to show how these methods can be used empirically. Next a guidance scheme is designed to select the optimal method for a given case study. The final section provides the overall conclusions and summarizes the principal findings.

2 Current practices in PRA and WRA schemes

According to ISPM 11, the present EPPO PRA scheme consists of three stages:

1. Initiation: to identify pests and pathways of phytosanitary concern which should be considered for risk analysis
2. Pest Risk Assessment: to determine whether the introduction of the pest will have unacceptable economic consequences. Short-term and long-term effects of all aspects of agricultural, horticultural, silvicultural, environmental and social impacts should be evaluated.
3. Pest Risk Management: to analyze which phytosanitary measures can be recommended to minimize the risks posed by a pest or a pathway.

In the Pest Risk Assessment Stage of the EPPO PRA scheme (EPPO, 2007), questions 2.1 to 2.5 concern commercial impacts. The following information is required: effects on crop yield, quality of products, possible conventional control measures, increase in production costs and reduction in consumer demand. Question 2.10 concerns losses in export markets and question 2.13 is used to assess possible costs for government and the crop protection industry resulting from introduction. Additional questions, such as the presence of natural enemies, are used to help clarify the economic importance of the impacts. The scheme has no other procedure to summarize the impacts than asking the analyst to list the most important potential economic impacts, to estimate how likely they are to arise in the PRA area, and to give an overall conclusion on the pest risk assessment and an opinion as to whether the pest or pathway assessed is an appropriate candidate for stage 3 of the PRA.

The UK Non-native organism risk assessment scheme (DEFRA, 2005) has a largely comparable structure to the EPPO scheme. However it provides, in a separate module (4), guidance for scoring impacts, by indicating for each level of impact (from minimal to massive) the amount of monetary loss and response costs as well as a description for each category of the impact likelihood. The Plant Health Risk Assessment scheme from Canada (ACIA-CFIA, 2008) contains only two questions about the potential economic impact. The first question concerns yield losses and reduced marketability and the second question concerns effects on existing production practices and control measures. Answers have to be scored in four categories ranging from no impact to high impact. In an appendix, rating guidelines are provided. The risk assessment scheme of the USA (USDA, 2000) recommends that attention is paid to determining a *lower yield of the crop, lower value of the commodity and loss of foreign or domestic markets',* scoring low, medium or high. Australia (Biosecurity Australia, 2007) provides guidelines for import risk analysis which state that '*the draft IRA report will … for each pest and disease on identified pathways, determine the likelihood of its entry, establishment or spread, and harm (consequences) that could result; specify whether the resulting risk exceeds Australia's ALOP (Acceptable Level of Protection).*

New Zealand has more detailed risk assessment procedures (Biosecurity New Zealand, 2006). It recommends that assessments are made of direct consequences, including production losses, and indirect consequences, separated into economic and environmental impacts. Economic considerations concern control and eradication costs, surveillance costs, reduced tourism and loss of social amenity, costs of environmental restoration, additional health care costs and potential trade losses. An example of consequence assessment is listed.

Three weed risk assessment schemes (USDA, 2004), Australia (Biosecurity Australia, 2008) and New Zealand (Williams, 2008) have been reviewed. None of these contains guidelines for assessing economic impacts.

3 Crop loss assessment

The different quantitative economic assessment methods described in the document all require the inputs of yield or quality loss estimates. The term crop loss assessment is often used for the study of the relationship between attack by harmful organisms and the resulting yield (or yield loss) in the crops. Estimating yield or quality loss is undertaken by obtaining data from a range of pest and disease outbreaks and then modelling the yield in relation to pest population densities and the disease progress (i.e. crop loss models). For plant pathogens, datasets should have a wide range of yield and disease values to characterize the yield loss in relation to the development of the epidemic (Teng & James, 2001). The required data can be obtained in two basic ways: quantitatively, from conventional field (or greenhouse) experiments and from surveys of fields with naturally occurring epidemics; or qualitatively, from expert opinion. Crop loss models can be classified into single point or multiple point models. In single point models, there are linear models, which provide the simplest empirical description of crop loss. An example of a single point model is that developed by Biossonnette et al. (1994) for oat yield in relation to crown rust caused by *Puccinia coronata*. In their linear equation, yield is expressed as metric tons per hectare (MT/ha) and disease intensity (y) at oat growth stage 75. In the absence of disease, the expected yield is 4 MT/ha. For each 1% increase in y, there is a decrease in yield of 0.057 MT. Non-linear models are suitable for describing many biological phenomena. They are especially useful when there are thresholds, when the response variable approaches an asymptote, and when the same model is required to describe different shapes for curves of crop yield versus disease intensity. Several non-linear models have been proposed to describe crop loss data (Madden & Nutter, 1995; Madden, 1983). Single point models could be criticized because they are based on only a very narrow time window that could be unsatisfactory for relating yield to the disease epidemic. As a result, multi-point models are proposed which relate yield (or losses) to disease intensity at two or more times during an epidemic. The concept behind a multiple point model goes back at least to Kirby & Archer (1927) who showed that yield estimates of wheat could be improved by using more than one assessment of stem rust. More formal consideration of this model was provided by Burleigh et al (1972) and James et al. (1972).

For integrated pest management (IPM), decision rules have been developed to guide farmers in managing pests and diseases (Meyer, 2003, Pedigo, 1996, Zadoks, 1985). Those decision rules are known as the EIL concept. First of all, a distinction is made between injury and damage. Injury is defined as the physical harm or destruction to a valued commodity caused by the presence or activities of a pest, whereas damage refers to the monetary value lost to the commodity as a result of the injury. Furthermore, a distinction is made between the damage boundary and economic damage. This is shown in figure A1.1, in which a non-linear relationship between injury level and yield is represented. The Damage Boundary is the lowest level of injury that can be measured, whereas the Economic Damage is the amount of injury at which damage equals suppression costs. If costs of control measures exceed the amount of damage, suppression of the pest cannot be justified economically. The Economic Injury Level is based on the Economic Damage and is defined as the lowest population density that will cause economic damage (figure A1.2). The EIL depends on the following variables:

- Market value of production (C),
- Market value per production unit (V),
- Injury units per pest (I),
- Damage per injury unit (D) and
- the proportional reduction in pest attack (K).

In the case of linear relationships the formula is:

EIL = C/VIDK

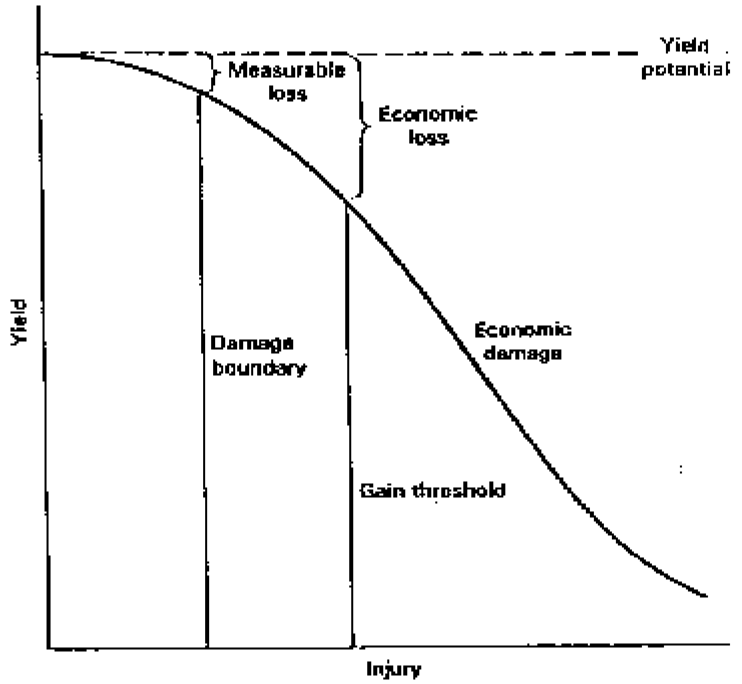


Figure A1.1: Relationships between damage boundary and economic loss (Pedigo, 1996).

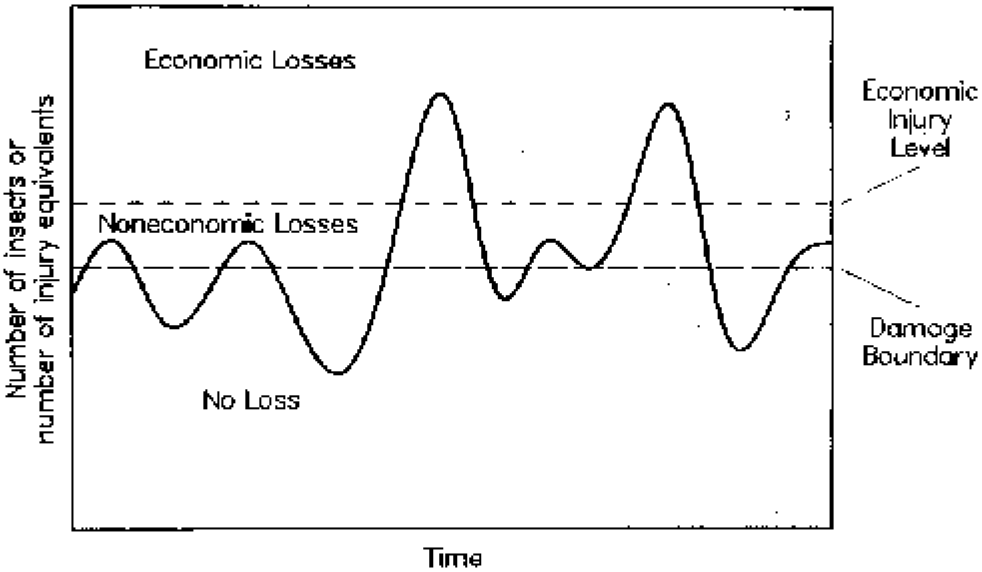


Figure A1.2: Relationships between Economic damage and Economic Injury Level (Pedigo, 1996).

Uncertainty has been incorporated into the EIL concept Peterson & Hunt (2003), taking into account the inherently uncertain nature of the EIL parameters and the pest itself. They used Monte Carlo simulation to calculate the probabilistic EIL (PEIL), by incorporating the uncertainty of the input variables.

The EIL concept is widely applied in the field of pest management by both phytopathologists and entomologists (Savary *et al.*, 2006) and is also of fundamental importance in assessing pest impacts in PRA since it relates pest density to injury and damage, highlights the difference between injury and damage, emphasized the fact that not every invasion results in economic damage and indicates which variables determine the level of damage linking biology, ecology and economics. However, even if the rare cases where the EIL is known, building population dynamics models for pest invasions is extremely difficult and unlikely to give sufficient precision due to lack of data and time to perform experiments. Any information on the relationship between population density and injury level should be obtained from the area where the pest is present and the risk analyst should take account of the differences in physical, climatic and growing conditions compared with the endangered area. Oerke et al. (1994) and Oerke (2005) provide yield loss data for many crops.

4 Selection criteria

Each evaluation method captures a certain range of pest-impacts but also requires resources in terms of the data, skills and time required. A trade-off exists between the resources required by the method and its accuracy in estimating pest impact. Therefore, a balance must be found between these two objectives. An optimal economic method minimizes costs, given that the method is able to accurately estimate impacts.

Table A1.2 provides a detailed description of the data, skills, and time requirement for each method. The range in the accuracy of economic impacts can be classified according to (1) scale of impact, and (2) scope of impact. The impact scope ranges from direct to indirect economic effects and the impact scale ranges from the consequences from the producer level to the macro-economic level. Table A1.3 provides a detailed illustration of the ability of each method to capture the pest impact.

The availability of data, skills and time required for the simplest quantitative method is used to indicate whether it is appropriate for the PR-analyst to employ a quantitative as well as a qualitative approach.

Direct impacts reflect the effects of a particular pest on the host while the indirect impacts are non-host specific impacts (Bigsby & Whyte, 2001). Direct impacts include losses in crop yield and quality, costs of control, while indirect impacts include effects on domestic (prices, consumer demand) and export markets, changes in economic welfare (change in income distribution between producers and consumers) and impacts on other related markets, sectors (i.e. industry, tourism) and other economic entities, i.e. government (FAO, 2004).

The producer level focuses on the additional costs and reduced revenues affecting the individual producer, while the inclusion of the sector level extends the analysis to the consumers in a particular sector or market (e.g. for potatoes) and also to other partners in the production chain (e.g. processors and retailers). The macro-economic impact covers not only a particular sector or market but also other sectors (e.g. industry, services), markets (e.g. labour) and stakeholders (e.g. government) in the economy. Whether the impact scope is at the level of the producer, the sector or the macro-economic, the spatial scale of a PRA analysis is generally undertaken at a national or trading bloc level (e.g. producers in the EU or the agricultural sector in the Netherlands).

5 Quantitative economic methods

This section evaluates the following six quantitative methods: partial budgeting, linear programming, partial equilibrium, dynamic programming, input-output analysis and computable general equilibrium. The methods evaluated are ordered according to their complexity level. The complexity of each method is measured by the amount of resources needed to perform the analysis; giving the highest weight to data requirement, then to skill requirements, followed by the time needed to invest.

5.1 Partial budgeting (PB)

5.1.1 Theoretical background

Partial budgeting (PB) is a simplified procedure designed to estimate the economic consequences of a change in the producer business (Roth & Hyde, 2002). It is called partial because it includes in its budget analysis only the resources that will be changed, leaving out those that are unchanged (e.g. fixed assets), and supports the assessment of alternatives. It identifies all the costs and returns that result from a proposed change (see figure A1.3). PB is commonly used in PRA by assuming that the pest invasion is the change that occurs to the producer budget. However, in PRA the focus is on the negative impacts on the producer budget (i.e. additional costs and reduced revenues). The reliability of the results depends to a large extent on the data used. Therefore, care should be taken when estimating values for the various components. Sensitivity analyses or Monte-Carlo simulation (see below) for key elements of the model can be used to highlight their effect on the final result.

In PRA, PB is used in the risk assessment while cost benefit analysis (CBA) is used in the analysis of risk management options. PB and CBA use the same methodology to either estimate impacts or to evaluate pest management options (Brent, 1996). Both techniques weight costs against benefits, as PB looks only at the income and expense items in the budget that are affected by the proposed change, while CBA assesses the ongoing costs and expected benefits of different management options measured in comparable units within and across time. However, the main difference in application between the two methods is the spatial level of analysis and decision criterion. Partial budgeting is commonly applied at the farm level and uses total net benefit (Appendix A) as its decision criterion. Cost-benefit analysis analyzes the impacts at higher aggregated levels (e.g. national) and uses net present value (Appendix A) and cost benefit ratio (Appendix A) as its decision criterion. Due to the scope of our paper, we are dealing only with PB.

The strength of PB is its simplicity and the low level of skills required. PB gives a detailed analysis of the direct impact at the producer level. The spatial scale of PB is the farm level. But it can also be used at the national or continental level by scaling up the impact from the representative farm to higher levels (Rich *et al.,* 2005). However this methodology ignores important indirect effects, which could lead to misleading results. Quantifying indirect impacts such as those on related markets, export and employment losses go beyond the ability of partial budgeting. However, these indirect impacts can be quantified by other methods (i.e. partial equilibrium) and then added to the partial budgeting.

PB is more suited to estimating short-term impacts rather than the long term. Due to the ignorance of the model to the dynamics of many variables in the long term (Rich *et al.*, 2005) such as prices, the endogenous (Appendix A) behaviour of consumers and producers, market conditions and productivities. PB leads to an imprecise estimation of the long-term impact.

PB has the lowest complexity level with respect to resource needs as it requires a limited amount of data, skills, and time investment in comparison to other proposed methods.

Define the change analyzed: Pest invasion	
Costs	**Benefits**
Additional costs: what will be the new added costs?	Additional revenues: what will be the new added revenues?
Reduced revenues: what revenues will be reduced or eliminated?	Reduced costs: what costs will be reduced or eliminated?
Total costs:	**Total benefits:**
Net change in profit:	

Figure A1.3: Partial budgeting

5.1.2 Applications

PB is the most commonly used method in plant and animal health economics. In plant health economics, Macleod *et al*. (2003) used partial budgeting to estimate the impacts of *Thrips palmi* in England. The partial budgeting included the following costs: lower quality and yield, increased control costs, additional research and export losses over 10 years. Two scenarios of pest spread, slow and rapid, were designed. The slow spread scenario assumed that 62.5 % of the host area was infested by the pest, while the rapid one assumed a sigmoid spread that affected the whole endangered area. The economic impact was estimated between £16.9 and £19.6 million.

Sinden *et al.* (2004) estimated the economic impact of weeds in Australia. They combined direct and indirect impact together using partial budgeting and partial equilibrium. Partial budgeting was used to measure financial costs such as yield loss and control costs (i.e. chemical use). Additional costs accompanied with applying control measures (e.g. weed chipping, slashing, grazing strategies and tillage practices) were also included. The partial equilibrium model was used to calculate the reduction in social welfare (indirect impact) due to changes in prices. Finally, both costs were added together to obtain the total impact. The results showed that the producer losses account for 80% of the total cost while the consumer losses account for the remaining 20%.

In animal health, Meuwissen *et al.* (1999) used partial budgeting to estimate the impact of a Classical Swine Fever outbreak in 1997/1998. The impact was classified into direct costs and consequential losses. Direct costs covered extra control costs for producers and the compensation paid by government, while consequential losses covered losses suffered by producers (e.g. supply and delivery problems) and related supply chain industries such as slaughterhouses, animal traders, feed suppliers. The distribution of the losses among national government, EU and participants in the livestock-production chain were calculated. Indirect impacts such as losses of exports for animal traders were not included.

Laszlo *et al*. (2007) used partial budgeting to estimate the cost of bovine foot diseases in dairies and Fourichon *et al*. (2005) used partial budgeting to quantify the losses of bovine viral diarrhoea virus (BVDV) infection in a dairy herd.

5.2 Linear Programming (LP)

5.2.1 Theoretical background

Linear programming solves a problem by finding the optimal value of a linear equation (objective function) over a set of linear and non-negativity constraints, e.g. resources used cannot be a negative number (Hazell & Norton, 1986).

LP can be used within pest risk assessments through a comparative analysis between two situations, e.g. one with and without a pest invasion, to estimate the pest impact. The LP can be used to calculate the control costs (i.e. direct impact) by specifying the objective function as finding the least cost control option. Also the reduction in revenues resulting from pest invasion can be estimated by specifying the objective as finding the combination of the available resources, e.g. fertilizers, labour, machines and control options, which maximize the producer’s profit. As a result, the difference between alternative combinations of resources and the resulting profits in both situations reflects the impact of the pest.

The impact scope of linear programming can be determined from the producer to the sector level. In addition to analyzing the impact of a pest at the producer level, the analysis can be extended to measure the impact at the sector level by including prices and aggregated production.

The strength of the LP method lies in its assumption of optimized behaviour by the economic actors in the economy, i.e. producers or consumers. However, its weakness is its limited coverage of impacts, since only direct costs are studied.

The complexity level is low, relatively higher than PB but lower than the other methods proposed. This is due to the higher requirement for skills to apply the method (e.g. mathematical programming). Special software, such as GAMS (Rosenthal, 2008), is usually needed to generate the results.

5.2.2 Application

Only a few papers have used the LP approach in plant health economics. Livingston *et al*. (2004) measured the potential economic consequences of introducing Asian soybean rust to the USA. A spatial equilibrium, mathematical linear programming model (USMP) was used. The model considered the production of the major crops comprising about 75% of agricultural production and 90% of livestock production. USMP simulated the impacts of reduced soybean yields and increased production costs for a number of scenarios exploring different geographic assumptions of soybean rust establishment. In the model, the producers maximized their net return subject to the market clearing condition (i.e. quantity supplied equals quantity demanded).

Johnson and Nganje (2000) used the linear programming approach to estimate the impacts of Deoxynivalenol (DON) on the value of malting barley. In order for barley to be sold in the malting market, it must have a low DON level as a proof of acceptable quality. Otherwise, market discounts must be applied. The LP model used crop quality data and market discounts to drive the optimal blends of barley supplies. The results showed that there was a decline in market discounts in 1999 that reflected an increase in the barley quality.

In animal health, various LP studies have been performed to estimate the economic impact of animal diseases. For instance, Stott *et al*. (2003) used LP to assess the costs of various animal disease control methods at the producer level.

5.3 Partial equilibrium (PE)

5.3.1 Theoretical background

Due to the inability of PB and LP to assess indirect impacts (e.g. export losses and reduction in social welfare), partial equilibrium (PE) provides an alternative method that can be used to perform more complete impact assessments.

PE studies how the market equilibrium is determined in a single market in isolation from all other markets in the economy (Mas-Colell, 1995). A pest invasion may lead to a loss in crop yield or quality and an increase in pest control costs. Both factors will affect the production capacity leading to an upward shift in the supply curve from *S* to *S'* (figure A1.4). This shift in the supply curve moves the equilibrium point from a to b. This movement implies a decrease in quantity supplied from Q_1 to Q_2 and an increase in market price from P_1 to P_2. Producer losses that result from the new equilibrium point can be calculated by the reduction in producer welfare. Producer welfare is the difference between producer revenue and the cost of production, which is represented by the area under the market price and above the supply curve. Therefore, the difference between the initial producer surplus (P_1ea) and the producer surplus after invasion (P_2cb) is the reduction in producer welfare. In the same way, changes in consumer welfare can be calculated by analyzing shifts in the demand curve. Consumer demand could be affected by loss in quality and increased prices. Both producer and consumer welfare will provide changes in social welfare.

The main assumption behind PE model is that the market equilibrium is achieved at the point where social welfare is maximized. This occurs when consumers and producers, in aggregated terms, maximize their utilities and profits. The main sources of uncertainties in PE arise from model elasticises and assumptions.

Analyzing pest impact using a PE model is only appropriate when the indirect impact of the pest is not expected to significantly affect other markets (e.g. substitute crops) or generate measurable macroeconomic changes (e.g. changes in income and employment level). The scope of the method chosen should be proportional to the expected impact in the market. Therefore, when the impact expands to more than one market, multi-market PE could be proposed**.** Multi-market PE tries to capture spill over effects between the main markets. However, unlike the general equilibrium model (see CGE below), multi-market analyses do not attempt to capture impacts to the entire economy.

The strength of the PE approach is the consideration of both direct and indirect impacts as it includes in its analysis the change in consumer and producer welfare. Welfare may be measured either cardinally in terms of dollars or ordinally in terms of Pareto efficiency[2]. Prices are also determined within the model, i.e. endogenously, instead of assuming fixed prices as in the previous methods. The weakness of the model is the estimation of the indirect impact of a single market, while ignoring the indirect impact on the rest of the economy.

PE has an intermediate level of complexity, higher than PB and LP but less than the rest of the proposed methods. However its impact-coverage includes both direct and indirect impacts.

[2] An allocation of resources where there is no any other allocation in which some other individuals is better off and no other individual is worse off

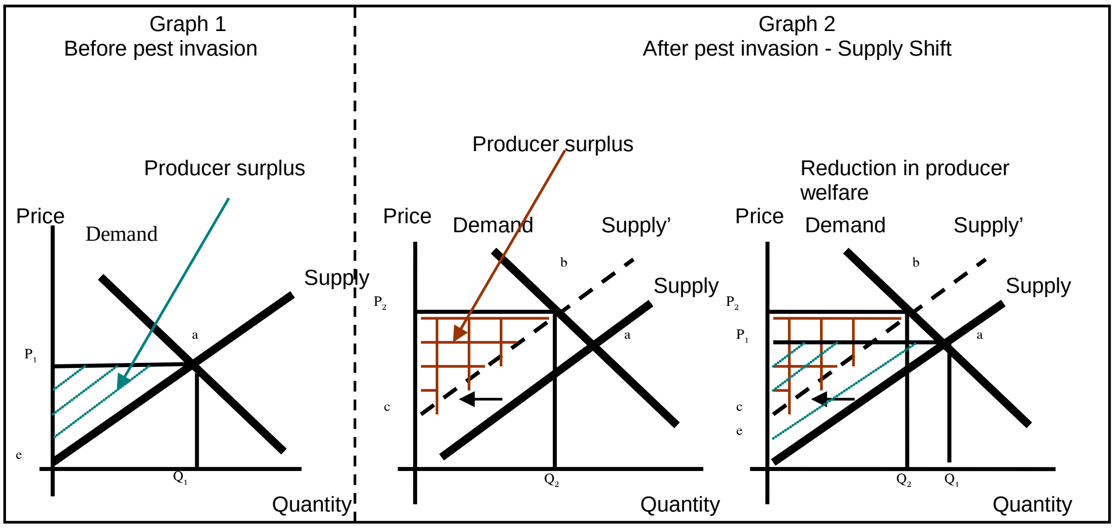


Figure A1.4: Partial equilibrium model

5.3.2 Application

Partial equilibrium analysis is a commonly used tool to estimate impact in several research areas. In plant health economics, Breukers *et al.* (2008) used a single market partial equilibrium model to quantify export losses resulting from the potato brown rot disease in the Dutch potato market. They assumed that export losses are based on the previous levels of detection. By developing a relationship between brown rot incidence and the level of export restriction, four export restrictions scenarios were designed. They showed that, with average supply, the losses resulting from export restrictions ranged from 4.2 million to 192 million Euros.

Arthur (2006) used partial equilibrium to compare the benefits and costs of liberalizing the Australian apple market by permitting infected New Zealand apples with fire blight to enter the Australian market. The benefits were presented in terms of the consumer welfare gain that results from lower apple prices due to higher competition, while the costs arise from the loss in production and increased expenditures to control the pest. Six scenarios were designed representing different levels of spread of the pest. The results showed that a positive social welfare was achieved in all scenarios.

Surkov *et al.* (2007) determined the optimal phytosanitary inspection policy in the Netherlands given the estimated costs of different pests that may be introduced through imported commodities. The Partial equilibrium model was used to estimate the indirect impact (e.g. social welfare changes).

Hoddle *et al.* (2003) used the partial equilibrium model to estimate the impact of *Scirtothrips perseae* Nakahara (Thysanoptera: Thripidae) in Californian avocado orchards. The establishment of *Scirtothrips perseae* would increase producer control costs that in turn would increase the production cost. These extra costs resulted in an upward shift in the supply curve leading to a new equilibrium point, resulting in a reduction in producer welfare. However, producers of avocado where *S. perseae* was not yet established benefited from the increase in prices as they didn't experience the increase in their production cost. The increase in prices stimulated the producers that did not have the pest inside USA to increase their production in addition to a rise in avocado imports. The new production replaced part of the production lost by infested producers in California. The total economic effect on the USA avocado industry depended on changes in producer costs, market supply, and market prices.

PE has also been used in animal health science. Schoenbaum and Disney (2003) used a multi-regional multi-market PE model to trace the effect of foot and mouth disease (FMD) and to compare the governmental costs and net welfare of alternative disease control. Also Paarlberg *et al*. (2002) used a single PE model to estimate the effect of FMD outbreak in the USA.

5.4 Dynamic programming (DP)

5.4.1 Theoretical background

DP is a mathematical programming method that seeks the optimal solution for sequential sub-problems in order to find the optimal solution for the whole problem (Bellman,1957).

DP solves problems that involve sequential decision-making in uncertainty situations. It can be used to identify optimal strategies and determine the equilibrium state of a wide class of sequential decision problems (Rust, 2006). The method can be applied in both discrete and continuous time (i.e. when the time interval between successive decisions tends to zero) settings. The value of dynamic programming is that it is a practical method for finding solutions to extremely complicated problems.

The DP model consists of sub-stages in which each stage can be described completely by a state variable. The states are the various possible conditions in which the system might be at any stage in the problem. Moving from one state variable to another occurs as a result of a specific decision. Each decision has a cost or generates a benefit and the general objective of the problem is to minimize this cost or maximize the benefit.

In plant health economics (Olson, 2006), the growth and spread of a pest is determined by a biological transition equation. Any control measure aims to reduce the population size through different management strategies such as chemical, biological, mechanical, manual or any other means. Each management strategy or combined management strategies will have a cost and will lead to different levels of pest population reduction and, accordingly, pest impact. The decision maker is trying to achieve the desirable level of pest control using the cheapest available option, given input prices. Thus, the dynamic programming problem will minimize the expected discounted control cost and pest impact over time by choosing a control option at each point in time given the biological transition equation of the pest and the prices of the control options.

The advantage of using DP over other mathematical programming techniques in PRA area is its ability to incorporate dynamic parameters in the problem that come from the nature of the pest (e.g. the biological equations of motion can be employed in the dynamic programming problem). The other strength of the DP method is in providing an insight into the potential behavioural responses of producers and consumers. However, DP is primarily used to estimate direct impacts, e.g. crop losses, and is not suitable to estimate indirect impacts (e.g. inter-sectoral consequences and changes in social welfare).

The complexity level of the method is medium to high, relatively higher than PB, LP and PE but lower than the other proposed methods, since it requires relatively advanced skills and a greater amount of data.

5.4.2 Application

One of the first articles to use dynamic programming in the economics of plant health was Jaquette (1972). He employed DP to find the optimal policy for pest control. His model is characterized by its ability to measure costs and benefits generated from pest development and control options. He showed in his model that under a set of general conditions, it was possible to determine the critical pest population density above which control measures should be applied otherwise no action should be taken.

Onstad and Rabbinge (1985) used the DP approach to calculate the cost and benefits of controlling *yellow rust* and *cereal aphids* in wheat production by comparing the cost of crop loss with the costs of control at each stage in the production process.

Zacharias *et al*. (1986) investigated different management strategies for *Soybean Cyst Nematode* (SCN) using the DP technique. They calculated the costs and benefits of each strategy at each stage of the DP outbreak.

In animal health, Bicknell *et al.* (1999) combined animal disease dynamics with a bio-economic dynamic programming model to evaluate different control strategies against bovine tuberculosis in New Zealand. By deriving the first order condition of the model, the reasons for producers to control the disease and maximise profits was clarified. As the ratio of health to infected animals increases, the cost of identifying infected animals also increases. The results showed that, if applied, national management strategies resulted in lower levels of prevalence than in the absence of a national strategy.

5.5 Input-Output Analysis (I-O)

5.5.1 Theoretical background

Input-Output analysis is a method which uses a matrix to represent a nation’s or a region’s economy to predict the impact of changes in consumer demand, government spending and exports of a particular sector in the economy. This impact is traced through the inter-sectoral linkages in the economy, with the output of one sector serving as inputs for the other sectors that create interdependence between sectors in the economy (Miller & Blair, 1985).

In an I-O transaction table, each column represents the value of primary and intermediate inputs purchased by a specific sector shown at the top of the column, while each row represents the value of intermediate and final outputs sold by a specific sector shown at the left of the row. The main assumption in I-O model is that supply is equal to demand or, in other words, inputs are equal to outputs. A technical coefficient matrix can be driven from the transaction table. It shows the fixed input proportion needed from each sector to produce one unit of output. To estimate the pest impact using I-O model, a pest incursion is assumed to change one or more of the final demand components (e.g. reduction in exports of the infested crop) and the model will then calculate the reduction in intermediate inputs in the entire economy in order to meet this new cutback in the final demand. The reduction in exports and intermediate inputs are added to calculate the total impact of the pest incursion.

For example, when the economy loses one euro of yield loss due to pest invasion, part of that euro is recovered by reducing expenditures on inputs from other sectors within the economy and the rest is recovered from savings or by reducing payment for imported goods. By dividing €1 reduction in output by the multiplier, for instance, an output multiplier of 1.42, the first transaction yields €0.70 recovered by savings or by reducing payment for imported goods and €0.30 is recovered by reducing expenditures on inputs from other sectors. Dividing the remaining €0.30 that stays in the economy by the same multiplier of 1.42 yields €0.21 (€0.30/1.42 = €0.21) recovered by saving or reduction in imports and €0.09 (€0.30 - €0.21 = €0.09) staying within the economy in the second round. These steps are repeated in subsequent impact rounds until the amounts staying within the economy have disappeared. Adding all the amounts calculated as staying in the economy plus the original euro yields the multiplier of 1.42.

Three common types of multipliers, for output, income and employment, are calculated in input-output analysis.

The strength of the model is its straightforward calculations and its ability to capture a wide range of indirect impacts. However, its weaknesses are mainly in its large data requirement. A highly disaggregated I-O table is required in order not to overestimate the indirect impact. If a highly disaggregated I-O is not available, disaggregation of the required sector must be undertaken by depending on secondary sources such as questionnaires to obtain data about inter-sector coefficients between this new disaggregated sector and other sectors of the economy. In addition, input-output analysis assumes that prices are fixed and only takes changes in demand into account. However, the assumption of fixed prices can be justified if the I-O technique is used only to analyze short-term impacts. Due to the assumption of fixed coefficients in the inputs consumed, the model doesn’t account for changes in production technology. In addition, the model assumes that producer and consumer behaviour is determined exogenously (Appendix A).

The complexity of the method is high despite the low skills requirement. This is due to the large data requirement. However, the method has a high ability to capture indirect impacts.

5.5.2 Application

Input-output analysis has been used to trace direct and indirect impacts in many applications. Julia *el al.* (2007) applied I-O analysis to calculate the total costs of yellow star thistle in the rangelands of Idaho. In their analysis, the direct impacts were based on the supply side of the market. They were divided between direct agricultural costs (e.g. reduction in income of growers and reduction in production outlays) and direct non-agricultural costs (e.g. reductions in wildlife recreation expenditure and increases in water treatment costs). The direct impact of the pest invasion was then injected into the I-O model by converting the direct impact components into their equivalent parts in the final demand variables of the I-O model (e.g. consumer, government, exports and investment demand). The direct losses were estimated to cover 64% of the total impact while the resuming 36% was related to indirect impacts.

Bangsund *et al.* (1993) estimated the direct and indirect impact of the establishment of leafy spurge in the wild lands of Montana, South Dakota and Wyoming. The direct impact included reduced wildlife-associated recreation and reduced off-site soil and water conservation. Direct impacts were used as a starting point to estimate the indirect impacts using the I-O model. Due to inter-sectoral linkages in the economy, their results showed that the most highly affected sectors were households, government, tourism and recreation, retail activity and agriculture-crops.

Leistritz *et al.* (1992) developed a regional input-output model in order to estimate the total impact of leafy spurge in North Dakota. The indirect impact was divided between reduction in personal income and reduced business activity for different sectors in the state economy. The direct impact was estimated at $30 million while the indirect impacts equalled $75 million.

Eiswerth *et al.* (2005) used the I-O model to calculate the economic impacts of non-indigenous invasive weeds on Nevada’s economy. A link between weed infestations in Nevada and the extent to which state residents tend to switch to non-infested recreation sites or other forms of non related wildlife recreation expenditure was determined. Direct impacts were calculated first, and then used to determine the indirect impacts on income and employment by using direct impacts in the I-O model as an estimate of the reduction in the final demand components of the I-O model. The annual negative impact result of the I-O model was then used to estimate future flows over a 5-year time horizon. Due to the uncertainty in model input, three scenarios were designed (low, medium and high) to give insights in the variation of possible outcomes and level of risk.

In animal health science, I-O has been used to trace the total impact on output, income and employment that result from a specific disease outbreak

(Caskie *et al.* (1999); Ekboir (1999); Garner and Lack (1995); Mahul and Durand (2000)).

5.6 Computable General Equilibrium (CGE)

5.6.1 Theoretical background

Computable general equilibrium is a technique used to estimate impacts over the whole economy that result from an external factor such as a pest invasion. The CGE model has the following characteristics (Dixon & Parmenter, 1996):

1. General. It describes the full economic cycle by showing the relationships between different economic actors in the economy.
2. Optimization. The model assumes optimized behaviour by several economic actors ranging from households and firms to government, exporters, importers and investors in order to emphasize the role of input and output prices in influencing the decisions taken by different economic actors.
3. Equilibrium. It assumes market equilibrium in which total supply is equal to total demand, so that demand and supply decisions made by different economic actors determine input and output prices.
4. Computable solutions. It provides numerical solutions by estimating parameters and coefficients in a set of solvable equations. These equations are derived from a numerical database that is based on the social accounting matrix (SAM). The social accounting matrix represents flows of all economic transactions that take place within an economy.

The strength of the CGE model is its consistency with accounting and economic theory, assessing winners and losers in the economy that produce changes in social welfare. CGE can capture the spillover effect through its economic linkages and can therefore be used to forecast medium to long-term trends and structural responses to pest invasions.

However, the main drawback of the CGE model is that its results are fundamentally dependent on the model assumptions that in turn rely on the definition of the problem. For example, determining which macro accounts are going to be balanced endogenously and by which mechanism could significantly lead to different consequences in the model. In addition, building the CGE model requires an intensive dataset obtained from national accounts and survey data to construct the social accounting matrix (SAM). Considerable skills are required to build such a framework. In addition, by nature the CGE model is very highly aggregated, making it very difficult to analyze a change in a sub sector of the economy. For example, many CGEs are disaggregated into only two agricultural sub-sectors, such as tradable and non-tradable crops, or food crops and cash crops. Finally, the sophisticated nature of the model includes a large number of parameters to be estimated which leads to a problem of calibration. CGEs are suitable to address problems that are most likely to generate measurable macroeconomic impacts. However, pest invasion problems rarely generate such major effects as changes in aggregate employment, income or inflation rate.

Although CGE is able to capture the broadest range of indirect impacts in the economy it is also the most complex method to apply and requires the greatest amount of data, skills and time.

5.6.2 Application

Wittwer *et al*. (2005) used a CGE model in order to quantify the impact of a hypothetical outbreak of the *Tilletia indica* fungus on the wheat crop in west Australia. In their analysis, the effects on output, income, employment, wages, capital stocks and exports were estimated. The analysis was divided into two phases: a first phase from 2005-2009 and a second one from 2010 onwards. The results showed that employment in the agricultural sector of Western Australia was reduced by 22%, while consumption and income were reduced by 2% and 0.14% respectively.

In another paper, Wittwer *et al.* (2006) investigated the economic consequences of introducing Pierce’s disease of grapevine in South Australia. A dynamic multi-regional CGE model was used and special attention was given to the adjustment in the labour market as a result of the disease outbreak. The loss in welfare was measured and its relationship to the adjustment in the labour market was determined.

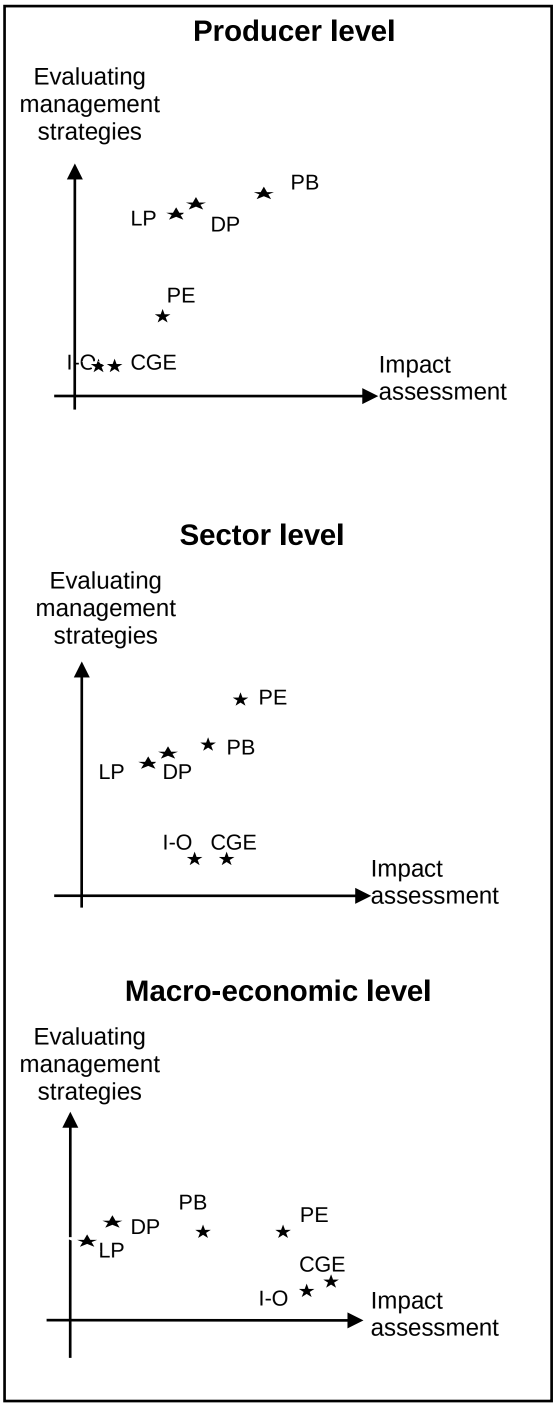
Wittwer *et al* (2005) used a multi-regional dynamic general equilibrium model to estimate the effect of improving weed control. The authors tried to calculate the impact of a rise in R&D expenditure by 50 million $ over five years. The net present value of the national welfare gain for the period 2002-2019 was estimated at 700 million $A. The calculation of welfare gain was based on changes in real aggregated consumption.

In animal health, CGE has also been used to estimate the impact of animal diseases. Chang *et al.* (2007) estimated the impacts of avian flu in Taiwan using input-output and CGE models. The input-output model was used to measure the short-term effects while the CGE was used to measure the long-term effects. They found that the economic impact of avian flu is lower in Taiwan than in other Asian countries.

6 Qualitative Analysis

In many cases, the data required for quantitative analysis are insufficient or too uncertain. There may also be too little time or resources for detailed analysis. The scale of the economic impacts may also be clear without calculation. In such cases, expert judgment (qualitative analysis) provides an alternative approach. Expert judgment can be expressed as probabilities, ratings, scores, odds, uncertainty estimates and weighting factors with a qualitative justification (a textual description of the expert’s assumptions in reaching an estimate together with reasons for selecting or eliminating certain data or information from analysis). In addition to asking experts to complete the risk assessment, the elicitation of expert judgment can also be obtained through specially designed methods. The most well known methods are (1) the Delphi method, and (2) Conjoint analysis. For example, the Delphi method (Rowe and Wright, 1999) is a systematic, interactive forecasting method that relies on a panel of independent experts. The experts answer questionnaires in two or more rounds. After each round, a summary of the experts' forecasts from the previous round as well as the reasons for their judgments is provided. Thus, feedback used to share information will lead to convergence of the views. On the other hand, conjoint analysis (Green and Srinivasan, 1978) is a statistical technique that determines what combination of a limited number of attributes is most influential on respondent choice or decision-making. A controlled set of potential products or services is shown to respondents and, by analyzing how they make preferences between these products, the implicit valuation of the individual elements making up the product or service can be determined. Delphi and conjoint analysis have been used in some animal health economics applications. For example, Van der Fels-Klerx (2002); Horst *et al.* (1996); Horst *et al.* (1998); Staerk *et al.* (1997) and Van Schaik *et al.* (1998) have used them to elicitate expert judgments.

7 Similarity in methods to assess impact and to evaluate management strategies



Within a PRA, the assessment of pest impacts is undertaken separately from the analysis of the cost effectiveness of management options. However, the economic impact assessment methods used in the pest risk assessment stage can also be employed to evaluate different management strategies. In addition, the ability to perform each function differs from one method to the other. For instance, methods such as linear programming (LP) and dynamic programming (DP) are more suitable for evaluating management strategies than quantifying pest impacts. On the other hand, methods like partial equilibrium (PE), input-output analysis (I-O), computable general equilibrium (CGE) and partial budgeting (PB) are more suitable for the quantification of pest impacts than the evaluation of management strategies. The two dimension graph in figure A1.5 shows the extent to which different methods can perform both functions. This graph is categorized according to the scale of the impact (producer, sector and macro-economic level)

Figure A1.5: Comparison of the performance level of each method by the objectives of risk assessment and evaluation of risk management, categorized by the scale of impact.

8 Modelling uncertainty in economic impact assessment

8.1 Stochastic simulation; Markov Chains and Monte Carlo modeling

8.1.1 Theoretical background

Evaluations of pest impacts or management options often involve considerable uncertainty. Uncertainty (Cullen and Frey, 1999) is defined as lack of knowledge about the true value of a quantity. Uncertainty can exist in any economic or biological parameter used to construct a quantitative model. Markov chain and Monte Carlo simulation are stochastic modelling techniques that can be used to evaluate the influence of uncertainty (Vose, 1996). They are used to support decision making by evaluating the impact of alternative control strategies on the spread of pests and by estimating the impact of pests on production.

Both Markov chain and Monte Carlo simulation methods can be used to explore the effect of uncertainty or stochasticity on any parameter in economic impact models. However, they differ in their methodology. The Markov chain model (Howard, 1971) uses probability distributions and provides the expected value of the results by carrying out a single run, while Monte Carlo simulation (Vose, 1996) uses random sampling and, for each input, multiple runs are carried out from a range of possible values. The variance in input values is then transmitted to the output of the model such that it indicates the probability of values that could occur. As a result, the model provides insight on the variation of possible outcomes and therefore on the level of risk.

8.1.2 Application

Markov chain and Monte Carlo simulation models have been used in plant and animal health. In plant health, Pemsl and Waibel (2007) used a stochastic partial budgeting method to evaluate the benefits from using BT varieties. BT varieties are used to control the cotton bollworm in china. To account for uncertainty in the factors that determine the quality of the BT varieties, Monte Carlo simulation was applied. Different control strategies, such as use of insecticides and routine sprays in addition to combination of insecticides and BT varieties, were investigated to find the optimal control option. Different pest densities were examined. The results showed that the most successful option for medium and high pest density was a combination of the low quality BT varieties and essential applications of insecticides while, for low pest density, using only insecticides was the optimal option.

Peterson and Hunt (2003) included uncertainty in the economic injury level (EIL) concept by using Monte-Carlo simulation. They investigated the EIL for two pests, alfalfa weevil larvae and *Hypera postica.* By running 10,000 iterations values in a Monte-Carlo simulation model, a lognormal distribution for model inputs was generated. The inputs of the model were injury per pest

(I), damage per unit injury (D), market value (M), cost control (C) and proportional reduction in injury with management (K). The resulting distributions reflected a high mode (maxima) and positive skewness. A sensitivity analysis was carried out to rank the contribution of each input to the variance in the results. For alfalfa weevil, the ranking was as follows with the contribution percentage in brackets: D (72%), I (22%), V (5%), K (0.5%), while for *Hypera postica*: D (54%), I (40%), V (5%), K (0.1%).

Hyde et al. (2003) used a decision tree approach to estimate the value of Bt-corn to producers in the southwest Kansas region. Bt-corn is used to control the European corn bollworm (ECB), *Ostrinia nubilalis*. Uncertainty in the input variables, such as yield losses from insects, cost of spraying, cost of other controlling methods, corn prices and corn yield was modelled using Monte-Carlo simulation. The results showed that the ECB infestation probabilities, corn price and yield are important factors in estimating Bt-corn value.

Ranjan (2004) investigated the economic impact of pink hibiscus mealy bug in Florida and US. He integrated the estimated economic impact with a Markov chain model to simulate the spread of pink hibiscus mealy bug. The result showed that the annual damage in Florida was $162.856 million while in the USA as a whole the damage was $1,580.997 million.

9 Guidance scheme

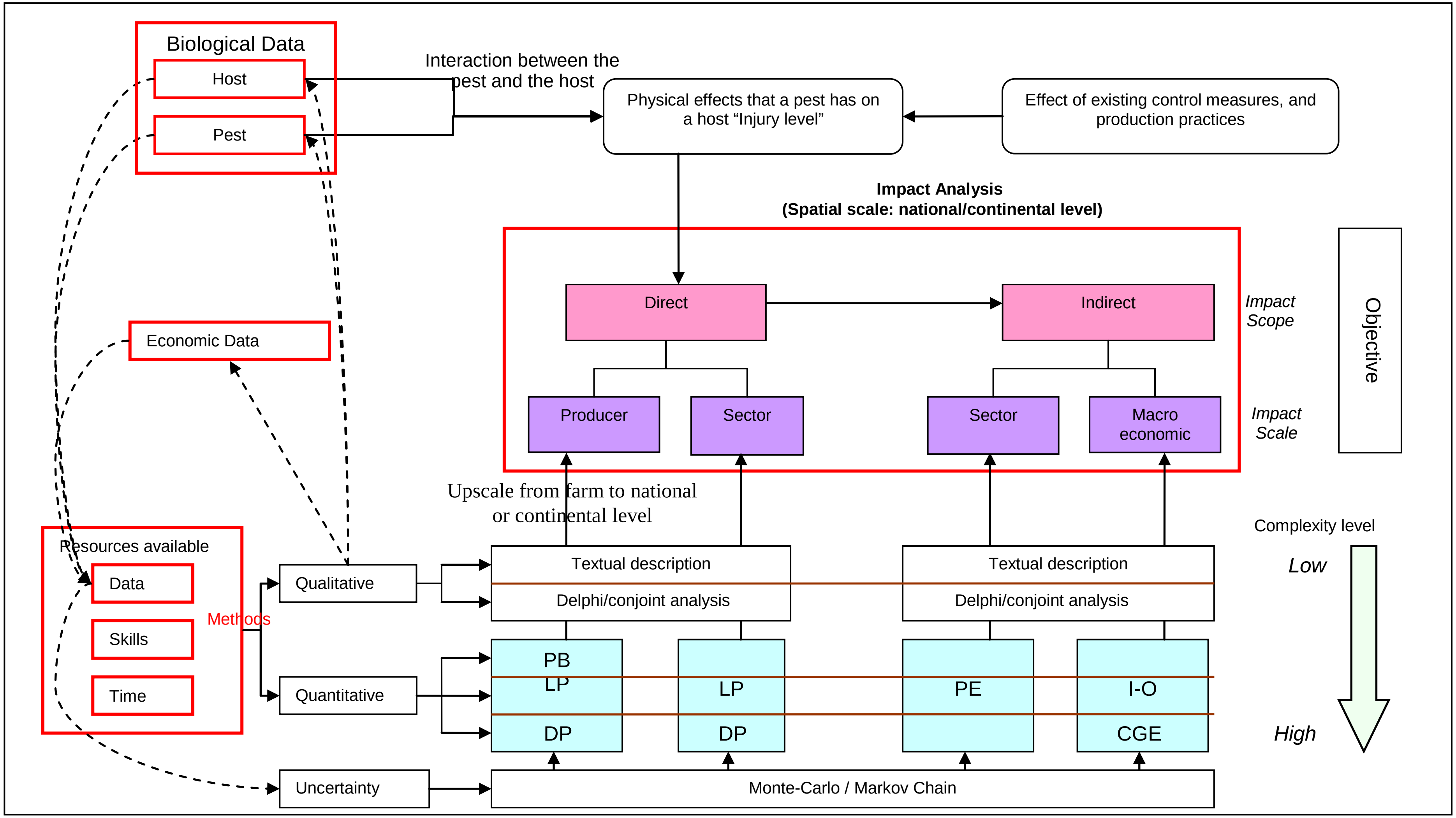
Based on the results obtained from the literature, a scheme is developed to support the selection of the optimum method to conduct a PRA (figure A1.6). The selection scheme consists of two stages:1) the observation of the available resources for the PR-analyst in terms of data, skills, and time and 2) the definition of the extent of the pest impact in terms of scope and scale of impact. Based on these two elements, the PR-analyst should be able to choose the most appropriate method, i.e. the method that requires the least resources while capturing the minimum acceptable level of impact for his particular case study.

The scheme starts by assessing the availability of resources in terms of data, skills, and time. The data element is concerned with both biological and economic data. The biological data provide scientific information about the pest and its interaction with hosts (i.e. potential establishment and spread of the pest in the endangered area). Skills are the second element in defining the complexity level of the method or the resources required for the economic method. It refers to skills needed to apply the methods (e.g. mathematics, economics). The third element is the time available for the PR-analyst to carry out the economic assessment.

The second stage of the scheme starts by linking the data available on the pest and the host with the expected economic impact. The first step is to define the physical effect of the pest on the host, what is known as “injury level”. The injury level is affected by existing control measures and current production practices along with the ability of the pest to reach high population densities above the economic injury threshold, which is basically driven by the biological data. The economic data provide an indication of the appropriate economic impact scope and scale. Accordingly, such play a fundamental role in defining the most appropriate method for estimating economic impacts. The key factor to consider here is that the type or method of economic analysis required depends on the economic consequences that have been identified as a result of the effects of the particular pest and host interaction. Each situation could be different, with economic effects possibly limited to a minor effect or a minor crop, or having a major effect on a key plant in an agribusiness sector. In this context, the pest’s presence and way that the pest’s effects are manifested are important considerations.

For many biological and economic variables, there will generally be little data on which to base estimates. Consequently, for these parameters, there is a need to model uncertainty by using specific techniques. Modelling uncertainty will provide insight in the variation of possible outcomes that is of great importance to the decision maker.

In conclusion, knowledge of the potential establishment and spread of the pest in the endangered area, its capacity to reach economically damaging population densities and the economic importance of the host crop should be used to provide an approximate estimate of the scope, *i.e. direct vs. indirect impact and,* the scale, *i.e. producer, sector and macro-economic level.* Adding the results of both stages, the optimal method can be found.


Biological Data
Host
Pest
Interaction between the pest and the host
Physical effects that a pest has on a host "Injury level"
Effect of existing control measures, and production practices
Impact Analysis
(Spatial scale: national/continental level)
Direct
Indirect
Impact Scope
Objective
Producer
Sector
Sector
Macro economic
Impact Scale
Economic Data
Upscale from farm to national or continental level
Complexity level
Low
High
Resources available
Data
Skills
Time
Methods
Qualitative
Quantitative
Uncertainty
Textual description
Delphi/conjoint analysis
Textual description
Delphi/conjoint analysis
PB
LP
DP
LP
DP
PE
I-O
CGE
Monte-Carlo / Markov Chain

Scope: Direct= host specific impact/ Indirect= non-host specific impact/ **Scale:** Producer= impact on producer/ Sector= impact on supply chain partners (producers, processors, retailers) and consumers in one sector/ wide economy= impact on other sectors and economic entities (government)

Figure A1.6: Guidance scheme

10 Mapping the quantitative economic methods to the EPPO scheme

The EPPO Panel on PRA has been developing the EPPO decision support schemes for pest risk analysis for quarantine pests. The current EPPO scheme is entirely based on ISPM no. 11 and addresses all elements of this ISPM in a logical sequence of questions to carry out the process of PRA in an efficient way. In the EPPO scheme, the questions addressing the economic risk assessment, including social and environmental impacts, are from 2.1 to 2.15. Table A1.1 proposes the most suitable economic methods that can be used to answer the questions involving economic impact assessment.

Table A1.1: Mapping the economic methods to the EPPO scheme

EPPO scheme questions	Proposed economic method
2.1. How great a negative effect does the pest have on crop yield and /or quality to cultivated plants or on control costs within its current area of distribution?	(1) Partial budgeting (2) Linear programming and (3) Dynamic programming
2.2 How great a negative effect is the pest likely to have on crop yielded and /or quality in the PRA area without any control measures?	(1) Partial budgeting, (2) Linear programming and (3) Dynamic programming
2.4. How great an increase in production costs (including control costs) is likely to be caused by the pest in the PRA area?	(1) Partial budgeting and (2) Linear programming and (3) Dynamic programming
2.5. How great a reduction in consumer demand is the pest likely to cause in the PRA area?	Partial equilibrium. The demand analysis in the partial equilibrium model can be used to identify the determinants of the demand. The demand elasticity resulting from the analysis will provide a direct answer to this question.
2.8. How important is social damage caused by the pest within its current area of distribution?	(1) Partial equilibrium and (2) CGE can be used to calculate the change in social welfare (i.e. change in consumer and producer welfare), employment, social structure.
2.9. How important is the social damage likely to be in the PRA area?	(1) Partial equilibrium and (2) CGE can be used to calculate the change in social welfare (i.e. change in consumer and producer welfare), employment, social structure.
2.10. How likely is the presence of the pest in the PRA area to cause losses in export markets?	(1) Partial equilibrium and (2) CGE can quantify the losses in export market and its consequences, while (3) I-O can quantify the impact that result from losses in export market (i.e. intersectoral effects on output, employment and income in the entire economy).

Note: The remainder of the questions address environmental and social impacts.

11 Discussion and conclusions

Expert judgment (qualitative analysis) is frequently used in pest risk assessments when the risks are clear-cut, there is insufficient good quality data, and resources for a quantitative assessment. The current practice for elicitation of expert judgment is undertaken by experts acting on their own and collectively and it is rarely that an objective method to obtain expert judgment is used (e.g. Delphi method or conjoint analysis).

In quantitative analyses, each economic method is able to assess a different range of impacts and requires specific resources to conduct the analysis. In order to select the optimal method for a particular PRA, the pest risk analyst needs to select the method that requires minimal resources in terms of data, skills and time, while providing an appropriate level of accuracy in assessing the scale and scope of the potential impacts. We conclude that partial budgeting is the most suitable method for estimating direct impact as it requires the least resources and provides more detailed results in comparison to LP and DP. LP and DP basically find the optimal decision and the value of that optimal decision is interpreted as the impact. The optimization process provides overall results without showing the impact of the individual components. Partial equilibrium is the most appropriate method for the estimation of indirect impacts, e.g. export losses, consumer demand, price effects, social welfare and intersectoral consequences. This can be justified in two ways. First, PE requires the least resources compared to the I-O and CGE methods and, second, the additional advantage of I-O and CGE in their ability to capture indirect impacts to the entire economy is very rarely needed in PRA since it is very unlikely that a pest will have a wide economy impact. In most cases, a combination of the two methods, PB and PE, are sufficient to provide a detailed analysis of both direct and indirect impacts.

The main differences between these recommendations and those in ISPM_11 are that

- CGE is not appropriate method for PRA and can be replaced by a multi-market PE, and
- a combination of PB and PE will provide good quality of analyses for those cases where both direct and indirect impacts occur.

The current practice for evaluating economic impacts usually stops with the estimation of direct impacts at the producer level. However, from an economic point of view, even if we assume that the direct impact is large, it is not good practice to stop the assessment and conclude immediately that the pest will lead to a high overall negative economic impact since it is also important to take into account the possibilities of adaptations. A direct negative impact on a producer could be countered by a substitution effect with a switch to other crops that are not vulnerable to the pest. If producers can adapt by growing less vulnerable crops, the total overall impact for all producers could be less severe than that indicated if only direct impacts are evaluated. The factors that can affect the possibilities of adaptation for producers can be summarized in the following:

- risk level, the higher the risk, and the greater the tendency to switch, as people are expected to be risk averse.
- Competence of the substitute crop, the better the performance of the substitute crop, the more the tendency to switch. Producers are expected to be profit maximizers.

Assuming the data are available to carry out partial budgeting and partial equilibrium models, partial budgeting is relatively straightforward to apply because limited skills are required. However, for partial equilibrium analysis, the higher skills requirements may limit the application of this method. There is a trade off between the costs of investing in the skills needed and the benefit from using the PE technique. The alternatives can be summarized by comparing the costs of:

1. econometrics and micro-economics courses to teach the PR-analyst the required skills
2. hiring an economist to assist the PR-analyst
3. building a fully computerized partial equilibrium model (which, however, is not feasible to use without prior knowledge of economics/econometrics).
4. a combination of (1) and (3)

While the benefits lie, for the EPPO PRA scheme, in providing a quantitative answer to two “economic impact” questions (2.5 and 2.10) and assistance in answering two “social impact” questions (2.8 and 2.9), a key question is whether the costs for acquiring the PE skills can be justified by the benefits of adding such quantification to PRAs.

Recently, the importance of using quantitative analyses in risk assessment has increased in order to provide an objective justification for decisions (e.g. regulate or ban plant imports). If carried out correctly, quantitative analyses can be more effective than qualitative assessments in providing this justification.

Table A1.2: Mapping between selection criteria and economic methods

Criteria	PB	LP	PE/Multi market PE	DP	Input-output Analysis	CGE
Scope of analysis						
Direct cost	+	0	0/0	0	0	0
Prices	-	0	+/+	0	-	+
International trade	-	-	+/+	-	0	+
Inter-sector linkages	-	-	-/0	-	+	+
Social Welfare	-	-	+/+	-	0	+
Employment	-	-	-/0	-	+	+
Scale of analysis						
Producer	+	+	0/0	+	-	0
Sector	-	0	+/+	0	0	+
Wide economy	-	-	-/0	-	+	+
Resource criteria						
Simple skills requirement	+	0	0/0	-	0	-
Availability of data required	+	0	0/-	0	-	-
Short time investment	+	0	0/0	0	0	-
Misc. criteria						
Low uncertainty in results	+	0	0/0	0	0	-

Source: Modified on Rich *et*. Al. (2005) by adding other criteria and methods
- : Inappropriate **0:** Somewhat appropriate **+:** Appropriate
PB: Partial budgeting **LP:** Linear programming **PE:** Partial equilibrium **DP:** Dynamic programming **CGE:** Computable General Equilibrium

Table A1.3: Resources requirement for the economic methods

Requirement	PB	LP	PE/Multi market PE	DP	Input-output Analysis	CGE
Data	(1) production volumes, (2) yield loss, (3) production prices, (4) control costs and (5) estimation for export losses	(1) values for the economic or biological variables used to construct LP model, (2) the expected reduction in crop production due to pest incursion/yield loss	(1) a complete parameterization for supply and demand functions in the market(s) directly affected by the pest (2) a determination of the closures of the market(s) being modelled and (3) percentage loss in crop yield.	(1) values for the economic or biological variables used to construct DP model, (2) the expected reduction in crop production due to pest incursion/yield loss	(1) a detailed input-output table, (2) income and employment for each sector in the economy and (3) the expected reduction in export volumes or reduction in crop production due to pest incursion/yield loss	(1) social accounting matrix, (2) elasticities which are parameters that capture behavioural response (3) the expected reduction in crop production due to pest incursion./yield loss
Time	1 week to one month	one month to three months	Few weeks for a simple model to few[1] months for very detailed models.	one month to few months	one month to few months	few months to a year
Skills	Basic accounting skills	Mathematical background (e.g. mathematical programming).	Familiarity with basic partial equilibrium modelling and micro-econometric estimation techniques.	Mathematical background (e.g. mathematical programming)	Basic macro economic theory and mathematical skills (e.g. matrices).	Solid economical/statistical background. Also experienced modellers with substantial prior exposure to computable general equilibrium models are required
Software	Excel	GUASS, GAMS or any other available software to solve mathematical programming problems	Excel, Stata, E-views, SAS, GAMS or any other available software to solve a system of potentially non-linear equations for the endogenous prices and quantities	GUASS, GAMS or any other available software to solve mathematical programming problems.	GUASS, GAMS, MATLAB or any other available software to solve matrices	GUASS, GAMS and MATLAB

Source: Holland J. (2007). Tools for Institutional, Political, and Social Analysis of Policy Reform. The World Bank.

N.B. Economic data such as production [area harvested, yield, and production quantities], consumption, trade [quantity and values of exports and imports], prices, income and employment) can be founded in public databases of FAO "FAOSTAT", OECD and national statistical agencies.

[1] More than three months and less than a year – Note: For all methods, we assume that the PR-analyst has basic agricultural/plant production background.

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Appendix A:

1. Total net benefit: obtained by subtracting total costs from total benefits. If the net benefit is positive, then that proposed change may have some economic advantages. However, if the net benefit is negative, the business would be better off staying with the current situation (i.e. without the proposed change).
2. Net present value: the total present value (PV) of a time series of cash flows. It is a standard method for using the time value of money to appraise long-term projects.

   Formula: Each cash inflow/outflow is discounted back to its present value (PV). Then they are summed. Therefore NPV is the sum of all terms

   $\frac{R_t}{(1+i)^t}$, where

   t - the time of the cash flow

   i - the discount rate (the rate of return that could be earned on an investment in the financial markets with similar risk.)

   R_t - the net cash flow (the amount of cash, inflow minus outflow) at time *t* (for educational purposes, R_0 is commonly placed to the left of the sum to emphasize its role as (minus the) investment).
3. Cost-benefit ratio: is an indicator, used in the formal discipline of cost-benefit analysis, which attempts to summarize the overall value for money of a project or proposal. A BCR is the ratio of the benefits of a project or proposal, expressed in monetary terms, relative to its costs, also expressed in monetary terms. All benefits and costs should be expressed in discounted present values.
4. Endogenous: variables that are determined inside the model
5. Exogenously: variables that are determined outside the model

Annex 2: Review of Environmental Impact Assessment Methods in Pest Risk Analysis

1 Introduction

Alien plant pests (invertebrates, diseases and plants) can affect native biodiversity and ecosystem services and processes through various mechanisms (Levine et al., 2003; Baker et al., 2005; Desprez-Loustau et al., 2007; Kenis et al., 2009) and there is a multitude of methods for assessing environmental impacts in field and laboratory conditions (Parker et al., 1999; Kenis et al., 2009). Herbivorous invertebrates and plant pathogens feeding or developing on native plants can have a direct effect on their populations. Alien species may hybridize with native species, causing disturbances in native genetic resources. They can also affect the native flora and fauna and ecosystems indirectly, through cascading effects, or by carrying pathogens, competing for food or space or sharing natural enemies with native species. Alien plants can also affect native plant populations and communities through hybridization, competition for space or resource, or via more complex ecosystem disturbances. However, these ecological impacts, their strength and the mechanisms underlying these impacts are poorly studied. Their interaction between alien species and the native flora and fauna has been rarely investigated, particularly if their habitat is of little economic concern. In their extensive literature survey on the ecological effects of alien insects, Kenis et al (2009) identified 72 alien insects worldwide for which an ecological impact had been investigated. Among these, only about half can be considered as true plant pests, the others being predators, parasites, parasitoids or pollinators. This represents a very low proportion of the thousands of alien plant pests occurring worldwide. Desprez-Loustau et al. (2007) and Levine et al. (2003) made similar observations for alien fungi and plants, respectively.

All pest risk analysis procedures include, as part of the evaluation of the consequences of an introduction and establishment of a pest, the assessment and prediction of the environmental impact of the target pest, together with its economic and, sometimes, social impacts. In general, experts are asked to assess both the current impact in the area of present occurrence and the potential impact in the PRA area, using all available data. The environmental impact assessment carried out in PRAs relies mainly on expert judgement. However, in contrast to the economic impact for which standard assessment methods exist and are used (see Annex 1), there is no standard and easily applied method to assess the current and potential environmental impact of a plant pest. The complexity and the variety of mechanisms involved in the environmental impact of alien invertebrates, plant pathogens and plants requires that each case is studied separately, usually through long field or laboratory studies. These are usually not possible within the usual framework and budget of a PRA. Thus, the assessment of the potential environmental impact of a pest in a PRA is likely to be based on expert judgements for a long time to come.

It must be noted that economists have attempted to develop methods to give a monetary values to environmental impacts, which are traditionally measured in non-monetary value. Although ecologists often criticize the validity and usefulness of these methods, they may provide useful tools when, in PRAs, economic and environmental impacts have to be assessed together. In this report, these methods are described in Annex 4.

Although all PRA schemes rely on expert judgement to assess the potential environmental impact of pests, they often use different approaches, e.g. asking different questions and using different scoring systems. In this section, we will review methods used to assess and predict the environmental impact in risk and impact assessment schemes for alien pests. It will start with a survey of how environmental impact assessment is covered in seven main pest risk analysis and pest risk assessment schemes used by RPPOs and NPPOs worldwide (Table A2.1). PRA schemes and guidelines that provide only general recommendations, such as ISPM 11 of the IPPC (FAO, 2004) will not be discussed. Two procedures that particularly focus on environmental impact assessment of alien invasive species will then be analysed. Finally, we also review six weed risk assessment schemes, which have been developed mainly to assess the invasion potential of alien plants used in horticulture, forestry or agriculture. These schemes are included here because some of them have a strong environmental impact component that is largely based on the assumption that the same traits that correlate with the invasiveness of plants can also be used as indicators of their ecological impact in the absence of true impact studies. This correlation, however, has recently been criticised (Ricciardi and Cohen, 2007). Weed risk assessment schemes are discussed separately in this report because they tend to use a very specific methodology, which, for the moment, has been applied only to plants, but could also be developed for other alien organisms including plant pests.

Table A2.1. The risk and impact analysis and assessment schemes reviewed

Schemes	**Target organisms**	**Reference**
Pest risk analysis/assessment		
EPPO PRA scheme	Plant pests and weeds	EPPO (2007)
UK non-native species risk analysis scheme	All aliens	DEFRA (2008) Baker et al. 2008 (Neobiota paper)
ACIA-CFIA (Canada) – Plant health risk assessment	Plant pests	ACIA-CFIA (2008)
Biosecurity New Zealand – Risk analysis procedures	All aliens[1]	Biosecurity New Zealand (2006)
Biosecurity Australia – Guidelines for import risk analysis	All aliens[1]	Biosecurity Australia (2001, 2007)
USDA-APHIS guidelines for pathway-initiated pest risk assessments (USA)	Plan pests	USDA-APHIS (2000)
Conabio (Mexico) Evaluación de riesgo de invasión por especies no nativas o exóticas	All aliens	Conabio (2008)
Impact assessment		
Belgium	All aliens	Branquart (2007)
Biopollution in aquatic ecosystems	Aquatic organisms	Olenin et al. (2007)

Weed risk assessment		
WRA system Australia	Weeds	Biosecurity Australia (2008)
Weed-Initiated PRA guidelines for Qualitative Assessments (USDA-APHIS)	Weeds	USDA-APHIS (2004)
Hawaii Exotic Plant Evaluation Protocol	Weeds	Denslow and Daehler (2006)
WRA scheme New Zealand	Weeds	Williams et al. (2008)
Prioritization system for the management of invasive alien plants in South Africa	Weeds	Robertson et al. (2003)
NatureServe	Weeds	Morse et al. (2004)

[1]The generic Biosecurity Australia and Biosecurity New Zealand schemes are generally not used for plants because these countries have built specific risk assessment schemes for weeds.

2 Consideration of environmental impact in national and international PRA schemes

2.1 EPPO PRA scheme

In the EPPO PRA scheme, which is the most commonly used PRA scheme in Europe and other EPPO countries and is designed to follow ISPM11 (FAO, 2004), the questions on environmental impact are part of the section "Assessment of potential economic consequences". In this scheme, the general terms "economic consequences" encompass economic, environmental and social impacts, as recommended in Supplement 2 of ISPM5 (FAO, 2007). However, questions regarding environmental impacts are separated from those that relate solely to economic and social impacts.

In the categorization section, the risk assessor has to answer the question *"With specific reference to the plant(s) of habitats which occur(s) in the PRA area, and the damage or loss caused by the pest in its area of current distribution, could de pest by itself, or acting as a vector, cause significant damage or loss to plants or other negative economic impacts (on the environment, on society, on export markets) through the effect on plant health in the PRA area?"* to justify further risk assessment. The following two questions are asked in all pest risk assessments: "*How important is environmental damage caused by the pest within its current area of distribution?"* and *"How important is the environmental damage likely to be in the PRA area?*" Depending on other questions, three other questions related to environmental impact may also be asked: "*How likely is it that natural enemies, already present in the PRA area, will not reduce populations of the pest below the economic threshold?*", "*How likely are control measures to disrupt existing biological or integrated systems for control of other pests or to have negative effects on the environment?*" and "*How likely is it that genetic traits can be carried to other species, modifying their genetic nature and making them more serious plant pests?"*. For each question, experts are asked to choose among five qualitative scores, e.g. "*minimal, minor,* *moderate, major, massive"* and three levels of uncertainty: "*low, medium or high*". There is no mechanism to combine scores. Instead, a general assessment for the potential economic (i.e. economic, environmental and social) consequences is asked.

The assessment of environmental impact in the EPPO scheme starts with a question on the impact within the current area of distribution of the pest. This is appropriate because the fact that a pest causes environmental concern elsewhere is clearly the best indicator of a potential impact in the PRA region (Williamson, 1996). However, this question is relevant only if the pest is already invasive in other regions because the environmental impact of a native species is an unclear concept. Furthermore, even if the target pest is already invasive elsewhere, the chance that its environmental effect has been properly studied is very low (Kenis et al., 2009). For the majority of cases where the environmental impact has never been studied, there is no guidance on how to assess the possibility that an impact occurs, or will occur. In these cases, the experts will have the greatest difficulties to answer the questions on the current and potential environmental impact. Furthermore, there is no guidance on how to score the environmental impact, even when actual impacts have already been recorded, leading to low consistency. It must be noted that EFSA[3] (2009) has recently drafted a more detailed note to question 2.4 of the EPPO PRA scheme, primarily to ensure that detailed consideration of the impact on ecosystem services is made.

2.2 UK Non-native Species Risk Analysis Scheme

The UK non-native species risk analysis scheme (DEFRA, 2008; Baker et al., 2008) (cited herein as the DEFRA scheme) has been developed recently to analyse the risk linked to the introduction of alien organisms (all taxa). It is based on the EPPO PRA scheme and asks the same questions regarding environmental impact (see 2.1. above). However, it also provides guidance on the selection of responses to the impact questions, in particular, definitions for scoring impacts (Table A2.2). This system is based on the Australia and New Zealand Risk Management Standard (SA/SNZ, 1999), but with some modification of the monetary values, and of the wording in the other three dimensions. The DEFRA scheme also provides lists of potential biological receptors that may by threatened by the alien species and guidance on how to combine impact scores with impact likelihood and uncertainty.

Table A2.2. Definitions for scoring economic, health, environmental and social impact in the UK Non-native Species Risk Analysis Scheme

Score	Des-cription	Monetary loss, costs	Health impact	Environmental impact	Social impact
1	**Minimal**	Up to £10k /yr	Local, mild, short-term, reversible effects to individuals	**Local, short-term population loss, no significant ecosystem effect**	No social disruption

[3] http://www.efsa.europa.eu/EFSA/efsa_locale-1178620753816_1211902676628.htm

2	**Minor**	£10k-£100k /yr	Mild short-term reversible effects to identifiable groups, localised	**Some ecosystem impact, reversible changes, localised**	Significant concern expressed at local level
3	**Mode-rate**	£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
4	**Major**	£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 over wider area
5	**Massive**	£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 area

The definitions for each impact score provide a significant improvement compared to the EPPO scheme, on which the DEFRA scheme is based. It may be particularly helpful in providing a more consistent score in relation to species for which the impact has already been studied. However, while the definitions for scoring the economic impact are very precise because they are expressed in monetary units, those for scoring the environmental impact remain vague. For example, pest risk analysts may not understand what the scheme means by definitions such as “some ecosystem impact”, “localised” or “serious ecosystem effects”. Furthermore, two of the major problems identified in the EPPO scheme remain. Firstly, it will be difficult to score, in the time frame of a PRA, species for which the environmental impact has not yet been studied. Secondly, there is no guidance to help predict future impacts in the PRA region.

It is interesting to note that this scheme is probably the most conservative, i.e. the one that will provide the lowest environmental impact score (compare in particular with the USDA-APHIS and the Conabio schemes below). Very few plant pest species will score “Major” and hardly any will score “Massive” because these two scores require irreversible and widespread effects, which in most cases, is not easily measurable in a short time scale. Furthermore, it is not clear how to score species that have a very serious but local impact. In most cases, these species are simply spreading very slowly, but might eventually be as threatening as the fast spreading species.

2.3 ACIA-CFIA (Canada) – Plant health risk assessment

In the scheme used by the Canadian Food Inspection Agency (ACIA-CFIA, 2008), the “potential environmental impact” is one of the four evaluation criteria used to assess the consequences of introduction, the three others being “establishment potential”, “natural spread potential” and “potential economic impact". The analysts need to provide information under four sub-headings: direct impacts of the pest in natural ecosystems; indirect impacts; discussion of rating; uncertainty and gaps. As for the other components of the PRA, the potential environmental impact has to be given by selecting one of the four scores: negligible (0), low (1), medium (2) or high (1). The consequences of introduction are evaluated by simply adding the four individual scores obtained for each of the evaluation criteria, assuming that all four criteria are equally important.

The scheme provides guidelines to help the analyst score the environmental impact (Box A2.1). However these guidelines are rather vague and brief and mainly consist of one single example per score category. No specific indicator for environmental impact is given. The examples may help pest risk analysts understand the expectations, but they only cover some of the numerous mechanisms underlying environmental impacts. In contrast to the EPPO and DEFRA schemes, the ACIA-CFIA scheme requests only an evaluation of the potential impact of the pests in the PRA region. It does not ask whether the pest already causes impacts in the regions where it already occurs, nor does it suggest that this information may be helpful in the evaluation of the potential impact.

Interestingly, there is no separate category "social impact", which is included partly in the economic impacts and partly in the environmental impacts. For example, impacts on recreational activities and aesthetic impacts are mentioned as environmental impacts.

Box A2.1. Text provided with the ACIA-CFIA (Canada) – Plant health risk assessment scheme to help scoring the potential environmental impact.

This section considers potential impacts on non-agricultural host(s) and natural ecosystems. This may include subjective consideration of direct biotic effects on endangered or threatened natural species (e.g., feeding) and reduction of biodiversity. Examples of abiotic impacts considered include ecosystem destabilisation, environmental degradation, fire hazard, erosion, and impact on recreation and aesthetic values. It may also be appropriate to consider potential negative impacts of risk management options (e.g., pesticides) as indirect environmental impacts.

Rating = negligible (numerical score is 0): There is no potential to degrade the environment or otherwise alter ecosystems by affecting species composition or reducing longevity or competitiveness of wild hosts. Example: Cherry rasp leaf virus has a limited host distribution and is unlikely to spread to natural ecosystems.

Rating = low (1): There is limited potential impact on environment, slightly reducing wild host longevity, competitiveness, as well as recreation or aesthetic impacts. Example: The natural host range of Winter Moth (*Operophtera brumata* L.) includes a wide range of trees other than apple, i.e., oak, sitka spruce. Infestation does not kill the host and would have minimal to moderate impact on forests and no impact on recreational activities.

Rating = medium (2): There is potential to cause moderate impact on the environment with obvious change in the ecological balance, affecting several attributes of the ecosystem, as well as moderate recreation or aesthetic impacts. Example: Oak wilt (*Ceratocystis fagacearum* (Bretz) Hunt) is insect-transmitted and attacks all oak species, although it is most severe in those species in the red oak group. It causes rapid death (within one year) of red oaks and gradual decline or branch death in white oaks. The oaks are an important forest species in eastern Canada, particularly in the deciduous and Great Lakes forest regions.

Rating = high (3): There is potential to cause major damage to the environment with significant losses to plant ecosystems and subsequent physical environmental degradation. Example 1: Chestnut blight (*Cryphonectria parasitica* (Murrill) Barr) spread rapidly throughout the eastern forests of the USA from Maine to Georgia, destroying chestnut trees and subsequently causing tremendous economic and ecological disruption throughout the Appalachian forests. Example 2: Outbreaks of nun moth (*Lymantria monacha* (L.)) in Europe have resulted in losses of large areas of forest. In the immense outbreak of 1853-1863, 147,000,000 m3 of timber was killed and the forest was permanently lost. The area was subsequently converted to agriculture.

2.4 Biosecurity New Zealand – Risk analysis procedures

The Risk Analysis Procedures produced by Biosecurity New Zealand (2006) is a very long (103 pages) and broad document that covers not only pests but also other organisms. Unlike the other schemes reviewed herein, it does not provide a very detailed scheme with precise questions and scoring systems but rather various principles and considerations on how to comply with international agreements and standards and domestic legislation, particularly the Biosecurity Act, which is *"an Act to restate and reform the law relating to the exclusion, eradication, and effective management of pests and unwanted organisms"*. Therefore, the document is probably less user-friendly for pest risk analysts than the other, simpler schemes. However, in contrast to most others, it provides fairly precise definitions of the environment and what can be considered as an impact on the environment (see '. 48-52 in Biosecurity New Zealand, 2006).

Following the Biodiversity Act, the proposed criteria to assess the consequences of an invasion are: (a) ecosystems and their constituent parts, including people and their communities; (b) all natural and physical resources, including organisms of all kinds, air, water, and soil in or on which organisms may live, landscape and land forms, geological features, structures of all kinds and systems of interacting living organisms; (c) amenity values; (d) aesthetic, cultural, economic and social conditions that affect or are affected by any criteria (a) to (c). These criteria are explained and examples are given. The procedure then suggests that each potential hazard or group of hazards should be dealt with separately with a reasoned, logical and referenced discussion to: (i) identify the likely spread within the risk analysis area; (ii) identify the potential biological, environmental, economic and human health consequences associated with the entry, establishment, and exposure of the potential hazard; (iii) estimate the likelihood of these potential consequences. The document also provides possible factors to consider during consequence assessment, including environmental consequences, as well as a brief discussion on analytical techniques. It does not provide any particular technique to assess environmental impacts, but it states that "*The assessment of the likelihood and consequences of environmental impacts often involves greater uncertainty than the assessment of impacts on cultivated or managed plants/animals. This is due to the lack of information, additional complexity associated with ecosystems and variability associated with unwanted organisms or diseases, hosts or habitats and the lack of baseline data. In these cases it is again necessary to document the areas of uncertainty and the degree of uncertainty in the assessment, and to indicate where expert judgement has been used*"

2.5 Biosecurity Australia – Guidelines for import risk analysis

The current handbook for import risk analysis edited by Biosecurity Australia (2007) is a rather general document that provides little information on how to assess environmental impact in a PRA. However, an unpublished document (Biosecurity Australia, 2001) provides much more detailed guidelines on how to manage data and scores obtained in the evaluation of impact and consequences of introductions (see p. 103-107). Nevertheless, the guidelines remain rather vague compared to, e.g. Biosecurity New Zealand (2006), regarding indicators of environmental impact. The document differentiates between direct and indirect consequences, but does not clearly distinguish between economic, environmental and social impacts (Box A2.2). It also suggests the following factors to consider when an impact is evaluated:

1. *all on-site and off-site impacts*;
2. *the geographical scope and magnitude of the impact*;
3. *the frequency and duration of the action causing the harm*;
4. *the total impact which can be attributed to that action over the entire geographic area affected, and over time (i.e. cumulative impact)*;
5. *any synergistic effect of hazards on impact*
6. *reversibility of the impact*;
7. *the sensitivity of the receiving environment (recognised environmental features of high sensitivity)*;
8. *the degree of confidence with which the impacts of the action are known and understood.*

An innovative aspect of the guidelines is that it is recommended that impacts are estimated at four different geographic scales: local, district, regional and national. Definitions of these scales are provided. At each scale, the magnitude of impact is described as ‘unlikely to be discernible’, of ‘minor significance’, ‘significant’ or ‘highly significant’ (Box 2). The impact score combines the magnitude of impact and the geographic scale, through a score matrix. The impact score is then integrated into the risk assessment score following precisely described procedures.

Box A2.2. Description of direct and indirect consequences associated to a pest or disease following Biosecurity Australia (2001) and definitions of quantum of impact categories.

Direct consequences
Direct harm to:
- animal or plant life, health or welfare (whether native or introduced species), including animal and plant production losses
- human life, health or welfare
- any other aspects of the environment not covered above (e.g. the physical environment or other life forms — microorganisms, etc.).

Indirect consequences
Indirect consequences are the costs resulting from natural or human processes associated with the incursion of a pest or disease:
- new or modified eradication, control, surveillance/monitoring and compensation
- strategies/programs
- domestic trade or industry effects, including changes in consumer demand and effects on other industries supplying inputs to, or utilising outputs from, directly affected industries
- international trade effects, including loss of markets, meeting new technical requirements to enter/maintain markets and changes in international consumer demand
- indirect effects on the environment (see below), including biodiversity, endangered species, the integrity of ecosystems, reduced tourism, reduced rural and regional economic viability and loss of social amenity, and any ‘side effects’ of control measures.

Categories of magnitude of impact
- an ‘unlikely to be discernible’ impact is not usually distinguishable from normal day-to-day variation in the criterion
- an impact of ‘minor significance’ is not expected to threaten economic viability, but would lead to a minor increase in mortality/morbidity or a minor decrease in production. For non-commercial factors, the impact is not expected to threaten the intrinsic ‘value’ of the criterion— though the value of the criterion would be considered as ‘disturbed’. Effects would generally be reversible
- a ‘significant’ impact would threaten economic viability through a moderate increase in mortality/morbidity, or a moderate decrease in production. For non-commercial factors, the intrinsic ‘value’ of the criterion would be considered as significantly diminished or threatened. Effects may not be reversible
- a ‘highly significant’ impact would threaten economic viability through a large increase in mortality/morbidity, or a large decrease in production. For non-commercial factors, the intrinsic ‘value’ of the criterion would be considered as severely or irreversibly damaged.

2.6 USDA-APHIS Guidelines for Pathway-Initiated Pest Risk Assessment

In the USDA-APHIS guidelines for pathway-initiated pest risk assessment (USDA-APHIS, 2000), the environmental impact is assessed as one of the five risk elements in Step 5 “assess consequences of introduction”, together with “climate-host interaction”, “host range”, “dispersal potential” and “economic impact”. The five components have a similar weight in the assessment. Scores (1, 2 or 3) are given for each component and summed to produce a cumulative risk rating. There is some information on how to score the environmental impact (Box A2.3).

As for most schemes, the indicators are rather vague and the assessment is based mainly on the expert’s estimation of a potential impact. There is no mention of using the current impact in other regions as an indicator. What is more unusual is that the scheme suggests that the precautionary approach should apply. When the host range in the region of introduction is not known, a very usual case, every plant in the same family as a known host is expected to be attacked. Furthermore the fact that a pest is of economic importance and would stimulate chemical treatment or biological control is sufficient to classify the environmental impact as medium. As a result, many species may score high in the environmental impact assessment simply if they are likely to induce chemical or biological control and if they attack plant species within the same family as endangered species.

Interestingly, amenity values or other socio-environmental values are not taken into account. Much emphasis is placed on endangered and threatened species. This may be a valuable criterion in countries, such as the USA, where lists of endangered and threatened species at national and local level are well developed and maintained, but it is the case for only few countries worldwide.

Box A2.3. : How to score environmental Impact (Risk Element #5) in the USDA-APHIS guidelines for pathway-initiated pest risk assessment (USDA-APHIS, 2000)

The assessment of the potential of each pest to cause environmental damage proceeds by considering the following factors:

- Introduction of the pest is expected to cause significant, direct environmental impacts, e.g., ecological disruptions, reduced biodiversity. When used within the context of the National Environmental Policy Act (NEPA) (7CFR §372), significance is qualitative and encompasses both the likelihood and severity of an environmental impact.
- Pest is expected to have direct impacts on species listed by Federal Agencies as endangered or threatened (50CFR §17.11 and §17.12), by infesting/infecting a listed plant. If the pest attacks other species within the genus or other genera within the family, and preference/no preference tests have not been conducted with the listed plant and the pest, then the plant is assumed to be a host.
- Pest is expected to have indirect impacts on species listed by Federal Agencies as endangered or threatened by disrupting sensitive, critical habitat. Introduction of the pest would stimulate chemical or biological control programs.

Low (1): None of the above would occur; it is assumed that introduction of a nonindigenous pest will have some environmental impact (by definition, introduction of a nonindigenous species affects biodiversity).
Medium (2): One of the above would occur.
High (3): Two or more of the above would occur.

2.7 Conabio (Mexico) Evaluación de riesgo de invasión por especies no nativas o exotica

This short risk assessment scheme for alien species in Mexico (Conabio, 2008) is mainly designed for animals and plants that are intentionally introduced into Mexico, but can also be used for unintentionally introduced pests. It suggests an assessment is conducted in six steps, step 3 being the negative impact assessment. Interestingly, there is also a step 4 to assess the benefits of introduction. The economic and ecological impacts are combined in single, simple definitions of the scores (box A2.4). The maximum score is 100, the other options being 95, 90, 80, and 0. The three highest scores imply that the species has already caused an impact elsewhere. If there is only suspicion that it may have an economic or ecological impact, the score remains at 80. These scores are added to scores obtained for the likelihood of establishment and positive impact (negative scores). As a result, species for which only an expert's opinion on impact is available will score nearly as high in the full risk assessment as species for which impacts have already been scientifically measured. As for the USDA-APHIS scheme, the precautionary approach applies.

Box A2.4.Criteria for scoring the potential impact of alien species in Conabio (2008)

100: La especie exótica ha producido de manera consistente daños económicos serios o moderados en otras localidades y/o ha causado de manera consistente daños ecológicos serios o moderados a una o más de las siguientes: 1) especies clave, 2) algún componente biótico importante de ecosistemas valorados por el hombre u otros cambios significativos a hábitats valorados, 3) biodiversidad nativa, o 4) especies amenazadas o en peligro de extinción. Este daño potencial estaría dirigido hacia componentes similares presentes en el país
95: Se ha reportado que la especie exótica, en ocasiones ha causado daños económicos serios o moderados en otras localidades y/o ha causado ocasionalmente daños ecológicos serios o moderados a una o más de las siguientes: 1) especies clave, 2) algún componente biótico importante de ecosistemas valorados por el hombre u otros cambios significativos a hábitats valorados, 3) biodiversidad nativa, o 4) especies amenazadas o en peligro de extinción. Este daño potencial estaría dirigido hacia componentes similares presentes en el país 95
90: Se ha reportado que la especie exótica raramente ha ocasionado algún impacto económico, o que las características de la especie exótica raramente han ocasionado algún impacto ambiental, o que las características de la especie exótica muestran de manera convincente que el potencial para impactos moderados o severos en un área natural protegida es posible para una o más de las siguientes: 1) especies clave, 2) algún componente biótico importante de ecosistemas valorados por el hombre u otros cambios significativos a hábitats valorados, 3) biodiversidad nativa, o 4) especies en amenazadas o en peligro de extinción
80: No existen registros de que la especie exótica haya causado algún impacto económico, no obstante sus características muestran de manera convincente que el potencial de un impacto negativo en un área natural protegida es posible, y/o no existen registros de que la especie exótica haya causado algún impacto ambiental, pero sus características muestran de manera convincente que el potencial de un impacto negativo en un área natural protegida es posible para una o más de las siguientes:1) especies clave, 2) algún componente biótico importante de ecosistemas valorados por el hombre u otros cambios significativos a hábitats valorados, 3) biodiversidad nativa, o 4) especies amenazadas o en peligro de extinción
0: No existen registros de que la especie exótica haya causado algún impacto económico; sus características muestran de manera convincente que no tiene el potencial para convertirse en una plaga que cause impactos económicos, y no existen registros de que la especie exótica haya causado algún impacto ambiental, y sus características muestran de manera convincente que no tiene el potencial para convertirse en una plaga que cause impactos ambientales

3 Environmental impact assessments

Aside from the official PRA schemes used nationally and internationally by NPPOs and RPPOs, national research organisations and individual scientists have developed procedures to assess the current or potential environmental impact of invasive organisms. Although they do not present a full risk assessment scheme, the methodologies used in these procedures may be very useful for the development of new environmental assessment tools in PRAs. Two particularly interesting procedures are briefly discussed below, the guidelines for environmental impact assessment used in Belgium, and a biopollution index proposed for evaluating the impact of invasive organisms in aquatic ecosystems.

3.1 Guidelines for environmental impact assessment and list classification of non-native organisms in Belgium

The Belgian guidelines for environmental impact assessment and classification of non-native organisms (Branquart, 2007) are used to assess the actual and potential environmental impact of alien species already established in Europe, and to select species to be placed on black lists. The environmental impact criteria are central in this scheme, in contrast to the PRA schemes presented above. Thus, impact assessment criteria are particularly detailed. Assessments are based mainly on documented invasion histories in previously invaded areas.

Experts assess the total impact by summing scores obtained in the following sections:

1. Dispersion potential or invasiveness.
2. Colonisation of high conservation value habitats
3. Adverse impact on native species, which can be: (a) Predation/herbivory; (b) interference and exploitation competition (including competition for plant pollinators); (c) Transmission of diseases to native species (parasites, pest organisms or pathogens) and (d) genetic effects such as hybridisation.
4. Alteration of ecosystem functions, which can be: (a) modification of nutrient cycling or resource pools (e.g. eutrophication); (b) physical modifications of the habitat (changes or hydrologic regimes, increase of water turbidity, light interception, alteration of river banks, destruction of fish nursery areas, etc.); (c) modification of natural successions and (d) disruption of food webs, i.e. a modification of lower trophic levels through herbivory or predation (top-down regulation) leading to ecosystem imbalance.

For each of these sections, a score from 0 to 3 is given. If sufficient information exists in the literature (low level of uncertainty), the impact scores can be low (1), medium (2) or high (3). If the parameter is poorly documented (high level of uncertainty) and the assessment is based only on expert judgment, it is either scored unlikely (1) or likely (2). If nothing is known on the impact of the species in a particular section, it is considered as having deficient data and scored 0. For sections 3 and 4, the highest score in the different categories of impacts is taken.

This procedure has the advantage of providing more detailed impact assessment criteria. The different mechanisms underlying environmental impacts are clearly defined, although the scoring is not designed to show what is low, medium or high. As explained by the authors, this scheme is designed for species that already have an invasion history, particularly in neighbouring countries. Species that have not yet invaded anywhere cannot be assessed using this scheme.

When data are lacking for a particular type of impact, a zero score is given. Thus, more studied species will score higher than the less studied ones. The scheme probably assumes that species that have been less studied and, thus, have attracted less attention for their environmental impact are less likely to be harmful than those for which the impact has been assessed. This may be the case when comparing closely related taxa, but much less so among different taxonomic groups. This approach is clearly justified when, as for this scheme, the purpose is to establish lists of the most threatening invasive species. However, if this scheme had to be adapted for PRAs, the lack of data may have to be considered differently.

3.2 Biopollution assessment in aquatic ecosystems

This procedure to assess the environmental impact of species in marine habitats was developed by aquatic invasion ecologists (Olenin et al., 2007). They developed an index that classifies alien marine species impacts on native species, communities, habitats and ecosystem functioning. The main aim of this procedure is to evaluate the impact of alien species at five different levels of biopollution and compare, both spatially and temporally, different aquatic ecosystems according to their level of biopollution. Alien species to be scored are first given an “abundance and distribution range class” by combining the abundance and distribution of the species in a given area. The actual impact is then assessed, separately considering impacts on native species, communities, habitats and ecosystem functioning. Each of these is explained in detail. These impact and abundance/distribution scores are combined to obtain a biopollution level, which can also be obtained using a decision support scheme. Biopollution levels of all invasive species in a given area can be used to assess the general biopollution level of the area and can be used, e.g. to compare the level of biopollution in time, between areas, or to assess management methods.

This scheme has the same qualities and drawbacks as the Belgian scheme (Branquart, 2007) described above. Impact criteria are relatively well described (although they are not necessarily relevant for terrestrial organisms) and, in addition, the concept and technique of combining abundance, distribution and various kinds of impacts is particularly interesting. On the other hand, it focuses only on species that are already invasive. Thus, it is not a “risk” but rather an “impact” assessment scheme. Furthermore, in many cases the lack of knowledge implies that scores are given following expert judgments. It is also not clearly explained how uncertainty is considered. Nevertheless, it would be worth trying to use a similar approach for other organisms, in particular for invasive plants or pests and pathogens.

4 Environmental impact in Weed Risk Assessment (WRA) Schemes

4.1 WRA system of Australia

The WRA system developed by Pheloung (1995) and adopted by Biosecurity Australia (2008) (Box A2.5) was one of the first of its kind and has become the basis for several other WRA schemes worldwide. It has also been employed for other taxa and, e.g. used by the UK non-native risk assessment scheme (Baker et al. 2008) to screen organisms for invasive attributes before undertaking detailed risk assessments. The system includes characters that tend to reduce weediness in its question set, because scientists have shown that non-invasive characters can be used as a predictive tool as well as weedy characters. The large number of questions (49) minimises the effect of assessor subjectivity by reducing the weighting for any one question. The system allows for knowledge gaps, that is, not all questions need to be answered if the information is not available. Nevertheless there are a minimum number of questions to be answered before an assessment is made. This system may be used to assess species that are not well described in the general scientific literature and may only be included in botanical floras. These features increase the system's effectiveness as a pre-entry tool as the system enables an assessment from limited information sets. The WRA system also has some ability to differentiate between weeds of agriculture and weeds (invasive plants) in the wider environment.

Box A2.5. Questions in the WRA scheme of Biosecurity Australia (2008) that address environmental and/or economic impact.

Section 3:

3.03 Weed of agriculture/horticulture/forestry
The plant is generally a weed of agriculture/horticulture/forestry and causes productivity losses and/or costs due to control.

3.04 Environmental weed
The plant is documented to alter the structure or normal activity of a natural ecosystem.

Section 4 :

4.02 Allelopathic: the plant is well documented as a potential suppressor of the growth of other species by chemical (eg. hormonal) means. Such evidence is rare throughout the whole plant kingdom.

4.03 Parasitic: The parasite must have a detrimental effect on the host and the potential hosts must be present in Australia. This question includes wholly and semi-parasitic plants. Such plants are rare.

4.05 Toxic to animals: There must be a reasonable likelihood that the toxic agent will reach the animal, by grazing or contact. Some species are mildly toxic but very palatable and could cause problems if heavily grazed.

4.06 Host for recognised pests and pathogens: the main concerns are plants that are hosts of toxic pathogens and alternate or alternative hosts of crop pests and diseases.

4.08 Creates a fire hazard in natural ecosystems
This question applies to species that have a documented growth habit that leads to the rapid accumulation of fuel for fires when growing in natural or unmanaged ecosystems.

4.10 Grows on infertile soils: Australian soils are generally very infertile. Species that tolerate low nutrient levels could potentially grow well here. Legumes, tolerant of low soil phosphorus, are a particular concern since they would also modify the soil environment.

4.11 Climbing or smothering growth habit: this trait includes fast growing vines and ivy's that cover and kill or suppress the growth of the supporting vegetation. Plants that rapidly produce large rosettes could also score for this question.

4.12 Forms dense thickets: the thickets produced should obstruct passage or access, or exclude other species. Woody perennials are the most likely candidates, but this question may include densely growing grasses.

4.2 Weed-Initiated PRA guidelines for Qualitative Assessments (USDA-APHIS)

USDA Plant Protection and Quarantine (USDA-PPQ, http://www.aphis.usda.gov/plant_health/index.shtml) risk assessment procedures are harmonized with those of the North American Plant Protection Organization (NAPPO) and the International Plant Protection Convention (IPPC) of the United Nations Food and Agriculture Organization (FAO). The PRA scheme estimates the economic and environmental consequences of introduction, considering the establishment, spread and economic importance potential in the PRA area (FAO, 1995).

Step 5 of the PRA scheme focuses on the Assessment of Economic and Environmental Importance, i.e. on the consequences of introduction. It includes four risk elements (A-D). Risk element A deals with establishment potential or habitat suitability in the protected area, risk element B with the spread potential after establishment, and risk element C addresses economic impact. Issues related to environmental impact are considered in risk element D (Box A2.6).

Box A2.6. Risk element D in the Weed-Initiated PRA guidelines for Quality Assessments (USDA-APHIS 2004).

It should be considered whether or not the weed, if introduced, could:

- Cause impacts on ecosystem processes (alteration of hydrology, sedimentation rates, a fire regime, nutrient regimes, changes in productivity, growth, yield, vigor, etc.)
- Cause impacts on natural community composition (e.g., reduce biodiversity, affect native populations, affect endangered or threatened species, impact keystone species, impact native fauna, pollinators, or microorganisms, etc.)
- Cause impacts on community structure (e.g., change density of a layer, cover the canopy, eliminate or create a layer, impact wildlife habitats, etc.)
- Have impacts on human health such as allergies or changes in air or water quality.
- Have sociological impacts on recreation patterns and aesthetic or property values.
- Stimulate control programs including toxic chemical pesticides or introduction of a nonindigenous biological control agent.

Ratings should be assigned as follows:

Rating	Numerical Score	Explanation
High	3	Three or more of the above. (Potential to cause major damage to the environment with significant losses to plant ecosystems and subsequent physical environmental degradation.) (Population reduction of endangered or threatened species would elevate that one factor to a high rating.)
Medium	2	Two of the above. (Potential to cause moderate impact on the environment with obvious change in the ecological balance, affecting several attributes of the ecosystem, as well as moderate recreation or aesthetic impacts.)
Low	1	One of the above, unless the factor is potential to reduce populations of endangered or threatened species, which rates High. (Limited potential impact on environment.)
Negligible	0	None of the above. (No potential to degrade the environment or otherwise affect ecosystems.)

Finally, all the numerical estimates for the four risk elements should be added together to produce an overall estimate of the Consequences of Introduction Risk Rating for the weed. The cumulative Risk Element Score ranges from 0 – 12, with values of 0-2 rated as negligible risk, 3-6 low risk, 7-10 medium risk and 11-12 as high risk. The Consequences of Introduction Risk Rating is an indicator of the potential of the weed to become established and spread, and its potential to cause economic and environmental impacts.

It should be noted, however, that risk element D not only addresses issues related to environmental impact, but also the human health impact. This may eventually make sense in those countries where allergies are (also) covered by Environmental Law (e.g. when air is considered as a vector of the allergenic pollen). However, combining environmental and human health issues in one-risk element score risks a reduction in the transparency of the final outcome of the WRA. For example, an allergenic plant may reach the maximum score in risk element D even if it has no environmental impact.

4.3 Hawaii Exotic Plant Evaluation Protocol

The Hawaii Exotic Plant Evaluation Protocol developed by Denslow and Daehler (2006) is based on the premise that no areas of Hawaii are wholly undisturbed by human activity (e.g., ungulate grazing, trails, fragmentation, fires). Arguing that the impacts of exotic plants are of less concern where the vegetation is composed largely of exotic species, as in many low-elevation plant communities that are chronically disturbed by human actions, the WRA focuses on the impacts of exotic plants on 1) natural ecosystems being maintained, managed or restored for conservation values and/or 2) ecosystems actively managed for economic production, such as for cattle production, timber, annual crops, landscape nurseries and plantations.

Section 2 of the WRA aims to evaluate the severity of ecological impacts caused by an invasion. This evaluation of ecological impacts is independent of any assessment of the economic benefit or value of the species. Indices for ecological impacts are determined separately for three main environmental zones in the State of Hawaii: 1) wet/moist conditions, <3000 ft asl; 2) dry conditions, <3000 ft asl; and 3) montane conditions >3000 ft asl (see glossary). The first part of Section 2 lists indices that address current impacts of natural areas at the worst affected site(s) (Box A2.7). The other two parts of Section 2 address current impacts on agriculture and forestry areas and on ‘Quality of Life’, respectively. Some of the indices in the section concerned with impacts on agriculture and forestry areas are identical to those in the first section (e.g. i) in Box A2.7), while others directly address economic issues (e.g. costs of management, reduction in carrying capacity). A section entitled ‘Quality of life’ asks whether the naturalized plant has thorns, stinging nettles, or other structures, contains toxins, releases allergenic pollen, or is otherwise noxious and causes physical harm or discomfort to humans thereby reducing human recreational enjoyment of the outdoors. These questions do not directly address issues related to the environmental impact of naturalized plants, and are therefore not presented in detail here.

The documentation of evidence must include specific locations of observed impacts on natural areas as well as the community type affected and the extent of infestation for High (H) or Moderate (M) impact answers. Infestations of species scoring High (H) should meet at least one of the following distribution criteria (an acre is almost the size of an association football field):

1. collectively adds up to at least 10 acres (4 ha)
2. 5 infestations of at least 0.25 acres (0.1 ha) each
3. 5 infestations that each cover an entire localized community
4. 5 infestations some of which are at least 0.25 acres (0.1 ha) and others of which cover entire localized communities

This WRA includes a weighting factor (High vs. Moderate Impact Factor). While answers regarding hybridization are considered as moderate impact answers, answers regarding ecosystem functioning or impact on Rare and threatened are high impact answers.

Box A2.7. Indices used in the Hawaii Exotic Plant Evaluation Protocol (Denslow and Daehler 2006) to address current impacts on *natural areas* at worst site(s)

i) Causes long-term alterations in ecosystem processes, influencing multiple species (e.g. changes fire regime; increases shoreline sedimentation; see glossary);

ii) Has negatively affected Federal or State listed Threatened or Endangered plants or animals or species listed as rare on the Hawaii Heritage Program database as

evidenced by either displacement, death or hybridization,

iii) Displaces or precludes native vegetation;

iv) Affects plant community structure in ways other than vegetation displacement (e.g. alters wildlife abundance, adds a new stratum, or substantially increases stem density within a stratum;

v) Hybridizes with native Hawaiian plants in the field;

vi) Capable of hybridizing with known invasive plant species.

4.4 Conservation weed risk assessment system for the New Zealand border

The authors of the conservation weed risk assessment system for the New Zealand border Williams et al. (2008) argue that it is premature to attempt to quantify, at the border, a new species' likely impacts in New Zealand. Assessing the impacts of a potential new weed involves predicting the interaction between a species not in the country and the environment and biota of that country. Where the species has a history of weediness in other countries with similar climates, soils and biota, some predictions may be possible. Otherwise, predictions of possible interactions are likely to be highly speculative. Even so, some impacts are probably more readily predictable for some life forms in certain ecosystems than in others. According to the authors, the best one can probably do is to try and indicate the relative degree of invasibility of different vegetation/community types by a range of life forms, and combine this with the kinds of effects one suspects may occur based on the life form a new species belongs to. The following life form combinations were used in the scoring system:

- Herbaceous species, including grasses and rushes (and ferns)
- Vines
- Trees and shrubs

The impacts associated with these three groupings are not exclusive to them. For example, some tussock grasses and bamboos probably have impacts more similar to shrubs than to other herbaceous species, so that potential plant height must always be considered.

Furthermore, the authors suggest that it is similarly possible to combine the vegetation types that these weed species impact into three groups:

- Forest
- Scrub, shrub land, tall tussock land, short tussock land, herb field, and fern
- land
- Bare land (all land with < c.10% cover), i.e. riverbeds, bluffs, salt flats

This WRA scheme is specifically designed to assess the risks of plant species that have not yet entered New Zealand. Therefore, the authors argue that predictions of possible future interactions are likely to be highly speculative. The only indicator for possible ecosystem impacts included in their WRA is life form. However, it is not clear why this indicator should offer less speculative predictions.

4.5 Prioritization system for the management of invasive alien plants in South Africa

The 'Prioritization system for the management of invasive alien plants in South Africa' proposed by Robertson et al. (2003) was designed to assess objectively the research and control priorities of invasive alien plants at a national scale in South Africa. The evaluation consists of seventeen criteria, grouped into five modules that assess: invasiveness, spatial characteristics, potential impact, potential for control, and conflicts of interest for each plant species under consideration. Total prioritization scores, calculated from criterion and module scores, were used to assess a species' priority. Prioritization scores were calculated by combining independent assessments provided by several experts, thus increasing the reliability of the rankings. The classification of the impact on biodiversity is very rough, and it is quite obvious that this scheme has not been developed in order to carefully assess the environmental impact of invasive weeds. In the description of the scheme the word 'biodiversity' does not even appear (Box A2.8).

Box A2.8. Criteria in the 'Prioritization system for the management of invasive alien plants in South Africa' to address potential environmental impacts.

e) Biodiversity:
Reduction in biodiversity where the species occurs is:
1) none
2) minor (1–30%)
3) moderate (31–80%)
4) profound (>80%)

f) Water resources:
The species' impact on water resources is:
1) no impact
2) reduction of stream flow by 10–30%
3) reduction of stream flow by > 30%
4) flow eradicated

g) Negative economic impact
The negative economic impact of the species is:
1) no negative impact
2) <10% reduction in profit
3) 11–30% reduction in profit
4) >30% reduction in profit
5) land unusable

h) Positive economic impact
The positive economic impact of the species is:
1) none
2) informal
3) small business
4) commercial (industrial)
5) any two or more of the above

i) Poison status
The species is poisonous to stock or humans
1) yes
2) no

4.6 NatureServe invasive species assessment protocol

NatureServe, in cooperation with The Nature Conservancy and the U.S. National Park Service, developed this Invasive Species Assessment Protocol (Morse et al., 2004) as a tool for assessing, categorizing, and listing non-native invasive vascular plants according to their impact on native species and natural biodiversity in a large geographical area such as a nation, state, province, or ecological region. This protocol is designed to make the process of assessing and listing invasive plants objective and systematic, and to incorporate scientific documentation of the information used to determine each species' rank.

The text part of the assessment protocol includes a detailed description of how biodiversity (or biological diversity) has been defined, and how it could be quantified. Biological diversity has been defined as the variety of life on earth, but is often considered as the variety of naturally occurring life in a specified area. Biodiversity can be assessed at any geographic scale (*e.g.,* countywide, ecoregional, state/provincial, national, continental, or global) and includes:

- Genetic diversity, or variations in genetic structure among individuals of a species or populations;
- Species diversity, or the variety of species (and intraspecific taxa);
- Higher taxonomic diversity, or the variety of higher taxonomic groups *(e.g.,* families or orders);
- Community diversity, or the variety of identifiable groups of species that occupy and interact in the same habitats;
- Ecosystem diversity, or the variety of ecological units composed of biological communities interacting with the physical environment.

The Invasive Species Assessment Protocol consists of two yes-no screening questions and 20 weighted multiple-choice assessment questions grouped into four sections that address four major aspects of an invasive species' total impact:

I. Ecological Impact (5 questions)

II. Current Distribution and Abundance (4 questions)

III. Trend in Distribution and Abundance (7 questions)

IV. Management Difficulty (4 questions)

The Invasive Species Impact Rank (I-Rank) is then determined from the four sub ranks. Section 1 (Ecological Impact) makes up for 50% of the total of I-Rank and consists of following five categories (Box A2.9):

1. Impact on Ecosystem Processes and System-Wide Parameters (33 points)
2. Impact on Ecological Community Structure (18 points)
3. Impact on Ecological Community Composition (18 points)
4. Impact on Individual Native Plant or Animal Species (9 points)
5. Conservation Significance of the Communities and Native Species Threatened (24 points)

Each of the categories start with a short introduction to the general topic and then lists parameters that may/should be considered when assessing the ecological impact of a species.

Clearly, this is the WRA protocol with the most detailed Environmental Impact assessment. It highlights – among others – that biodiversity can and should be measured in different ways, and also covers cases in which an exotic species strongly outcompetes an individual native species, even if the native species is not a rare or threatened species (e.g. the grey squirrel outcompeting the red squirrel). It is remarkable that questions dealing with Ecological Impact make up for 50% of the total of the I-Rank (invasive species impact rank), while questions addressing current or predicted distribution and abundance have a relatively low weighting.

Box A2.9. The five criteria in the 'Ecological Impact' section of the Invasive Species Assessment Protocol (Morse et al. 2004)

1. Impact on Ecosystem Processes and System-Wide Parameters

Some non-native species can alter the natural range and variation of abiotic ecosystem processes and system-wide parameters in ways that significantly diminish the ability of the native species to survive and reproduce. Alterations in ecosystem processes and system-wide parameters that determine the types of communities that exist in a given area are of greatest concern.
Examples of abiotic ecosystem processes include:
• fire occurrence, frequency, and intensity
• geomorphologic changes *(e.g.,* erosion and sedimentation rates)
• hydrological regimes (including soil water table)
• nutrient and mineral dynamics
Examples of system-wide parameters include:
• system-wide reductions in light availability *(e.g.,* an aquatic invader covering an entire water body which would otherwise be open)
• changes in salinity, alkalinity, or pH
A single-letter answer (A,B, C, or D)or an answer range (e.g. AB, BC etc.) should be selected that best characterizes the species, or else 'U' (Unknown) if none of the four answers have been eliminated. However, if the question has not been substantially considered, the answer should be left null.

A. **High significance.** Major, possibly irreversible, alteration or disruption of abiotic ecosystem processes and system-wide parameters, such as:
   - The species promotes fire in habitats that otherwise rarely support fires;
   - The species drains water from open water or wetland systems through rapid transpiration, making these unable to support native wetland plant and animal species; or
   - The species is a nitrogen fixer and invades systems with few or no known native nitrogen fixers, and consequently causes soil nitrogen availability to increase to levels that favour other non-native invaders at the expense of native species

B. **Moderate significance.** Significant alteration in abiotic ecosystem processes and system-wide parameters *(e.g.,* increases sedimentation rates along coastlines, reducing open water areas that are important for waterfowl)

C. **Low significance.** Influences abiotic ecosystem processes and system-wide parameters *(e.g.,* has perceivable but mild influence on soil nutrient availability)

D. **Insignificant.** No perceivable impact on abiotic ecosystem processes and system-wide parameters

U. **Unknown.**

2. Impact on Ecological Community Structure

Some non-native species overtop other vegetation, or otherwise alter the vegetation structure (at least at some sites), thereby affecting many native species.
As above, an answer (from A to D, or U) should be given.

A. **High significance.** Major alteration of ecological community structure *(e.g.,* covers canopy or creates new canopy, changing or eliminating most or all layers of vegetation below)

B. **Moderate significance.** Changes number of layers below canopy, or significantly alters structure of at least one layer of the vegetation *(e.g.,* creation of a new layer, elimination of an existing layer, substantial change in density or total cover of an existing layer)

C. **Low significance.** Influences structure of at least one layer *(e.g.,* moderately changes density or total cover of a layer)

D. **Insignificant.** No impact; establishes within existing layers without influencing their structure

U. **Unknown.**

3. Impact on Ecological Community Composition

Some non-native species greatly alter the composition of ecological communities (whether or not they also alter their structure), changing the relative abundance of native species or altering successional patterns.
As above, an answer (from A to D, or U) should be given.

A. **High significance.** Causes major alteration in ecological community composition. For example, results in:
   - the extirpation or sharp reduction in abundance of several locally common native plant, animal, or fungal species *(e.g.,* effects of increased shade, competition for water or nutrients, or allelopathy), or
   - significant increases in the proportion of other non-native species in the community, or

Box 9 (continued)

• suppression of seedlings of native successional or climax species, leading to altered community composition over time

B. **Moderate significance.** Significantly alters ecological community composition *(e.g.,* produces a significant reduction in the population size of one or more locally common native species in an ecological community)

C. **Low significance.** Influences ecological community composition *(e.g.,* reduces recruitment of one or more locally common native species which will likely result in significant reduction in the long-term abundance of these species)

D. **Insignificant.** No impact; causes no perceivable change in locally common native species populations

U. **Unknown.**

4. Impact on Individual Native Plant or Animal Species

Non-native species often impact the native species of an area broadly, in rough proportion to their local abundance. However, some non-native species disproportionately affect particular individual native plant, animal, fungal, or other species (at least at some sites), even if their impacts on community structure or composition are not great. For example, butterflies or other invertebrates that feed on specific native plants may deserve particular consideration here.

Examples of such *disproportionate* individual impacts on one or more particular individual native species include:

• Strongly outcompetes a particular native species
• Hybridizes with a particular native species
• Parasitizes a particular native species
• Poisons a particular native species
• Hosts a non-native disease that damages a particular native species
• Distracts pollinators from a particular native species

Note that this question focuses on unusual, disproportionate impacts on particular native species, and should not be used to catalogue long lists of species generally impacted.

As above, an answer (from A to D, or U) should be given.

A. **High significance.** Major impacts on particular native species *(e.g.,* in places they co-occur, has negative impacts on more than 50% of the individuals of one or more native species)

B. **Moderate significance.** Significant impact on particular native species *(e.g.,* has negative impacts on 20 to 50% of the individuals of one or more native species)

C. **Low significance.** Occasional impact on particular native species *(e.g.,* has negative impacts on 5 to 20% of the individuals of one or more native species)

D. **Insignificant.** Little or no impact on particular native species *(e.g.,* no known reports of competitive suppression, hybridization, parasitism, or other particular disproportionate negative impacts)

U. **Unknown.**

5. Conservation Significance of the Communities and Native Species Threatened

Many non-native plants occur primarily in disturbed, low quality habitats that are dominated by widespread native species and other non-native species. Non-native plants have a greater impact if they:

• Directly or indirectly threaten native species or ecological communities that are considered rare or vulnerable *(e.g.,* legally protected in the region, such as those federally listed in the U.S.A.), or
• Threaten outstanding, high quality occurrences of common ecological communities.

As above, an answer (from A to D, or U) should be given.

A. **High significance.** For example, often threatens one or more rare or vulnerable native species or ecological communities, and/or high-quality occurrences of more common ecological communities

B. **Moderate significance.** For example, may occasionally threaten one or more rare or vulnerable native species or ecological communities, and/or high-quality occurrences of more common ecological communities

C. **Low significance.** For example, usually inhabits common, unthreatened habitats and rarely threatens rare or vulnerable native species or ecological communities, and/or high-quality occurrences of more common ecological communities

D. **Insignificant.** For example, found primarily or only in human-disturbed habitats and not known to threaten any rare or vulnerable native species or ecological communities, and/or any high-quality occurrences of more common ecological communities

U. **Unknown.**

5 Discussion

There is no doubt that the assessment of the potential environmental impact is one of the most difficult stages in a PRA. It is a fundamentally uncertain process and relies heavily on expert opinion. However, the survey of the most commonly used PRA schemes and guidelines worldwide showed that these schemes vary in their approach to environmental impact assessment and have different strengths and weaknesses. Therefore, it is possible to combine strengths of different schemes to improve the procedure in the EPPO scheme, as well as in other schemes. Furthermore, new ideas and approaches could be gained from studying impact assessment procedures and weed risk assessment procedures. From this review, we have the following comments and recommendations:

- Some schemes (e.g. EPPO, DEFRA, Conabio) base their prediction of potential environmental impact at least partly on the current impact in other invaded regions. We believe that this is a very sensible approach because, for example, Williamson (1996) has shown that being invasive elsewhere is one of the few predictors of alien plant invasiveness. The assessment of potential impact should be based not only on information on the impact of the target pest in invaded areas, but also, where information is lacking, on the impact of closely related species.
- The lack of information on current environmental effects of alien species and the difficulty to access and analyse this information for pest risk analysts is clearly an important issue, especially if the pest risk analyst is more familiar with crop ecosystems. A database of studies that have investigated the environmental impact of plant pests and pathogens would be very useful for pest risk analysts to search for examples and help them make their assessments. The EU project ALARM has built such a database for insects (Kenis et al., 2009) and the project PRATIQUE could update the database, make it available for pest risk analysts and, if possible, extend it to other invertebrates and pathogens.
- In most schemes, the criteria and indicators to assess potential environmental impacts are too vague to be applied accurately and consistently. It is essential that the pest risk analyst knows what he/she should search for and how each objective criterion, e.g. minimal, minor, moderate, major or massive, corresponds to a particular impact score. From all the surveyed schemes, the guidelines for environmental impact assessment to classify non-native organisms in Belgium seems to provide the most comprehensive description of environmental impact categories. The Biosecurity New Zealand scheme also includes a detailed description of possible impacts, however, in this case, environmental, economic and social impacts are mixed up together. Other schemes also aggregate economic and environmental impacts (e.g. Conabio). However, we do not believe that it is a sensible approach because there are more powerful tools, specific to economic impact assessments (see annex 1), that could not be used if economic

and environmental impacts are assessed together in a single stage of the procedure.

- PRA schemes largely differ in the way they treat the issue of missing information. The USDA-APHIS and the Mexican Conabio schemes tend to follow the precautionary approach and, therefore, species for which little is known may score very high. In contrast, in other schemes, such as the DEFRA scheme or the Belgian environmental impact assessment scheme, a poorly known species will in general have a low score. In such situations, ecologists and economists may have a different view of which approach should be preferred. The approach chosen by a scheme may also depend on its objective. PRA schemes assessing species prior to their importation and establishment may prefer the precautionary approach whereas schemes to classify the risk and impact of species already known to be invasive, e.g. to prioritise management actions, may be more conservative in their procedure. Specific guidance on what to do when information is missing is occasionally given in PRA schemes, e.g. to refer to closely related species in the EPPO PRA scheme.
- The approach of the PRA scheme of Biosecurity Australia and the biopollution assessment procedure for aquatic ecosystems, which combine the amount of impact and the geographic scale to obtain an impact score, is interesting and may be considered for the improvement of other schemes. The DEFRA scheme also includes the importance of the geographic area affected, but in a less defined manner.
- For the moment, no scheme provides satisfactory guidelines on how to predict the environmental impact of a species that has not yet invaded any region, or for which the environmental impact has never been studied. Species traits characterizing species of environmental concern are presently being studied in the framework of PRATIQUE and may bring some solutions. However, it is recognised that the assessment of environmental impacts is perhaps the most challenging component of PRAs.
- The structure of most weed risk assessment schemes is totally different from the classical PRA (i.e. they do not necessarily comply with ISPM11) and their objective is rather different than most PRA schemes since, in most cases, the goal is to assess the potential invasiveness of a plant already present in a region or suggested for introduction for ornamental or agricultural purposes. Most weed risk assessment schemes that have been surveyed in this review are better at taking environmental impact into account than classical PRA schemes. This is mainly because it is assumed that environmental impact and invasiveness (the variable that is usually assessed in WRAs) are closely related. However, a recent study (Ricciardi and Cohen, 2007) showed that the invasiveness of an introduced species is not necessarily correlated with its impact. Furthermore, the New Zealand WRA scheme rightly says that, unless the plant is already invasive and having an impact elsewhere, predictions of possible

environmental impacts are likely to be highly speculative. Nevertheless, since WRA schemes are available worldwide and have shown their applicability and success in many regions, we recommend that they should be developed and also used in regions where weeds are currently being assessed using classical PRA schemes (e.g. Europe). As employed by the UK non-native risk assessment scheme, WRA schemes may play the most appropriate role at the categorisation stage of the PRA for taxa, like plants, for which the potential for invasiveness is difficult to determine. However, as Williamson (1996) has shown for the UK, identifying common invasive attributes may be difficult for broad taxonomic groups and a PRA area containing wide varieties of ecosystems.

- Although it may be difficult to use the structure of WRA schemes to assess plant pests, we believe that much can be learned from them to improve classical PRA schemes, particularly in the way they assess potential environmental effects through a variety of species and environmental traits. The PRATIQUE project will investigate the possibility of integrating some of the WRA approaches in PRA schemes.
- The difficulty in assessing environmental impacts is compounded by the fact that invasive alien species, in particular plants and vertebrates, commonly go through a lag phase following introduction during which no impact is observed and any literature may wrongly indicate the potential for invasiveness in a new area.

6 Acknowledgements

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Annex 3: Methods for social impact assessment

1 Introduction

Methods to assess economic and environmental impacts are described in previous annexes. However, in some cases, social impacts may occur and also need to be assessed as part of the pest risk assessment stage of PRA before management measures can be evaluated.
Social impacts are not defined in the IPPC glossary. Therefore, the following description of social impacts provided in the EPPO PRA scheme (EPPO, 2007) is used. "*Social effects may arise as a result of impacts to commercial or recreational values, life support/human health, biodiversity, aesthetics or beneficial uses. Social effects could be, for example, changing the habits of a proportion of the population (e.g. limiting the supply of a socially important food), damaging the livelihood of a proportion of the human population, affecting human use (e.g. water quality, recreational uses, tourism, animal grazing, hunting, fishing). Effects on human or animal health, the water table and tourism could also be considered, as appropriate, by other agencies/authorities*".

Social impacts receive less attention in impact assessment than economic and environmental impacts. The main reason is that social impacts predominantly occur as indirect impacts resulting from economic or environmental impacts. If economic and environmental impacts provide substantial evidence for regulation, there is no need to assess social impacts additionally.

2 Guidelines in risk assessment schemes

In the Pest Risk Assessment Stage of the EPPO PRA scheme (EPPO, 2007), questions 2.8 *"How important is social damage caused by pest within its current area of distribution?"* and 2.9 *"How important is social damage likely to be in the PRA area?"* deal with social impacts.

The UK Non-native organism risk assessment scheme (DEFRA, 2005) uses the same definition and contains the same questions as the EPPO PRA scheme. In its risk assessment procedures (Biosecurity New Zealand, 2006) New Zealand makes a distinction between direct and indirect consequences. Indirect consequences are subdivided into economic and environmental considerations. Some social impacts (reduced tourism and loss of social amenity) are listed among economic considerations and other social impacts (e.g. amenity values, effects on human use) are listed among environmental considerations. None of these schemes provides procedures for determining social impacts. Risk assessment schemes from Canada (ACIA-CFIA, 2008), USA (USDA, 2000) and Australia (Biosecurity Australia, 2007) don't pay attention to social impacts at all and neither do the weed risk assessment schemes from USA (USDA, 2004), Australia (Biosecurity Australia, 2008) and New Zealand (Williams, 2002).

3 Methods to assess social effects

Although social effects concern all aspects affecting human well-being, generic methods to assess them are lacking, because of the diversity of effects. Some of the social effects are directly linked to economic impacts. Unemployment is the social consequence of loss of turnover in industries and is more straightforward to assess than other social effects that are directly linked to environmental impacts, such as tourism, amenity values and landscape effects. Each of these effects requires their own method to assess them. No studies in the phytosanitary field are known, in which such methods are applied, except for Areal (2007) who applied monetizing methods as outlined in annex 4.

The only exception is a study in the Netherlands, in which a design for a method to estimate impacts on landscape values has been developed in order to determine the cost effectiveness of phytosanitary measures. Three criteria determine the impact on the landscape value: the perceived beauty of the landscape, the uniqueness of the landscape, and the relative contribution of host plants to both the beauty and uniqueness of the landscape (Bremmer et al., 2007). Discussion of potential methods for separate effects is beyond the scope of this study.

4 Conclusion

Since social impacts are very difficult to assess and there is a diversity of methods it is recommended that quantitative estimates are not undertaken in pest risk analysis and assessments are confined to qualitative judgements based on the 5 levels of risk in the EPPO PRA scheme. The results can then be combined with economic and environmental impacts (see annex 4). Since social impacts generally only occur as a result of major or massive economic and/or environmental impacts, they are unlikely to significantly change overall risk ratings. However, as noted in ISPM11, such potential hazards should be communicated to the appropriate authorities that have the legal responsibility to deal with these issues.

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Annex 4: Methods for quantitatively integrating economic, environmental and social impact assessments

1 Introduction

Methods to assess economic and environmental and social impacts are described in previous annexes. Economic impacts are usually measured in monetary values whereas environmental and social impacts are generally measured in non-monetary values although monetary values can also be used. Integrated methods enable the risk analyst to compare and sum the different impact categories.

The objective of work package 2 is to provide methods to improve the assessment of impacts caused by the pest itself. Assessment of the costs of measures to manage the pest belongs to work package 5. Therefore, we only focus on methods related to pest risk assessment. However, methods for pest risk assessment and the analysis of pest risk management options should be consistent. The objective of this paper is to review the way different impact categories are compared and combined in PRA-schemes and to discuss potential methods.

2 Guidelines in risk assessment schemes

2.1 Guidelines in ISPM 2, 5 and 11.

The International Plant Protection Convention provides guidelines for phytosanitary measures in a number of Standards. ISPM 2 (FAO, 2007) contains guidelines for Pest Risk Analysis, ISPM 5 (FAO, 2006) is a glossary of phytosanitary terms and ISPM 11 (FAO, 2007) contains more detailed guidelines for PRA for quarantine pests, including environmental risks. ISPM 2 states that the conclusions for PRA stage 2, Pest risk assessment, should be based on the 'assessment results regarding introduction, spread and potential economic impacts for quarantine pests'. ISPM 11 elaborates the guidelines in more detail. To perform a PRA, 'there should be clear indications that the pest is likely to have an unacceptable economic impact (including environmental impact) in the PRA area (section 2.1.1.5). Section 2.3.2 deals with the analysis of the economic consequences, both direct, which imply also non-commercial and environmental consequences. As described in the conclusion (Section 2.3.3) '*wherever appropriate the output of the assessment of economic consequences described in this step should be in terms of a monetary value. The economic consequences can also be expressed qualitatively or using quantitative measures without monetary terms*.' In ISPM 5, supplement 2, the understanding of potential economic importance is further explained, by listing all terms used by the IPPC to indicate economic impacts. It is clear that economic impacts cover both commercial effects (which are measured in monetary values) and non-commercial effects (which are usually not measured in monetary values).

The ISPM standards nowhere describe what the level of unacceptability implies, nor give guidance on how it can be determined. However, regardless of the level of unacceptability, the analyst has to present a general conclusion with respect to all economic consequences. This presupposes a procedure to sum the commercial and non- commercial impacts.

2.2 The EPPO PRA scheme

According to ISPM 11, the present EPPO PRA scheme (EPPO, 2007) consists of three stages:

1. Initiation: to identify pests and pathways of phytosanitary concern which should be considered for risk analysis
2. Pest Risk Assessment: to determine whether the introduction of the pest will have unacceptable economic consequences. Replies should take account for both short-term and long-term effects of all aspects of agricultural, environmental and social impact.
3. Pest Risk Management: to analyze which phytosanitary measures can be recommended to minimize the risks posed by a pest or a pathway.

In stage 2, questions 2.1 to 2.5 concern commercial impacts, such as effects on crop yield, quality of products and productions costs, question 2.6 and 2.7 deal with environmental impacts and questions 2.8 and 2.9 concern social damage. Question 2.10 covers losses in export markets. Some additional questions may generate information to sharpen the determination of the economic importance of the impacts. The scheme has no other procedure to aggregate the impacts than by asking the analyst to list the most important potential economic impacts, to estimate how likely they are to arise in the PRA area, and to give an overall conclusion on the pest risk assessment and an opinion as to whether the pest or pathway assessed is an appropriate candidate for stage 3 of the PRA.

2.3 Other PRA and WRA schemes

Five pest risk assessment schemes (UK (DEFRA, 2005), Canada (ACIA-CFIA, 2008), USA (USDA, 2000), Australia (Biosecurity Australia, 2007) and New Zealand (Biosecurity New Zealand, 2006)) and three weed risk assessment schemes (USA (USDA, 2004), Australia (Biosecurity Australia, 2008) and New Zealand (Williams, 2002)) have been reviewed to detect if they contain procedures to sum different impact categories, and what those procedures imply. Only the PRA and WRA schemes from the USA contain such a procedure, which are similar. In both schemes a number of economic and environmental impact categories are listed. Ratings ranging from negligible to high are provided with numerical scores form 0 to 3 and are assigned for both economic and environmental impacts depending on the number of impact categories, which are likely to occur. The numerical scores are then added together, including scores for habitat suitability (WRA) or climate/host interaction and host range (PRA) and dispersal potential. The magnitude of the impacts, and mutual weighting of the impact categories are not included. Furthermore, the assumption that ratings for establishment and spread can be added to ratings for impacts to calculate the overall risk is disputable because establishment and spread only contribute to the overall risk if economic or environmental impacts occur. This dependence is not included in the aggregation procedure.

3 Quantitative methods to sum impact categories

The European Commission distinguishes five methods for assessing impacts (EU, 2005): Cost-benefit analysis, Cost-effectiveness analysis, Multi-criteria analysis, Risk analysis and Sensitivity analysis. However, the selection of those methods is predominantly intended for the evaluation of policy options.

For integrated impact assessment, two mainstream methodologies can be applied:

1. Monetizing methods: all non-monetary impacts are transposed to monetary values and summed to obtain the overall economic impact, which is expressed in monetary values. These methods are mainly applied in a cost-benefit analysis framework.
2. Multi criteria analysis: the essential feature of this method is that impacts with different units are weighted in order to determine preferences. Both methods are described and evaluated below.

3.1 Methods for monetizing environmental values

3.1.1 Description of the methods

Different methods exist to determine the economic value of non-commercial effects. These methods have been mainly developed to evaluate the environmental consequences of political decisions. Such methods can be applied in a framework for cost-benefit analysis in order to compare the results of different policy options. However, in principle, the methods can also be applied to evaluate the social and environmental consequences of the establishment and spread of invasive plant pests. When the social and environmental impacts are expressed in monetary values, comparison with and addition to commercial impacts is possible.

Two basic categories of methods for valuing the environment are used:

1. Methods based on the costs of preventing or restoring the environment after damage.
2. Methods based on consumer preferences in relation to the environment.

The first category of methods assumes that damage to the environment can be completely restored. However, in many cases the introduction and spread of invasive pests causes irreversible effects. Therefore, this category of methods is not discussed in greater detail.

The second category of methods is based on consumer preferences. Several methods to determine the monetary value of non-monetary effects are used. For environmental impacts, a distinction is made between the ‘use’ value and the ‘non-use’ value of goods and services supplied by species, habitats and ecosystems (Turner, 2000; Ruijgrok, 2004; Heide, 2006). Direct and indirect use values are distinguished (figure A4.1). Examples of goods with direct use values include products like wood and fish for human consumption and examples of services include recreation. Products with indirect use values include the biological recycling of pollutants. The non-use value consists of three concepts: existence value (the valuation of the species habitats or ecosystems by individuals that do not obtain any direct benefit from them), bequest value (the value that people are prepared to pay in order to maintain the environment for the benefit of future generations) and the philanthropy value (the value that people are prepared to pay in order to maintain the nature or environment for the benefit of the present generation)(Turner, 2000). In addition, there is the option value for both use and non-use values (the price that people are prepared to pay to maintain the quality of the environment in order to provide goods and services in the future.

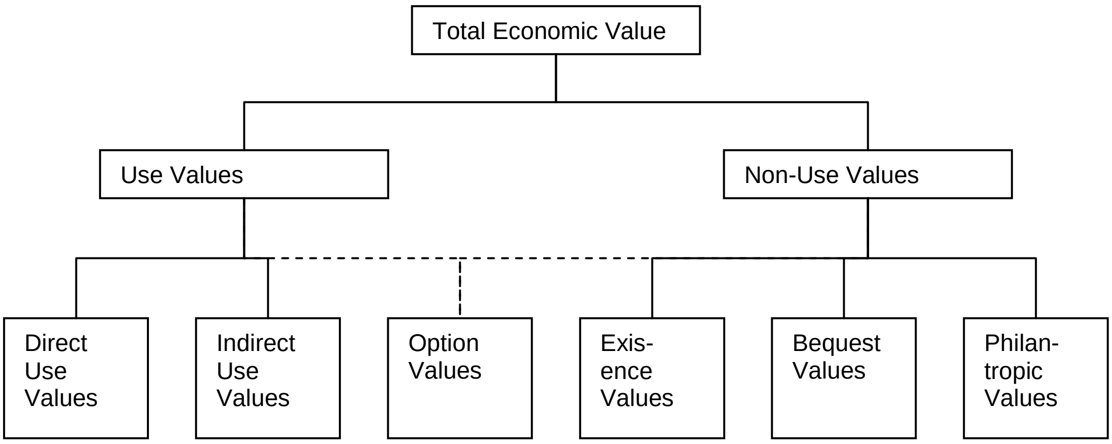

Figure A4.1. Components of Total Economic Value (TEV)

The methods to determine the value of the environment can also be divided in two groups.

1. Methods based on market behaviour (revealed preference): Travel Cost Method (TCM) and Hedonic Pricing Method (HPM). Both methods only measure the use value.
2. Methods based on questionnaires (stated preference): Contingent Valuation Method (CVM) and Conjoint Analysis (CA). These methods are applicable for measuring both use and non-use values.

The travel cost method (Clawson, 1966; Parsons, 2003) is based on three conditions:

1. The costs of visiting a nature reserve consist of travel costs and the entrance fee.

2. People living at different distances from the nature reserve incur different costs in order to visit the nature reserve.
3. If the value visitors are prepared to pay does not systematically depend on the travel distance, travel costs can be used as a basis for the derivation of a demand curve.

From the demand curve the consumer surplus per visitor can be calculated. By summing up the consumer surplus for all visitors, the total value of the nature reserve can be determined.

TCM can be applied for nature reserves that are threatened.

The advantage of this method is that it is based on observed behaviour and the results are unambiguous. The disadvantages are that a great number of assumptions have to be made, such as valuation of the time people spend in the nature reserve. It is assumed that people don't derive benefit from travelling by it. Furthermore, it neglects the fact that visitors of the nature reserve can also live in the direct neighbourhood of the nature reserve. The application of the method requires the collection of a lot of data on travelling distances, travelling costs and characteristics of the nature reserve. The TCM measures only the use values. A recent example of an application of the TCM is the valuation of deer hunting ecosystem services from farm landscapes (Knoche, 2007)

The Hedonic Pricing Method (Taylor, 2003) derives the value of a nature reserve or the environment from differences in prices of market goods such as houses. The price of houses is determined by a large number of characteristics such as the size of the house, the neighbourhood of facilities, the view etc. In econometric models, the attribution of each characteristic to the price of the house can be calculated. People are prepared to pay higher prices for a house near a nature reserve than far from a nature reserve. If the attribution of physical aspects of the house to the price is known, the remaining differences can be explained on the basis of environmental factors, such as the neighbourhood of a nature reserve. In the USA, (Ready, 2005) has applied this method to value the positive and negative externalities from farmland.

The disadvantages of the HPM are multicollinearity with other environmental factors. Furthermore, the method assumes the functioning of a free market for houses. This is often not the case. This method also requires a large amount of data on house prices, characteristics of the houses and characteristics of the environment of the houses. HPM measures only the use values.

The Contingent Valuation Method (CVM) (Bateman, 2002) is often applied. By means of a survey, people are asked how much they are prepared to pay for a hypothetical change in the supply of a public good, such as a nature reserve, landscape feature or biodiversity. The commonly used term for this is 'Willingness to Pay'. In a CVM-survey, three aspects must be present:

1. A detailed description of the public good that must be valued and the way the price for the good must be paid.
2. Questions to derive the willingness to pay.

3. Questions about the demographic and socio-economic background of the respondent.

Based on the information from the surveyed population, a valuation function for the public good is estimated, using the demographic and socio-economic background of the participants in the survey to extrapolate to the whole population. On the base of this function the total willingness to pay or the consumer surplus can be determined.

The CVM is the most widely applied method among environmental economists to value public environmental goods. The main advantages of CVM are that people are directly asked for their willingness to pay, and that both use values and non-use values are included. However, CVM is also a widely criticized method. The main objection is that the method is hypothetical: only the intention and not the fact is measured (Heide, 2006). The question is if the measured willingness to pay reflects the true preferences. In most cases measuring the willingness to pay overestimates the total economic value. A second disadvantage is that the willingness to pay depends on the method of payment. Payment of taxes has a negative connotation reducing the willingness to pay. Furthermore, there is an inconsistency in the valuation of a part of a total good in comparison with the whole good. Above all, straightforward guidelines to identify who can value the public good are lacking. Gowdy (2007) shows from a behavioural economics point of view that income cannot be equated with well-being, which losses are valued more than gains, that people use different discount rates for different circumstances and the value of gains and losses depends on the relative position of the evaluator compared to others.

Some problems of CVM can be overcome with Conjoint Analysis (CA)(Hair, 1998). CA is a multivariate technique that is used to understand how respondents develop preferences for products or services. This method can also be applied to public goods. In the application of this method, respondents have to choose repeatedly between alternative choices. By statistical analysis, the preferences of the respondents for the underlying characteristics can be derived. By including prices for the public goods in the questionnaire, the preferences can be linked to the price. On the basis of this information, the value of public goods such as nature reserves and biodiversity can be derived. An example is the valuation of the IJmeer Nature Reserve in the Netherlands, because of the building of a new residential area in the direct neighbourhood (Baarsma, 2003). The advantage of this method compared to CVM is that respondents are able to compare different characteristics of goods. The other advantages and disadvantages are comparable with CVM.

3.1.2 Applications in PRA

There are some studies in which methods for monetizing environmental values are used to assess the impacts of the introduction and spread of pests. Aimi (2006) used the approach developed by Cesaro (1998) to assess the impacts of the pine processionary moth in northern Italy. This approach consists of a financial analysis, covering all financial flows, and two extended economic analyses, the first covering all market effects, and the second covering non-market effects on recreation and landscape. The value of environmental goods was derived from the willingness to pay by tourists, investigated in a comparable project. The advantages and disadvantages are not discussed in this paper. The same approach has been followed in a study of the processionary moth in pine forests in Portugal (Gatto, 2008). Both studies were conducted in a well-demarcated area of Italy and Portugal.

Areal & Macleod (2007) applied the Contingent Valuation method in the UK in a pilot study to determine the value of all trees in the UK susceptible to *Phytophthora ramorum*. The staff of the Central Science Laboratory served as sample of the British population. The results of this study are consistent with a comparable study executed in the USA (Thompson, 2002). Despite some limitations of the study (e.g. limited geographical spread of the sample), the authors identified CVM as a potentially useful method to apply in Pest Risk Analysis.

It must be noted, however, that the application of a method such as CVM to measure the potential environmental impact of an alien species supposes that, before asking stakeholders what they are willing to pay, the potential environmental effects of the target pest have to be precisely evaluated and this is often very difficult (see annex 2).

3.1.3 Applications in comparable policy areas

Cost Benefit Analysis has been applied in numerous studies to evaluate ex ante effects of policy decisions on environmental goods such as biodiversity (Nunes, 2001; Turner, 2003). CVM is particularly used to derive values. Although CBA is widely applied, it is also severely criticized. (Jones forthcoming) discussed the method in order to recommend which approach to use for the impact assessment of alien species in aquaculture in the FP6-project IMPASSE. The principal objections are:

1. CBA ignores the difference between income and well-being. Therefore, monetizing environmental goods reduces the true value of environmental goods.
2. CBA does not adequately describe actual human behaviour, and has poor predictive power.
3. There is a large discrepancy between the willingness to pay (WTP) and the willingness to accept (WTA) showing that human preferences are not consistent. Losses are valued higher than gains.

In general, the scope of the methods for revealing preference is too limited. Non-use values are not involved. The stated preference methods inaccurately estimate the value of environmental goods. (Nunes, 2001) concluded that the empirical literature fails to apply economic valuation to the entire range of biodiversity benefits. The estimates are based on an incomplete perspective, and can be considered as the lower bound of the value of biodiversity changes. (Turner, 2003) concluded that the shortcomings of CBA increase both with the involvement of multiple stakeholder groups and geographical scope.

3.2 Multi Criteria Analysis

3.2.1 Description of the methods

Multi Criteria Analysis-methods (MCA) differs from the methods presented above because they do not present environmental and social impacts in monetary values. MCA methods are mainly developed to compare alternative options, with different scores for different impact categories. However, underlying algorithms can also be used in the impact assessment of a single event to detect if threshold values are exceeded. MCA-techniques, which do not allow this possibility, are not discussed in this paper.

A potential algorithm can be derived from the Multi-Attribute Utility Theory (MAUT) (Hardaker, 1997). In the case of multiple options, the MAUT assumes that the total utility value of each option can be determined. The total utility value reflects the perceived change in human well-being resulting from the sum of effects of that option on each objective. For each option and each objective with corresponding criteria (or attributes in the MCA terminology), the utility value is determined. By multiplying the utility value with a weight factor, and summation over all objectives, the total utility value of each option can be determined. Weight factors reflect the mutual priorities of the objectives by a stakeholder group. The option with the highest total utility value is preferred.

In the case of a single event, such as the establishment and spread of an invasive pest, the procedure to determine the total utility value can be applied. The essence of this procedure is that different impacts are mutually weighted, by comparison with the worst cases for each impact. For example, the worst case for economic impacts (all plants of a certain variety die at the nurseries) is compared with the worst case for environmental impacts (e.g. all plants of the variety die in the environment, causing damage to the landscape) and provided with mutual weight factors by stakeholders.

The advantage is that this approach is accessible and easy to understand for pest risk analysts. However, this method has strong assumptions:

1. Preferential independence of objectives (which is often not the case) and
2. Linear additivity of the utility function.

If the number of options is limited, and both assumptions are not strongly violated, this method is helpful for pest risk analysts. The application of MAUT includes the following steps:

1. Define decision context
2. Select options
3. Determine objectives and criteria

4. Determine weight factors for each criterion
5. Determine scores for each criterion
6. Calculate total score for each option
7. Analyze results
8. Apply sensitivity analysis.

This method can also be applied in a modified form. For example, the Deliberative multi-criteria evaluation technique is closely related to the Multi-attribute utility theory. It also allows freedom in awarding qualitative weight factors. The essential feature is that the decision making process is interactively performed (Proctor, 2006).

3.2.2 Applications in PRA

Applications of the Multi Criteria Analysis method in the field of Pest Risk Analysis are rare. Cook (2007) applied the Deliberative multi-criteria evaluation technique to prioritize a set of quarantine plant pests and diseases. Although this application differs from the assessment of impacts of one pest, they concluded that this technique is promising for application in pest risk analysis since it revealed interesting insights into the perceptions of invasive species risk. They recommend further investigation.

In the Netherlands a software tool based on the Multi Attribute Utility Theory has been developed in order to assist policy makers in the phytosanitary decision-making process (Bremmer, 2008). The objective was to enhance consistency in the decision-making process and support decisions. This tool has been applied in two case studies: PSTVd and *Anoplophora chinensis*. Results show that decision makers experience difficulties in distinguishing between scoring and weighting impacts. The application of the whole model is only necessary when multiple effects occur. This is often not the case. However, this model has future potential if modules to determine impacts separately are constructed.

3.2.3 Applications in comparable policy areas

MCA techniques are rarely used in comparable research areas. Mourits (2007) studied the control strategies of animal diseases using multi-criteria decision making techniques, based on (Huirne, 2005). They conclude that MCA based upon the MAUT provides a more balanced approach ensuring that all criteria are entered in the evaluation.

4 Discussion

In order to recommend which methods will be applied in pest risk analysis, it is important to understand that methods to monetize impacts and MCA are not fully comparable alternatives. The emphasis of monetizing methods is to estimate the impacts in monetary terms as accurately as possible. However, the usefulness of applying monetizing methods depends on the following factors (Gowdy, 2007)(figure A4.2):

1. Time. It can be applied when the effects of a particular event stabilize after a certain period. If effects are not stable and highly uncertain, monetizing methods are not recommended. Furthermore, it is assumed that a certain effect is valued higher at present, than the same effect sometime in the future. This can be taken into account by calculating the Net Present Value of those amounts. However, future changes in biodiversity can be valued higher (after retirement) than current changes (when still at work).
2. Scale. Monetizing methods are predominantly applied when effects concern a relative small clearly defined area. This is for example the case when impacts of a new bridge or a new road on a nature reserve have to be determined. When impacts cover a larger area, the calculation of the impacts is much more complicated, both from a theoretical (aggregating impacts, longer time span, increasing uncertainty) and a practical point of view (involvement of large populations).

Furthermore, the investment to apply monetizing methods should be in line with the accuracy of the impact assessment in non-monetary values, which are input values for the monetizing method. If these input values are highly uncertain, results are even more uncertain. It does not make sense to conduct an extended research in order to monetize highly uncertain non-commercial impacts.

In conclusion, monetizing methods should not be applied in cases when environmental impacts are highly uncertain, have a long time horizon or when impacts cover a large area. In Pest Risk Analysis, the endangered area can be a whole continent.

Discussions on MCA methods show that they can have added value in complex policy decision-making processes. However, the emphasis of these methods is not an accurate estimation of the impacts, providing an alternative to monetizing methods, but in structuring the process, enabling all relevant aspects to be incorporated and maintaining consistency. The risk analyst himself can derive weight factors, if he has little time. On the contrary, when comparable statistical procedures are followed as in the application of monetizing methods to derive weight factors by consultations of stakeholder groups or a representative sample, the quality of the results are comparable.

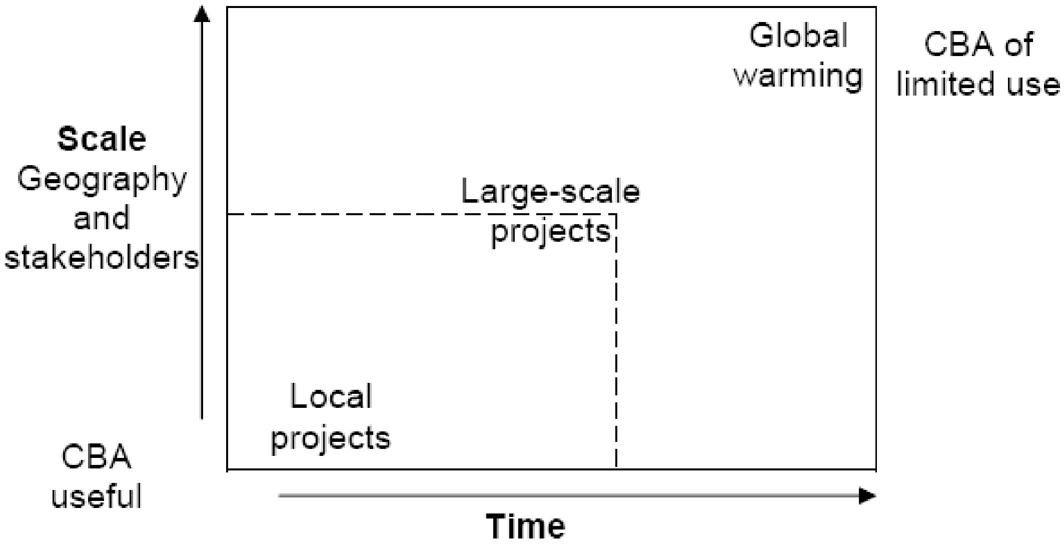

Figure A4.2. Usefulness of CBA dependent on time and scale based on Gowdy (2007).

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