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Enhanced Risk Analysis Tools

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1. Executive Summary

The diversity of pest and disease threats facing agricultural industries makes planning for future biosecurity scenarios extremely difficult. Advance planning for the most severe threats will greatly reduce reaction time and maximise the chances of successful eradications, but when the future is so difficult to predict it is hard to forge agreement between potentially affected parties as to what course of risk-mitigating actions to take. The *Enhanced Risk Analysis Tools* (ERAT) project has developed an interactive approach to priority setting for the future. It draws on state-of-the-art simulation modelling and novel approaches to communicating risks to industries and government in advance of pest outbreaks.

This report provides a detailed overview of the project and the path we have followed in the development of this risk management and communication approach. Amongst other things, it includes: a comprehensive review of decision-making techniques involving multiple criteria; an exploration of the role of economic tools in biosecurity management; a theoretical discussion of quantitative impact simulation modelling; a technical discussion of the quantitative bioeconomic model we have developed to estimate pest and disease impacts on industry; a description of the workshop approach used to combine the outputs of quantitative models with expert testimony to prioritise biosecurity threats; and a detailed summary of the most significant pest and disease threats facing new and emerging industries in Australia.

This report and the project on which it is based explore the potential to use bioeconomic models and expert testimony to help industries to prioritise risks. This has necessitated the careful design of quantitative models with the capacity for interactive groups from diverse backgrounds and model outputs that communicate complex components of pest and disease impacts to decision-makers. Here, we report our experiences with using our model with diverse stakeholder groups, and present the results of specific pest and disease outbreak simulations carried out for new and emerging industry groups. However, the framework we present is intended to be as flexible as possible and is readily applicable to other industry groups and biosecurity issues.

The ERAT project has designed a variant of Multi Criteria Decision Analysis (MCDA) to invasive species of plants, or Emergency Plant Pests (EPPs). Some EPPs have a significant effect on agricultural production when they enter a new area and become established. In some cases entire industries can be closed down due to the introduction of a new EPP, so the cost of introduction becomes the value that industry would have contributed to the economy had it not been lost. A more intangible social cost would also be induced with a community, once reliant on the industry, having to deal with unemployment and related socio-economic challenges such as potential crime or health decline. When an EPP destroys an area of native bushland the same principle applies for environmental criteria. The only problem is that there is no market price for native bushland or the species within it which we can use to establish the cost of the EPP and rank the destructive capacity of one EPP relative to another. The environment is a non-market good. We know that a great deal of damage has been caused to the environment that we would rather have avoided, but we are incapable of putting a dollar and cents value on it. Using a specialised MCDA approach in combination with bioeconomic models projecting future agricultural damages, both market (i.e. agricultural) and non-market (i.e. environmental and social) damages associated with biosecurity threats can be assessed, discussed and taken into account when planning for the future.

Our research shows that MCDA is an effective vehicle for the communication of results of economic analyses, technical scientific information and personal experiences to groups of decision-makers. These decision makers may be deciding on how much industry money to invest in EPP-specific R&D activities, government agencies forming part of the biosecurity continuum, industry and regional cooperative institutions, or local governments allocating money to pest and disease control activities. If supported by a transparent, interactive tool revealing group and individual preferences, experts capable of conveying their knowledge in a clear fashion and adequate technical information about EPPs, the technique we develop in this report is an effective decision-facilitation device. We report on a workshop in which the MCDA approach we have developed is used to prioritise a diverse list of pests and diseases affecting different industries, and clearly show that the technique works even under the most complex of scenarios.

An interesting finding of our research is that the effects of introducing information about uncertainties in future EPP impacts are not clear. While the use of quantitative models to provide effective expert testimony on the market impacts of EPPs proved very successful, the level of uncertainty of that information appeared to have little effect on decision-maker priorities. To use a statistical analogy, the mean of quantitative model outputs was much more of a concern to decision-makers than the variance. This being the case, there may be scope to truncate the deliberative process to make the process of group decision facilitation more rapid.

Based on our research, the ERAT project team make the following recommendations:

1. Strategies for the effective communication of risk and uncertainty in emergency plant pest prioritisation and preparedness decisions should form a part of future research proposals.
2. Traditional economic analysis should retain a significant role in resource allocation decisions, but be supplemented by communication mechanisms.
3. Traditional economic analyses intended for circulation and future use by diverse groups of decision-makers should be designed to be as functional and flexible as possible to cater for this diversity.
4. Deliberative multi-criteria evaluation should be considered as a relevant framework for making invasive alien species prioritisation decisions and planning future biosecurity R&D investments accordingly.
5. Efforts to simplify a deliberative multi-criteria evaluation should not be made at the expanse of disempowering participants.
6. Broad sensitivity testing exploring the trade-offs between decisions should be conducted.
7. The flexibility of the deliberative multi-criteria evaluation method should not prevent it from being used with narrow, well-defined decision-making groups with relatively small numbers of discrete options to choose between.

2. Aims and objectives

The ERAT project is all about finding a simple, practical solution to a highly complicated problem: how do we prioritise invasive species threats based on trade-offs among their economic, environmental, and social impacts. We advocate the use of Multi-Criteria

Decision Analysis (MCDA) – a technique that assesses different 'options' on the basis of several criteria. Each criterion can be weighted according to people's perception of the relative importance of a criterion compared to the others. A group of decision-makers simply assigns a score to each criterion in relation to each option being considered, and the weighted scores are then tallied to establish a priority listing. This technique can be applied to a host of circumstances in which decisions depend on a range of objectives.

The aim of the ERAT project was to design a variant of MCDA to invasive species affecting plant industries. Some Emergency Plant Pests (EPPs) have a significant effect on agricultural production when they enter a new area and become established. In some cases entire industries can be closed down due to the introduction of a new invasive species, so the cost of introduction becomes the value that industry would have contributed to the economy had it not been lost. In other cases, agricultural effects may occur along with sizeable environmental damage. In contrast to agricultural damage, there is no market price data for native bushland or the species within it which we can use to value the environmental cost of the pest. This is because the environment is a non-market good. We know that damage has been caused to the environment that we would rather have avoided, but we are incapable of putting a dollar and cents value on it. Using a specialised MCDA approach in combination with bioeconomic models projecting future agricultural damages, both market (i.e. agricultural) and non-market (i.e. environmental and social) damages associated with biosecurity threats can be assessed, discussed and taken into account when planning for the future.

The implications of ERAT's research for all members of the biosecurity continuum are that practical tools have been developed to enable both market and non-market impacts of pests and diseases to be accounted for when planning for the future. To be most effective they require diverse groups coming together and talking about specific threats and a willingness to understand alternative points of view and joint approaches to risk mitigation. The range of possible impacts society may face in the future as a result of pest and disease incursions should be taken account of when planning risk mitigation activities. For instance, industry and government R&D programs targeted towards future threats should take into account forgone opportunities to invest in other activities that could potentially produce large benefits for the community. This is particularly true of invasive species that have both cultivated and wild native hosts since an outbreak can produce both market and non-market impacts. If only the market impacts are taken into account during industry and government strategic plans, there is a danger species with environmental and social impacts may be under-funded. In the long term this will have the effect of distorting R&D investments away from a socially optimal position.

The three objectives of the research project were as follows:

1. Develop a national biosecurity planning framework for new and emerging industries;
2. Provide more rigorous tools for identifying and prioritising threats;
3. Communicate the plant biosecurity message to industry and the general community.

3. Key findings

There are two methodological challenges we have tackled in this project, each of which has taken a large amount of research drawing from diverse literatures on environmental economics and ecological economics. The first involves the mechanics of decision making, and how diverse groups of stakeholders (from private industries, government and the community) might best be brought together and helped to make decisions in regard to uncertain future EPP threats. We achieve this through the use of a specific form of MCDA called Deliberative Multi-Criteria Evaluation (DMCE). The second involves providing expert testimony to these groups of decision-makers about the severity and dynamics of possible economic damage caused by EPP threats to Australia such that a wide variety of them can be compared and contrasted using a common framework. This challenge has been met through the design of a bioeconomic model capable of simulating a large number of EPP outbreak scenarios and communicating results back to decision-makers in a DMCE environment.

The aim of section 3 is to describe the process we have followed in reaching our research outcomes. Given that the amount of material reviewed and drawn from by the project is significant, we have broken the section into 10 sub-sections:

- 3.1. Methodological Review – provides a comprehensive literature review concerning the use of economics in EPP management;
- 3.2. The Need for Decision Facilitation – explains why there is a demand for methods that translate EPP risks into forms that are easily absorbed into decision-making processes;
- 3.3. An Introduction to Multi-Criteria Decision Analysis – introduces multi-criteria analysis as a general option to be considered by decision-makers facing complex choices;
- 3.4. Form and Extent of Multi-Criteria Decision Analysis – describes some of the many different types of multi-criteria approaches put forward in the literature to date;
- 3.5. Form and extent of deliberative participatory decision-making frameworks – takes a more detailed look at group decision making methods that harness group learning;
- 3.6. Prioritising Emergency Plant Pest Risk with the use of Deliberative Multi-Criteria Evaluation – outlines the general approach we have designed, having extensively reviewed all available techniques, to prioritise EPPs based on their predicted agricultural, environmental and social impacts;
- 3.7. Conceptual Framework for the Bioeconomic Model – provides a stylised representation of the economic theory underpinning the bioeconomic model we have designed to fit within the deliberative EPP prioritisation methodology outlined in 3.6;
- 3.8. Bioeconomic model structure and function – gives a more detailed overview of the model software, design and functionality;
- 3.9. Quantitative impact simulation results – reports quantitative results of EPP impacts predicted by the bioeconomic model detailed in 3.8, pest rankings by industry and the sensitivity of the model to changes in key parameters;
- 3.10. Application of Deliberative Multi-Criteria Evaluation to Emergency Plant Pest prioritisation – provides details of a workshop in which we combined the results of the bioeconomic model (3.8) and the deliberative group EPP prioritisation technique (3.6), and reports the effectiveness of the combined approach in prioritising EPPs.

3.1. Methodological Review

Invasive species can be both a blessing and a curse. Humans depend heavily on non-native species for food, medicine, and aesthetic enjoyment. Over 70% of the world's food comes from just nine species and each is cultivated beyond its natural range (Ewel, O'Dowd et al. 1999). On the other hand, invasive species and their associated damages impose significant financial costs to a society. A recent US study showed that invading alien species cause losses adding up to almost $120 billion per year nationwide (Pimentel, Zuniga et al. 2005). In Australia loss to agriculture due to weed invasion alone was estimated as $3.9 billion per year (Sinden 2004). Moreover, the spread of invasive plants is now ranked second, behind species extinction, as the greatest threat to ecosystem functions worldwide (MEA 2005). The rate of invasion or introduction of species into new ranges globally is already high and continues to accelerate with growing economics trade and faster commercial transportation.

It is widely asserted that economic forces are the main driver of this worsening invasive species problem, and that we therefore require economic solutions (Perrings, Williamson et al. 2002). However, economic analyses of invasive species issues (i.e. biosecurity economics), it is still very much in its infancy. Of the work economists have thus far carried out concerning invasive species, one of three problems tend to restrict their use in risk management decisions:

(1) Past efforts focus mostly on partial estimation;

(2) While market and direct costs are well understood, non-market and indirect costs are not;

(3) Ex-post, rather than ex-ante evaluations have been favoured in the literature.

Each of these problems is discussed below. Our premise is that the invasive species problem is characterised by inter-disciplinarity, public good and uncertainty, and that these characteristics have in turn led to the three aforementioned problems. We then discus three solutions tackling these problems after reviewing existing literature within both Cost-Benefit-Analysis (CBA)/Cost-Effective-Analysis (CEA) and MCDA frameworks.

We have drawn the following conclusions from our review:

- Invasive species should be regarded as part of human-ecosystem dynamics;
- Biosecurity business has to move towards being proactive with appreciation of the role of uncertainty in making risk management decisions;
- Biosecurity policy-making must involve the public when making decision on public goods;
- Deliberative multi-criteria evaluation techniques may be used to facilitate highly-complex policy decisions regarding invasive species, particularly those species with both market (e.g. agricultural, industrial) and non-market (e.g. environmental, social) impacts.

This review chapter also identifies the following information gaps that must be filled by future research activities:

- System models that are broad enough to incorporate both ecological and economic information plus the feedbacks in between, yet flexible enough to incorporate new information when uncertainty becomes less uncertain;
- Multi-criteria decision analyses are required that clearly communicate the full set of values and impacts on system dynamics to the general public.

3.1.1. Introduction

3.1.1.1. Definition of invasive species

Numerous terms have been used around biological invasions, including "non-indigenous", "non-native", '"alien", "exotic", "invasive", "noxious", "nuisance", and "weed". This proliferation of terms has caused considerable confusion and misuse of existing terminology[1]. The term 'invasive' in particular has been problematic as ecologists typically use it in reference to species which spread quickly and/or widely beyond the location of initial establishment, whereas in policy and legal documents it tends to imply negative effects caused to human beings even though invasiveness of a species does not necessarily predict its impact (Ricciardi and Cohen 2007).

For the purpose of this review invasive species was defined as a species that does not naturally occur in a specific area and whose introduction does or is likely to cause economic or environmental harm or harm to human health. Throughout the review we use the words "impacts" or "effects" without necessarily suggesting a negative connotation. We note in passing that most existing economic analyses focus on negative impacts of invasive species.

3.1.1.2. Scope of this literature review

The approach employed in this investigation was to review all published biosecurity economic literature with an emphasis on Australian examples (see Appendix for a list of Australian studies).

The focus of this review is methodology. Building on other literature reviews in the area (Lovell 2006; Olson 2006; Gren 2008), we attempted to propose solutions to the problems currently associated with biosecurity economics (Sinden 2004). Studies included in our discussion introduce new method(s), while we have generally excluded those studies that apply established methodologies in case studies with "new" invasive species. The decision to focus mainly on methodology was partially due to our research interest, and partially due to the availability of existing comprehensive CBA/CEA reviews focusing on the species dimension (Hill and Greathead 2000; Born, Rauschmayer et al. 2005).

A number of issues are closely related to biosecurity economics, including research that explores the "*predisposing economic conditions"* (Perrings et al. 2005). Studies focus on the impact of infectious disease on human health (Delfino, 2000), and that designs policy instruments (e.g. tradeable permits) to combat invasion (Horan 2005), are not the focus of this review. Instead we focus mainly on economics related to the impacts, control and prevention of bio-invasion.

3.1.1.3. Approach used

The literature search involved an intensive review of databases on the World Wide Web. Several keywords—invasive, non-indigenous, non-native, alien, exotic noxious, nuisance, weed, damage cost, economics, economic impact, economic cost, CBA, CEA, and MCDA were combined in various patterns to elicit studies that might be relevant. From these studies we selected a small subset of papers for discussion. Most papers were rejected

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[1] Discussions of terminology and related issues are available in Richardson et al. (2000), Lodge and Shrader-Frechette (2003), Colautti and MacIsaac (2004), and Lodge and Williams et al. (2006).

either because they simply mentioned economics but did not conduct an economic analyses, or because they did not offer any new methodological insight.

3.1.2. Three problems in current biosecurity economics research

Biosecurity issues pose significant challenges to economists (Perrings, Dalmazzone et al. 2000). Along with other reviewers we believe that research in this field is still primitive (Office of Technology Assessment 1993; Hill and Greathead 2000; Born, Rauschmayer et al. 2005; Colautti, Bailey et al. 2006). From these reviews three major problems in existing biosecurity literature can be identified and summarised as follows:

(1) There has been little systematic economic analysis (Perrings, Dalmazzone et al. 2000). Existing effort tends to focus on a partial damage estimate of a limited number of species for several industries only (e.g. agriculture, forestry, fisheries and human diseases) (Perrings, Dalmazzone et al. 2005). Little attention is paid to the interaction between invasive and native species and the long-term impacts of invasion to the environment. In addition, human responses to the invasion threat are usually not included. In one nation-wide study for example, Pimentel et al. (2005) examined a small subset of harmful species and did not include much of the environmental damage caused by the species examined. This study is still an improvement compared to another nationwide study a decade earlier which included only one-tenth of the number of species (Office of Technology Assessment 1993).

(2) Most studies focus on direct and/or market impacts and fail to quantify indirect and non-market impacts (Born et al. 2005; Binimelis et al. 2007). If we group impacts in a 2 × 2 framework, they may be direct or indirect (i.e. mediated through effects on other species or through ecosystem), and may affect either market (e.g. food and fuel) or non-market (e.g. aesthetic enjoyment and existence value of native species) aspects of the invaded ecosystem (Colautti et al. 2006). Indirect and non-market impacts are often neglected as they usually are not directly reflected in markets and have to be measured separately. For example, if it is difficult to estimate invasive species' indirect, albeit market impact on the loss of global tourism (Olsen et al. 2005), then how about the indirect and non-market impacts of genetic information loss due to biotic homogenisation? **Table 1** below, taken from de Wit et al. (2001), presents another example (black wattle, *Acacia mearnsii*) using the same framework.

Table 1. Examples of negative impacts associated with the black wattle invasion (de Wit, Crookes et al. 2001).

	Direct impact	**Indirect impact**
Market impact	Loss of grazing potential	Loss of recreational opportunities
Non-market impact	Loss of native biodiversity	Nitrogen pollution

(3) Existing research efforts concentrate on ex-post (i.e. post-invasion) assessment and neglect ex-ante (i.e. pre-invasion) considerations (Born, Rauschmayer et al. 2005). The largest class of studies to date includes ex post analyses of controlling invasions that have already taken place (Naylor 2000). This approach provides information on the overall cost of existing invasion and offers insights in terms of control strategies that are economically viable. Another category of study is ex ante analysis that compares the costs and benefits of strategies that prevent invasions from occurring with those that allow invasions to occur. Ex ante research tends to be more challenging since it requires researchers to predict how an invasion will affect different species, ecosystem services, economic activities and human wellbeing.

These three problems must be addressed before current practices of biosecurity economics can possibly be improved. What are the solutions? Before reviewing them we will first attempt to identify the causes of these problems. Our premise is that the inter-disciplinary, public good and the uncertain nature of biosecurity economics might contribute to these problems[2].

3.1.2.1. Interdisciplinary nature and lack of systematic analysis

In academia there are disciplines, but in the real world there are problems. Environmental problems in particular are often so complex that no single discipline is equipped to resolve them and biological invasion is one of them. Therefore researchers and practitioners in the field have to transcend artificial disciplinary and institutional boundaries in order to solve the problem.

As early as the 1950s Elton embraced the socio-political implication of his ecological work and steered his research toward solving societal problems (*The Ecology of Invasion by Animals and Plants, 1958*). In the preface of a recent text book the authors claimed "*Invasion ecology by its nature is integrative, requiring its practitioners to understand (at the least) economics, evolution, population genetics, biogeography and ecology* (Lockwood, Hoopes et al. 2007)."

When considering biosecurity economics and the role economics plays in biosecurity decision-making, calculations of the costs of invasions readily spring to mind as *the* fundamental contribution of the discipline. But, economics is much more than just a method for calculating costs (or control benefit). It is "*A framework for understanding the complex causal interactions between human behaviour and natural processes…*(Perrings, Williamson et al. 2002)". Indeed many biosecurity economic papers have co-authors from ecology/biology (to take care of the natural process part) and economics (to deal with the human behaviour component). This type of interdisciplinary research has been jointly conducted by researchers from different disciplines to tackle common problems (biosecurity economic analysis our case).

Why is an interdisciplinary approach necessary? Because when we assemble each of the individual system components studies in isolation, system behaviour might be seen to change. For instance, in a cost effectiveness study of invasive oyster drills Buhle et al. (2005) found that adding economic considerations could cause the optimal control strategy to shift.

However, there are certain hurdles to overcome before people from different backgrounds can work effectively together. Sometimes different academic disciplines lack even a common language to communicate with (Bingham, Bishop et al. 1995). The word "value", for instance, has very different meaning for ecologists and economists (Farber, Costanza et al. 2002)[3].

The list of differences between these two groups is a long one. At an operational level, steady-state equilibrium and large temporal scale data (often yearly) are the norms for economists. But ecologists are more interested in abrupt changes beyond thresholds and their data are often at shorter temporal scale (daily or monthly) (Bockstael 1996). In addition, spatial components are at least as important for ecologists as temporal ones but

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[2] For the purpose of clarity the causes and problems were portrayed as a one-to-one relationship, but in reality they probably intertwine with each other.

[3] See section 3.1.2.3 for a definition of linguistic uncertainty, and section and 3.10.7.5 for a discussion of how it can be dealt with in group decision-making settings.

only recently did economists start to focus on the spatial part of the story (e.g. Wilen 2007).

With these differences in mind it is perhaps easier to understand why there has been little systematic economic analysis of species invasion. This is only the reason from the supply side though, if we regard the interdisciplinary research team as the suppliers of a biosecurity economic analysis. Of course reason from the demand side could be equally important. Typically people who demand a biosecurity economic analysis, i.e. policy makers, do not consider invasive species as a part of an ecological system, but instead are concerned with their effects on one system component (e.g. cultivated crops) (Foxcroft 2004). In other words, the market for systematic analyses would be a limited one, even if they were widely available. However, failure of control programs focused on single species and the increasing pressure from new invasions is forcing policy makers to adapt new approaches where invasive species are accepted as part of the human-ecosystem dynamics.

3.1.2.2. Public goods and non-market valuation issues

A public good is defined as "*A commodity or service whose benefits are not depleted by an additional user and from which it is generally difficult or impossible to exclude people, even if people are unwilling to pay for the benefits* (Baumol and Blinder 2000, p. 256)". Examples of public good include national defence system, public roads, street lighting and biodiversity. One common concern about the provision of public goods is who provides them since they normally don't have a market price (i.e. providers can not exclude users from consuming the good). Therefore their provision can not be financed by private parties (Doering 2007), and government must pay for public goods if they are to be provided at all.

The management of invasive species is an international and frequently global public good (Perrings, Williamson et al. 2002). If we classify impacts of invasive species into economic, environmental, or social in nature[4], the last two types of impacts often touch the public good domain so it is difficult to quantify them in dollar terms.

For this reason environmental and social impacts are often labelled as indirect and non-market and then neglected in a CBA or CEA. An example of social impacts is health problems caused by invasive species, which are difficult to quantify and not obviously linked to monetary costs. The loss of native biodiversity through invasions is an example of environmental impacts. Of course these impacts are sometimes intertwined for instance, biodiversity loss also indirectly derogates social welfare though the loss of genetic information with potential pharmaceutical value. While most-policy makers, indeed anyone with a social conscience would regard such indirect and non-market effects as significant, a lack of quantifiable evidence frequently prevents their inclusion in economic analyses.

3.1.2.3. Uncertainty and lack of ex-ante analysis

Uncertainty is a pervasive feature surrounded by invasive management issues (Perrings 2005; Caley, Lonsdale et al. 2006; Touza, Dehnen-Schmutz et al. 2007), where either the probability distributions have not been assessed through experience or they have been

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[4] Economic impacts are those of direct consequences to humans, typically leading to monetary losses. Environmental impacts are those that affect ecosystem structure and function. Social impacts include human health, quality of life, cultural heritage, etc. (Charles and Dukes 2007).

believed to be changing over time (Ewel, O'Dowd et al. 1999). Parameters remain uncertain at least including arrival (Batabyal and Nijkamp 2007), demography and dispersal (Buckley, Brockerhoff et al. 2005) of invasive species, on-site plant biomass data (Rinella and Luschei 2007), rates of industry growth (de Wit, Crookes et al. 2001), discounting rate (Settle and Shogren 2004), and impacts of invasive species (Horan, Perrings et al. 2002) in the existing biosecurity economic analyses.

There are two general types of uncertainty that affect our ability to make clear and objective EPP risk management decisions or to identify priority species:

1. Epistemic uncertainty which affects our ability to accurately measure important variables (e.g. probability of arrival, rate of spread, yield loss, effectiveness of control activities, etc.). It is caused by measurement error, systematic error and most importantly *natural variation*. The latter occurs in systems that change with respect to time, space and other variables in ways that are difficult to predict (Regan, Colyvan et al. 2002);
2. Linguistic uncertainty which is brought about by difficulties in translating the causes and effects of EPPs to individual and collective stakeholders (i.e. who are either impacted by or have the inclination and capacity to react to an EPP outbreak)[5].

In this section we will concentrate on epistemic uncertainties, of which there are several different types that we summarise as *risk*, *pure uncertainty* and *ignorance*. Risk characterises situations in which possible outcomes and their probabilities are both known (e.g. throwing a dice or tossing a coin). Pure uncertainty describes instances where we only know the possible outcomes but not the probabilities of these outcomes (e.g. estimating wildlife reproductive rates where we can not accurately predict the multitude of factors that affect the rates but we do know the range over which reproduction is possible). Ignorance or absolute uncertainty occurs when we do not even know the range of possible outcomes. Predicting the alternate state into which an ecosystem might flip when it passes an ecological threshold (e.g. global warming), and how humans will adapt, are cases of absolute ignorance (Farley and Daly 2003).

In the case of invasive species we are often faced with a situation of ignorance (Williamson 1999)[6]. We have great difficulty predicting whether any human actions will result in introduction, naturalisation and spread of an invasive species or whether a successful invader will have economically significant effects. For instance, the red fire ant *Solenopsis invicta* is an invasive species in the southern USA, and was deemed a nuisance to humans, an agricultural pest and a threat to wildlife upon its arrival. Yet 12 years after fire ants invaded Texas, they became a "benign presence" (Strayer, Eviner et al. 2006).

These uncertainty and ignorance features are likely to become more prominent in the future in association with a wider range of global changes. Indeed, a major uncertainty in assessing patterns of invasion will be in predicting the "time bombs" or sudden non-linearity of invasions that occur in the context of global environmental change (Naylor 2000).

Given this situation it is difficult to predict events with an ex-ante study when there is so much uncertainty and ignorance involved. Furthermore, we usually become motivated to

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[5] See section 3.10.7.5 for a discussion of how linguistic uncertainties can be overcome through the use of DMCE.

[6] A recent paper found though high-impact invaders (i.e. those that displace native species) are more likely to belong to genera not already present in the system (Ricciardi and Atkinson 2004).

study invasions after a species has spread extensively (Parker, Simberloff et al. 1999). For these reasons there have been a lot less ex-ante economic analyses conducted compared to ex post studies (Born, Rauschmayer et al. 2005). Exceptions include (Higgins, Richardson et al. 1996; Higgins, Azorin et al. 1997; Sharov and Liebhold 1998; Settle, Crocker et al. 2002; Cook, Thomas et al. 2007). In the following section we investigate the current methodologies used to predict invasive species risk with the topic of uncertainty in mind.

3.1.3. Solutions in biosecurity economics research

As stated above, there has been little systematic analysis in biosecurity economics (Perrings, Dalmazzone et al. 2000). This point is demonstrated in the brief review of leafy spurge (*Euphorbia esula*) research provided below. We have selected these studies because leafy spurge is an intensively studied invasive plant species in terms of its impact on the economy[7]. Four recent studies completed by a research group in North Dakota are reviewed here since they are comprehensive in scope and offer relatively up-to-date information[8].

Initiated in 1989 a bioeconomic model was developed to estimate the economic impacts of leafy spurge on grazing land and wildland[9] in a four-state region (Montana, North Dakota, South Dakota,and Wyoming) (Leitch, Leistritz et al. 1994; Leistritz, Bangsund et al. 2004). The evaluation process started with estimating the effect of changing levels of leafy spurge infestation on land output. Next the changes in biophysical outputs were used to estimate direct/primary economic impacts. Changes in grazing land output were used to estimate effects on livestock producers (reduced income) and local agribusiness firms (reduced sales or receipts). Similarly, reductions in wild land output were used to estimate changes in outdoor recreation expenditures and outlays necessary to mitigate damages from runoff and soil erosion. The secondary economic impacts[10] were estimated using input–output analysis. The total (direct plus secondary) economic impacts measure the effects of leafy spurge infestations on the economy of the four states in the northern Great Plains region.

Leafy spurge infestations on grazing land were estimated to result in a loss in regional grazing capacity sufficient to support a herd of 90,000 cows. Direct economic impacts on stock growers, landowners, and agribusiness firms were estimated to exceed $37 million annually, whereas secondary impacts totalled almost $83 million. Losses on wild land were $3.4 million and $6.4 million per year for the primary and secondary impacts, respectively. Total impacts (primary and secondary) for the four state region were calculated to be $129.5 million annually (in 1993 US dollars). The group went on conducting an economic analysis using sheep as a biological control agent to improve grazing output for cattle in leafy purged infested ranchland (Bangsund, Nudell et al. 1999).

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[7] A research group in North Dakota State University has studied the benefit of Leafy Spurge control since the late 1970s (Harris 1979; Coon, Leistritz et al. 1985; Bangsund, Baltezore et al. 1993; Bangsund, Leistritz et al. 1997; Leistritz, Bangsund et al. 2004), and more recently in Canada the Leafy Spurge Stakeholders Group (LSSG) was formed in the fall of 1998 to examine impacts of leafy spurge (Leafy Spurge Stakeholder's Group (LSSG) 1999).

[8] Key data regarding land capacity and leafy spurge infestations used in these studies was often obtained from the results of previous studies (Bangsund, Leistritz et al. 1997; Leistritz, Thompson et al. 1992; Wallace, Leitch et al. 1992; Leitch, Leistritz et al. 1996).

[9] Wildland was defined as land not classified as urban or build-up, industrial or agricultural land. Wildland include forest, range, or recreation areas.

[10] Those resulted from the direct/primary effects through the multiplier process.

A bioeconomic model incorporating relationships between sheep grazing, leafy spurge control, grass recovery and forage use (by cattle) was developed to evaluate the viability of using sheep to control leafy spurge (see **Figure 1**). Costs and benefits of using sheep control were discounted over 5-year, 10-year and 15-year periods[11]. A numbers of scenarios were used to evaluate the returns of adding a sheep enterprise to existing ranches to control leafy spurge.

Perhaps the most pronounced finding of this study was the inverse relationship between infestation size and treatment payoff. Economic returns across all treatments decreased $30 to $55 per acre when an infestation area was increased from 0.25 to 50 acres. Furthermore, returns diminished quickly when infestation area was increased beyond one acre but this decrease was not as prominent when the infestation area increased beyond 5 acres. This result was attributed to patch expansion dynamics. Small patches (less than one acre) spread much faster (as a percentage of original area) than do large infestations.

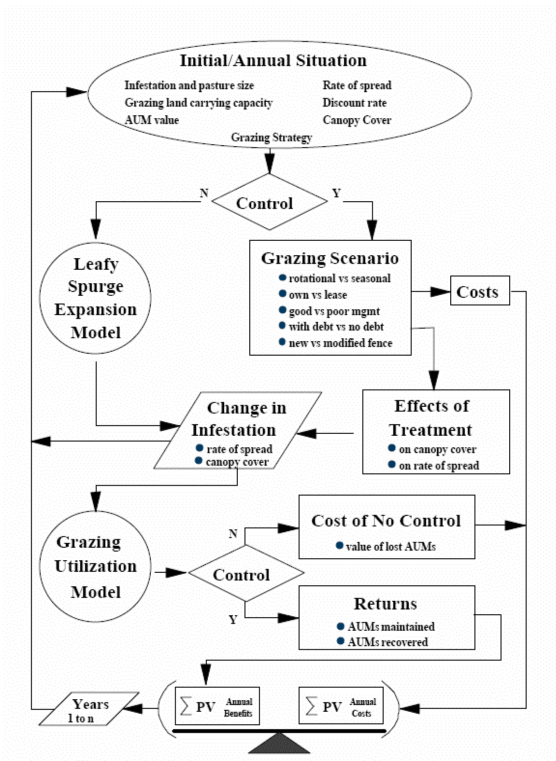

Figure 1. Bioeconomic model of the control of leafy spurge using sheep grazing (Bangsund, Nudell et al. 1999)

This series of state-of-the-art studies demonstrate the tendency for existing CBA/CEA efforts to focus on impacts to specific industries by a single species, rather than systemic effects. The loss related to agricultural production featured most prominently, and impacts to conservation and recreation were considered as secondary impacts. Little attention was

[11] A discount rate of 4% was used in this study.

paid to the interaction between leafy spurge and native species[12] and the impacts of invasion to the environment. To repeat, this is perhaps a reflection of the interdisciplinary nature of invasive species issues, which makes it difficult to integrate information between natural and social sciences. As a result few systematic analyses exist.

A bridging framework is required to structure the connection between the information flows, and *Ecosystem Services* have been proposed as such a bridging concept (Binimelis, Born et al. 2005). The term "ecosystem services" first appeared in Ehrlich and Ehrlich's work (1981). It was popularised by two publications in 1997 by the book of *Nature's Services* (Daily et al. 1997) and a paper on valuing the services provided by global ecosystems published in *Nature* (Costanza et al. 1997). Recently it was also employed by MEA as its main conceptual framework (MEA 2003).

Ecosystem services are the benefits people obtain from ecosystems (Costanza et al. 1997; Daily 1997; MEA 2003). These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other nonmaterial benefits (**Figure 2**, from MEA 2003).

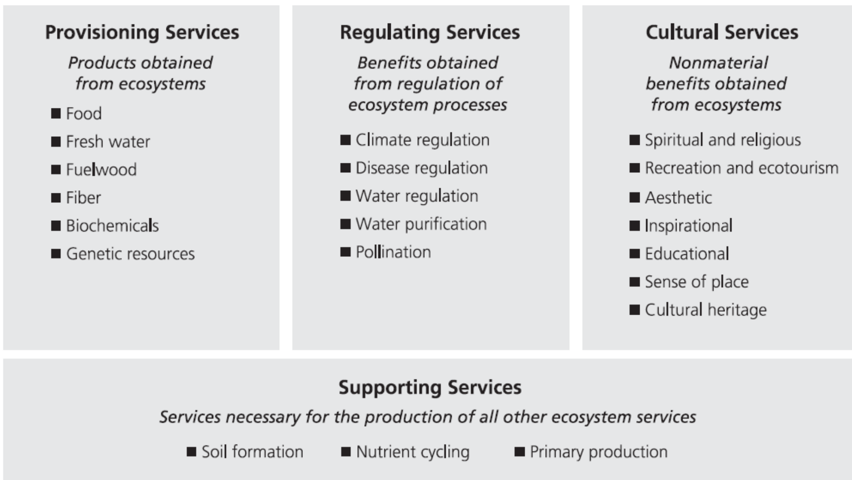

Figure 2. Four categories of ecosystem services (MEA 2003).

The concept of ecosystem services has been proven useful for at least two reasons. First, it helps synthesise essential ecological and economic concepts, allowing researchers and managers to link human and ecological systems in a viable and policy relevant manner. Second, scientists and policy makers can use the concepts to evaluate economic and political tradeoffs in a CBA/CEA framework (Costanza, Wilson et al. 2007).

Although CBA/CEA results could be easily fit into an ex post ecosystem service framework (i.e. see **Table 2**), few studies have attempted this. "*Valuing ecosystem services lost to Tamarix invasion in the United States*" (Zavaleta 2000) is one example. Here the author

[12] Recently there have been several papers on the interaction between invaders and native species (Barbier 2001; Knowler 2005; Finnoff and Tschirhart 2005; Gutierrez 2005).

identified three major ecosystem services affected by *Tamarix* invasion of the riparian ecosystems: water provision, flood control and wildlife. Next she calculated annual monetary benefits of replacing *Tamarix* with native vegetation to each service by using benefit transfer approach (see Box 1 for more about benefit transfer). Last Net Present Values (NPV) of the eradication program was derived (0% discount rate applied). The result showed that the presence of *Tamarix* will cost an estimated $7-16 billion in lost ecosystem services over the next fifty-five years (**Table 2**).

Table 2. Summary of 55-year values lost to *Tamarix* (0% discount rate) (Zavaleta 2000)

Ecosystem Service	Lowest Estimate ($)	Highest Estimate ($)
Irrigation water	2.124 billion	6.671 billion
Municipal water	1.448 billion	3.730 billion
Floor control	2.860 billion	2.860 billion
Hydropower (Colorado river)	876.5 million	2.402 million
Wildlife habitat	85.65 million	360 million
River recreation	29.17 million	132.1 million
Sedimentation	-71.81 million	-71.81 million
Dove hunting	-21 million	-21 million
Total	7,331 billion	16,062 billion
Total 55-year value lost per acre	6,318	9,981
Excluding WTP values	6,219	9,675
Estimated per-acre lost of eradication and vegetation	3,006	3,006
Net benefit per acre of eradication	3,312	6,975
Net total benefits of eradication	3,843 billion	11,225 billion

We have compiled examples from existing CBA/CEA studies illustrating the impacts of invasive species on different ecosystem services in **Table** 3[13]. Note that there are many pathways by which invasive species can impact ecosystem services, and that the most frequently estimated impact is providing services (Charles and Dukes 2007). This is perhaps not surprising due to the difficulty of assigning values to the other types of ecosystem services (which mostly are public good, and hence fall into the indirect and/or non-market categories). A common practice in the literature is to include non-market and/or indirect values in a theoretical model but neglect them in the subsequent quantification (e.g. Barbier 2001). But, the research question remains: how to value these ecosystem services that don't have a direct price signal in the market?

[13] Only a limited number of studies differentiated ecosystem service type. For the rest we associated an ecosystem service type with each impact estimated.

Table 3. Examples of impacts of invasion on ecosystem services.

Eco-Services		Impact Description	Invasive Sp.	Location	Methodology Used	Loss in $ (if available)	Reference
Provisioning Services	Food	Predator for small oysters	Oyster drills	Willapa Bay, WA, USA	Market-based	NA but <0	(Buhle, Margolis et al. 2005)
		Loss of grazing potential	Black Wattle	KwaZulu-Natal province, South Africa	NA	NA but <0	(de Wit, Crookes et al. 2001)
			Yellow starthistle	CA, USA	Market-based	NA <0	(Eiswerth and van Kooten 2002)
	Raw material	Tanning agents used in the production of leather	Black Wattle	KwaZulu-Natal province, South Africa	Market-based	+ NPV $ 363 Million	(de Wit, Crookes et al. 2001)
		Pulp	Black Wattle	KwaZulu-Natal province, South Africa	NA	NA	(de Wit, Crookes et al. 2001)
		Building materials	Black Wattle	KwaZulu-Natal province, South Africa	Market-based	+ NPV $ 22 Million	(de Wit, Crookes et al. 2001)
		Hay	Yellow starthistle	CA, USA	Market-based	NA, <0	(Eiswerth and van Kooten 2002)
	Fuel, wood	Timber	Black Wattle	KwaZulu-Natal province, South Africa	NA	NA	(de Wit, Crookes et al. 2001)
		Firewood	Black Wattle	KwaZulu-Natal province, South Africa	Market-based	+ NPV $ 143 Million	(de Wit, Crookes et al. 2001)
			Weed *Acacia Saligna*	Lowland fynbos in South Africa	Market-based	NA, >0	(Higgins, Azorin et al. 1997)
	Medical product	Possible us as styptics or astringents	Black Wattle	KwaZulu-Natal province, South Africa	Market-based	Not known	(de Wit, Crookes et al. 2001)

Regulating Services	Carbon sequestration	Sequester carbon in the atmosphere	Black Wattle	KwaZulu-Natal province, South Africa	Market-based	+ NPV $ 24 Million	(de Wit, Crookes et al. 2001)
	Soil regulation	Planting wattles can decrease erosion from river courses	Black Wattle	KwaZulu-Natal province, South Africa	NA	Not known	(de Wit, Crookes et al. 2001)
		Increase in fire intensity lead to increased erosion	Black Wattle	KwaZulu-Natal province, South Africa	NA	<0	(de Wit, Crookes et al. 2001)
		Destablisation of river banks	Black Wattle	KwaZulu-Natal province, South Africa	NA	Not known	(de Wit, Crookes et al. 2001)
	Water supply	Reduction of surface steam flow	Black Wattle	KwaZulu-Natal province, South Africa	Market-based	- NPV $1425 Million	(de Wit, Crookes et al. 2001)
	Fire regulation	Increase in fire hazard	Black Wattle	KwaZulu-Natal province, South Africa	Market-based	- NPV $ 1 Million	(de Wit, Crookes et al. 2001)
Cultural Service	Recreation	Loss of recreation opportunities	Black Wattle	KwaZulu-Natal province, South Africa	Could be estimated by CV	NA	(de Wit, Crookes et al. 2001)
		Decline of sporting panfish population	Rusty crayfish	Vilas Country, Wisconsin	CV & Benefit transfer	- 1.5 M/year	(Keller, Frang et al. 2008)
		Predator of the native trout	Lake trout	Yellowstone national park, WY, USA	Market-based	NA, <0	(Settle and Shogren 2002)
	Aesthetic	Invader detract from the wilderness character	Black Wattle	KwaZulu-Natal province, South Africa	NA	NA	(de Wit, Crookes et al. 2001)
	Existence value	Predator of the native trout	Lake trout	Yellowstone national park, WY, USA	NA	NA, <0	(Sharov and Liebhold 1998; Settle and Shogren 2002; Settle and Shogren 2004)
Supporting Services	Nutrient cycling	Addition of nitrogen through fixation by roots	Black Wattle	KwaZulu-Natal province, South Africa	NA	Not known but > 0	(de Wit, Crookes et al. 2001)
		Nitrogen pollution	Black Wattle	KwaZulu-Natal province, South Africa	NA	NA but <0	(de Wit, Crookes et al. 2001)
Comprehensive Services	Loss of biodiversity	Displacement of species-rich indigenous species	Black Wattle	KwaZulu-Natal province, South Africa	NA	Not known but significant	(de Wit, Crookes et al. 2001)
	Reduce production	Clogging pipes and reducing water flow	Zebra mussels	Lakes in the US	Production function	-0.3M/year	(Leung, Lodge et al. 2002)
	Reducing land value	Grazing land	Leafy spurge	17 States in the US	Market based	-8~34 M/year	(Rinella and Luschei 2007)

Box 1. Benefit Transfer

Benefit transfer is defined as the adaptation of existing ESV information or data to new policy contexts which have little or no data. The transfer method involves obtaining an estimate for the value of ecosystem services through the analysis of a single study, or group of studies, that have been previously carried out to value "similar" goods or services in "similar" locations. The transfer itself refers to the application of derived values and other information from the original 'study site' to a 'policy site' which can vary across geographic space and/or time (Brookshire and Neill 1992, Desvousges et al. 1992). For example, an estimate of the benefit obtained by tourists viewing wildlife in one park (study site) might be used to estimate the benefit obtained from viewing wildlife in a different park (policy site).

Over time, the transfer method has become a practical way of making informed decisions when primary data collection is not feasible due to budget and time constraints (Moran 1999). Primary valuation research is always a "first-best" strategy in which information is gathered that is specific to the location and action being evaluated. However, when primary research is not possible or plausible, then benefit transfer, as a "second-best" strategy, is important to evaluating management and policy impacts. For instance, EPA's regulation development process almost always involves benefit transfer. Although it is explicitly recognised in the EPA's *Guidelines for Preparing Economic Analyses* (2000) that this is not the optimal situation, conducting an original study for anything but the most significant policies is almost impossible. This is due to the fact that any primary research must be peer-reviewed if it is to be accepted for regulation development, which requires both time and money (Griffiths 2002).

3.1.4. Non-market valuation tools for estimating impacts on ecosystem services

Since there are no markets for most ecosystem services, there are no observable prices. Consequently, a suite of valuation techniques have been developed to value them (Freeman 2003; Champ et al. 2003; US National Research Council, 2005). These include both non-monetising valuation methods within the multi-criteria decision analysis framework as well as conventional economic techniques within the CBA/CEA framework (see Box 2, over page).

The traditional economic tools used for non-market valuation include stated and revealed preference techniques. The critical distinction among these economic valuation methods is based on the data source, that is, whether they come from observations of people's behaviour in the real-world (i.e. *revealed-preference approaches*) or from people's responses to hypothetical questions (*stated-preference approaches*) such as "How much would you be willing to pay for a reduction in invasive species damage?"

When an ecosystem service is difficult to value using any of the above methods, researchers (mainly ecologists) have resorted to using the method of *replacement/avoided cost* (e.g. de Wit, Crookes et al. 2001). However, economists believe these cost-based approaches should be used with great caution, if at all (Shabman and Batie 1978; Bockstael 2000; US National Research Council 2005). This is because any value estimates derived from them should be on the cost side of the benefit-cost ledger, not counted as a benefit, and the conditions under which these cost estimates can serve as a last resort proxy are often too rigid to be met.

Box 2. Non-Market Valuation Tools

<u>CBA/CEA framework:</u>

Revealed reference approaches

- Market methods: Valuations are directly obtained from what people must be willing to pay for the service or good (e.g., timber harvest).
- Travel cost: Valuations of site-based amenities are implied by the costs people incur to enjoy them (e.g., cleaner recreational lakes).
- Hedonic methods: The value of a service is implied by what people will be willing to pay for the service through purchases in related markets, such as housing markets (e.g., open-space amenities).
- Production approaches: Service values are assigned from the impacts of those services on economic outputs (e.g., increased shrimp yields from increased area of wetlands).

State-reference approaches

- Contingent valuation: People are directly asked their willingness to pay or accept compensation for some change in ecological service (e.g., willingness to pay for cleaner air).
- Conjoint analysis: People are asked to choose or rank different service scenarios or ecological conditions that differ in the mix of those conditions (e.g., choosing between wetlands scenarios with differing levels of flood protection and fishery yields).

Cost-based approaches

- Replacement cost: The loss of a natural system service is evaluated in terms of what it would cost to replace that service (e.g., tertiary treatment values of wetlands if the cost of replacement is less than the value society places on tertiary treatment).
- Avoidance cost: A service is valued on the basis of costs avoided, or of the extent to which it allows the avoidance of costly averting behaviours, including mitigation (e.g., clean water reduces costly incidents of diarrhoea).

<u>MCDA framework:</u>

- Individual index-based method, including rating or ranking choice models, expert opinion.
- Group-based methods, including voting mechanisms, focus groups, citizen juries, and stakeholder analysis.

Box 2 reveals that some valuation tools are more appropriate for an ecosystem service than for others. For example, the Travel Cost Method (TCM) is primarily used for estimating recreation values while Hedonic Pricing (HP) for estimating property values associated with aesthetic qualities of natural ecosystems. Contingent Valuation (CV) and Conjoint Analysis (CA) are the only methods available that can measure non-use values like existence value of wildlife[14]. In many applications, multiple ecosystem valuation techniques will be required to account for total value of ecosystem services affected by invasive species and only then CBA/CEA calculations will provide guidance for determining a broadly acceptable strategy for controlling invasions (Naylor 2000). Unfortunately, this is not possible in most cases due to time and budget limitation and lack of know-how.

Brown, Lynch et al. (2002) highlighted the importance of this missing piece of information. Two possible biological control methods for controlling Pierce's disease in wine grapes were examined. Growers can increase profits either by planting barriers next to a source area to block insect movement into the vineyard or by clear-cutting the source of the disease. The research found the clear-cut policy is optimal only if the value of the environmental benefit of barrier vegetation is more than $5,500. But, since little is known about society's willingness to pay for riparian

[14] The concept of economic value is much more inclusive than many people realise. Much of what is typically considered non-economic value, like moral and bequest values, are in fact to some degree captured by "existence value".

vegetation the "optimal" strategy might not lead to a social optimum. As an indirect beneficiary, it is difficult to include social values in an assessment.

The difference the inclusion of social values can make to an invasive species control assessment is demonstrated in Milon and Welsh (1989). Using a CV approach control of the aquatic plant Hydrilla (*Hydrilla verticillata*) was shown to be economically valuable to both interstate people and local anglers sport fishing on Lakes Harris and Griffin in Lake County, Florida, USA. This is reflected by fishers' Willingness To Pay (WTP) for different levels of control. Average WTP for Hydrilla control ranged from $19.13 to $27.67 per person for a comprehensive control plan (A) and from $13.56 to $18.11 per person for a partial control plan (B)[15] (1989 USD). The higher bound values are associated with Lake County residents' value and lower bound with out-of-state anglers. Aggregate WTP of all anglers was $175,840 for plan A and $119,362 for plan B. Interestingly, the WTP of anglers from Lake County was approximately 50% of the total. This indicates that non-residents (from out-side Lake County and outside Florida) had a significant interest in, and place a high value on, Hydrilla controls in the lakes.

Nunes (2004) also looked at the private and social WTP for the control of Harmful algal-bloom species (HABs). HABs, collectively known as "flagellates", are invasive exotic species that are primarily introduced in North European waters through ballast water of ships. The economic value of a marine protection program, including non-market benefits associated with beach recreation, human health and marine ecosystem impacts, was estimated with a joint TCM-CV survey undertaken at Zandvoort, a famous beach resort in the Netherlands. According to the TCM model estimates, if the beach was closed to visitors for an entire year due to HABs the total recreational welfare loss equalled €55 per individual per year. The contingent valuation estimates indicated that the annual WTP amounts to €76 per respondent. The comparison of the TCM and CV estimates implied the importance of marine ecosystem non-market benefits because the CV result mainly referred to non-market impacts caused by HABs. The economic value of the marine protection program was estimated between 225 to 326 million Euros per year (Nunes 2004).

While techniques like CV can be used to measure differences in private and social WTP, it remains difficult to interpret this information. Generally, people tend to be more averse to a loss than they are attracted to an equivalent gain (Coursey, Hovis, & Schulze, 1987; Kahneman, Knetsch, & Thaler, 1990; Knetsch & Sinden, 1987). So, there tends to be a disparity between an individual's *willingness to pay* to prevent environmental damage and their *willingness to accept* compensation for that damage. The disparity between the two can be reduced with repeated experimentation, but this makes the process of revealing environmental values extremely costly (Portney, 1994).

Nevertheless, growth in the environmental valuation literature in the advent of the Exxon Valdez disaster in 1989 has been unprecedented (Adamowicz 2004)[16]. But, significant though this body of work is, it is of very little use in terms of quantifying invasive species impacts. A number of problems with stated preference techniques have been identified and discussed, many relating to the tendency of respondents to act strategically when expressing their preferences. There are

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[15] For Plan A, Hydrilla would be controlled so that only a few small isolated patches are present in areas of the lakes with water depths less than 5 feet. No Hydrilla in boast ramp areas. For plan B Hydrilla would be allowed to cover many areas of the lakes less than 5 feet deep. Hydirlla would be mixed with other aquatic plants in these shallow areas. Some Hydrilla would be grown in boat ramp areas.

[16] The *Exxon Valdes* was an oil tanker which ran aground in Prince William Sound, Alaska in March 1989. The resulting 30 million US gallons of crude oil that poured into the Sound affected over 1,900km of coastline, and had a devastating impact on resident wildlife. Exxon spent US$2 billion on the clean-up, and a further US$1 billion on penalties. Contingent valuation was used to derive an estimate of total damage resulting from the spill of US$287 million, and punitive damages of US$5 billion. In the process, a lively debate ensued concerning the reliability of these estimates and of the survey approach in general. The appeals process continues. Non-market valuation has remained one of the most subscribed areas of economics

several additional reasons why results should be treated with caution when working in invasive species space.

Firstly, environmental effects attributable to invasive species often involve changes in the population or health of an environmental resource, rather than its complete destruction. Eliciting values for these marginal changes is yet to be attempted, and simply taking an aggregate value and extrapolating ignores changes at the margin resulting from scarcity. Secondly, the WTP to protect an environmental good (or to guard against changes in its wellbeing) can not be explained without understanding the sociological elements involved in that agent's decision-making process[17]. Factors such as age, income and background can have a dramatic influence on willingness to pay. A related issue involves the non-use values associated with environmental amenities[18]. While an agent may not receive tangible benefits from knowing these amenities are in a state of 'health', they may respond to questions to enjoy the "warm glow" of contributing towards environmental welfare (Kahneman and Knetsch 1992). This becomes particularly complex when the concepts of irreversibility and irreplacability are considered. Finally, the resources required to accurately calculate the true value of environmental externalities are often prohibitive with high levels of uncertainty to consider.

3.1.5. System modelling and incorporating uncertainty

Traditionally, the epistemic uncertainty described in the previous section has not been formally incorporated into CBA/CEA studies. In a survey of 27 economic assessments of biological control programs, Hill and Greathead (2000) found that although the vast majority of studies had a benefit-cost ratio larger than 1[19], very few had attempted to estimate the variability surrounding point-estimates of a benefit:cost ratio [20]. It is therefore impossible for decision-makers to make an informed judgement about the explanatory power of the analyses, or the appropriate level of confidence that should be placed in the results. This situation is gradually being changed with formal economic frameworks for risk management being put forward in the literature to address uncertainty issues.

Examples of these frameworks having been used assume that probabilities associated with arrival and impacts of invasive species can be identified and assessed. Shogren (2000), for instance, developed an optimal control model for reducing risks from invasive species by characterising uncertainty through probabilities (i.e. treating (pure) uncertainty as essentially the same as risk and then risks could be reduced by either mitigation or adaptation). But, a practical limitation of these risk-based models is that it may be difficult to assign a probability to a one-time event such as the entry, establishment, spread and impact creation of invasive species, without historical precedent (Gren 2008).

Several studies attempt to address this problem in different ways. Eiswerth and van Kooten (2002) use an expert judgment questionnaire to assign invasive yellow starthistle (*Centaurea solstitialis*) infestation rate as one of the four possibilities, minimal, moderate, high and very high. Using stochastic dynamic programming they then analyse the control of the weed in California and compare the efficiency of five management options. Cook et al. (2007) develop a stochastic

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[17] The income elasticities for environmental goods are thought to be large and positive. Comprehensive empirical evidence for such a pattern of income elasticity is currently lacking (Whitby 2000; Waage *et al.* 2005).

[18] Values can be derived for environmental amenities from the cost of 'using' them (e.g. recreation, sport and tourism), but there are also 'non-use' values to consider. These include existence, moral and bequest values (mentioned above) that depend on the continued existence of the amenity and extend over generations in time. These non-use values make valuation extremely difficult.

[19] Only 1 out of the 27 studies has a ratio of 0.99.

[20] This is not to say control programs themselves have a high success rate. To the contrary, most attempts at classic biological control are failures or have adverse side effects (Hill and Greathead 2000).

bioeconomic model to predict the economic impact of the varroa bee mite (*Varroa destructor*) to the ecosystem service of pollination), and apply a combined probability of entry and establishment using a uniform distribution. Ten thousand iterations are then run with values randomly sampled across the range of each distribution using Monte Carlo simulations to represent uncertainty in the arrival process. Rinella (2007) adapts hierarchical Bayesian statistics to quantify uncertainty related to local and regional plant abundances and impacts of leafy spurge (*Euphorbia esula* L.). Without such a hierarchical approach 19 non-hierarchical models for each local site would have been constructed and sample-to-sample variation within each site would have been ignored. In contrast the hierarchical model employed a probability distribution of each site mean.

However, Horan et al. (2002) argued that in the face of ignorance, where neither the range of possible outcomes nor the possibility of these outcomes are known, decision models based on stranded expected utility theory or Bayesian methods have limited value. They developed a model where policy makers were assumed to be uncertainty averse. Their result showed that under ignorance it is optimal to devote more resources to confronting high-damage events that are considered possible even if the probability considered to be low (low potential surprise), and to allocate few or no resources to confronting events that are considered less possible (high potential surprise). Another important finding from their research was that the choices and associated policy implication arising under ignorance could be substantially different than those that would arise if the information on probability was available.

Addressing this issue, Moffitt and Osteen (2006) developed a model based on the minimax criteria. According to the model the loss-aversive policy makers tried to minimise their maximum possible loss. Therefore, a policy option with the greatest difference between estimated damages and costs of action would be selected. The minimax/relative cost approach has an advantage over risk management based evaluations if decisions have to be made under ignorance. Moffitt et al. (2006) propose a more general model designed for solving the uncertainty problem. The basic principle is that a policy maker searches for maximum robustness, in other words, a decision regardless of possible events was more preferable. In this decision-making environment, reward is neither the least uncertain outcome nor the minimised cost. Rather it is a probability distribution over rewards.

The research on uncertainty is critical because biosecurity decisions often have to be made under risk, uncertainty, and even ignorance (Horan and Lupi 2005), and ex ante research is in great demand (Perrings, Williamson et al. 2000; Raghua, Dhileepan et al. 2007). One recent review on CBA/CEA of biosecurity found that the existing small set of ex-ante studies largely employ system models (Born, Rauschmayer et al. 2005). This modelling approach offers at least three advantages:

1. It is not restricted by the *status quo*. In biosecurity economic analysis there is often empirical difficulty in collecting the necessary information. In contrast, system models permit the calculation and comparison of an essentially unlimited range of measures, because they are not subject to the logistic constraints of collecting empirical data (Parker, Simberloff et al. 1999). By running scenario analysis, for instance, results of different management options could be compared and then the most effective strategy could be easily selected.
2. It has the flexibility to incorporate the entire invasion process, including both ecological and economic components (preferably results from non-market valuation also) (Leung, Lodge et al. 2002). Furthermore, it also can incorporate human action towards bio-invasion which could be an important feedback in such a model (Finnoff, Shogren et al. 2005).
3. It permits uncertainty to be included in the analysis either by running sensitivity analysis[21] for parameters associated with uncertainty (Pimentel, McNair et al. 2001; Cook, Thomas et al. 2007) or by incorporating results from other techniques designed for tackling uncertainty

[21] Sensitivity analysis rarely applies to ecological behaviour (Born and Rauschmayer 2005).

issues, such as Bayesian (Rinella and Luschei 2007) and neural network analysis (Worner and Gevrey 2006).

Examples from the small set of ex ante invasive species analyses include a system modelling approach presented in Stansbury (2002). This is applied to quantify the probability of Karnal bunt (*Tilletia indica*) entering and establishing in Western Australia, and to stimulate spread, containment and the economic impact of the pathogen to agriculture. A sensitivity analysis shows that increase in quarantine funding can reduce the entry probability from about one entry per 25 years to 50 years and the establishment probability from one every 67 years to about 100 years. The economic impact ranges from 8% to 24% of the total value of wheat production depending on the resources allocated for detection and the spread rate of the pathogen.

Another example is Raghua et al. (2007) where a life-cycle model for chrysomelid beetle (*Charidotic auroguttata*) is developed within the STELLA software environment to predict the risks and benefits of introducing the beetle to control the invasive liana *Macfadyena unguis-cati* in Australia). The model predicts that risk to the non-target plant becomes unacceptable when the ratio of target to non-target species in a given patch ranged from 1:1 to 3:2. This simulation result was used to identify regions where the biocontrol agent might pose an unacceptable risk.

3.1.6. Cost Benefit Analysis (CBA) and Cost Effectiveness Analysis (CEA)

The traditional and most widely used method in biosecurity economics is cost-benefit analysis (CBA), which requires that the expected present value of the benefits (of any control program) be no less than the expected present value of the costs. Cost effectiveness analysis (CEA) has a similar structure, although only the costs of alternative means of achieving a previously defined set of objectives are analysed, and generally the lowest cost method(s) preferred. So, essentially CBA provides an answer to the question "should we take action?", and CEA answers the question "what action should we take?"

The main strength of CBA and CEA analyses is that they break down the multidimensionality of invasive species' impacts into one-dimensional estimate in dollar terms (Born, Rauschmayer et al. 2005). If the information on invasion impact is presented solely as a list of consequences in physical terms, then we encounter the classic problem of comparing apples and oranges. The purpose of CBA/CEA is to make the economic, environmental and social impacts comparable to each other, using a common metric.

However, this strength can also be a weakness, especially at large spatial and temporal scales which are more relevant to humans. This is because large-scale studies may be confounded by spatial gradients or temporal trends in the environment such as climate change. To demonstrate the effects of scale we need look no further than the widely-cited attempts to aggregate the economic costs of invasions at national level that vary widely. The costs of invaders to the American economy from two studies, Office of Technology Assessment (1993) and Pimentel, Zuniga et al. (2005), have a difference of two orders of magnitude. Perhaps the numbers generated in these studies do not mean much by themselves but do offer a general indication of both the scale of the problem (Perrings, Dalmazzone et al. 2005) as well as the level of difficulty encountered in biosecurity economic analyses.

CBAs have also been used to assess the net gains or costs that may open up as a result of commencing trade with international sources in various commodities, but they have not followed a consistent format. Those studies that have been completed tended to follow persistent requests from high-profile sources concerning specific quarantine decisions as opposed to the broader social welfare implications of policy options (Nunn 2001; Roberts 2001). The way in which the economic implications of imports have been estimated appears to have been done on a case by case basis, rather than using a standardised method. Case studies have used a variety of economic analyses, including those that simply assume an outbreak scenario only affecting producers, those that seek to put a probability on this occurrence, those considering both consumer and producer impacts, or combinations of these (Cook and Fraser 2008).

Hinchy and Low (1990) addressed a New Zealand request made in 1989 to import apples into Australia, where the major disease transference concern was Fireblight, a disease caused by the bacteria *Erwinia amylovora* that affects apples and pears. Australia's detailed response to this request, coordinated by the Australian Quarantine and Inspection Service (AQIS), included an economic component (Hinchy and Low (1990)) which took the form of a benefit cost analysis comparing expected consumer and producer welfare changes resulting from relaxing quarantine laws protecting the apple industry. In 1995 New Zealand made another request to access the Australian apple market. This time the economic analysis, Bhati and Rees (1996), was quite different in approach. Expected consumer welfare change is not discussed. The analysis only considers possible producer surplus losses to pome fruit growers if a fireblight outbreak were to occur (Cook and Fraser 2008).

A market access application concerning salmon products from New Zealand, potentially forming a pathway for Whirling Disease of salmon, also prompted an analysis of economic consequences, McKelvie (1991), which uses a deterministic model. This analysis builds an entry scenario involving the introduction of whirling disease to three prominent Tasmanian fisheries and derives possible damage estimates. Neither the likelihood of disease arrival, the effect on domestic salmon consumers, nor the likelihood of scenario occurrence is discussed. Following a similar market access request from Canada a second economic analysis was prepared, McKelvie et al. (1994). This analysis dealt with two salmon diseases considered an importation risk, Furunculosis and Infectious Haematopoietic Necrosis (IHN). Again, the analysis comprises of a gross estimate of producer welfare loss in the event of a disease incursion, rather than a net welfare assessment (Cook and Fraser 2008).

Applications by the U.S.A., Denmark, Thailand and New Zealand to export chicken meat to Australia were the topic of another economic impact assessment. The potential economic implications of importing from these countries were examined in Hafi et al. (1994), which used one potentially imported disease (Newcastle disease) to illustrate the possible consequences of relaxing quarantine protocols. The method used in this analysis is similar to that of Hinchy and Low (1990) in that a critical probability of disease arrival is determined which brings the benefits and probable costs of trade into balance (Cook and Fraser 2008). Trade benefits were calculated as the change in consumer welfare resulting from lower domestic prices for chicken products, while the costs calculations were based on a severe Newcastle disease outbreak scenario causing a contraction in domestic supply of close to 20 per cent (Cook and Fraser 2008).

The analysis presented in James and Anderson (1998) focused on Australia's ban on international banana imports and compared consumer surplus losses resulting from import protection to a hypothetical producer surplus loss induced by a relaxing of trade restrictions. Here, the consumer gains are shown to outweigh production losses, casting doubt over the validity of the ban in terms of net social welfare (Cook and Fraser 2008). This analysis was not prompted by a market access request, rather it was designed to highlight possible problems in the application of sanitary and phytosanitary measures in accordance with the World Trade Organization's SPS Agreement.

Next we summarise three general solutions to the key problems identified (i.e. interdisciplinary, public good and uncertainty) by reviewing how researchers have tackled various aspects of these problems.

3.2. The Need for Decision Facilitation

Given the different methodologies, models and techniques economics has presented in the literature to help us make resource allocation decisions for invasive species, how do we actually go about using them in the decision-making process? This is not a straightforward question when we consider that decision-making groups, be they in government, NGOs or the private sector, seldom represent of a single discipline. More often these groups house a diversity of opinions, expertise, knowledge and experience, not necessarily including economics or social science. This can make it difficult for technical analysts to communicate their results to the group in a way they can understand, and in a form easily used in the decision-making process.

In the most comprehensive review of the Australian biosecurity system to date, Nairn (1996), the so called Nairn review, it is clearly stated that communication forms a critical part of risk analysis. They defined the process of risk analysis as comprising of three parts:

(a) Risk Assessment – the process of identifying and estimating risks associated with a policy option and evaluating the likely consequences of taking those risks;
(b) Risk Management – the process of identifying, documenting and implementing measures to reduce these risks and their consequences; and
(c) Risk Communication – the process of interactive exchange of information and views concerning risk between analysts and stakeholders (Nairn et al. 1996; Nunn 1997).

This asserts that a successful risk assessment should exhibit each of these principles if it is to facilitate a socially optimal allocation of relatively scarce resources. The Nairn review went on to list several fundamental principles to be included in the analytical process, which included: stakeholder/industry consultation; objectivity and robustness in scientific methodology and political independence; transparency; consistency and harmonisation; subject to appeal on process, and; subject to periodic external review (Cook 2002). Twelve years on however, economists continue to struggle to make their findings and opinions heard and understood by decision-makers.

The task of resource allocation is particularly complex in cases where regulatory measures such as quarantine or invasion responses protect non-market (e.g. the environment) as well as market (e.g. agriculture) goods. Environmental decisions are particularly complex, multi-faceted, and involve a variety of stakeholders with different priorities or objectives (Linkov et al. 2004). In these cases, economic analyses using a narrow single commodity method of assessing risk must be supplemented by other information. Generally, the difficulties involved in quantifying the non-market impact of invasive pests (described above) prevent their inclusion in economic analyses of quarantine strategies. However, if policies directed by such analyses are to reflect social welfare preferences, a more formal recognition of potential non-market damage is needed.

In addition to environmental consequences of invasion, other non-market goods that receive little attention in the literature but often need to be considered by policy-makers involve the socio-economic disposition of rural communities. But, as with environmental amenities, quantifying these effects is difficult. In the same way an environmental resource may have an existence or moral value, so too might a rural community. As such, a majority of the community may be willing to pay to preserve it even if they spend most of their time in urban areas and have little social or economic ties to rural communities. Bennett et al. (2004) presents evidence to this affect in three very different regions of rural Australia[22].

Animal welfare is also emerging as a non-market good requiring greater attention, particularly in the wake of the 2001 foot and mouth disease outbreak response in the United Kingdom. Here, the

[22] Here the maintenance of rural populations is associated with environmental damage mitigation, so it is difficult to draw conclusions about the willingness of society to pay for the preservation of rural communities *per se* due to embedded environmental values.

rules of the Office International des Epizooties (OIE) (or the World Organisation for Animal Health) necessitated a mass culling as a disease response. This distressful situation was made worse by an inflated compensation schedule which led to over-application for payments and competition between legitimate claimants and those reacting to financial incentives (Whiting 2003). The non-market values associated with animal welfare were not used to influence the response policy. Evidence presented in Frank (2008) suggests positive income elasticities for animal welfare (i.e. the wealthier we are the more animal welfare we demand), possibility attributable to scientific, philosophical and theological advances over the past 30 years, as well as an increased number of companion animals in the developed world.

Given the complications of taking into account all market and non-market impacts of invasive species in a single measure of impact, MCDA techniques may offer a practical solution to the dilemma facing biosecurity policy makers. Rather than striving for definitive proof of the right decision, MCDA can be used to stimulate discussion amongst the decision-making group about possible resource allocation choices, trade-offs and uncertainties. Instead of the exclusive use of quantitative estimates of non-market policy implications, semi-quantitative estimates can be used to make decision-makers aware of the full consequences of their decisions.

In the following sections we provide background information on the growth of MCDA as a decision aid, and work towards a technique allowing group participation in the resource allocation process.

3.3. An Introduction to Multi-Criteria Decision Analysis

3.3.1. Decision-making and associated human behaviours

The sheer quantity of biophysical and socio-economic data can quickly overwhelm stakeholders who are trying to make sense of a natural resource-related issue (Hajkowicz et al. 2000). Complexity and uncertainty lead to more difficult decision-making and justification of selecting a course of action.

> "The number and variety of elements and interactions in the environment of a choice process, is so great that the extreme degrees of complexity characterising ecological problems are potentially devastating to some of our familiar conceptions of problem solving." (Drycek 1987).

Behavioural decision research indicates humans are generally poor at solving, unaided, problems containing the aforementioned characteristics of environmental decisions (Linkov et al. 2004). Naturally, humans would address these problems by reducing the complexity until the problem seems more manageable intuitively (Linkov et al. 2004). In the reduction process, important information may be lost, opposing points of view may be discarded, and elements of uncertainty may be ignored (Linkov et al. 2004). This is essentially the same as the process found in traditional Western science where thinking places detailed knowledge of one certain topic at the centre of the investigation (Sposito et al. 2007). This view fails to achieve a continuous and complete understanding as the aim is to understand only a certain component. A more holistic view of the issue is required and this need has led to an approach called systems thinking. Contrary to the reductionist view, systems thinking helps to understand the linkages and interactions among the elements that comprise the whole system (Sposito et al. 2007).

3.3.2. The requirement for policy decision support

In general, a policy system process begins with the decision-makers establishing goals, finding a suitable means of achieving them (policies), and they will not decide on a final means until enough background information has been collected on the issue. A comprehensive overview and evaluation of the issue is then completed using decision support methods to determine the best possible decision. Often, this process assumes that participants will simply agree, however, in practice, difficulties will always be experienced in group situations. Also, the need for collecting informative data, analysing it and translating it into decisions can combine for a costly and time consuming process.

A policy system has several components working together that shape the way it evolves. The history of the system and the direction it is moving is dictated by participating institutions, groups, networks and resulting relationships. Policy systems are based on shared understandings, values, common sources of disagreement, and patterned interactions (Considine 1994). Considine goes on to describe the policy system as being built from material and intellectual aspects, specifically the political economy and the culture respectively (**Figure 3**). The two fields are linked to the main actors and institutions representing the basis for political structure and processes. Policy systems might have some structure as seen in **Figure 3**; however, the process is highly complex. With the vast array of actors previously mentioned, often times, consensus may not be reached due to the high level of uncertainty. Policy decision-makers are the key actors in the systems in that their values and decisions serve as the basis for any given outcome. Policy actors (or makers) can be key politicians and bureaucrats who have the authority to ultimately give approval to a decision (Considine 1994). In other words, a policy maker is one who possesses enough authority to be able to influence their group's structure. A policy maker can be an individual or a group. Often there is no formal line separating policy makers and there can be confusion or cloudiness surrounding who has more authority.

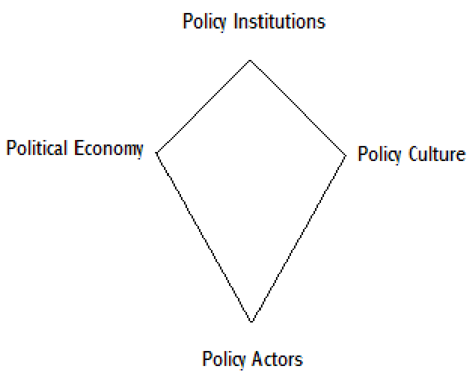

Figure 3. The structure of policy systems (Considine 1994).

A policy stems from a governmental body making decisions, setting goals, and taking action toward an issue. Considine (1994) defines the instrumental view of a public policy as an action using governmental authority to direct resources to support a favoured value. The instrumental or standard view is limited in its context and has to be viewed with caution. The view implies that policy is assessed by numerical means rather than what is really happening in terms of social conditions and opinions. The instrumental view turns policy into a theory of choice and a study of costs (March and Olsen 1989). To work toward a more effective policy tool in practical terms, an alternative means of looking at the system must be considered. As opposed to looking at current environmental and socio-economical conditions in space and time, the policy system should be regarded as a process. No initiatives in real world issues stay fixed for long due to the simple fact that problems and people are ever changing. Policy systems therefore need to have an adaptive and iterative nature. This requirement coincides with the Dynamic view which states that public policy is the ongoing effort of a collaboration of policy planners who use available public establishments, to demonstrate what they value (Considine 1994). The need for two views toward policy definition is due to the complex nature of underlying principles. Policy is in fact when resources are directed toward a preferred value as the instrumental view suggests. The dynamic view, however, adds a second dimension to the policy definition by showing that it is a process and not simply a theory of choosing values or assessing resources. Where possible, a policy decision-making evaluation exercise is not done only once, but takes place as an iterative learning process (De Marchi et al. 2000, Proctor and Drecsler 2006).

An effective decision-making process is thus dynamic so that judgements regarding the relevance of criteria or alternatives may be flexible and adaptive in nature through a cyclic framework (De Marchi et al. 2000). The cyclic nature of a decision-making process can contain embedded continuous feedback loops among the multitude of steps and consultations (Nijkamp et al. 1990). The continuous feedback loops create a higher likelihood that the resulting decision output is comprehensive of the participants' views and the scope of the problem (Nijkamp et al. 1990; Munda et al. 1994). An additional characteristic of a dynamic policy framework is that certain stages are tiered, allowing the decision-maker to carry out screening, evaluation and prioritisation of alternatives before progressing to more detailed appraisals (Sposito et al. 2007). This flexible setup enables an effective holistic thinker to iterate frequently within and between phases, and work simultaneously in more than one phase (Sposito et al. 2007).

As previously mentioned, there is evidence to expect that individuals, be they lay or expert, will likely not make informed, thoughtful choices about complex issues involving uncertainties and value tradeoffs (McDaniels et al. 1999). In order to help guide a decision-maker in effectively resolving an issue, a set of rules is required to transform the broad goals into conclusions or agreements (Munda et al. 1994). This set of rules is called an evaluation method which aims to rationalise a given problem by systematically structuring all relevant aspects of policy choices following the cyclic and dynamic process previously mentioned (Munda et al. 1994). Evaluation methods fall under the broad category of systems methodologies. This way of thinking encompasses a variety of methods that are systematic in that they include rational and ordered steps grouped in stages, and take a range of alternative perspectives into account (Sposito et al. 2007). Brown et al. (2001) state that decision processes are comprised of three separate stages which include identifying the problem, developing possible courses of action, and selecting a course of action from the choices available. Similarly and with finer detail, Sposito et al. (2007) present six primary stages of a rational decision-making framework: problem formulation, diagnosis (system description and analysis), solution (system synthesis / system modelling), decision-taking, implementation, and monitoring.

We will provide an overview of the form and extent of both MCDA as well as deliberative participatory process as separate entities in the following section (3.4). In doing so, we provide an explanation of how MCDA should be used within a participatory setting. Later, in section 3.6 we will report how these two methods can be combined to form DMCE, and how the framework will guide the prioritisation of EPPs. For now we explain the contextual and theoretical background to MCDA, some common application mistakes to avoid, and the different participatory group context settings that MCDA can be used within.

3.4. Form and Extent of Multi-Criteria Decision Analysis

3.4.1. Background

The MCDA framework (or also known as Multi-criteria Evaluation) began to take shape in the 1970s and the 1980s where policy development required more comprehensive solutions (Roy 1985, Roy 1990, Nijkamp et al. 1990). The MCDA process was developed as a method for breaking down complex policy problems involving multiple stakeholders, several possible outcomes and a range of incompatible criteria by which to assess the outcomes (Proctor and Drechsler 2006). The MCDA provides a foundation to evaluate criteria to help to make a decision while simultaneously garnering an active participation role by the stakeholders. MCDA should be used as an aid in making decisions rather than a process to identify or make the decision (Proctor 2001). With this said, MCDA should not be used to come up with a single final number, but rather in the use as a process to help unravel issues in the decision-making problem and add to the knowledge available to a decision-maker.

Environmental management is essentially conflict analysis characterised by socioeconomic and environmental value judgements making straightforward solutions difficult (Munda et al. 1994). Multi-criteria methods can provide an adaptive way to deal with quantitative and qualitative multidimensional factors and to help guide conflict analysis toward effective solutions. In general, preferred alternatives represented by criteria are weighted by stakeholders (Munda et al 1994, Rauschmayer and Wittmer 2006). These weightings are then aggregated into a single `compromise' rank order in order to work toward a decision solution. MCDA encloses the central theme of modelling human judgment through this structured framework to help guide and improve the decision-making (von Winterfeldt and Edwards 1986).

3.4.2. Purpose and objectives of MCDA

The purpose of using MCDA models is to find solutions to complex and uncertain decision-making issues, characterised by multiple alternatives that can be evaluated using weighable criteria (Jankowski and Nyerges, 2001). MCDA provides policy decision-makers with a holistic insight and structure in order to effectively assess complex problems. MCDA offers possibilities outside of economic efficiency such as non-market considerations of ecological and social evaluation criteria on which a decision can be based in the analysis (Brouwer and van Ek 2004). This feature will be discussed further in a later section of the review. Proctor (2001) outlines the advantages of MCDA as the ability to structure decision-making, include a variety of values, unravel complexities, include community and stakeholder preferences, encourage transparency of the process, and to avoid monetary valuation of intangible environmental assets.

3.4.3. Characteristics and processes of MCDA

The decision-making component within MCDA can generally be characterised as flows of information inputs into a procedure leading to the output of a decision (Brown et al. 2001). MCDA usually begins by discussing the structure of the problem by identifying criteria and alternatives in order to create a transparent understanding of the issue for the participants (Munda et al. 1994). MCDA can be a process-orientated or an outcome-orientated tool. Process-orientated analyses use the MCDA to facilitate the deliberations of stakeholders by offering opportunities to present the trade-offs and to rank different priorities and criteria in a systematic manner (Brown et al. 2001). Outcome-orientated MCDA specifies an overall single value. In any case, the MCDA is used to support stakeholder weighting of criteria with the decision outcomes being a result of different preferences (Munda et al 1994). Typically, participants do this through applying the weights to economic, social and ecological criteria that constitute the problem. MCDA is generally characterised by the following features (Munda et al. 1994):

1. While a consensus can be worked towards, there is most likely no one solution where all participants are 100% satisfied with all the criteria weightings leading to the decision-maker having to find compromise solutions.
2. Preference and indifference are in conflict in this approach due to relative comparisons leading to actions that are better for some criteria and inferior for others.

Process-orientated MCDA allows the sensitivity of the data to be tested, and makes trade-offs between competing impacts and stakeholders in an explicit manner (Brown et al 2001). This sensitivity analysis is essential in exploring the robustness of the rank order guiding the decision (Roy, 1993). Assessing the sensitivity of the rankings to different criteria weights gives an indication of how robust the decision is to uncertainty. With sensitivity being analysed and considered, a preferred option(s) based on a rigorous ranking of preferred options can be communicated to the decision-makers.

MCDA has been applied to a wide range of natural resource and environmental issues and is also a common technique amongst social issues such as education and healthcare (refer to Appendix). The MCDA methods that seek to address this range of issues are also vast in options and operational characteristics. Each MCDA technique has an aim to achieve outcomes that are broadly acceptable to the relevant participatory groups. While MCDA is a valuable tool for achieving resolution of environmental conflicts within a group, there can be constraints in practice including the necessity for clear identification of the groups, the interactions between them, and their socio-economic activities (Brown et al 2001).

There is currently a wide variety of MCDA methods available (refer to Appendix). Although diverse in nature, the methods have a common goal of evaluating and selecting among alternative options. This evaluation is based on multiple criteria and completed through the use of systematic analyses that overcome limitations of unstructured individual and group decision-making (Linkov et al. 2004). The methods differ in use as each requires different types of raw data and follow different optimisation algorithms. Techniques can rank options, identify single optimal alternatives, sort alternatives into groups, provide an incomplete ranking, or differentiate between acceptable and unacceptable alternatives (Roy 1985, Linkov et al. 2004). The former three approaches (choice, ranking, sorting) lead to an evaluation outcome (Zopounidis and Doumpos 2002). Choice and ranking methods are based on relative judgments and are thus products of the set of alternatives considered in the study, while alternatively, the use of a sorting technique requires absolute judgments (Zopounidis and Doumpos 2002).

There are no set rules for selecting a method from the plethora of those available. Zak, (2006) suggest that Electre and the Analytical Hierarchy Process (AHP) are the most reliable and user-friendly MCDA methods. This claim is based on the appreciation of both the process and final rankings. The Utility Theory Additive (UTA) method is recommended for decision issues with a larger number of criteria, while Electre, Oreste and Mappac methods should be applied to smaller criteria numbers, with the AHP method applicable to both scenarios (Zak 2006). Moffett and Sahorta (2006) suggest that Regime or Non Dominated Set (NDS) be used if the process requires only that alternatives be qualitatively ordered. When alternatives and criteria can be quantitatively evaluated, and the criteria are independent of each other, then multi-attribute value theory (MAVT) should be used (with preferences obtained by a modified Analytic Hierarchy Process (mAHP) (Moffett and Sahorta 2006). Overall, the choice may be based on subjective values such as the preference for a method with certain algorithmic characteristics or the choice may be purely pragmatic with decision-maker ease being the primary driver (Linkov et al. 2004). For clarity in this review, methods will be categorised into Elementary methods, Single Synthesising Criterion, Outranking, and Mixed Methods based on Guitouni and Martel, (1998) (see Appendix). A description of some of the common approaches in each group will be provided.

3.4.4. Software selection

Similar to the vast array of MCDA techniques, the available software options to carry out the MCDA is also numerous and diverse. In practice, high-quality supporting software is required for the effective conduct of MCDA (Belton and Stewart 2002). The use of effective and tried software permits the facilitator, analyst and decision-makers to focus on the fundamental value judgments and choices as opposed to technical implementation details (Janssen and van Herwijnen 2006). The software should be visual and interactive in order to facilitate communication about the problem and to facilitate the interpretation of results requiring re-evaluation (Janssen and van Herwijnen 2006).

Vassilev et al. (2008) outlines software as either falling under the categories of general purpose or problem-oriented software systems. General-purpose software aids the solution of different multi-criteria analysis and optimisation problems by different decision-makers (Vassilev et al. 2008). Problem-oriented multi-criteria analysis is embedded in other information-control systems serving to support the solution of specific multi-criteria analysis problems (Vassilev et al. 2008). As another example, Janssen and van Herwijnen, (2006) categorise MCDA software tools into four groups according to the type of support they provide. The division is defined by being one of problem structuring for discrete choice problems, discrete choice problems, discrete group choice problems, or discrete spatial choice problems. Spatial software types can be categorised as GIS-based, Stand-alone designed for specific applications, or Hybrid approaches that combine GIS with MCDA and other programming capabilities (Lesslie et al. unpublished report). For a selected bibliography of readily available MCDA software see Belton and Stewart (2002), Janssen and van Herwijnen (2006), Vassilev et al. (2008) and Lesslie et al. unpublished report.

Although important, consideration of which MCDA method to use with what software package is not the only step to ensure an effective decision-making framework. Group dynamics and risk communication are essential to consider in the preparation for a MCDA-based workshop that includes a mixed stakeholder group.

3.4.5. Group dynamics and communication issues

Environmental decision-maker characteristics can be vast and varied to include experts, stakeholders, and the general public. There is a growing trend toward the use of participatory approaches, particularly in the public sector, to create a more democratic and open process (Gilmour and Beilin 2006). The rationale for stakeholder involvement in decision-making processes can be classified as being substantive, instrumental, or normative (Gilmour and Beilin 2006). Substantive reasoning to include stakeholders is simply that these players combine to form an otherwise absent multidisciplinary local knowledge base incorporating natural, physical, and social sciences, medicine, politics, and ethics (McDaniels et al. 1999). The instrumental argument sees the involved parties being more likely to accept the decision outcome due to the transparency and inclusion of their respective voices and opinions within the negotiation process (Gilmour and Beilin 2006). The normative aspect is present due to the tendency for the issues to involve common resources meaning that group decision processes are called for, thus requiring a diverse mix of local people and knowledge (Linkov et al. 2004).

Group discussions that lead to the resolution of an issue can be effective exercises. Policy emerges from identifiable patterns of interdependence between key social actors (Considine 1994). There are advantages of group decisions over individual processes as more perspectives may be considered, there is a higher chance of having systematic thinkers involved, as well as deliberative and well-informed members (Linkov et al. 2004). On the other hand, the involvement of different groups conveying a range of priorities and outlooks can make for a convoluted criteria selection and evaluation process (Dragan et al. 2003). Groups are susceptible to the tendency of establishing ingrained positions or to prematurely adopt a status quo perspective that excludes contrary and often relevant information (McDaniels et al. 1999). Due to this potential discrepancy in group opinion, effort must be committed to providing as much background knowledge and social context as logistically possible to the groups involved in the process (Dragan et al. 2003). Participants should distinguish between interests which are their underlying concerns, and positions which are their stands on the issue being negotiated. By focusing on interests rather than positions, parties can engage in integrative bargaining and find creative ways to benefit all parties and help work toward consensus (Fisher and Ury 1991).

Criteria are typically evaluated by the conversion of initial relative comparisons into sets of weights that allow the trade-off between divergent factors (Linkov et al. 2004). For the weighting process to function effectively, the group setting should allow for access to a wide range of information and decision support tools to facilitate this analysis and deliberation (Jankowski and Nyerges, 2001, Burgman et al. 2006). If this presented information reflects the issue in an unbiased way and participants act rationally, group judgements can be expected to be better than individual ones (Burgman et al. 2006).

3.4.6. Group choice shift

Group choice shift is an issue in group deliberation processes as it can lead to a false representation of true participant opinions. Over the course of the iterations, group choice shift leads to group judgments tending to shift in the way of the most popular, likely more conservative judgment (Stoner 1968), often masking outlying risky individual estimates (Burgman et al. 2006). Conversely, however, if the group majority favours a more risky alternative, then after iteration, the group opinion will favour this view (Fox and Irwin 1998).

3.4.6.1. Psychological anchoring

Human perception of value is greatly persuaded by any reasonable number that enters a negotiation environment and as these numbers pull judgments toward themselves, they are known as anchors (Galinsky 2004). Psychological anchoring is a common simplifying strategy in negotiation in which an arbitrarily chosen reference point is assigned early on in the process which thereby creates an excessive influence on impending judgments (Carnevale and Pruitt 1992). Where a high degree of uncertainty is present, initial numbers or opinions have a strong anchoring effect in that they exert a strong pull throughout the rest of the negotiation (Galinsky 2004), which is the case with biosecurity risk, where agreements on decision outcomes are executed in a group setting.

Experts are not immune to the anchoring effect (Galinsky 2004). A study by Northcraft and Neale (1987) demonstrated this using the example of how Real estate agents should be immune to anchoring effects of a property's list price due to their skill at estimating property values. In the study, real estate agents inspected houses and estimated both appraisal value and purchase price with the housing list prices being manipulated to represent high and low anchors. Northcraft and Neale (1987) found that although denying the list price as an aspect, all of the agents' estimates were influenced by the list price. Group decision-making situations are likely to experience anchoring in a similar manner whereby one participant states an opinion which influences future discussion, no matter if participants are lay or expert.

3.4.6.2. Framing

Criteria to be weighted need to be stated in a clear and standardised format and worded as objectively as possible so that participants are on common ground. A framing effect is present when different presentations of options or questions influences participant behaviour, even when the objective outcomes are not changed (Burgman et al. 2006). A procedure has to be standardised so that interpretation is the same and opportunity to weight criteria is consistent for each expert (Bijl 1992). The decision-making process could be impaired if experts have different perspectives on how the task should be accomplished (Bijl 1992). Before a group process begins, participants need to be provided with a detailed summary of the objectives, the procedure, and examples of how weighting should be carried out with opportunities to discuss any misunderstandings.

In an MCDA, the uncertainty in stakeholder responses stemming from communication discrepancies should be minimised. The perfect scenario would be to have stakeholders sharing a common understanding of the meaning, context, and underlying objective of any question or criteria so that their weighting or probability can be given as accurately as possible. This linguistic uncertainty will, however, always be present to some degree in group processes as the social, individual background, motivational, and communication context that exists are present in constructing beliefs and the resulting statements (Fox and Irwin 1998). This context influences what is expressed by speakers and what is understood by listeners (Burgman et al 2006). When the context is value-laden with multiple participants, the values and attitudes of the participant also influence the interpretation of information and resulting judgement (Burgman et al 2006).

3.4.6.3. Decision-maker statement formation – beliefs, goals, context, assumptions, and bias

Different stakeholder cultures will inevitably clash and in order to develop strategies for the most efficient goals and their implementation, the actor's values, assumptions, and language must be understood. Uncertainty arising from communication within a group context is an influential concern to decision-making outcomes and thus requires attention. Fox and Irwin (1998) suggest a framework for investigating communication issues related to uncertainty by considering the speaker's constraints and motives, as well as the listener's goals and sources of information. When mapping words into numbers, a listener will be influenced by a prior state of mind and beliefs about the particular issue at hand. In addition, these beliefs may or may not be adaptable depending on the person and their respective worldview and experience. With these phenomena being considered, Fox and Irwin (1998) developed a flow chart of six information sources that can influence the communication of uncertainty (**Figure 4**) whereby the sources of information available to listeners depend on the process a speaker goes through in formulating dialect. The left-hand side of **Figure 4** shows the stepwise formation and expression of the speaker's beliefs, judgements and statements. These steps are embedded in the context of informational constraints, motivational state, and situational goals (Fox and Irwin 1998). The right-hand side illustrates the information available to the listener, who not only relies on the understanding of the verbal and body language used by the speaker, but as previously mentioned, may also be influenced by their own similar beliefs and worldviews.

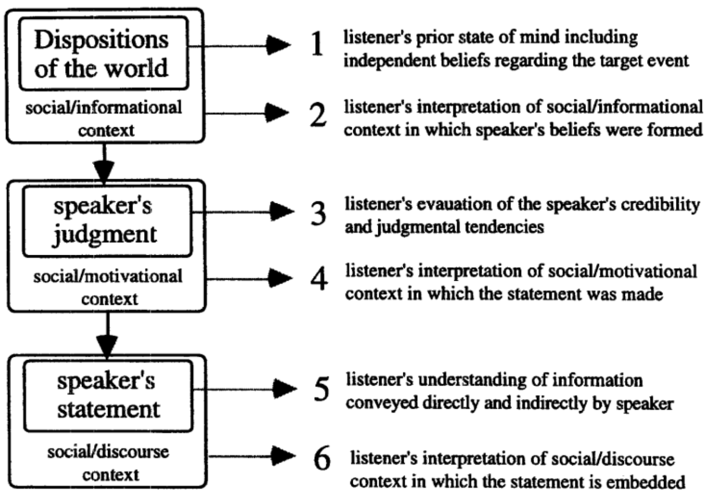

Figure 4. Six sources of information in the communication of uncertainty (Fox and Irwin 1998).

3.4.6.4. Interpretation of probability classification

Participants and decision makers may have difficulty in the interpretation of probability classification. The issue is magnified when a number of participants are involved as each will inevitably have a different view of the classification meaning. Caponecchia (2006) adds that in the case of Biosecurity Australia, probability categories and results need to be communicated to different stakeholder groups who may have little experience with probabilistic information. Participant experience aside, the problem may lie in how the probability information is presented with notable differences between qualitative or quantitative data, or between categorical definitions (Gigerenzer & Edwards, 2003). Before issues with the presentation of probability are discussed, the understanding and interpretation of low probabilities will be referred to. Participants can have difficulty in understanding low probability information as the events rarely occur in nature (Stone et al. 1994). For low occurrence events, Stone et al. (1994) found that using a relative risk format (e.g. 3 × risk for one choice over another) leads to risk avoidance compared to probability estimates (e.g. 0.0006 probability versus 0.0018).

A phenomenon that deserves attention is that personal beliefs of the likelihood of an event can lead to a different understanding of verbal risk (Caponecchia 2006). Smits and Hoorens (2005) provide an example of this by providing two probability references, each with the same verbal likelihood but with different consequences. The first reference states: "This winter you will probably develop a common cold" while the second states "This winter you will probably develop a lung infection". As people most likely believe that common colds are more likely, the verbal expression of "probably" would be assigned a higher numerical expression compared to the "probably" when referring to lung infections (Smits & Hoorens, 2005). When using verbal terms describing risk, this occurrence is likely exaggerated when the participants are considered experts as they are likely to have *apriori* perceptions of likelihood (Caponecchia 2006).

The interpretation of a risk or probability statement can be manipulated by the way it is presented or worded. No matter how the statement is made, a useful exercise is to define the reference class to assist in understanding the information. Gigerenzer et al. (2005) define a weather forecast example of a 30% chance of rain tomorrow by clarifying that this percentage means that on days like tomorrow, it will rain 3 out of 10 times. They further define the reference class by explaining that the percentage does not refer to the amount or the area in which rain will fall. These dynamics related to probability interpretation combine to create a situation that may require clarification which would require in additional time and resources (Caponecchia 2006)[23].

Alternatives to numerical and verbal probability expressions exist in the form of visual and non-visual aids which aim to improve the aforementioned communication issues. Examples of visual aids include (Caponecchia 2006):

- Vertical bars for large-scale judgements;
- Stick figure diagrams common for showing numbers or risk of injuries represented by stick figures;
- Systematic or random oval arrangement where a number of ovals corresponding to the denominator are presented and the numerator is coloured-in;
- Paling perspective scales showing ranges of likelihoods, risk ladders whereby a range of risks are presented in ascending order;
- Dart board and roulette wheel style diagrams where coloured regions around the circle are in proportion to the likelihood of different outcomes.

Examples of non-visual aids include (Caponecchia 2006):

- Natural frequencies with the use constant denominators can aid in understanding probability. For example stating 1 in 100 compared to 5 in 100 is more easily understood than saying "1 in 100 compared to 1 in 20";

[23] See definition of linguistic uncertainty, section 3.1.2.3.

- Presenting probability across different timeframes may make the risk seem smaller or larger. For example probability across a lifetime may make it appear smaller. The timeline for presenting probabilities has direct implications for biosecurity risk where the risk of damage occurs over a period of time. The selection of a temporal scale is therefore a critical consideration;
- Communicating uncertainty is typically conveyed in the form of statements such as "our best guess is" or confidence intervals where varying degrees of uncertainty can be shown in numerical form;
- Evidence for the calculation procedure and the probability values such as the source of the input data from which they were derived should be transparent;
- Translating verbal probability terms into standardised numbers across individuals by assigning the verbal probabilities to "membership functions" which numerical probabilities belong to.

3.4.6.5. Qualitative versus quantitative decision formation

Not only do communication, prior values, and beliefs influence a decision outcome, but the format or method in which an answer is produced may bias the perception of participants' true knowledge. Decision-making has been carried out using either qualitative (e.g. "very likely"), quantitative (e.g. "90% chance"), or a mixture of both. There is no overall definitive evidence for an increase or decrease in accuracy levels, when using qualitative or quantitative methods to elicit probability estimates (Wallsten et al. 1993; Burgman et al. 2006). With that said, qualitative expressions can be initially more simplistic for speakers while quantitative information is generally preferred by addressees (Erev and Cohen 1990; Wallsten et al. 1993). The vague and more encompassing nature of qualitative expressions can help to interpret some of the uncertainty. Qualitative expressions have been considered to be as accurate as quantitative methods when used in a Bayesian updating paradigm (Rapoport, et al. 1990).

Conversely, quantitative expressions can be perceived to be more precise, though can be argued to be unnatural (Fox and Irwin 1998). As quantitative expressions allow participant attitudes to be compared, the process involves reducing complex interpretation and formation of statements into a single index (Burgman et al. 2006). As qualitative expressions have the disadvantage of requiring translation to numerical values for typical risk assessment aggregation, Burgman et al. (2006) propose that these verbal terms be used for an initial gauge of expert knowledge, which could then lead to a more accurate final transformation to numerical values. In the following section, we move on to explain different approaches to making decisions in a deliberative workshop environment within the context of these group dynamics.

3.5. Form and extent of deliberative participatory decision-making frameworks

3.5.1. Background of deliberative participatory approaches

The review of MCDA methods in the previous section highlights the large number of approaches that are available for use depending on the characteristics of the issue at hand. Irrespective of the MCDA method selected, the deliberation framework must be determined in order to define the overall participatory decision-making flow process. Similar to MCDA methods, the available participatory deliberation techniques for application to natural resource and environmental issues are also numerous and differ in name, categorisation, and objective (Cohen and Uphoff 1980; Creighton et al.1998; Rauschmayer and Wittmer 2006). Deliberation techniques also differ in extent and form and must be considered based on a number of considerations including but not limited to the types of participants, extent of participation, and the nature of how the MCDA is embedded within (Rauschmayer and Wittmer 2006). The application of the deliberative participatory framework to environmental problems is effective as their characteristics include complexity (Brown et al. 2001), uncertainty (Fox and Irwin 1998), large temporal and spatial scales (Faith et al. 1996), and irreversibility (Van den Hove 2000). This section will review participatory deliberation frameworks to further provide context for a future section which will combine deliberative frameworks with MCDA methods to form the Deliberative Multi-Criteria Evaluation (DMCE).

3.5.2. Application of citizens' jury to environmental issues

Community involvement in decision-making regarding environmental policy formulation is a growing, recognised, and now essentially required consideration in Australia (Proctor and Drechsler 2006). The 'Citizens' Jury' combines public participation with a deliberation process and is similar to criminal proceedings with 10-20 randomly selected people deciding on an issue that has public implications (Proctor and Drechsler 2006). A mediator is commonly used to ask jury participants to deliberate, ask questions and call upon expert opinion. Also, expert opinion or evidence can help the decision-making process by forcing participants to consider the likely impacts that their proposals and alternatives might incur (Considine 1994). The final outcome is ideally a consensus agreement reached by the jury; however, this is not often possible in practice. Environmental policy decisions are typically determined by the most appropriate ends sought as opposed to all parties fully agreeing (Walker 1999). A discussion on how much consensus is required to develop a reasonable decision outcome appears below in **Section 3.6.4.2.** (step (9) of the Delphi method).

3.5.3. The participatory approach

An array of participatory approaches is used in land-use planning and environmental conflict resolution including mediated modelling, consensus conference, participatory multi-criteria decision support IMA, multi-criteria evaluation in deliberative workshops, cooperative discourse, and mediation (Rauschmayer and Wittmer 2006). Generally, the decision-makers follow a path that confronts them with difficult but important issues, and permits them and others to scrutinise the way through which the method was applied and alter the process where deemed appropriate (Sposito et al. 2007). The systematic approach ensures that decisions can be planned, designed, evaluated and implemented (Skyttner, 2005). Participatory systematic methods can be broadly divided into methods with stakeholder involvement and methods with the involvement of the general public (**Table 4**).

Table 4. Participatory methods broadly divided into categories of stakeholder, general public or the involvement of both groups (Rauschmayer and Wittmer 2006).

	Stakeholders	General Public	Members of Both Groups
Consensus Conference		✓	
Mediation	✓		
Multi-Criteria Evaluation in Deliberative Workshops		✓	
Mediated Modelling	✓		
Ima	✓		
Cooperative Discourse			✓

Although different participatory approaches are developed and differ in format, each shares a similar goal of helping to make a decision on a complex and uncertain public issue. Creighton

(1999) outlines three common initial planning activities to consider before implementing a public participation process:

1. Decision analysis
   - Clarifying the decision to be made
   - Specifying the decision-making steps and schedule
   - Deciding whether you need public involvement, and for what purpose
2. Public participation planning
   - Specifying what you need to accomplish with the public at each step of the decision-making process.
   - Identifying the stakeholders
   - Identifying the technique(s) to be used in the process, taking into account the characteristics of the population involved
3. Implementation planning
   - Planning the implementation of individual public participation activities, e.g., developing a workshop agenda, venue, presentations, etc.

3.5.4. An overview of participatory approach types

3.5.4.1 Integrative group processes

Integrative Group Processes (IGP) were developed by Gustafson et al. (2003). IGP is considered effective in avoiding bias and provides researchers with detailed and elaborated input for developing different value models (Gustafson et al. 2003). Development has three main phases that generates a model that is ready for use and continuous refinement. The IGP process contains three phases. The process begins with pre-work including model type selection, literature review, and expert identification. The second phase involves expert meetings where decisions include model objectives, and measurable factors to include. Subjective probabilities are then collected and tested for expert bias. The third phase involves testing the model against an expert panel(s) and then against reality with continuous refinement throughout.

3.5.4.2 Delphi method

The Delphi method is a form of group communication that transpires among a panel of geographically dispersed participants (Adler and Ziglio, 1996). The technique comprises of a series of questionnaires sent to a pre-selected group of participants. The questionnaires are designed to elicit individual responses to the issue at hand with iterations providing an opportunity to alter opinions based on the replies of other participants. The primary theory behind the Delphi method is to avoid the weaknesses of the common face-to-face group settings. Key features of the Delphi technique include anonymous responses, feedback and information, independence, and participant equality (Stone Fish & Osborn 1992). Anonymity is provided for the participants to enhance the quality of the decision outcomes and to reduce external influences (Gavish & Gerdes 1998). Group interactions among participants are controlled by a mediator who filters out material not related to the purpose of the group bypassing the common problems of group dynamics. Fowles (1978) outlines the following ten steps of the Delphi method:

1. Formation of a team to undertake and monitor a Delphi on a given subject;
2. Selection of one or more panels to participate in the exercise. Customarily, the panellists are experts in the area to be investigated;
3. Development of the first round Delphi questionnaire;
4. Testing the questionnaire for proper wording (e.g., ambiguities, vagueness);

5. Transmission of the first questionnaires to the panellists;
6. Analysis of the first round responses;
7. Preparation of the second round questionnaires (and possible testing);
8. Transmission of the second round questionnaires to the panellists;
9. Analysis of the second round responses (Steps 7 to 9 are reiterated as long as desired or necessary to achieve stability in the results);
10. Preparation of a report by the analysis team to present the conclusions of the exercise.

3.5.4.3 Nominal group techniques

Nominal Group Techniques is a common name for face-to-face group methods that consist of processes such as brainstorming, clarifying and discussing ideas, individual reassessment, and ranking of ideas (Gustafson et al 1993). Nominal group processes are used in the Estimate-Talk-Estimate (ETE) technique which is a method to discuss model inaccuracies that may be caused by expert bias. ETE improves accuracy by forcing group members to consider the views and experiences of others and then independently revising their opinion based on what they have learned (Gustafson et al 1993). Each member clarifies and justifies responses and definitions to the group when the estimates differed. Members then re-estimate again individually and consensus is not required to finish the process. Remaining differences between members are typically resolved by giving an equal weighting to each expert's estimate, using the geometric mean as the final estimate (Gustafson et al 1993, Bosworth et al. 1999).

3.5.4.4 Social judgment theory

Social Judgment Theory is a group process based on cognitive feedback (Hammond et al. 1977). The method framework is structured to ask subjects to rate a sequence of scenarios. This is used to provide statistical feedback identifying the importance of different components within the scenarios. An initial consensus model is built based on component importance and is used to predict a new series of scenarios.

3.5.4.5 Group communication strategy

Group communication strategy originates from a set of normative instructions (Hall and Watson 1970) stating that conflict reducing techniques such as voting and bargaining should be avoided along with behaviours like arguing and win-lose statements if the objective is to develop high quality judgements where the group will later accept the outcome (Burgman et al. 2006).

3.5.4.6 Ulrich's Critical Systems Heuristics (CSH)

Ulrich's Critical Systems Heuristics (CSH) is an example of a participatory conflict resolution tool used to critically assess planning policies. CSH is a consultative method for policy makers and affected citizens to work together on issues of a normative nature. Ulrich's use of the term CSH can be interpreted as being a subjective and critical assessment of systems components that shape decision-making or planning encompassing metaphysical, political, ethical, and ideological considerations (Flood and Jackson 1991). The critical questions which form the basis of the CSH are asked by the citizens to help gain an understanding of the normative content of the policy system by contrasting the "is" and "ought" modes (Flood and Jackson 1991). The questions each address different concerns which are simply assumptions trying to reveal overall processes within the practical context of the system.

Based on these latter participatory group techniques and the MCDA characteristics and methods outlined in Section 3.4, we can now begin to explain the methodological framework that we enhanced and applied for the current ERAT project. The methodology named Deliberative Multi-

Criteria Evaluation (DMCE) combines MCDA with a participatory stakeholder jury component, by applying the structured decision-making framework in a group workshop setting. We applied the DMCE methodology within a multi-day workshop with the case study details being outlined in Section 3.10. First we explain the DMCE process.

3.6. Prioritising Emergency Plant Pest Risk with the use of Deliberative Multi-Criteria Evaluation

3.6.1. Introduction

As outlined in sections 3.3 and 3.4, MCDA can accommodate quantitative and qualitative information, in relation to potential consequences of a given decision option, in order to help guide complex multi-faceted natural resource issues toward effective outcomes. Section 3.5 outlined several methods of achieving group-based decisions through deliberative process. So, by combining these approaches, we can provide an ideal vehicle for Biosecurity risk management decisions involving large amounts of uncertainties and diverse groups of decision-makers. DMCE (Proctor and Drechsler 2006) does precisely this.

Generally, DMCE can be an effective tool for bridging the gap between science and policy communication by structuring participant judgements in a framework that guides decision-making (von Winterfeldt and Edwards 1986). DMCE can be used in an effort to facilitate a transparent process whereby decisions would be more likely to be accepted and supported in a democratic manner (Gilmour and Beilin 2007).

We recommend both DMCE and a more rapid intuitive ranking approach to prioritise the risk of EPPs. As the consequences of an EPP in Australia could be irreversible and not well understood, they may lead to an increase risk perception reaction from stakeholders, regardless of the impact factors. For example the extremely remote possibility of a catastrophic outcome due to a particular EPP entering Australia might immediately be given a high risk ranking using an intuitive and rapid appraisal of the situation. Conversely an EPP posing an extremely low risk might quickly be assessed as insignificant and given a low ranking. These rapid appraisals are examples of direct decision-making (Stanovich and West 2000) which seeks to capture intuition by being emotional, automatic, effortless, and rapid (Kahneman and Frederick 2002). On the other hand, more time, structure, and logic might be required to provide guidance to a decision maker, particularly in attempting to assign a ranking to EPPs of potential intermediate risk. DMCE is an example of this indirect form of decision-making that can rank risk by combining stakeholder opinion with the product of expected likelihood and consequence scores. Indirect decision-making can be characterised as being controlled, deductive, serial, self-aware, and rule based (Stanovich and West 2000, Kahneman and Frederick 2002).

Neither the direct not indirect approach is comprehensive with both having grounds for potential errors. Direct decision-making could have too many options to rank, show evidence of participant anchoring (on most visible, familiar EPP), implicit favour bias (positioning on a pet option), and/or sequencing bias (timing and order of EPP presentation listing). Likewise with indirect decision-making, participants could lack confidence in the assigned values, not include criteria or include overlapping criteria in the problem structuring phase. To address these potential errors, we recommend a multi-method approach that unites and compares direct and indirect decision-making. Stakeholder participants can directly rank EPPs in terms of their risk to Australia and then discuss these results in comparison to the rankings they produced using DMCE as a means of understanding and verifying the results for each approach.

3.6.2. Steps of the Deliberative Multi-Criteria Evaluation Approach

The DMCE process is iterative and flexible (**Figure 5**). The iterative nature of the process seeks to decrease variation while correspondingly increasing the likelihood of the resulting rank order being robust (Proctor and Drecsler 2006). Deliberation is an important component that can help to gather and understand information revealed throughout the process, resulting in the potential need for further weighting, and a re-iteration (Proctor and Drecsler 2006). We explain each component.

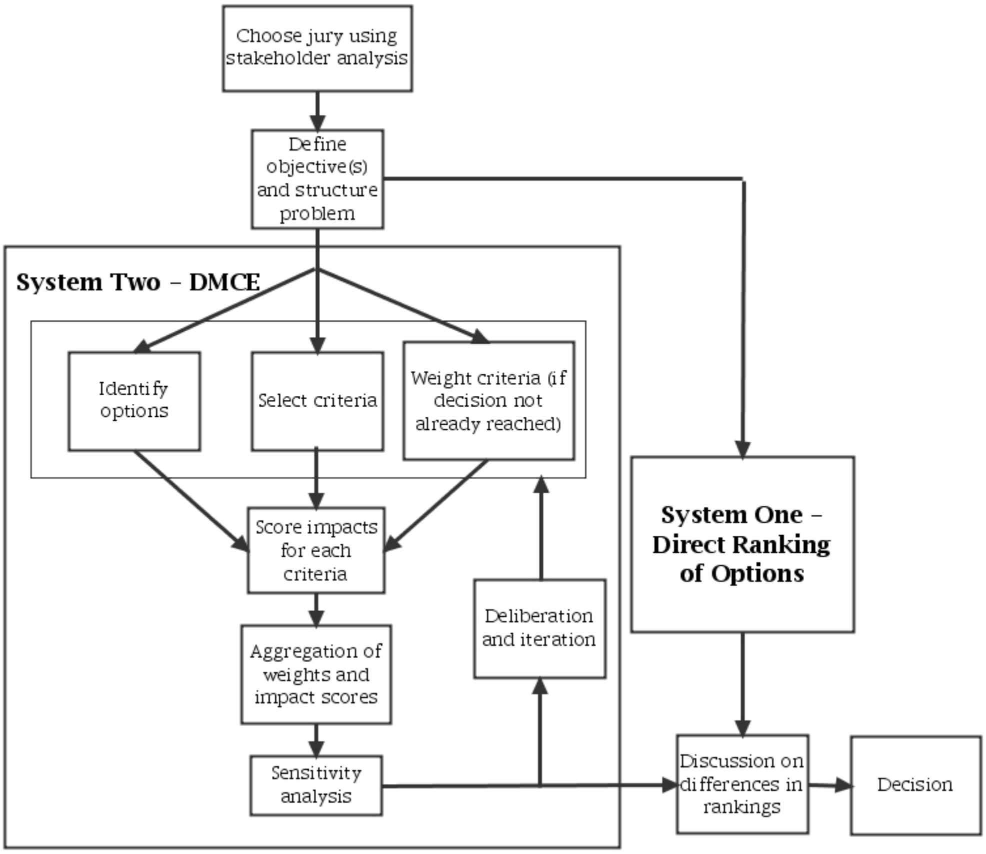

Figure 5. Deliberative Multi-Criteria Evaluation flowchart (Proctor and Drechsler 2006)

Choosing the jury

Stakeholder analyses can help to understand the context of the issue at hand, the key parties in the operating environment, the interactions among them, the values that are important to them, and what opportunities exist to mobilise their support (Frost 1995, Bryson 2004, Svendsen and Laberge 2006). Stakeholder analysis can be an effective strategic tool for gaining public acceptability of risk assessment through bridging the gap with facilitating risk management (Gilmour and Beilin 2007). Although stakeholder analysis cannot guarantee perfect representation (if such a pedestal in fact exists), the methodology can build trust, add transparency, and inclusiveness in engagement, which in turn may reduce the risk of issues becoming politicised (Gilmour and Beilin 2007).

The primary purposes of using stakeholder analysis are set out as being (Gilmour and Beilin 2007):

- gauging interest

- inquiry into knowledge of topic area
- understanding values and positions
- collecting the potential objectives and criteria
- realising networks of influence
- building support for the decision process and outcome.

<u>Stakeholder Analysis steps:</u>

Identifying stakeholders

Parties must be identified who could affect or may be affected by the decision. Considerations must be taken including power, attitude, interest, relationships, and those who could be affected.

Analysing stakeholders

Parties are then scored based on their influence over this issue, their interest type and overall significance of their interest, their attitude, and relationships with others (**Table 5**). The project group assigning these estimated scores also provides a confidence level to each of these measures. The scores may be required to be updated as time passes due to changes in relationships, personnel, or group objectives, making the analysis an iterative process.

Table 5. Stakeholder analysis scoring table

Stakeholder group	Power (Ability to influence outcome)	Interest (Public good, legal, scientific, financial)	Attitude	Relationships	Capacity to contribute	How to involve
A	High	High	For	Specific Organisations	Problem Definition	Consult
B	Medium	Medium	Indifferent	Unilateral/ Bilateral	Source of Knowledge	Participate in Decision Process
C	Low	Low	Against	Strong/Weak	Peer Review	Co-Researchers/ Co-Actors

(Dick, 1997)

Mapping stakeholders

Stakeholder mapping is a tool that visually represents stakeholder influence and interest along with the relationships among the groups within the contextual environment (**Figure 6**). The influence axis is defined by the stakeholder's ability to influence the decision based on providing or withholding resources (Gilmour and Beilin 2007). The interest axis is evaluated by the importance of the decision issue to a given party in relation to political, financial, social, environmental, technical, or a combination of these (Gilmour and Beilin 2007). Multiple parties can be placed on one graph. Those graphed in the top right hand corner are critical to project success, defining them as 'critical players' (Eden and Ackermann 1998). 'Subjects' graphed in the top left-hand quadrant are still significant players as although exerting limited influence on their own, with their high stake, may form alliances in order to gain more power for or against the cause. Those in the bottom right hand quadrant are also significant players, defined as being 'context setters' as their actions could strongly influence the outcome. The 'crowd' sits in the bottom left-hand quadrant. Although, these spectators may not have much capacity to influence the outcome, their consideration may be warranted depending on the impact that a decision could have on them, as often they might not have an apparent voice that can be heard. The final map was used as a picture for whom to include in the DMCE process, their potential concerns, actions, objectives, and organisational set-up (Gilmour and Beilin 2007).

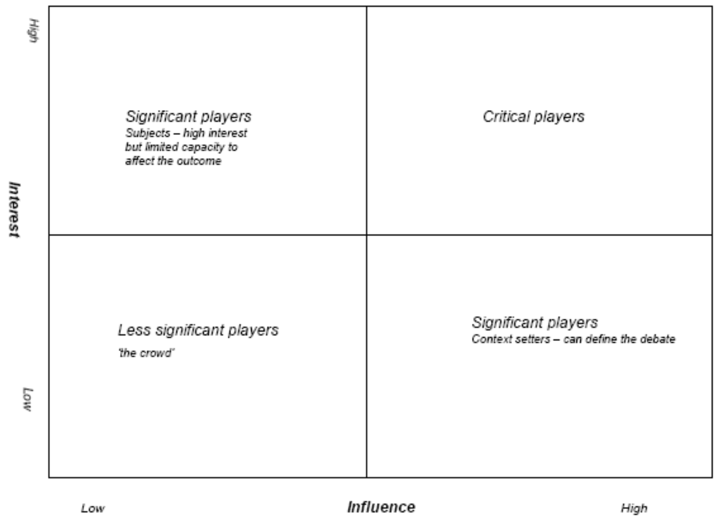

Figure 6. Stakeholder Influence vs. interest map (Eden and Ackermann 1998, Gilmour and Beilin 2007)

The final stakeholder map is used as a depiction for finalising the scoring table (**Table 5**), addressing potential stakeholder concerns, actions, objectives, and the organisational set-up (Gilmour and Beilin, 2007). Based on the results of stakeholder mapping, one can better gauge the participation level for each identified stakeholder. Table 5 is then re-visited in order to score the last two columns. Degrees of engagement include either being involved as informants, as consultants, as participants in the decision-making, or as co-researchers and co-actors (Dick, 1997). The next step is to continue building working relationships to ensure that, depending on their involvement, their expectations are met, their expertise acknowledged and the process is pertinent to their interests (Gilmour and Beilin 2007).

2) Choosing the options and the overall objectives

The choice of EPP options and the overall objectives can be developed by various sources including the jury, expert advice, databases, computer simulation models, and/or political processes (Proctor and Drechsler 2006).

3) Selecting the criteria

Criteria are included as a means to evaluate and rank each of the options, and must therefore fit within the overarching context as defined by the objective (Proctor and Drechsler 2006). The criteria must be measurable as they are weighted by participants and represent the preferred options for reaching a decision (Munda et al. 1994, Rauschmayer and Wittmer 2006). Keeney and Gregory (2006) state that a good criterion should be unambiguous, comprehensive, direct, operational, and understandable. Natural resource management-related issues can often be broken down into `ecological', `economic', and `social and cultural' based criteria groupings/objectives (Cook and Proctor 2007).

4) Assessing the options using model output

Each EPP must be scored in terms of their likelihood and consequence impact. This assessment is completed through an impact matrix whereby each criterion is evaluated in relation to each EPP (Proctor and Drechsler 2006). In making a determination of the impact of each EPP relative to each criterion, the following matters should be considered:

- the severity of the impact
- the extent of that impact

5) Weighting the criteria

Within the DMCE procedure, participant views are represented by the relative weighting of each of the criteria. The criteria are quantitatively weighted by each participant. The first and highest ranked criterion is given 100 "rating points", the second ranked criterion some number between zero and 100 that represents relative importance to the first ranked criterion, and the third ranked criterion a number between zero and the number for the second ranked criterion in terms of importance relative to the 100 given to the first ranked criterion. This procedure is continued until all the criteria have been weighted. Weights must reflect the range of the criterion being weighted, as well as its importance (Edwards and Barron 1994). It makes no sense to determine criteria weights independent of the scales used to score options against those criteria (Steele et al. 2008). This point should be emphasised throughout a workshop to ensure the criteria are weighted based on not only importance, but within the context of how wide an extent that the EPP impacts for a given criterion has been scored.

6) Aggregating the criteria

Multi Criteria Analysis Tool (MCAT) software version 1.0 beta (Marinoni 2008) aggregates the criteria weights with the impact matrix scores in order to calculate an EPP risk rank order (Guitouni and Martel 1998). MCAT software is based on compromise programming (Zeleny 1973), which was selected as a suitable approach given that it effectively creates scores of criteria within suitable lower and upper bounds (Marinoni et al. 2007).

In compromise programming we defined u^-_j as the disutility of option $j \in J$, which was calculated as:

$$u_j^- = \left[\sum_{i=1}^{m} w_i^c \left(\frac{f_i^+ - f_{ij}}{f_i^+ - f_i^-} \right)^c \right]^{1/c} \quad (1).$$

where:

f_i^+ = the upper bound score for criteria $i \in I$;

f_i^- = the lower bound score for criteria $i \in I$;

c = a parameter that reflects the importance of maximal deviation from the ideal solution. MCAT uses a c value of 1.

7) Sensitivity analysis and deliberation

Sensitivity analysis is a widely used tool for the investigation of the impact of uncertainty on the outcome of a particular analysis (Benke et al. 2007). Sensitivity analysis will generally focus on the variation around individual criterion, thus making it a tool that can target where key differences in weights lie among participants. For example, sensitivity analysis can help to pinpoint where more deliberation may be required by assessing individual weight outliers to the group mean, in terms of whether, taken alone would change the rank orders of EPP options (Proctor and Drechsler 2006).

The overall goal of the deliberation process is for the participants to reach an agreement on a set of criteria weights in order to rank the optimum order of EPP options (Cook and Proctor 2007). Real-time sensitivity analysis of the weights can help to guide deliberation in order to gauge which criteria to target. The MCAT aggregation software, described earlier in this section, is used interactively during the deliberation and the results of each weighting iteration displayed to the participants.

The DMCE is characterised by real-time interaction with the decision-makers. Criteria can be continuously updated, added, dropped, or modified (Proctor and Drechsler 2006). An iteration and further deliberation is required any time one of these processes occurs. In the DMCE, allowance for iterations and the process of interaction among a facilitator, participants, and expert presenters, are crucial for a final outcome to be reached (Proctor and Drechsler 2006).

In the next section, 3.7, we shift from discussing the DMCE technique to outlining the bioeconomic model to be used as part of the process of species prioritisation. This framework can be used interactively with a decision-making group. As we move on to explain in section 3.8, its predictions of EPP impacts can then be used to inform stakeholder decisions.

3.7. Conceptual Framework for the Bioeconomic Model

In this section we outline the theoretical basis of the EPP impact simulation model we will use to provide quantitative information about the effects of invasive species on social welfare. It is a conceptual outline of the methods used to estimate the likely effects of different species should they arrive and spread in Australia. In setting out the economic theory behind the model we pay particular attention to market effects; that is, the effects on plant industries that could potentially play host to invasive species. In so doing, we present the underlying methodology behind the quantitative impact simulation model presented in detail in the **section 3.8** of this report, and used to provide expert testimony on the market impacts of EPPs in a deliberative pest prioritisation exercise.

A static, partial equilibrium model can be used to examine the economic implications of invasive species. It is 'partial' in the sense that it only considers one or a relatively small number of markets. In our case, this might be one plant industry, or a series of small industries. The aim of partial equilibrium models is to examine the effects of shock from outside the system (termed an *exogenous* shock) like a pest or disease incursion on these markets, and the social welfare effects that result from moving from a pre-shock to a post-shock market equilibrium where the demand equals supply.

For simplicity, the following discussion centres on a species that is host-specific, affecting a commodity, q. We assume the following:

(i) The organism can be controlled by additional local activities, the costs of which are borne by producers (i.e. raising the Average Total Cost (ATC) of q production);

(ii) The domestic market for q is perfectly competitive;

(iii) The domestic price for q is above the 'landed' price of imported (identical) product;

(iv) The contribution of the Australia to the supply of q is insufficient to exert influence on the world price, exchange rate or domestic markets for other goods.

Consider an enterprise producing q. The *production function* describes the relationship between physical quantities of factor inputs (I) and the physical quantities of output involved in producing q given the state of technological knowledge possessed by the producer. So, the level of output he/she produces is some function, call it f, of I:

$$q = f(I) \qquad (2).$$

For the moment, assume any risky factors in the production process simply take on their average values.

Generally, to be of *biosecurity significance*, x must have a negative impact on output when established in a production area. An exception may occur where there are human health and/or environmental implications to invasive species introductions, as mentioned above. This will be discussed at length below, but for now assume the only host of x is the commodity q.

If this is the case, the production function contracts since the quantity of inputs required to produce any given level of output increases due to the presence of the organism. For instance, should a producer of q have to use an additional chemical treatment to those already used for other invasive species control to produce q_o, the quantity of inputs required will increase. Thus, an invasive species impact can be seen in much the same light as a negative technological change.

To examine the economic welfare implications of an invasive species-induced change requires some discussion about cost and revenue functions. In short, Total Revenue (TR) for any producer supplying the market for q depends on the quantity sold and the price (p) at which it is sold (i.e. $\text{TR} = pq$), while Total Costs (TC) are a function (call it c) of output (i.e. $\text{TC} = c(q)$). Profit (π) is simply stated as TR minus TC. Given that the price facing a competitive, profit-maximising producer of q is dictated by the market as a whole, their profit maximisation decision can be stated as:

$$\max_{q}.\ \pi = pq - c(q) \qquad (3).$$

To simplify the following discussion $c(q)$ will not be divided into its fixed and variable components. Hence, assume fixed costs of production are zero, so ATC equal average variable costs.

It should be noted that is not necessarily the case that the producer's choice of output of q will be positive. Where the minimum value of ATC exceeds the prevailing market price it is in the interests of a profit-maximising producer to produce no output in order to minimise losses. At prices above the minimum value of ATC the Marginal Cost (MC) curve relates the grower's profit-maximising output to price, and thus represents their supply curve, $q(p)$.[24]

The supply curve for the collective industry can simply be found by horizontally summing the supply curves of all producers supplying the market for q. If there are n suppliers and the supply curve for the i^{th} farm is denoted $q_i(p)$, then the supply curve for the industry ($Q(p)$) is given by:

---

[24] Hence, $q(p)$ must identically satisfy the first-order condition $p \equiv c'[q(p)]$ and the second order condition $c''[q(p)] \geq 0$.

$$Q(p) = \sum_{i=1}^{n} q_i(p) \qquad (4).$$

So, this industry supply schedule, which formalises the relationship between industry output and collective marginal costs of production, can be used to calculate industry profit under different production conditions.

Returning now to the production function of expression $q = f(I)$ (2)., the implications of an introduction for a grower's profit-maximising output decision become clear. As the level of inputs needed to produce each unit of *q* increases in response to costly efforts to keep a newly introduced invasive species at bay, or at least subdued, so too must MC and ATC. Recalling the characteristics of $c(q)$, the ATC curve will be U-shaped, as depicted in the left frame of **Figure 7**. Here, two sets of cost curves are shown dealing with both a 'with invasive species' (MC^* and ATC^*) and 'without invasive species' scenario (MC and ATC)

A profit-maximising producer will choose to produce a level of output corresponding to the point where *p* equals the MC of production. At this point, the differential between total cost and total revenue is maximised. Assuming the prevailing domestic market price, p, is below a closed market equilibrium price (shown here as p_D in the right hand frame of the diagram), a grower characterised by the cost curves MC and ATC would choose to produce quantity q_0 (i.e. where $p = \mathrm{MC}$) and earn a profit of ABC*p* in the absence of an invasive species. Once again, note that output will be positive as long as the price received by the producer remains above the minimum value of the ATC of production.

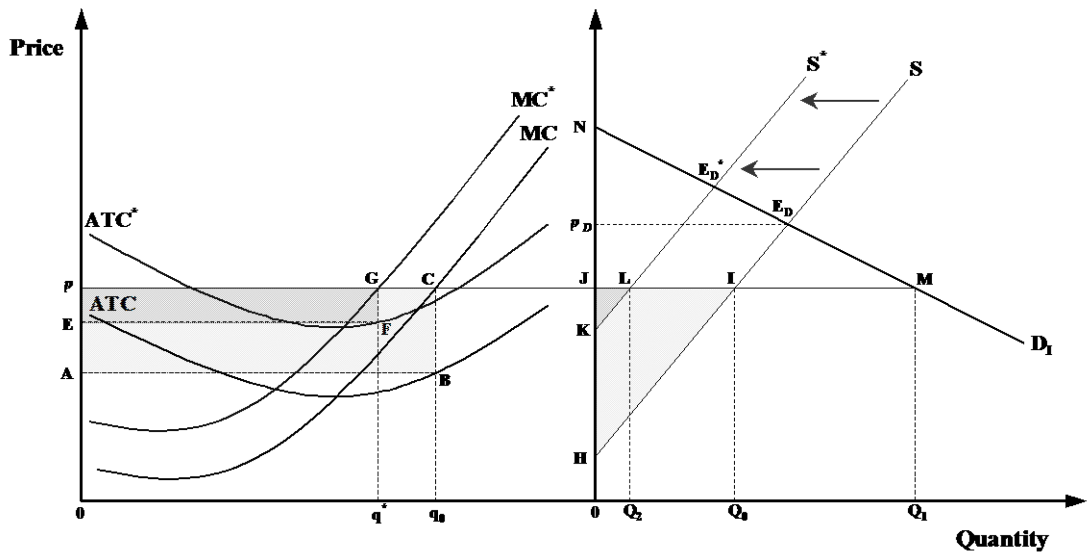

Figure 7: The economic impact of an invasive species – imported goods

Economists use *producer surplus* and *consumer* surplus to measure aggregate social welfare effects of changes within markets such as those brought on by the x. Producer surplus is defined as net revenue earned by a producer from the sale of a good at a price above the minimum acceptable price they would have been willing to sell for before having to leave the market. This is the welfare measure we will mostly deal with in this report. Consumer surplus is the financial equivalent of the extra utility gained by consumers from purchasing a good at a price lower than what they were willing to pay for it. These concepts are perhaps most easily understood with the aid of a diagram, and we describe changes in producer and consumer surpluses in the market for q below with reference to **Figure 7**.

If all growers in the industry respond to x in a similar manner, the industry supply schedule produced by the horizontal summation of each producer's output at different prices would resemble the curve S in the right hand frame of **Figure 7**. According to the industry demand schedule (D_I) domestic consumers will demand the quantity Q_1 at price p. Of this, Q_0 will be supplied by domestic growers, and $Q_1 - Q_0$ by imports. In this situation, producer surplus is given by the shaded area HIJ, and consumer surplus by JMN. Note that under a domestic closed-economy equilibrium scenario (i.e. E_D) producer surplus would be the larger area HE_Dp_D, and consumer surplus the smaller area p_DE_DN. Hence, the 'traditional' *gains from trade* is shown as E_DMI.

If an invasive species x were to now enter the production region and become established, the effect at the farm level will be rising ATC (and MC), recalling assumption (i) above. A greater cost is now involved in producing each unit of q after the outbreak than before it. At the prevailing market price p the increased costs of production would lower producer output from q_0 to q^* where producer surplus is the heavily shaded area EFGp.

If the probability of x's entry and establishment is P, then the expected loss of producer surplus at the farm level (ED_F) associated with the organism can be expressed as:

$$ED_F = P \times (ABCp - EFGp) \qquad (5).$$

At an industry level, the domestic supply curve will contract (from S to S^* in the right frame of Figure 7) in the face of added growing costs. Domestic producer surplus will decline to the heavily shaded area KLJ, representing a loss of HILK. So, the expected damage to the collective industry from x (ED_I) can be expressed as:

$$ED_I = P \times HILK \qquad (6).$$

Assumption (iii) above specifies that the domestic price of x is above a world price, but what if we now reverse this assumption? If the world price is now assumed to be above a domestic market equilibrium price, growers can earn more revenue by selling q on the world market. The effect of a pest like x on an exported commodity is illustrated in **Figure 8**. Here, the prevailing world price for q is p_w. Consider the pre-invasion supply schedule, S_0. At price p_w, the domestic demand schedule in the right hand frame of the diagram reveals the industry is willing to supply Q_0, while the domestic demand for q is only Q_1. The industry can sell the residual $Q_0 - Q_1$ and earn a total producer surplus of ABC (shaded). Consumer surplus is the area MNC. A producer within the industry characterised by the cost curves ATC_0 and MC_0 in the left frame of the diagram earns a profit of DEFp by producing and selling q_0 and the price p_w.

Now consider the impact of the invasive species x on the industry. Once again, necessary changes to the production process to deal with x raise the ATC and MC curves of a typical producer up to ATC_1 and MC_1. They still receive the world price p_w, but it is now only economic to produce q_1, at which they accrue the producer surplus $IJKp_w$. Therefore, if the probability of entry and establishment of x is denoted P, ED_F can be expressed as:

$$ED_F = P \times (DEFp_w - IJKp_w) \quad (7).$$

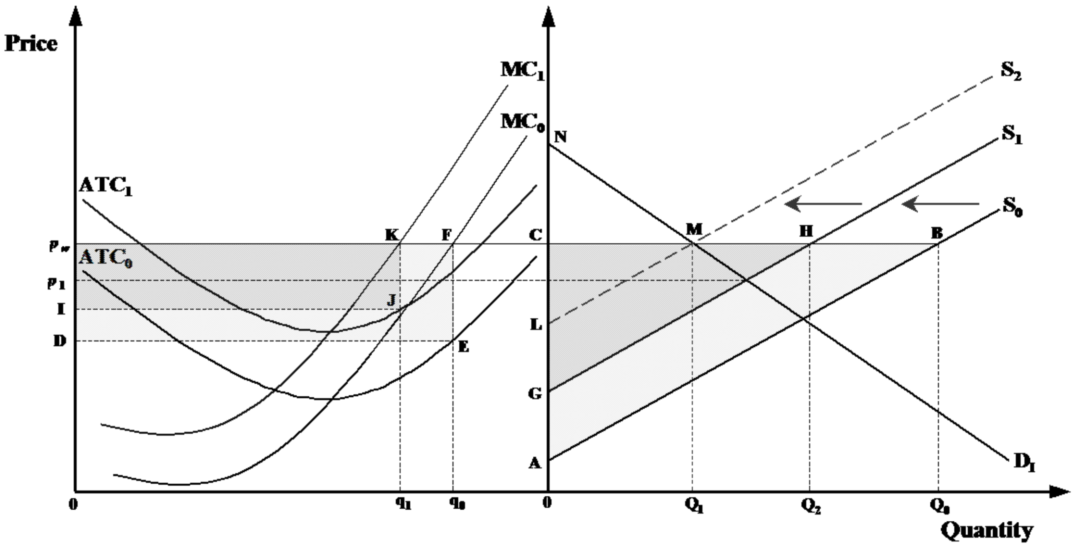

Figure 8: The economic impact of an invasive species – exported goods

The aggregate effect of *x* across the industry is a contraction of the supply curve in the right hand frame of the diagram to S_1. In a closed market situation this would result in a domestic market price of p_1. But, as this is below p_w the industry can continue to supply the world market and earn a higher amount than it would in a closed market. In terms of Figure 8, the heavily shaded area GHC indicates total producer surplus. Consumer surplus is unaffected since the price remains at p_w (recalling assumption (iv)), and remains MNC. Hence, in terms of the diagram ED_I can be expressed as:

$$ED_I = P \times ABHG \quad (8).$$

Note that had the contraction in supply induced by the entry of the invasive species been much worse, it could have spelled the end for all exports of the commodity *q*. If, for instance, the post-invasion supply curve resembles S_2, all exports would cease. The industry could still supply Q_1 to the domestic market, but only earn a producer surplus of LMC. Sales of $Q_0 - Q_1$ would effectively be lost to the effects of *x*. Note also that at the farm level, such a dramatic cost increase may be sufficient to push individual suppliers out of the market if the minimum value of their ATC function were to exceed p_w.

By describing how an invasive species impacts on the behaviour of economic agents, its strategic significance to the economy can be measured. Using the naturalisation assumption allows us to measure the true benefit to the economy of keeping a species out, and therefore its biosecurity significance. However, in the following section of this report we will examine the effects of relaxing this assumption, and consider different regimes of private and government control following an outbreak.

3.8. Bioeconomic model structure and function

We now turn our attention to the bioeconomic model software designed to provide expert testimony in regard to the economic implications of different EPP outbreaks in a DMCE setting. This model is based on a partial equilibrium modelling approach, and calculates the expected change in social welfare resulting from an incursion over time. In this section we provide specific details of the model, how it was constructed and applied to a range of EPPs threatening new and emerging Australian plant industries. The reader will note a distinct change in the language from the Methodology section since our intention here is to give technical details of the modelling process, rather than its theoretical underpinnings. The software platform chosen for the model is STELLA due to its unique communication-based format, and descriptions, formulae and results are presented as they appear in the model. As a point of clarification, model formulae contain the term *infested* to describe EPP presence regardless of taxonomic grouping. Hence, this section uses the terms infests, infested and infestation to describe the presence of pests and pathogens alike despite their common usage in reference to invertebrates.

3.8.1. Overview

In this section, we develop a bioeconomic model to simulate potential economic costs of EPP invasions for the whole of Australia. Although the model has the capability to run local and regional impact simulations, the scenarios detailed in the following sections involve incursions of national significance to Australian plant industries. The time over which the model simulates impact was arbitrarily chosen as 30 years (2010-2040). Over time the pest may spread to other areas in spite of management efforts at local and national levels, but if the efforts are sufficient then eradication occurs. The cost of these efforts and market revenue loss of infested host plants for the pest are estimated, based on 1,000 stochastic runs of the model. **Figure 9** below presents a conceptual overview of the overall model structure.

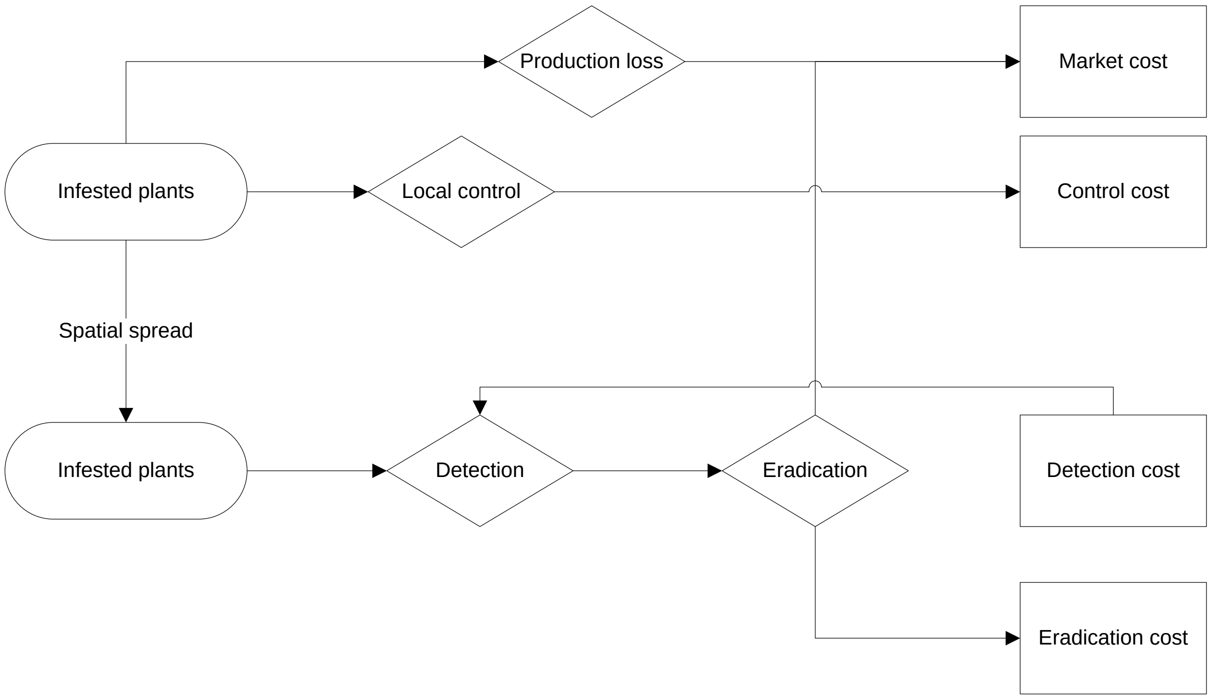

Figure 9. Structure of the bioeconomic model.

It is important to reiterate two central characteristics of the model presented in this section. Firstly, since our primary focus for developing the model is *risk assessment*, invasive species risks are measured in terms of potential economic costs. Secondly, the model is built to analyse biosecurity risks generally applicable across all taxa. This is a very difficult assignment when one considers the diversity of potential pest threats, but it is possible to break down species invasion to a relatively small number of key parameters that capture the idiosyncrasies of each pest. The list of these key parameters, and their definition and units are presented in **Table 6**.

Table 6. List of parameters, their description and unit

Parameter	Description	Unit
Ecological Parameters		
probability of entry	Likelihood of an exotic species entering Australia per year.	unitless
probability of establishment	Likelihood of an exotic species establishing in Australia per year given that it has entered.	unitless
local infestation rate	Number of hosts that will become infested (without control) if one host was infested in the previous year.	# newly-infested hosts/infested host
spatial infestation rate	Number of farms that will become infested (without control) if one host was infested in the previous year.	# newly-infested farms/infested host
average farm size	The average land area of a farm.	ha
total area of Australian production land	Total growth area for a certain type of agricultural produce.	ha
area occupied by a host	Average land area occupied by a host plant for an exotic species	# host/ha
time out of production	Average number of years an infested farm will be out of production in an eradication situation.	year
Economic Parameters		
cost of control technique	Total cost of all control (chemical, biological etc) efforts at farm level	$/ha
cost of inspection	Total cost of inspecting efforts	$/ha
cost of eradication	Total cost of eradication efforts	$/ha
inspection budget pre-1st detection	National budget for inspection before an exotic species is found.	$/year
inspection budget post-1st detection	National budget for inspection after an exotic species is found.	$/year
central control choke price	Cost beyond which Australians will give up both eradication and inspection.	$/year
preinfest export	Amount of agricultural produce exported before infestation happens.	kg
preinfest productivity	Average productivity before infestation happens	kg/ha
postinfest production left	Ratio of after and before infestation productivity.	unitless
postinfest export drop	Ratio of after- infestation-export-loss and pre-infestation export	unitless
preinfest domestic price	Average domestic sale price.	$/kg

Parameter	Description	Unit
domestic choke price multiplier	Used to estimate the price beyond which Australians will stop buying a certain produce, e.g. multiplier= 5 means customers will stop buying when the price increased to 500% of what it was.	unitless
supply elasticity	Used to measure the responsiveness of the quantity supplied of product to a change in price of product, e.g. in response to a 10% rise in the price, the quantity supplied increases by 20%, then the price elasticity of supply would be 20%/10% = 2.	unitless
demand elasticity	Used to measure the responsiveness of the quantity demanded of product to a change in price of product, e.g. in response to a 10% rise in the price, the quantity demanded decreases by 20%, then the price elasticity of demand would be -20%/10% = -2.	unitless
export price	Average export sale price	$/kg
discount rate	This parameter value is set to 8% in the model.	unitless
Within season multiplication factor	Used to estimate production loss due to infestation. For annual crops such as vegetables, it is necessary to know the proportion of infested plants at the end of a growing phrase, which is different from the proportion of infested plants that will carry forward into the next year. This parameter is bigger than 1 for annual crops and equals 1 for other plants.	unitless
Management-Related Parameters		
start control threshold	Ratio of infested hosts to maximum number of hosts on a farm above which local control will occur	unitless
control tech effectiveness	Percentage of infested hosts that would be saved by local control efforts.	unitless
detection prob if inspected	Likelihood of finding infested hosts when inspection is conducted.	unitless
search efficiency	Used to estimate the amount of searching effort needed to achieve the same numbers of detection. The value of parameter ranges from 0 to 1, 1 being the most efficient. In the current setting the value is always 1.	unitless
initial time since last detection	Number of years since last detection of an invader in Australia.	year
no detect years before eradication declared	Time since the last detection before a pest is presumed to be eradicated.	year

Box 3. Key assumptions in the bioeconomic model

Infestation	• When a pest is established, it becomes naturalised unless control effort is exerted against it. • There is spatial homogeneity at both farm and country level. • Population growth follows a logistic function. • Times of occurrence for spatial infestation, spatial spread, new arrivals (from outside Australia) and detection are all Poisson distributed.
Management	• There is no time lag between detection and eradication when calculating spatial infestation. • Not all infested farms go undetected detected due to factors such as surveillance budget and technological limitation. • Infestation does not occur in crops that have not come back into production after an eradication event.
Economic cost	• A decision-maker is only concerned about the economic costs for the next 30 years (2010-2040). Any economic cost incurred after 2040 is negligible. • Australian producers are price-takers on global markets, not price-setters. • The pest infestation happens only in Australia. No other major market contributor is affected by an incursion of the same pest at the same time. • The domestic market for the potentially affected commodity is perfectly competitive. • Transaction costs for Australian producers enter the export market are negligible. • There are measures (i.e. phytosanitary requirements) in place to restrict foreign producer access to the Australian market in order to protect area freedom from EPPs. • Production is restricted by the total area of production. Producers can not expand the amount of production in the short-run in response to upward price movements (i.e. supply elasticity = 0). • Demand elasticity is constant, and consequently the demand curve is non-linear. • Total market value without infestation remains constant over the simulation time.

3.8.2. Infestation

The first step in creating an economic model to examine the significance of exotic pest threats involves a biological model of spread. This spread happens at both farm and country level in our model. Two key assumptions made to model the spread are: (1) once an invasive species becomes established it becomes *naturalised* if no control measures are taken against it, spreading to the extent dictated by carrying capacity of the Australian environment (recall this assumption from section 3.7); (2) Spatial homogeneity is assumed in the sense that different host plants and farms, in spite of their different micro-environment (location, elevation, temperature, water etc), have the same likelihood of being infested.

3.8.2.1. Local infestation at farm level

In year t, the infested host plant population is calculated as the sum of that population in last year (year t-1) and the newly infested one, which is the difference between local infestation and infested hosts that are eliminated by control efforts:

$$infested\_host\_population_{t} = infested\_host\_population_{t-1} + local\_infestation_{t} - local\_control_{t} \quad (9).$$

In modelling local infestation, the model assumes that the population grows following a logistic function until the carrying capacity of the farm environment is reached. The carrying capacity is defined as the maximum number of hosts that could be potentially infested on a single farm.

$$local\_infestation_{t} = (infested\_host\_population_{t})*(1-infested\_host\_population_{t} /max\_infested\_host)*local\_infestation\_rate \quad (10).$$

3.8.2.2. Spatial infestation at country level

Following the logic of local infestation in section 3.8.2.1, the number of infested farms in year t is estimated as the sum of the infested farms in year t-1 and the newly infested farms, which is the difference between the sum of spatial infestation and new naturalisation and the infested farms detected and eradicated immediately after.

$$infested\_farms_{t}=infested\_farms_{t-1}+(spatial\_infestation_{t}+ expected\_naturalisation\_number_{t})- detection_{t} \quad (11).$$

Where:

$$spatial\_infestation_{t} = total\_infested\_host\_population_{t}*(1-infested\_farm_{t} /max\_infested\_farm)*spatial\_infestation\_rate \quad (12).$$

Here, the assumption of a logistic growth still holds and the carrying capacity is defined the maximum number of farms that could be potentially infested in the whole country of Australia.

In equation (12), $total\_infested\_host\_population_{t}$ is the sum of infested host population at different ages, *t* ranging from age 1 to age 30. The sum of infested host population at a certain age *t* is calculated is given by:

$$total\_infested\_host\_population_{t} = infested\_host\_population_{t} * spatial\_infestation_{t} \quad (13).$$

$Expected\_naturalisation\_number_{t}$ in equation (11) is approximated by the product of probability of entry and establishment (see equation 20 below).

3.8.3. Management

Three management efforts are simulated in the model: local control at farm level, and detection and eradication at country level. Their mechanisms and thresholds are summarised in **Table 7**.

Local control refers to all management activities that farmers engage in (chemical spray, biological control etc.) after a certain percentage of their crops is infested (as defined by the parameter of start control threshold in **Table 6**). Central detection is an ongoing process where a portion of Australian farms are inspected randomly. When an infested farm is found eradication immediately follows and the area of that farm will be deducted from the total production land in the country.

The model assumes that local control will stop when eradication starts. Both detection and eradication though, will not be terminated until it is too expensive to do so. A parameter called *central control choke price* is developed to indicate this point of "can not afford any more".

Table 7. Mechanism and thresholds for management efforts

	Control	Detection	Eradication
How?	By eliminating infested host plants	By randomly inspecting farms	By eliminating infested farm land from production area
When to start?	When density of the infested hosts exceeds the "start control threshold" parameter (Table 6) and when eradication stops	Year 1 and on-going	As soon as an infested farm is detected
When to stop?	Ongoing	When giving up eradication	When total eradication cost exceeds the "central control choke price" parameter (Table 6)

3.8.3.1. Local control at farm level

The $local\_control_t$ in equation (9) above is modelled as:

$$local\_control_t = infested\_host\_population_t \ * \ local\_control\_level_t \qquad (14)$$

Where:

$$local\_control\_level_t = \text{IF } fraction\_infested_t > start\_control\_threshold \text{ THEN } control\_tech\_effectiveness \text{ ELSE } 0 \qquad (15)$$

When the density of infested host plants ($fraction\_infested_t$) is larger then the "start control threshold," the local control level is dictated by the parameter called "control tech effectiveness" (**Table 6**). Unlike central detection, which is active as long as it is still affordable, farmers do not check for infestation as part of their routine activities. So the local control is not switched on until the central control terminates.

3.8.3.2 Central detection and eradication at country level

The $detection_t$ in equation (11) is given by:

$$detection_t = infested\_farm_t * \ prob\_of\_detection\_per\_farm_t \qquad (16)$$

Where,

$$\text{prob\_of\_detection\_per\_farm}_t = 1 - \text{EXP}(-\text{expected\_detection\_\#\_per\_farm}_t)^{25} \quad (17)$$

and where:

$$\text{expected\_detection\_\#\_per\_farm}_t = \text{infested\_host\_population}_t *$$

$$\text{proportion\_of\_area\_inspected} * \text{detection\_prob\_if\_inspected} * \text{search\_efficiency} \quad (18)$$

Equations (16) – (18) show that the number of eradicated farms will never be larger than than of infested farms. This is because our capability to detect and eradicate is constrained by proportion of area inspected (determined by inspection budget in the model), detection probability and search efficiency.

3.8.4 Economic costs

The model simulates both market revenue losses and increased management expenditures incurred as a result of EPP incursions. These two broad cost categories can be further divided into four key economic costs: market cost, inspection costs, control costs and eradication costs.

Market cost or revenue loss is comprised of direct losses of marketable product. Despite incorporating an invasive control and eradication program into normal management practice, a certain amount of production loss may still occur through the effects of an introduced organism. This effect may be as high as 100 per cent in some cases, while in others it may be negligible.

Inspection costs are reflected in the total budget allocated for surveillance activities related to an EPP. This is increased after infestation occurs.

Control costs are incurred as a result of additional management activities beyond those normally employed as part of the production process that are necessary to minimise crop damage from an EPP. Depending on the nature of the EPP concerned this may involve chemical applications (including additional vehicle and labour costs), and/or biological control techniques[26].

Eradication cost refers to the total expenses of removing infested production units (i.e. farms) from the system[27], and include expenses related to habitat manipulation and quarantine activities.

We calculate Net Present Values (NPV) of future invasion damages for these four economic costs using the technique of discounting.

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[25] The underlying assumption here is that probability of detection follows a Poisson distribution, where detection probability is constant per increment of time. If we define $F(t)$ as the probability that an event will occur before time t, we then have $F(t) = 1 - \exp(-kt)$, where k is the mean number of events per unit of time (Vose 2008, p. 180).

[26] No attempt is made to predict the development and availability of new and improved control agents for resistant pests, the likely cost of these products and the capacity of pest species to develop resistance to them.

[27] The model assumes the eradicated farms are immediately replanted. After a certain number of years (as defined by the parameter of time out of production), these farms become productive again. Another assumption made is infestation doesn't happen on immature land.

3.8.4.1 Discounting

Costs resulting from invasions that occur in the future, but are considered in the current time period, have a discount rate attached to them which erodes their present value. The discount rate is the rate of interest at which cash flows are to be discounted to reflect their opportunity cost. Any investment that takes place in the present necessarily means future investment opportunities have effectively been forfeited. Economists use the process of discounting to account for these opportunity costs. The Net Present Value (NPV) of a stream of expected damage resulting from a particular species becoming established in Australia over time is determined by summing the discounted benefits in each individual time period, *t* (i.e. year). This provides a decision-maker deciding whether or not to invest in this activity with a single, comparable measure of its desirability compared to other potential investment opportunities.

In the absence of clear information on opportunity costs relevant to a specific project (e.g. like the control of an invasive species), economists usually cite government guidelines which recommend a standard discount rate. For instance, in Australia the cited rate consists of a margin of 3% on top of a real risk free rate of 5% (Department of Finance 1991). This risk free rate, applying to streams of uncertain benefits adjusted for the cost of risk-bearing to risk-averse individuals, can be revised downwards to reflect a precautionary attitude to radical ecosystem changes (Cook et al. 2007). When applied uniformly to pest and disease impacts any positive discount rate erodes future values, thus affecting investment decisions made over multiple time periods.

The discounted future cost in year *t* is calculated as:

discounted_future_cost= future _cost/(1+discount_rate) ^ discounting_time (19).

The discounting time follows a gamma distribution which was used to estimate the time required for an event to occur (in our case, the naturalisation of an exotic species), given that event occurs randomly in a Poisson process (recalling footnote 25).

Expected number of naturalisations per year is required to calculate the discounting time. We used probability of naturalisation to approximate the expected naturalisation number in our model. This approximation is legitimate for events with small probability such as pest naturalisation.

expected_naturalisation_number = probability_of_entry*probability_of_establishment (20)

3.8.4.2. Market cost

Market cost is calculated as the difference of market value before[28] and after infestation occurs.

market_cost = market_value_without_infestation-market_value_with_infestation (21)

Estimation of market value without infestation is based on statistical data[29], and market value with infestation is a sum of market value of domestic and export markets in the model.

---

[28] Currently the model assumes market value without infestation remains constant over the simulation time of 30 years. For a fast-growing industry such as olive industry, this constant is based on the point estimate of the most recent statistical data (2006/07). For other industries, this constant is based on the average of the last five year's statistical data (2002/03 to 2006/07).

market_value_with_infestation= domestic_value + export_value (22)

In both markets, value is a product of price and quantity for sale. For export market, the model assumes Australian producers are price-takers. This is because the contribution of domestic producers of a certain affected commodity (e.g. olive) to total world supply is insufficient to exert influence on the world price, the exchange rate and domestic markets for other commodities.

Though the export market price remains the same after infestation happens (and only happens) in Australia, the domestic price after infestation is affected by two factors that have opposite effects, as shown in **Figure 10**. On one hand, some export markets stops purchasing from Australia in the fear of importing biosecurity risk[30], which results in more for sale for the domestic market and consequently a lower price. On the other hand, yield loss due to infestation[31] means there is less for sale for the domestic market, which indicates an increased domestic price.

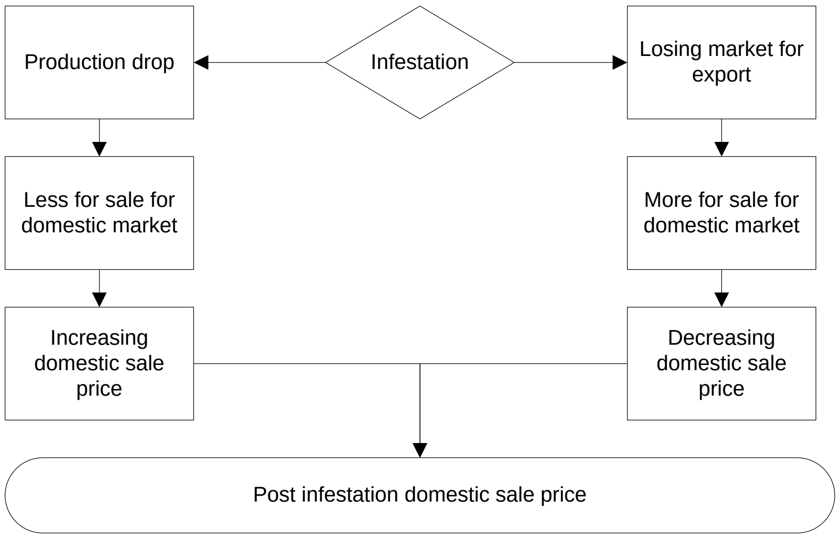

Figure 10. Two counteractive factors that affect post-infestation price for domestic sale.

[29] The model assumes market value without infestation remains constant over the 30 years of simulation time.

[30] In many cases the loss of pest-freedom status can have a profound impact on export revenue since the ability to sell products to markets around the world is compromised. This does not necessarily mean that all exports of an affected commodity are lost. Although high-priced markets may be lost, the good can often be sold to 'second-best' markets where a lower price is received. The subsequent loss of earnings represents a cost associated with an invasive species' naturalisation.

[31] The model doesn't simulate revenue loss due to quality drop for the produce. Infestation could have two effects on produces: yield loss and quality loss. Only the former is included in the model so from this perspective the market cost figure of the model should be regarded as an underestimate of the true cost. One example of the quality drop is that pomegranate still fruit after infestation but its quality is not good enough for retail but might still be acceptable for juicing.

In this section the concept of 'elasticity' is important. The degree to which the price of a host commodity changes in the model in response to changes in supply is determined by that commodity's demand elasticity. Similarly, the assumed elasticity of supply determines the responsiveness of the quantity of a commodity supplied to changes in prevailing market price[32]. In calculating the post-infestation price for domestic market, we assume a constant demand elasticity until a choke price (determined by domestic choke price multiplier) is reached, at which point demand falls to zero.

The post-infestation price for domestic sale is given by:

postinfest_domestic_price=(demand_coefficient/postinfest_domestic_sale/preinfest_domestic_sale/supply_coefficient)^(1/(supply_elasticity-demand_elasticity)) (23).

In estimating postinfest_domestic_sale in equation (23) the model assumes agricultural produce will always be first sold in the market with the higher price. For instance, if Australia's pest area freedom is protected through the implementation of costly market access requirements (such as sampling, chemical dipping or vapour heat treatment, for example), it may be that the resultant lack of competition from international suppliers means that domestic producers can earn higher prices in the domestic market. On the other hand, if export markets attract higher prices than the domestic market, producers will supply to foreign markets in preference to servicing domestic demand[33]. As circumstances regarding area freedom change over time, price differentials between the domestic and international markets can change. If, for example, Australia were to lose its area freedom from a pest as a result of an outbreak that can not be eradicated, domestic producers may be restricted from several export markets and therefore switch their supply to the domestic market. This will of course exert downward pressure on the domestic price as supply to this market increases.

The model makes three more assumptions in calculating the post-infestation price and demand in the domestic market. Firstly, we assume that there is perfect competition among domestic producers of the potentially-affected commodity, implying product homogeneity. Secondly, there is no transaction cost associated with Australian producers entering an export market. In other words, there are no impediments to selling produce in whichever market has the higher price. Thirdly, as indicated above, we assume that foreign producers that do not enjoy the same pest area freedom status as Australia face quarantine barriers when exporting goods to the Australian market.

3.8.4.3. Management costs

As demonstrated by equation (15), the local control level is dictated by the parameter called "control tech effectiveness," when the density of infested host plants is above the "start control threshold." The local control cost, is calculated as:

$$control\_cost_t = cost\_of\_control\_technique * affected\_area_t \quad (24).$$

Where:

$$affected\_area_t = infested\_farms_t * average\_farm\_size \quad (25).$$

---

[32] We assume an elasticity of supply of 1.0.

[33] We assume that Australian producers are relatively small in terms of their contribution to global supply of plant products, and therefore exert minor pressure on world commodity prices. They are therefore said to be 'price-takers'.

Eradication cost is simulated as a product of total area of detection and the parameter of average eradication cost per ha.

$$\text{eradication\_cost}_t = \text{area\_detected}_t * \text{cost\_of\_eradication} \quad (26).$$

Where:

$$\text{area\_detected}_t = \text{total\_detections} * \text{average\_farm\_size} \quad (27).$$

Here total_detections is determined by summing detections (equation (11)) across infestations of different ages.

3.8.5. User interface

Risk communication is paramount if the results of quantitative bioeconomic models such the one described above, are to be considered in decision-making processes by diverse groups of stakeholders/policy-makers. As such, the bioeconomic model interface was designed to be used in a facilitated group environment in order to generate discussion as well as increase group comprehension. The model was constructed with the aim of providing species-specific impact simulations over specified time periods. Hence, a workshop in which species are to be prioritised in order of their expected impact requires a number of different models, one for each EPP being considered. A user-friendly interface allowing real-time interaction through display, questions, and scenario building was incorporated into the model.

Upon opening the model in a workshop (i.e. DMCE stakeholder group) environment, the user/facilitator is greeted by a simulation dashboard, shown in **Figure 11**. As a default setting, this dashboard displays the key output of the model, total invasion cost (i.e. sum of revenue losses, inspection costs, control costs and eradication costs as defined in section 3.8.4 Economic costs), and a range of menu options, dials, indicators and controls. From this initial position within the model the workshop facilitator can clearly demonstrate the impact of different parameters on this output by manipulating the relevant control(s) and re-running the model in real time. A single model re-run can be used, although multiple runs are recommended due to the uncertainties in the invasion process described repeatedly in this report.

Using the dashboard, workshop participants can pose different model-related questions or build specific scenarios that relate to either their organisation's experience or more generally to the group. These may include multiple parameter changes with a compounding effect, such as the *Double Trouble* scenario outlined below (**section 3.9.9.4.**) in which a pest spreads faster than expected (high spatial infestation rate) while not being adequately budgeted for (low management cost/pre-inspection budget). The model can then be run in real-time by control buttons that include simple play, pause, stop and reset options.

In addition to the input dials and slide bars, other model setting can also be easily altered according to the needs of a particular decision-making group. These include sensitivity analysis options, and stochastic or deterministic model settings. Although the default output graph display is set to total invasion costs over time, this feature in fact has embedded within it four additional paginated graphs relating to each component of total invasion cost that can be scrolled through at will. So, the additional graphs include Market Cost, Inspection Cost, Control Cost, and Eradication Cost.

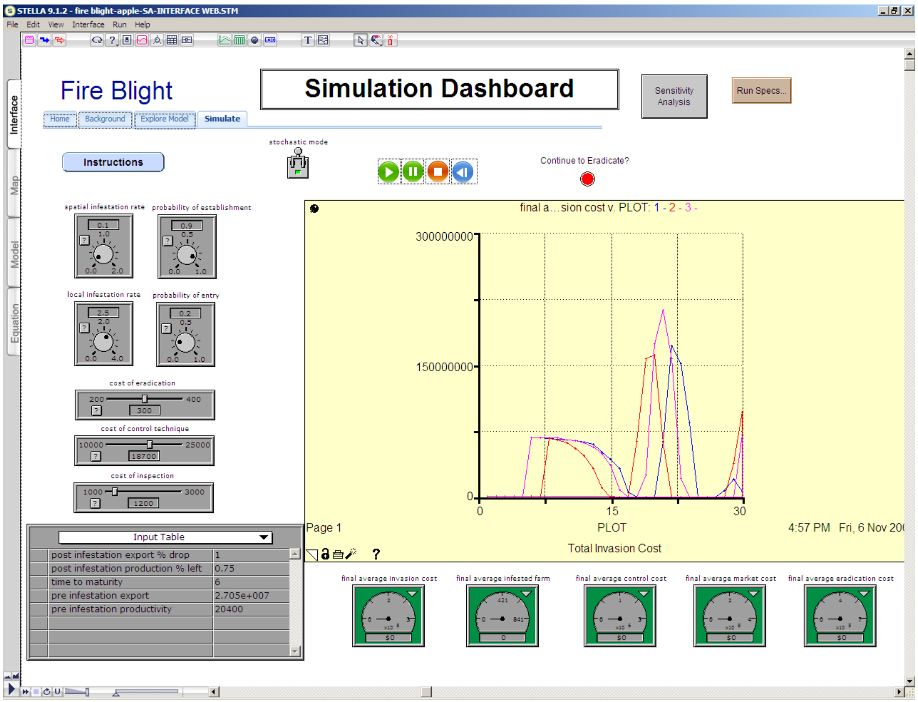

Figure 11. Simulation dashboard

Output gauges/dials calibrated to each of these outputs project a green signal for low level/low concern output levels, amber for moderate levels or red warning signals when certain thresholds are exceeded. In addition, a warning light displays green, amber or red during model runs to indicate whether or not EPP eradication should continue.

The interface features a website-style menu where background and context can be accessed for a particular EPP (**Figure 12**) as required. An overview of the model structure is also accessible to aid in conceptual discussions, parameter definition and output explanation (**Figure 13**).

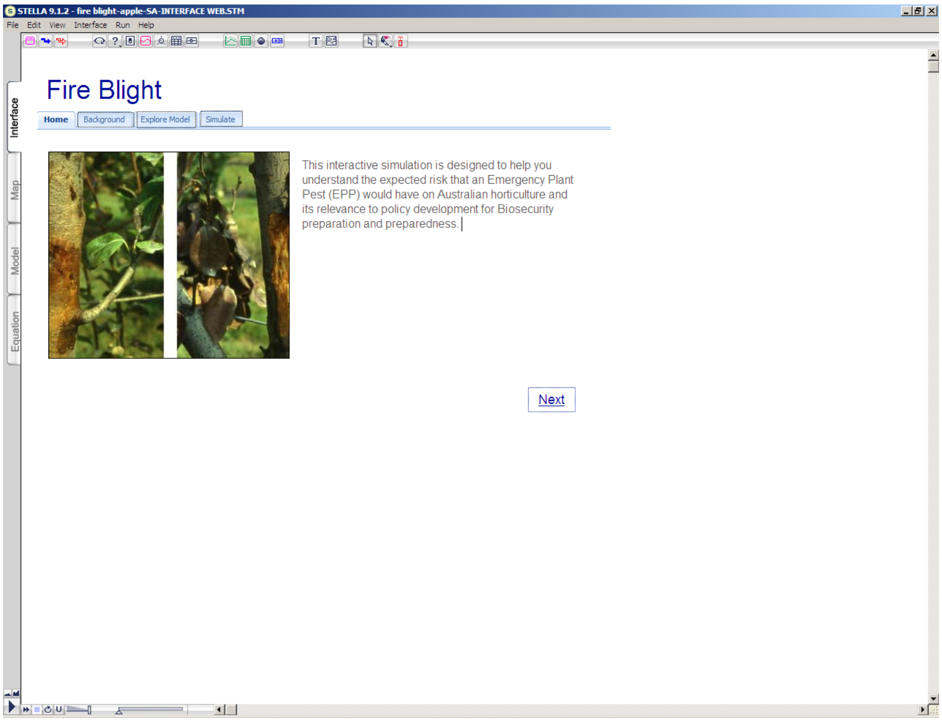

Figure 12. Menu features

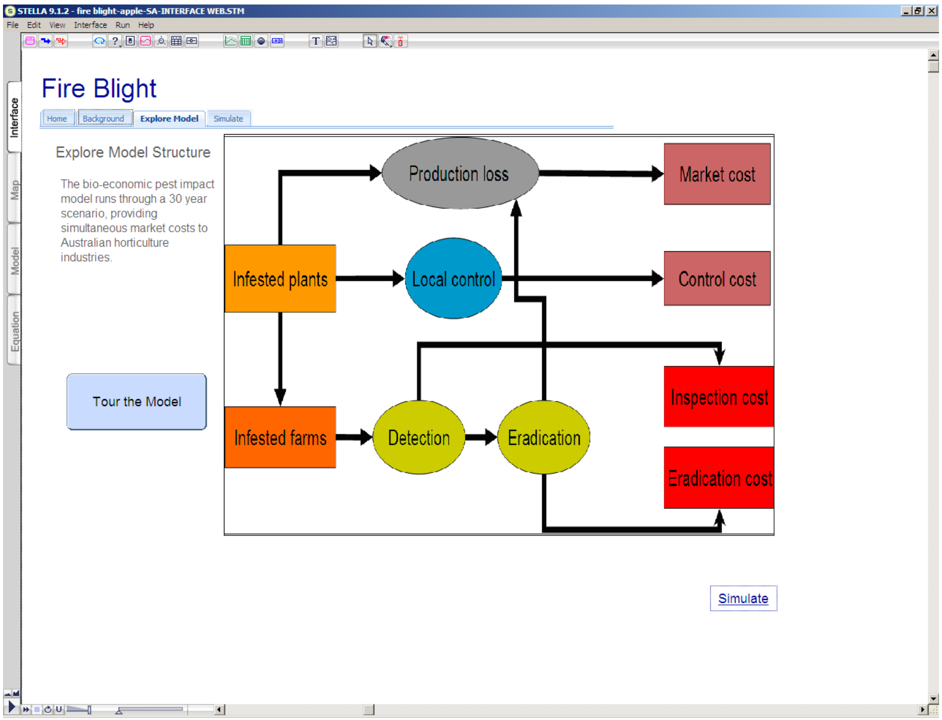

Figure 13. Schematic model structure

3.9. *Quantitative impact simulation results*

We present modelling simulation results for six key outputs: NPV of inspection cost ($), eradication cost ($), control cost ($), market cost ($) and total invasion cost ($) over 30 years and the number of infested farms at the end of the simulation period[34].

Two points should be noted when interpreting the model outputs. Firstly, the five economic costs are cumulative over time, yet we only report the point estimate at year 30, the biggest number of the time series. **Figure 14** below demonstrates the cost increase overtime. However, this feature of monotonic increase is not necessarily shared by the time-series of infested farm numbers. The number of infested farms can either mostly increase (**Figure 15**) or zigzag (**Figure 16**) over time. This is because the change of infested farms is co-determined by the numbers of spatial spread, new naturalisations and eradicated farm (Equation (11)). When this change is negative, the number of infested farms drops.

Secondly, we report point estimates because they are the clearest way to present results, especially for the purpose of compiling priority list (e.g. **Table 8**). However, point estimates can mask important details in the simulation results and cause misunderstanding. For instance, we report the number of infested farms in year 30, which as Figure 18b shows, may not be the biggest for the time series. In addition, all the results are averages across 1,000 iterations of the model which can hide extreme events such as that shown in **Figure 17** below.

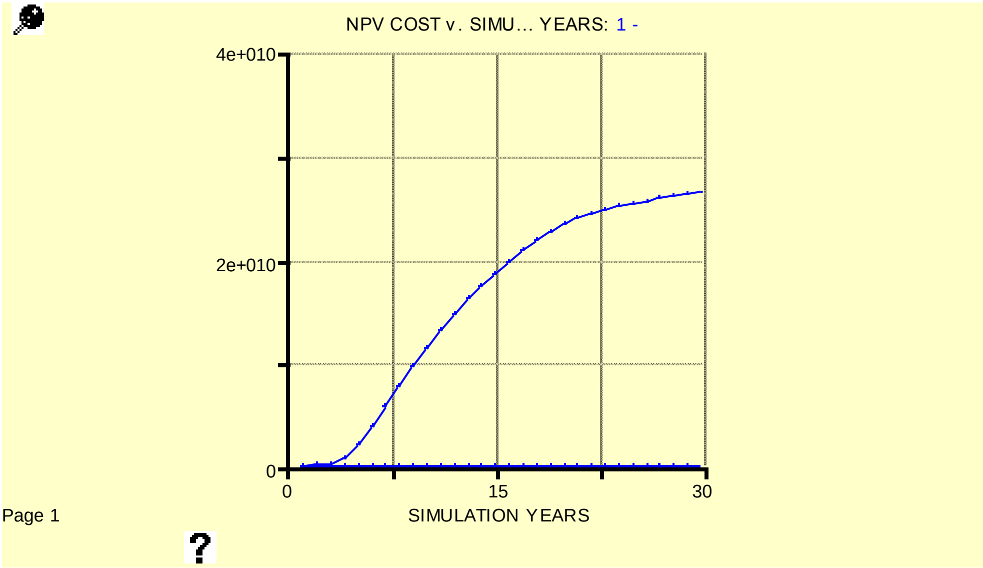

Figure 14. Total discounted market cost over time.

[34] The number of infested farms at the end of the simulation period is not the same as the total number of infested farms during that period. After replanting, those farms that are infested (then detected and eradicated from production land) in earlier stage of simulation will be in in production again and therefore, they might be infested again. Their first infestation will not be taken into account for the number of infested farms at the end of year 30.

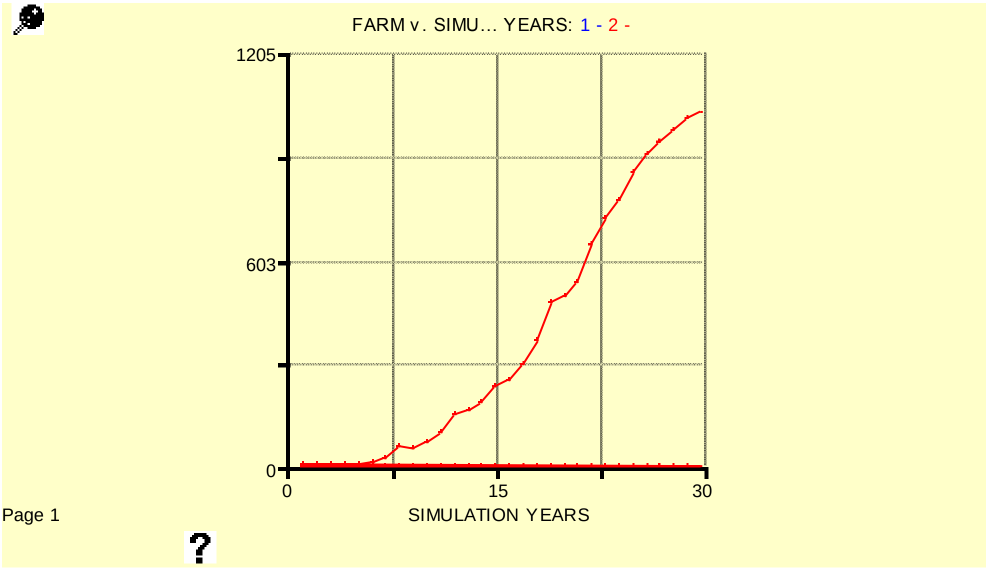

Figure 15. The general increase of infested farms over time.

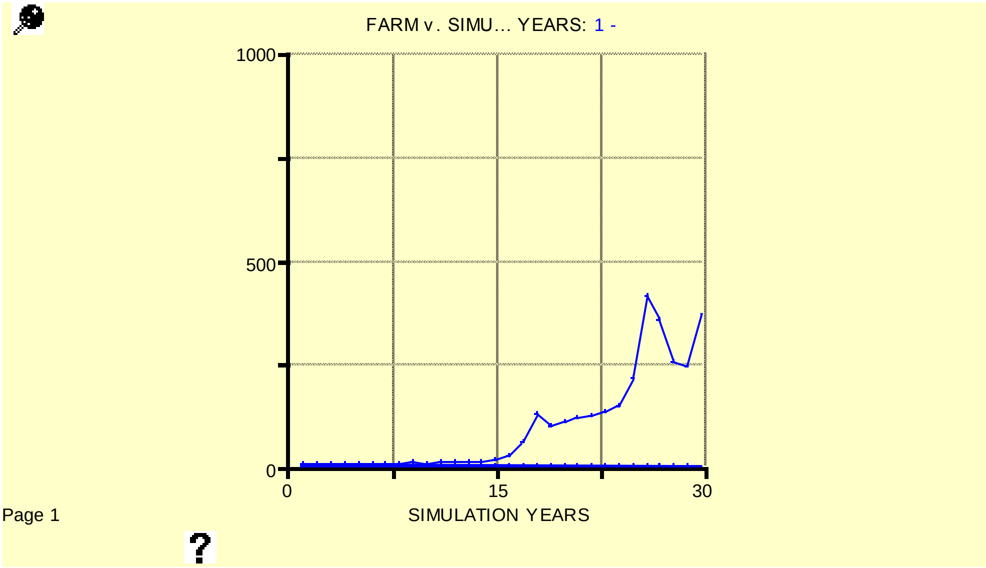

Figure 16. The change of infested farms over time.

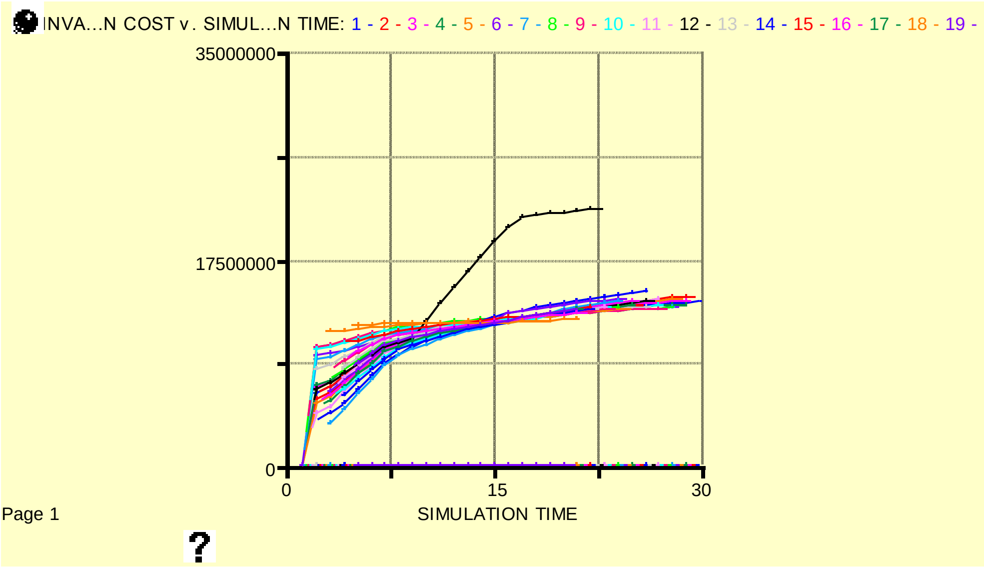

Figure 17. The total invasion cost of an extreme run in compassion to those of other non-extreme runs.

With these points in mind, we now move on to the results of impact simulations for pests of significance to specific industries.

3.9.1. Apple

For each EPP with apple as its potential host, we present the corresponding NPVs of inspection cost, eradication cost, control cost, market cost, total invasion cost for 30 years (2010 to 2040) and the number of infested farms in year 30.

Table 8. The NPVs of expected economic costs for the 30 year period (2010-2040) and the number of infested apple orchards in year 2040

EPP	Inspection Cost ($ million)	Eradication Cost ($ million)	Control Cost ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Fire blight	28	8	116	381	533	1,047
Apple maggot	3	0	0	487	490	27
Apple aphid	2	0	0	144	146	1
Rosy apple aphid	3	0	0	479	482	16
Black borer	23	1	0	311	335	19
Oriental fruit fly	1	3	98	845	947	1,205
Leopard moth	7	1	1	383	392	258
Pear leaf blister moth	2	0	1	255	258	67
Blister canker	20	1	1	176	198	178
Japanese apple rust	18	1	2	100	121	91
European canker	20	4	16	436	476	1,188
Brown rot	30	5	9	400	444	762
Apple blotch	19	0	0	38	57	13

If we rank the EPPs by their expected invasion costs, rosy apple aphid tops the list with the biggest NPV of $950 million over the next 30 years. **Table 9** presents the rank of the rest of the EPPs, and this table can function as a priority list for managing apple industry's biosecurity risk. The higher an EPP's position is on this list, the bigger effort should be made in mitigating the risk posed by that pest. Caution should be exercised when using this list, however, as it is derived from the set of modelling assumptions (Box 3) and most-likely parameters detailed in Appendix 1. These in turn have been put forward after reviewing available literature and scientific knowledge, summarised in the data sheets in Appendix 2. As we will demonstrate in the later section of this report, changing these modelling assumptions and parameter values may lead to changes in the results and subsequently the order of the priority lists.

Table 9. Rank of the apple industry's economic risk (as measured by expected total invasion cost) posed by 13 EPPs.

EPP	Rank
Oriental fruit fly	1
Apple maggot Rosy apple aphid Fire blight European canker	2
Brown rot	3
Leopard moth	4
Pear leaf blister moth	5
Black borer	6
Blister canker	7
Apple aphid Japanese apple rust	8
Apple blotch	9

In the following sections, we will follow the same format by presenting two tables of modeling outputs and priority list for each industry.

3.9.2. Pear

Table 10. The NPVs of expected economic costs (2010-2040) and the number of infested pear orchards in year 2040.

EPP	Inspection Cost ($ million)	Eradication Cost ($ million)	Control Cost ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Fire blight	9	2	49	59	119	676
Apple maggot	1	0	0	66	67	8
Apple aphid	1	0	0	0	1	1
Rosy apple aphid	3	0	0	500	503	11
Black borer	7	0	0	1	8	14
Oriental fruit fly	0	1	32	280	313	731
Leopard moth	3	0	1	29	33	159
Pear leaf blister moth	1	0	2	28	31	53
Pear psylla	1	0	0	7	8	9
Black spot	7	0	0	1	8	16
Blister canker	1	0	0	2	3	36
European pear rust	7	0	1	19	27	61
European canker	8	2	6	180	196	722
Brown rot	10	2	4	170	186	599

Table 11. Rank of the pear industry's economic risk (as measured by expected total invasion cost) posed by 14 EPPs.

EPP	Rank
Rosy apple aphid	1
Oriental fruit fly	2
European canker Brown rot	3
Fire blight	4
Apple maggot	5
Leopard moth Pear leaf blister moth European pear rust	6
Black spot Black borer Pear psylla	7
Blister canker Apple aphid	8

3.9.3. Potato

Table 12. The NPVs of expected economic costs (2010-2040) and the number of infested farms in year 2040 for the potato industry.

EPP	Inspection Cost ($ million)	Eradication Cost ($ million)	Control Cost ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Turnip moth	1	12	34	401	448	1,224
CPB	1	13	27	307	348	1,115
Potato leafhopper	1	4	18	87	110	297
Cotton leaf worm	1	15	37	474	527	1,010
Potato rust disease	6	13	74	280	373	1,172
Potato smut disease	11	6	0	116	133	70
Potato spot disease	10	7	0	69	86	53
Potato black blight disease	7	12	39	343	401	1,050
Potato wart disease	10	0	0	102	112	1

Table 13. Rank of the potato industry's economic risk (as measured by expected total invasion cost) posed by 9 EPPs.

EPP	Rank
Cotton leaf worm	1
Turnip moth	2
Potato black blight disease Potato rust disease CPB	3
Potato smut disease Potato wart disease Potato leafhopper Potato spot disease	4

3.9.4. Broccoli

Table 14. The NPVs of expected economic costs (2010-2040) and the number of infested farms in year 2040 for the broccoli industry.

EPP	Inspection Cost ($ million)	Eradication Cost ($ million)	Control Cost ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Cabbage looper	0	3	20	120	143	838
Cabbage moth	0	2	20	125	147	871
Texas root rot	1	1	0	18	20	149
Anthracnose	0	3	28	157	188	892

Table 15. Rank of the broccoli industry's economic risk (as measured by expected total invasion cost) posed by 4 EPPs.

EPP	Rank
Anthracnose Cabbage moth Cabbage looper	1
Texas root rot	2

3.9.5. Cauliflower

Table 16. The NPVs of expected economic costs (2010-2040) and the number of infested farms in year 2040 for the cauliflower industry.

EPP	Inspection Cost ($ million)	Eradication Cost ($ million)	Control Cost ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Cabbage looper	0	1	10	73	84	386
Cabbage moth	0	1	10	74	85	376
Texas root rot	0	0	0	3	4	84

Table 17. Rank of the cauliflower industry's economic risk (as measured by expected total invasion cost) posed by 3 EPPs.

EPP	Rank
Cabbage looper Cabbage moth	1
Texas root rot	2

3.9.6. Lettuce

Table 18. The NPVs of expected economic costs (2010-2040) and the number of infested farms in year 2040 for the lettuce industry.

EPP	Inspection Cost ($ million)	Eradication Cost ($ million)	Control Cost ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Cabbage looper	0	2	10	39	51	901
Cabbage moth	0	3	19	132	144	915
Texas root rot	1	1	0	6	8	159

Table 19. Rank of the lettuce industry's economic risk (as measured by expected total invasion cost) posed by 3 EPPs.

EPP	Rank
Cabbage moth	1
Cabbage looper	2
Texas root rot	3

3.9.7. Carrot

Table 20. The NPVs of expected economic costs (2010-2040) and the number of infested farms in year 2040 for the carrot industry.

EPP	Inspection Cost ($ million)	Eradication Cost ($ million)	Control Cost ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Cabbage root fly	0	3	15	494	512	336
Cabbage looper	0	2	5	13	20	319
Cabbage moth	0	3	16	166	185	328
Crater rot	1	1	0	69	71	36
Texas root rot	1	0	0	0	1	9

Table 21. Rank of the carrot industry's economic risk (as measured by expected total invasion cost) posed by 5 EPPs.

EPP	Rank
Cabbage root fly	1
Cabbage moth	2
Crater rot	3
Cabbage looper Texas root rot	4

3.9.8. Onion

Table 22. The NPVs of expected economic costs (2010-2040) and the number of infested farms in year 2040 for the onion industry.

EPP	Inspection Cost ($ million)	Eradication Cost ($ million)	Control Cost ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Onion fly	0	2	9	332	343	582
Cabbage moth	0	2	13	115	130	565
Cabbage looper	0	2	5	4	11	551
Cladosporium leaf blotch	0	2	6	0	8	582
Onion leaf blight	0	2	21	172	195	582
Onion bacteria blight	0	2	15	101	118	582

Table 23. Rank of the onion industry's economic risk (as measured by expected total invasion cost) posed by 6 EPPs.

EPP	Rank
Onion fly	1
Onion leaf blight	2
Cabbage moth Onion bacteria blight	3
Cabbage looper Cladosporium leaf blotch	4

Box 4. Model Applicability Across Taxa

Biological parameters in risk analysis models are the key elements in assessing impacts of any pest. Taxonomic classification divides pests into a number of taxa, mainly based on biology. However, there are common biological parameters among some taxa along with group-specific parameters. Depending on the objective, both common and specific parameters can be used to build a generic or specific model for risk analysis. For example, reproductive nature, survival capacity, spreading and infection mechanisms, management methods etc. are common biological parameters used in the model for pest belongs to same or similar taxa. However, selection of appropriate parameters that represent a similar group of pest is an important task for the biologist in modelling work.

In general insects, fungi and bacteria follow the same pattern of introduction, spread and infection, and control mechanisms, with some exceptions. For example, in soil-borne fungi these mechanisms resemble those of nematodes rather than other fungi. The virus taxon greatly differs from these other taxa in terms of its reproduction, spread mechanism and management issues, e.g. vector and host resistance are two essential components of viral spread and management that are unlike insects, fungi and bacteria. Therefore, the biological parameters for viral disease would be different to other pests and diseases.

For a reliable and consistent outcome of a risk analysis model, application of parameters that reflects a similar pattern of biology of the pest among the taxa is essential. The usual difference within the species and taxon can be addressed with different parameter values depending on biology of the pest, host nature, and many other factors that contribute to the system. A single parameter set is unable to accommodate taxa with a greatly different biological behaviour and would result in an inaccurate outcome of the model. For instance, the taxon that represents the viral group would not be suitable for risk analysis using the same parameter set for taxa such as fungi, insects and bacteria. This is due to the mechanism of viral spread, which requires vectors, and that management also heavily depends on host resistance rather then chemical application as for other taxa. However, addition/modification in the parameter sets could accommodate any new taxon; for example, the case of a taxon that represents nematodes needs few modifications in the parameter set before its application is suited to soil-borne fungi, which have similar modelled behaviours although they are evolutionarily distant.

3.9.9. Sensitivity analysis

Predicting bio-invasion impact is made difficult by inherent uncertainties. For instance, uncertainties can arise from limitations in knowledge (e.g. how an EPP will behave in the Australian environment), from randomness due to the stochastic nature of the biological invasion system (e.g. spatial spread of the EPP) and from human actions (future prices of the agricultural produces in global markets).

Reducing or eliminating these uncertainties is very difficult. An explosion of uncertainty inevitably arises when an impact assessment model aims to inform decision-making in prioritising EPPs because the uncertainties accumulate from the various levels of assessment. Moreover, when dealing with exotic pests, many have never been observed in the Australian landscape before. It follows that our model projections of future bio-invasion impacts represent extrapolations in to states of the system that have never before existed, making it impossible to calibrate the model for the forecast regime of interest.

Despite this limitation, the predictive modelling exercise embarked upon in this project serves a key purpose. The model itself organises data and synthesises our knowledge of complex bioeconomic systems. These systems are characterised by nonlinearities and spatial and temporal lags that must be reflected in models used for decision support. In building mental models humans often simplify systems by linearising relationships, disregarding the lags, and isolating system components from their surroundings. The dynamic model we present in this report overcomes these limitations. In addition, the model can be employed to explore the implications of a wide range of parameter values

(Appendix 1) and assumptions (**Box 4**) and to identify policy decisions that are less affected by the inherent and irreducible uncertainties.

Below a sensitivity analysis, a commonly-used technique for uncertainty analysis, is adopted to demonstrate how the output of the model (as reported in sections 3.9.1. to 3.9.8.) can be changed as the modelling assumptions and input values vary. The strength of such a technique is that it provides insight in the potential influence of changes in inputs. A limitation though, is the tendency of sensitivity analysis to yield an overload of information (Refsgaard et al. 2007). Therefore, we only present a baseline and *four* case scenarios to illustrate our point that the modelling outputs based on the built-in assumptions and parameter values should not be taken as the ultimate answers, but rather as a guideline within the larger framework of adaptive management (Costanza and Ruth 1998)[35]. In each scenario we use the example of fire blight affecting apples. For any other EPP-host combination, the same technique of sensitivity analysis applies since the model structure is essentially the same across all the combinations.

In case scenario one, we change the model assumption that "A decision-maker is only concerned about the economic costs for the next 30 years (2010-2040). Any economic cost incurred after 2040 is negligible". Instead of focusing on the economic cost of the next 30 years, a decision-maker is interested in EPP's impact of longer term. We therefore name this alternative modelling scenario "Extended Horizon". In case scenario two, the parameter value of central control choke price is decreased. In other words, the government has a smaller budget for eradication according to this modelling scenario termed "Small Government." For the third case scenario, "Relative Optimism," we lower the probability of fire blight entry and establishment in Australia. Finally, case scenario four, "Double Trouble", involves the values of both the "inspection budget pre-1st detection" and "spatial infestation rate" parameters being altered. Note that in case scenarios three and four we demonstrate the compounding effects that can occur with simultaneous multiple parameter changes.

3.9.9.1. Baseline scenario

As a *Baseline* scenario, we assume a policy-maker only looks at the expected impacts of an EPP (in our illustrative example, fire blight) for the period of 2010 to 2040 and any cost beyond 2040 is ignored. Recall from section 3.8.4.1 Discounting (also equation (19)) that an assumed positive discount rate essentially means that one dollar in the future is worth less and less in today's term as time goes by. As **Figure 18** shows, $100 in 30 years' time (2040) equals about $10 2010 with an 8% discount rate (the best-guess value used in our model).

[35] Stella has the capacity to incorporate new information fairly fast compared to other modeling software.

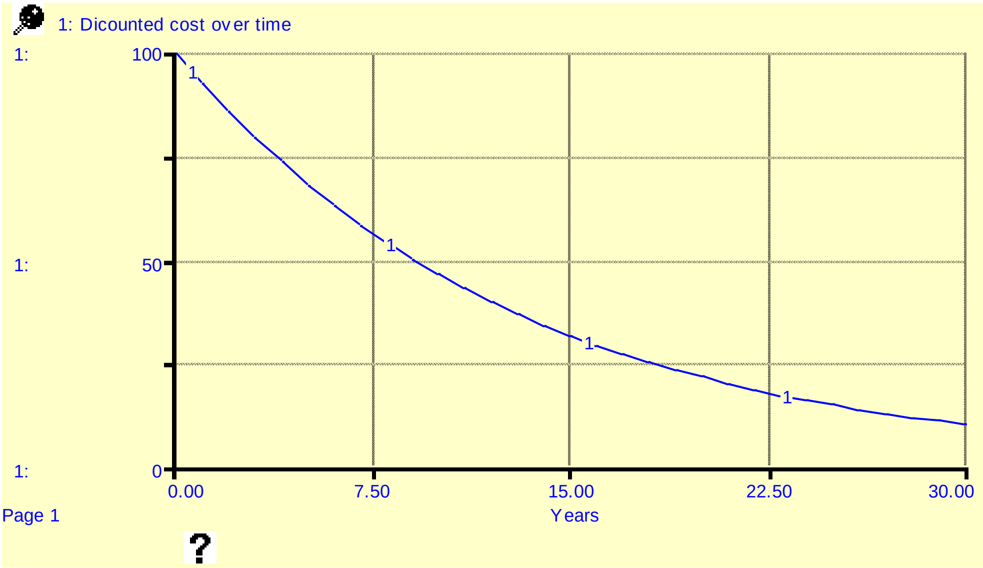

Figure 18. The discounted value of $100 in today's term (8% discount rate).

3.9.9.2. 'Extended Horizon' scenario

In the second scenario we examine, entitled *extended horizon*, a policy-maker will not apply the 2040 cut-off line in considering the EPP impacts. Instead, she/he takes into account the costs in a period of 30 years beginning in the year when infestation occurs in the simulations. For instance, if a model iteration predicts fire blight to arrive in Australia in 2020 the decision-maker considers the costs that this will create until the year 2050. If we compare this to the *baseline* scenario, as in **Figure 19**, the difference between the timelines considered by the decision maker becomes clear. In the baseline scenario costs between 2010 and 2040 are considered, while in the extended horizon scenario (in the example we have given here when fire blight arrival takes place in 2020) the period 2020-2050 is considered.

Based on **Figure 19** we can draw a general conclusion that the later an EPP starts infestation in time, the bigger the difference between the results of the two scenarios. The start time of an incursion in the model is jointly determined by the probability of entry and probability of establishment. The larger the product of these values, the sooner an EPP is likely to arrive.

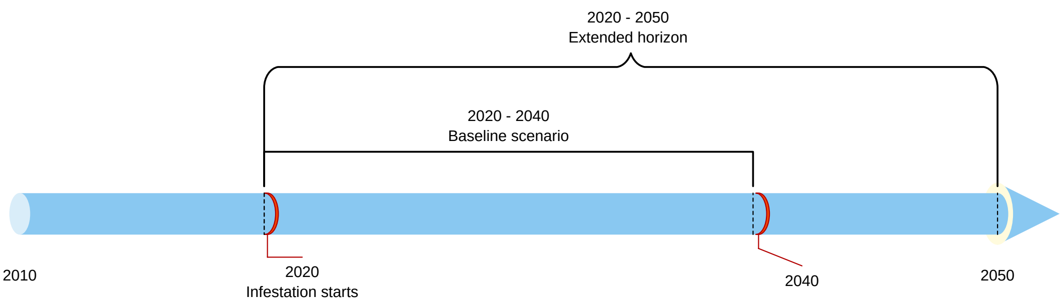

Figure 19. The difference between baseline scenario and extended horizon scenario for an EPP that starts infestion in 2020.

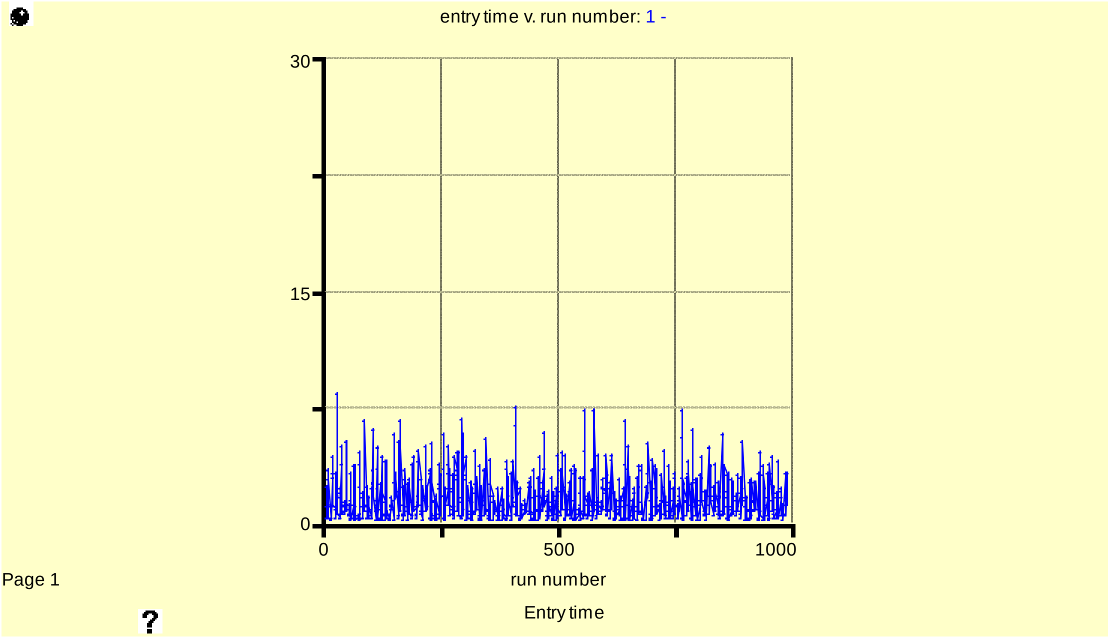

Figure 20. Starting infestation time for fire blight in the *baseline* scenario.

For fire blight the value of this product is fairly large, so simulated incursions have a tendency to start early. In fact, most simulated incursions happen within the first five years, as shown in **Figure 20** which plots the first year of incursion for 1,000 model iterations. It is therefore not surprising to see that the expected impacts of fire blight are similar for both the *baseline* and *extended horizon* scenarios (**Table 24**).

Table 24. Comparison of expected fire blight impact in the *baseline* and *extended horizon* scenarios.

Scenario	Inspection Cost ($ million)	Eradication Cost ($ million)	Control Cost ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Baseline	28	8	116	381	533	1,047
Extended horizon	29	8	126	416	579	1,098

However, this is not necessarily the case for an EPP with very low probability of entry and establishment, such as apple blotch. Compared to the *baseline*, the total invasion cost of this EPP is increased by about 50% for the *extended horizon* scenario (**Table 25**).

Table 25. Comparison of expected apple blotch impact in the *baseline* and *extended horizon* scenarios.

Scenario	Inspection Cost ($ million)	Eradication Cost ($ million)	Control Cost ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Baseline	20	0.09	0.01	40	60	13
Extended horizon	21	0.48	0.14	66	87	332
Relative difference	9%	452%	1,445%	71%	51%	2,533%

3.9.9.3. 'Small Government' scenario

The *central control choke price* parameter determines the cost beyond which governments will give up eradication and inspection. It functions as a threshold that determines the point where central government control (i.e. an eradication campaign) is stopped and local control starts. In other words, from this point on the farmers have to bear the cost of local control by managing the invasive species themselves since eradication is no longer deemed technically or economically feasible. Henceforth, productive land will not be closed for production since surveillance and eradication activities have ceased.

In the scenario of *small government*, the parameter value of central control choke price is one quarter of its value in the *baseline* scenario ($0.1 million per year instead of $4.0 million per year). In the fire blight example, this smaller choke price costs society approximately $75 million (in terms of total invasion cost) over a 30-year period. Apple farmers have to spend $50 million more to manage fire blight at a local level, but a smaller choke price still results in approximately $50 million more in terms of market costs (**Table 26**).

Table 26. Comparison of expected fire blight impact in the *baseline* and *small government* scenarios.

Scenario	Inspection Cost ($ million)	Eradication Cost ($ million)	Control Cost ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Baseline	28	8	116	381	533	1,047
Small government	26	2	167	428	623	1,205

In addition to calculating the point estimate of the expected costs, the dynamic model also enables us to detect whether there is a general trend in the change of dependent variable (in our case, NPV of total invasion cost) as independent variables are altered. Each point in **Figure 21** below corresponds to the result of a single stochastic run where only the value of the choke price is varied (between $1 million to $8 million). In total there are 1,000 points corresponding to 1,000 separate model runs.

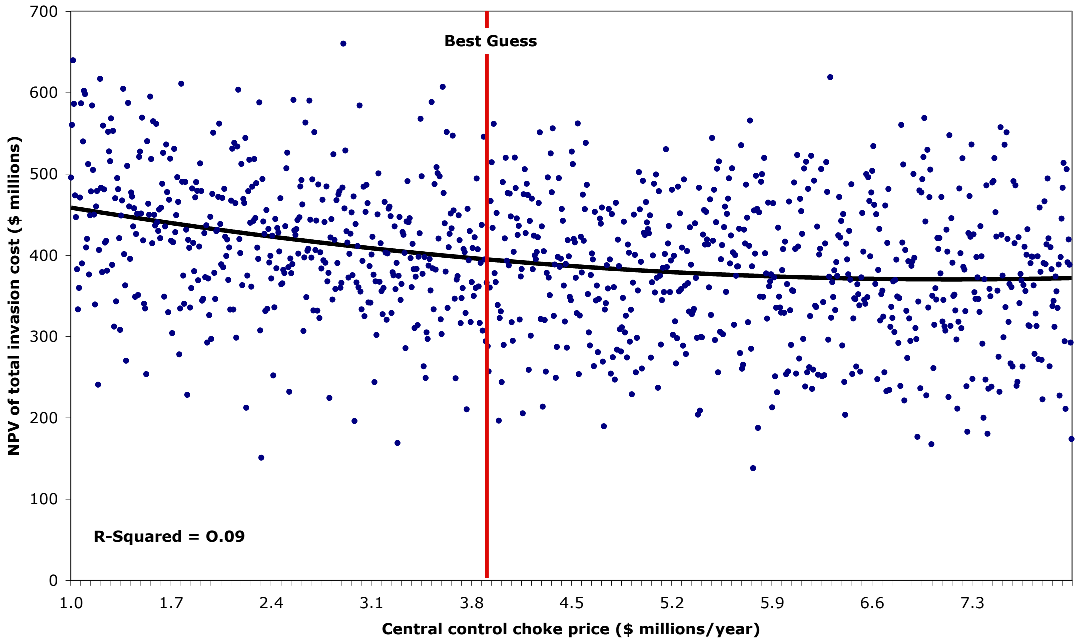

Figure 21. The relationship between central control choke price and total invasion cost.

From **Figure 21** we deduce that increasing the choke price by one dollar has an average effect of reducing the NPV of total invasion cost. But, as indicated by the R^2 statistic, this parameter only explains 9% of the NPV variation in the simulation, with the rest explained by the stochastic processes in the model. So, while an increased eradication budget exerts a negative influence on total invasion cost, the effect is relatively small and is likely to be distorted by other random processes within the model.

3.9.9.4 'Relative optimism' scenario

As mentioned in section 3.9.9.2 (also see equation (20)**, p. 63**), the start time of an incursion is jointly determined by the *probability of entry* and *probability of establishment*. Recall that the larger the product of these two values, the sooner an EPP arrives. For the *baseline* scenario, we assume values of 0.85 for both parameters (PHA, 2009), which implies a time of arrival in Australia of approximately two years (**Figure 20**). Intuitively, this seems high. So, in the *relative optimism* scenario we assume a much later entry time (**Figure 22**. Starting infestation time for fire blight according to the "Relative optimism" scenario.Figure 22) by applying a set of smaller probability figures (i.e. probability of entry 0.18, probability of establishment 0.5).

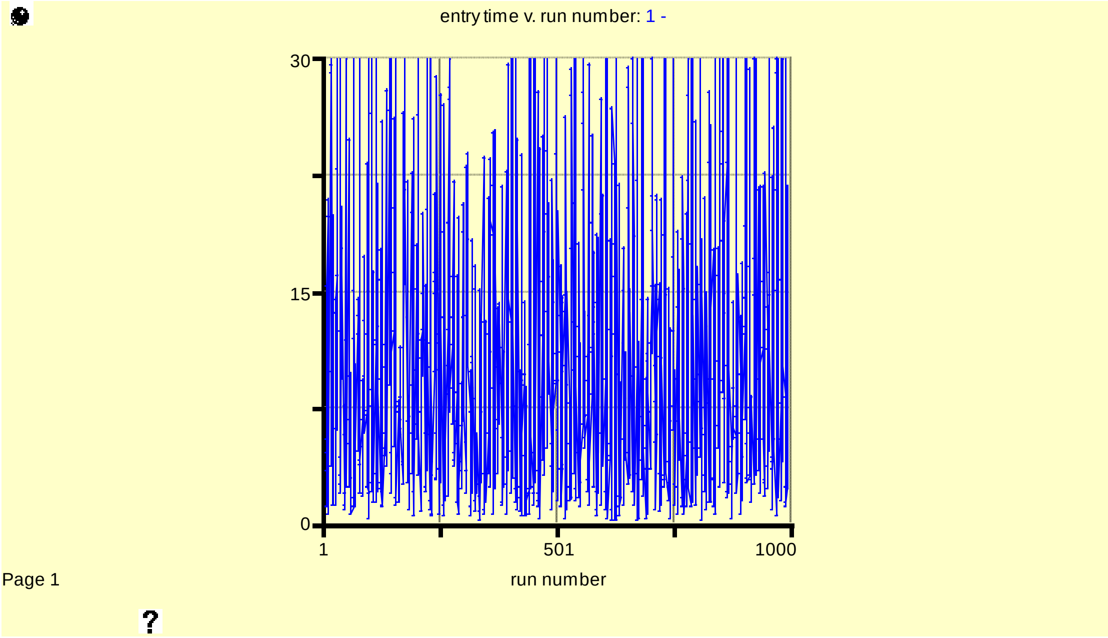

Figure 22. Starting infestation time for fire blight according to the "Relative optimism" scenario.

A later entry time means a larger portion of expected costs will be excluded as we assume decision-makers are only concern with the next 30 years (2010-2040, recalling **Figure 20**). Therefore, the expected risks for the *relative optimism* scenario are consistently smaller when compared to the results of the *baseline* scenario in all measures (**Table 27**).

Table 27. Comparison of expected fire blight impact under the *baseline* scenario and *relative optimism* scenarios.

Scenario	Inspection Cost ($ million)	Eradication Cost ($ million)	Control Cost ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Baseline	28	8	116	381	533	1,047
Supreme optimism	25	4	30	274	333	435

3.8.5.5 'Double trouble' scenario

For the scenario entitled *double trouble* we again alter the values of two parameters at the same time to demonstrate the compounding effects of covariance between them. *Spatial infestation rate*, a parameter measuring how a fire blight can spread between individual farms, is increased to four times its value in the *baseline* scenario (i.e. 0.1 to 0.4). The *Inspection budget pre-1st detection* parameter, which indicates the size of the annual surveillance budget before infestation occurs, is decreased to one quarter of its value in the *baseline* scenario (i.e. $1.6 million per year to $0.4 million).

By jointly changing the values of these two parameters, the *double-trouble* scenario describes an unfortunate situation where fire blight will not only spread a lot faster in Australia than expected, but an initial infestation will not be detected as promptly as in the *baseline* scenario due to the lower inspection budget. **Table 28** shows that in this case fire blight infestation will cost society over $35 million more (over a 30-year period) in terms of total invasion cost. In addition, about 20% more farms are expected to be infested by the year 2040.

However, the expected risks of fire blight in *double-trouble* are not consistently higher on all accounts. A close examination of **Table 28** reveals that inspection cost and market cost are both significantly lower than their *baseline* equivalents. It is perhaps not surprising to note that the former is lower considering the pre-infestation budget is set to a quarter of its value previous value. But, the smaller market cost is not as straightforward to comprehend and deserves some explanation.

The primary reason for a lower market cost under *double trouble* is that less infested apple farms are closed down (i.e. taken out of production entirely). One of the model assumptions (**Box 3, p. 58**) is that all trees within a farm or orchard on which fire blight has been detected will be removed as part of an initial eradication effort. Thereafter, the farm remains out of production and its owner will effectively lose all the market revenue. With a lower inspection budget, however, a smaller portion of apple orchards will be inspected and the corresponding rate of detection declines. Therefore, less market revenue is lost as a result of tree removal following detections.

Despite this, apple farmers are not better-off in the *double-trouble* scenario. While market costs are smaller than under the *baseline* scenario, the industry must spend a great deal more to control fire blight at the farm level (i.e. $100 million over 30 years). Indeed, for every dollar they save in terms of market cost, they must spend two dollars in controlling fire blight on-farm (**Table 28**). So, lowering the inspection budget is not necessarily a good idea for orchardists.

Table 28. Comparison of expected fire blight impact under the *baseline* and *double trouble* scenarios.

Scenario	Inspection Cost ($ million)	Eradication Cost ($ million)	Control Cost ($ million)	Market Cost ($ million)	Total Invasion Cost ($ million)	Infested Farms in 2040
Baseline	28	8	116	381	533	1,047
Double trouble	13	6	216	332	567	1,205

3.10. Application of Deliberative Multi-Criteria Evaluation to Emergency Plant Pest prioritisation

In this section we reveal details of a trial DMCE workshop held with industry stakeholders from government and private industry in May 2009 to produce a prioritised list pest species based on their expected economic, environmental and social impact. Participants were asked to rank 10 species according to scientific and anecdotal information, as well as expert testimony. The process of ranking EPPs involved scoring each species according to a list of criteria the participating group were comfortable with. To help them, the group had access to pest data sheets and simulation model results prepared for each species, a workshop facilitator and an interactive multi-criteria software tool. By the end of the workshop, the intention was for the group to be happy with their priority list, but also well informed about the key factors determining each EPP's potential impact on Australia should it become established.

As previously outlined in section 3.3, DMCE is a combination of both MCDA and a deliberative participatory process. Although DMCE was defined by Proctor and Drechsler (2006) the primary steps of the process including MCDA and a participatory application can be found dispersed in earlier literature. A large component of this literature is reviewed in sections 3.3 and 3.4 of this report. Before a specific DMCE framework is explained for use in EPP prioritisation, the context of DMCE application must be clarified in order to ensure effective decision-making. DMCE utilises MCDA structure and adds group participation and decision facilitation. This section clarifies what such a process can contribute to complex decision solution-forming.

Generally, the use of participatory decision-making to evaluate criteria is dependent on two convictions as fundamental pillars of effective practice:

(a) The assurance that objective and subjective elements within a decision context are interconnected and inseparable. Although objectivity is present in criteria characteristics, the value-laden subjectivity found within the human realm of decision-making is unavoidable (Bana e Costa et al. 2004);

(b) The assurance of constructivism and learning. The general MCDA process (again, see sections 3.3 and 3.4) though set up with defined steps, is generally an adaptive process with iterations and revisions making each decision problem a new and constructed entity. A constructivist methodological approach is ideal for decision-aiding, providing support for the modern paradigm of learning and modelling that should replace the paradigm of normative optimisation. Simplicity and interaction are fundamental tools for effective participation within this paradigm (Bana e Costa et al. 2004).

Crises, such as EPP incursion events, will always occur but are rare in nature. As a generalisation, governments typically modify, prune and adjust their commitments to a policy area with ideological positions and primary beliefs of decision-makers kept fairly constant (Considine 1994). This process of 'muddling through' aims to determine which resources are needed to bring normative values into action and influence change and development (Walker 1999). Incrementalism is a conservative approach as the policy can be altered if required and the adverse effects will not be permanent.

Box 5. Trial Emergency Plant Pest Prioritisation in Western Australia

The use of DMCE has been applied to prioritise EPPs in Western Australia in Cook and Proctor (2007). This study examines a case study using a citizens' jury to evaluate agricultural, environmental, and social impacts related to multiple high profile EPPs. Invasive pest species are complex in nature with the resulting potential to inflict damage to the environment, society, and the economy uncertain to establish.

Citizen/stakeholder jury workshops were conducted to involve a diverse range of decision-makers and to create a transparent and democratic process. In weeks leading up to DMCE workshops, participants were provided with materials to help inform their decisions such as objectives of the exercise, methodology and structure of workshops, ecological information on each EPP, economic impact assessment data, and photographic evidence of pest damage.

The first step in the workshop was to outline objectives and criteria (Figure 4). The next task involved the generation of an impact matrix to enable an estimation of a criteria score for each EPP under consideration. The impact scores were modified based on stakeholder agreement. Criteria weights were also estimated using a relative scoring distribution whereby a limited number of weighting units were available for each criterion. The multi-criteria analysis software was then used to aggregate the EPP criteria scores with criteria weights. Each EPP was ranked using a simple linear weighted summation. This method was used due to the relative ease in which participants could understand the details to ensure a transparent process.

Participant opinions from the DMCE process varied considerably for several of the criteria. The considerable presence of variance in EPP rank indicated high uncertainty and a requirement for further analysis. Participants were then asked to reach a consensus on criteria weights starting at the most variable criteria. Jury members were asked to reflect on their choices and respective justification. After the second round of weighting, the rankings of the top two EPPs swapped positions with Guava Rust now representing the highest threat instead of Red imported fire ant.

Although only two rounds of criteria weightings and small resulting decreases in variation were realised, the DMCE process used was a large step forward from current EPP prioritisation decisions (particularly due to the inclusion of environmental-related considerations).

Incremental type decision-making, however, can have perilous implications in the realm of environmental policies (Walker 1999). Often, the conservative approach is inadequate in terms of generating effective changes, particularly in the environmental realm, with numerous degradation examples including climate change, species extinction, forest clearing, desertification, and fishery stock declines. These alarms have led to policy-making changes going beyond the incremental style. The 1960s 'Green Bans' contributing to a protected area in Sydney represent an early Australian example (Walker 1999).

In Australia since European settlement, economic studies have largely concentrated on direct impacts which are easy to quantify, such as production losses in agriculture, while indirect effects are often neglected as typically they are not directly reflected in markets (Walker 1999; Born et al. 2005). This suggests that major political and cultural changes are required. Quantifying both potential market and non-market losses from an incursion event is necessary in guiding invasive species management decisions. Quantifying non-market losses from an incursion event can be complex due to uncertain ecological relationships and intrinsic values such as existence, bequest, or moral values (Cook and Proctor 2007). Non-market values include ecosystem services that serve as life-support activities in an unpriced manner (Proctor and Drechsler 2006).

MCDA approaches directly address the elements that tend not to be specified in traditional economics, but mentioned as "other factors" important in decision processes (Brouwer and van Ek 2004; Spash and Vatn 2006). An invasive pest out-competing native fauna and the resulting ecological and socio-economic consequences such as spoiling existing intricate relationships is one example of an indirect or non-market effect. The functioning and effectiveness of ecosystem services are under threat from potential incursion events and this risk has to be incorporated into invasive species management plans and decision-making. In addition to the near-impossibility in placing monetary values on ecosystems services, assessing their environmental and social significance can be complex and uncertain. The temporal scale of an incursion event must also be considered in the context of the decision framework as the uncertainty of the pest damage increases with time. The higher the level of uncertainty, the more difficult it becomes to make decisions and set ensuing policy objectives and targets.

EPPs can be described as invasive species that, if allowed to enter and establish in a given area, could potentially affect the agricultural market values, socio-economic and environmental viability of commercial and/or native plants. DMCE has been previously recommended as a framework to help construct a comprehensive assessment of the risk that biological invasions pose (Born et al. 2005) specifically the threat of EPPs (Cook and Proctor 2007). Born et al. (2005) suggest that the strength of DMCE is the ability to use qualitative data analysis in assessing aspects associated with risk other than monetary figures. Spash and Vatn (2006) add that existing environmental valuation practices need a more inclusive approach such as alternative decision processes including attitude and norm measures, multi-criteria analysis and participatory deliberative institutions.

3.10.1. Preparation and the Expert Reference Panel

Before conducting the DMCE EPP risk prioritisation workshop with a group of industry and government representatives, the project team held two preparation meetings in order to refine our methodology and include a decision-maker panel from the outset. This decision-maker panel, known as the *Expert Reference Panel* (ERP), was formed to maximise opportunities to deliver project outputs that could be easily absorbed by our stakeholder industries. Members of the panel provided us with valuable strategic direction in terms of how best to engage stakeholders and present information that they could understand and use to prioritise EPP threats. The ERP is distinct from our DMCE stakeholder jury, although a number of individuals were common to both.

The workshops conducted prior to the DMCE exercise with the ERP focused on the preparation of information sources with an emphasis on the bio-economic EPP impact model in order to develop the DMCE methodology in preparation for future deployment to the involved parties. In our first meeting, we worked with the ERP to design a model interface and associated model outputs in order to better communicate the most complex components of the prioritisation exercise to those involved (i.e. results of model simulations and biological EPP data). We sought to refine the model information, communication of this information, and subsequent decision methodology in a collaborative way. In the second workshop we embedded the findings and suggestions of the ERP into our model user-interface, and presented our criteria impact scores based on model and biological EPP information in order to inform the DMCE process. This enabled us to run through our draft methodology and seek improvements from our panel.

The two key outcomes from the workshops with the ERP were:

- Assessment of the EPP information and the means by which it is communicated to groups scoring individual EPPs according to their potential environmental, social, and economic impact;
- Evaluation and improvement of the DMCE approach to decision-making.

The DMCE methodology was then refined with the ERP using a trial structured facilitated decision-making workshop in December 2008 aimed at prioritising EPPs in order of their perceived national significance. The aim of this exercise with the ERP was to evaluate ten EPPs using a list of criteria developed in consultation with the ERAT project team. Since EPPs can have wide ranging impacts to multiple criteria and affected parties, DMCE was used for the evaluation of the EPP options in the ERP workshop in order to create a transparent group decision-making process. The ERP then provided the project team with information about what they found positive about the DMCE experience, and what they felt needed to be improved, clarified or changed to make the process more effective for the participants. This information was extremely valuable when we progressed to a more comprehensive test of the DMCE methodology with a more diverse group of stakeholder.

3.10.2. Stakeholder Analysis

In prioritising EPP risk, our first step was to identify our participatory group (or DMCE stakeholder jury) using stakeholder analysis. The initial step in this process was to distribute surveys to a range of potential participants to assess their interest and influence. Upon receiving survey information from respondents, follow-up telephone interviews were conducted with to clarify the information gathered in the surveys and discover more about the potential stakeholder jury members.

Using our initial list of potential parties as a base, the snowballing method (Patton 2002, Neuman 2004) was used to expand the number of potential participants. We then separated the list by broad categories (scientists, government representatives, horticulture growers, farmer organisation representatives, horticulture research, development, and marketing bodies, and non-profit organisations). We assessed the decision scope as a national initiative dealing with a public good, and defined the nature of the consequence scoring information that could be improved by participation as relating to expected environmental, economic, and social impact.

A mix of stakeholders was eventually chosen across the interest and influence spectrum for inclusion in the workshop to provide an opportunity to those that are not regularly at the forefront of the decision-making process. Likewise we sought to include a range of stakeholders with varying capacities to contribute to ensure representation across the skill base. The stakeholders selected for the DMCE workshop comprised 15 participants, including scientists, government representatives, horticulture growers, farmer organisation representatives, horticulture research, development, and marketing bodies. Six of these had previously been involved in our ERP that tested our methodology and recommended improvements, thus were well placed to take part in this case study using DMCE.

Once the stakeholder jury members had been chosen, they were mapped using the criteria and scoring method described in **Table 5** (p. **47**) (recalling **Figure 6.** Stakeholder Influence vs. interest map (Eden and Ackermann 1998, Gilmour and Beilin 2007), p. **48**). Influence and interest were then plotted to produce **Figure 23**, which shows that overall interest was high while the extent of stakeholder influence varied. All stakeholders were mapped in or near the upper half of the graph due to high levels of perceived interest in the issue, irrespective of influence. Although no stakeholders were mapped in the lower half of the interest spectrum, differences in interest levels were still present due to biosecurity being the primary responsibility for some one of a host of considerations for others. Biosecurity is an issue that we expected to garner relatively high interest levels from all stakeholders because it concerns a public good with a wide-ranging potential for social impacts.

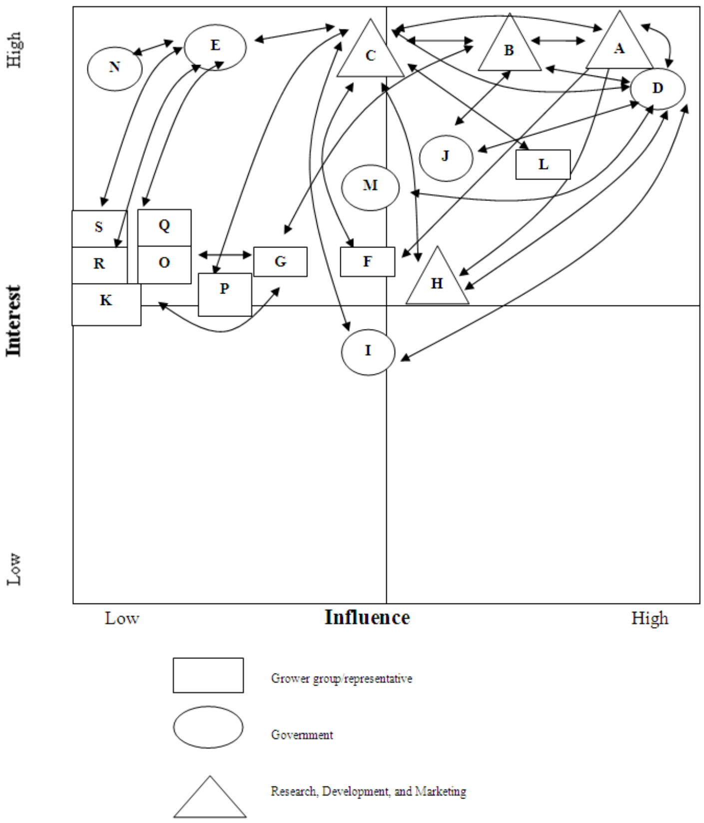

Figure 23. Final stakeholder influence versus interest map

As **Figure 23** shows, Stakeholders were placed into three distinct groups representing the major plant biosecurity institutions (i.e. grower/group representative, government, or research, development, and marketing) as depicted by one of three geometrical shapes on the map. Classifying the groups enabled a better understanding of stakeholder background and provided more insight into potential influence and coalition building when combined with identified relationships. Bilateral relationships among stakeholder groups, as symbolised by two-way arrows, as well as group clustering, helped to determine potential coalition building which in turn could increase influence. For example, some grower groups could combine to exert strong influence, particularly those with links to players in the top right quadrant. We considered participant groups across the influence spectrum in order to include those with high interest but minor political influence on a day-to-day basis.

3.10.3. EPP Selection

The EPPs to be prioritised by the stakeholder jury in a DMCE workshop were pre-screened to include species with potential impacts on new and emerging industries as well as large horticultural industries, and varied impact severity (**Table 29**). Several non-host specific EPPs were selected, in part, based on their potential to affect native flora. EPPs were selected from the Crop Protection Compendium (CPC), published by Centre for Agricultural Bioscience Information (CABI). We selected 10 out of a short-list 28 EPPs for inclusion in DMCE workshop prioritisation. The EPPs and their associated data sheets were summarised in a report which was mailed out to the stakeholders prior to the workshop to familiarise jury members with each species.

Table 29. EPP list

Selected for workshop

EPP	Potato	Apple	Pear	Olive	Pomegranate	Tea	Comments
Empoasca fabae C. Name: Potato leafhopper	++						Major & serious pest for USA. Host for many cultivated & wild plants.
Peridroma saucia C. Name: Cutworm	++						Major pest in USA and has multiple host range
Feltia subterranea C. Name: Granulate cutworm	++						Threat for tobacco in USA Wide host range. Limited information.
Leptinotarsa decemlineata C. Name: Colorado potato beetle	++						High impact. Difficult to control. Widespread found in Europe & N. America.
Spodoptera littoralis C. Name: Cotton leaf worm	++				++	++	Widespread in Africa. Wide host range & high impact.
Apate monachus C. Name: Black borer		+	+	+	++		Common in Africa. Wide host-range but low impact.
Aphis pomi C. Name: Apple aphid		++	++				Found in Europe, Middle East and N. America. Restricted host-range.
Bactrocera dorsali C. Name: Oriental fruit fly		++	++		++		Destructive fruit fly in Asia and part of USA. Very wide host-range with high impact.
Rhagoletis pomonella C. Name: Apple maggot		++	+				Widespread in USA & Canada. Apple is major host with high impact.
Dysaphis plantaginea C. Name: Rosy apple aphid		++	+				Major apple pest in N. America with high impact. Restricted host-range.
Cacopsylla pyricola C. Name: Psyllid, pear			++				Primary pest for pear in USA. Restricted host-range.
Leucoptera malifoliella C. Name: Pear leaf blister moth		++	++				Widespread in Europe and destructive pest for apple, pears, cherry etc.
Carposina sasakii C. Name: Peach fruit moth		++	++				Attack pome fruits and wild host, widespread in Asia, high impact.
Acrobasis pyrivorella C. Name: Pear fruit moth			++				Restricted to pear, high impact & widespread in Asia.
Bactrocera oleae C. Name: Olive fly, olive fruit fly fruit fly				++			Serious & primary pest for olive (restricted). Damaging pest for many olive growing regions. High impact.
Parlatoria oleae C. Name: Olive scale		++	++	++			Pest of olive, apple & pear, widespread in many countries, moderate impact.
Prays oleae C. Name: Olive kernel borer				++			Important olive pest in Mediterranean basin, restricted to olive with moderated impact.

EPP	Potato	Apple	Pear	Olive	Pomegranate	Tea	Comments
Zeuzera pyrina C. Name: Wood leopard moth		++	++	++	++		Important pest for apple, pear, olive in Mediterranean regions, moderate impact.
Thaumatotibia leucotreta C. Name: False codling moth				++	++	++	Wide host range including fruit & field crops, difficult to control, high impact.
Indarbela dea C. Name: Bark borer					++	++	Attack many host (mainly trees) in China, moderate impact.
Xylosandrus compactus C. Name: Black twig borer						++	Important tea pest in Japan, reported in USA, Africa & in Fiji, high economic impact.
Agrotis segetum C. Name: Turnip moth	++					++	Has wide host-range including tea, cotton, tomatoes, cereals etc. Common in Europe. High impact.
Parasa lepida C. Name: Nettle caterpillar					++	++	Widespread in Asia, attack multiple hosts, serious for coconut plant, high impact.
Papuana huebneri C. Name: Taro beetle							Major taro pest in PNG, difficult to control, high impact.
Adoretus versutus C. Name: Rose beetle		+	+				Major taro pest in south pacific, also attack coffee, cocoa, rose etc., no control measure, high impact.
Tarophagus proserpina C. Name: Taro planthopper							Attack mainly taro and related members of the same family, common in taro growing regions, also reported in Australia (may be different sp.), moderate impact.
Hippotion celerio *C. Name:* Taro hawkmoth							Serious pest of taro, sweet potato, tobacco, grape etc., widespread in Asia, Europe & Africa. Moderate impact.
Patchiella reaumuri *C. Name:* Taro root aphis							Serious taro pest, host specific, no effective control measures, high impact.

++ indicates major host

+ indicates minor host

3.10.4. Criteria Selection

Criteria selection was determined on the basis of a combination of literature reviews, stakeholder surveys, and workshop discussion. The workshop discussion in particular served to clarify the criteria which were important to participants. These included criteria covering environmental, social, and economic issues by which EPPs could be assessed (i.e. scored) in terms of risk. The final five criteria decided upon were:

- Impact on native host range and distribution
- Natural landscape amenity (aesthetics)

- Man-made infrastructure (services)
- Environmental health
- Economic impact

3.10.5. Criteria Definitions

Having decided upon the criteria to be used to determine the extent of threat posed by EPPs, it is essential that they be clearly defined. Each jury member must have a clear understanding of what each criterion means, and this understanding must be consistent across all jury members. The criteria definitions we settled on are stated below, and further discussion of criteria deliberation in the workshop continues in section 3.10.7.1.

3.10.5.1 Impact on native host range and distribution

EPP with a wide host range capacity are able to attack many native plants and destroy local forest that will contribute to air pollution and climate change, with an expected lifecycle disruption (including reproduction, feeding/nutrient uptake, migration or resting behaviour) of a native host.

Depletion of native forest will have an expected negative influence on wildlife species (food and habitat), hydrology, forest fires regimes and nutrient cycles.

3.10.5.2 Natural landscape amenity (aesthetics)

Amenities in this criterion are any intangible benefits especially those which increase the attractiveness of the landscape (i.e. viewscape)

Intangible benefits might include a "pleasant view" or any landscape aesthetics.

3.10.5.3 Man-made infrastructure (services)

Amenities in this criterion are any tangible benefits that include a facility or related service which contributes to comfort or convenience. Community stability and well-being would expect to be affected if an EPP attacked a major crop of particular region, causing a socio-economic crisis due to significant loss in the production. This may increase crime in the society where law and order would decorate.

Examples of tangible amenities might include services such as farmers markets or leisure facilities.

3.10.5.4 Environmental health

The expected magnitude of the adverse impact that an EPP would have in regards to the direct pathological effects of chemicals, biological agents, and the effects (often indirect) on human health and the physical environment. Example: Water, air, and soil.

3.10.5.5 Economic cost to industry

The total expected market damage in dollar value per year as defined by the Stella bio-economic impact model.

3.10.6. Assessment of the EPP options and the impact matrix

The expected risk of a given EPP was defined by the likelihood probability of entry, establishment, and spread of that EPP and subsequently combined with the consequence impacts from DMCE for that EPP using the equation:

$$\text{Risk} = \text{Likelihood} \times \text{Consequence} \quad (28)$$

Where:

Likelihood = Probability of Entry, Establishment, and Spread (P{EES});

Consequence = Impact matrix score from the DMCE.

Two impact matrices, one for probability and one for consequence, showing the scores for each EPP option in terms of their impact on each of the different criteria, were completed with the aid of the following data sources:

- Pest data sheets
- Pest at a glance sheets
- Scientific literature
- Expert opinion
- Bio-economic Stella model (for economic cost criterion)
- European and Mediterranean Plant Protection Organization (EPPO)
- The Crop Protection Compendium (CPC – CABI)
- CRC NPB Plant Biosecurity Toolbox
- PaDIL - Pests and Diseases Image Library.

The likelihood of EPP entry, establishment and spread were calculated as the (P{EES}) defined by scored indicators as per **Table 30**.

Table 30. P{EES} scoring legend

Invasiveness Elsewhere[1]	Cultivated/Native Host specificity (range/availability)[2]	Geographic distribution[3]	Quarantine Risk[4]
1 = No	1 = Localised and rare	1 = Restricted to specialised climatic conditions	1 = Low
2 = Yes (51-100 yrs ago)	2 = Widespread and rare	2 = Restricted to generalised temperate/tropical etc	2 = Medium
3 = Yes (11-50 yrs ago)	3 = Localised and common	3 = climatically plastic	3 = High
4 = Yes (last 10 yrs)	4 = Widespread and common		

[1] Time periods have been used in an attempt to address the issue of newly EPP species, which may not have reached their full extent in new habitats. Thus, newly EPP species are regarded as higher risk.

[2] Combining extent and abundance was seen as a way to address the perceptions of speed of spread.

[3] Scores reflect the potential for a species to adapt to novel conditions.

[4] Proximity to Australia is accounted for in this criterion. For instance, if an EPP species can reach Australia via natural spread (because its source country is very close to Australia) then it is considered to have a high quarantine risk. Quarantine risk also includes potential smuggling.

The expected consequence of an EPP was defined by the scoring legend as per **Table 31**. The matrices included both tangible and intangible indicators.

Table 31. Consequence impact scoring legend

Impact on native host range and distribution	Natural landscape amenity (aesthetics)	Man-made infrastructure (services)	Environmental health	Economic impact
1 = Specific host range and limited distribution	1 = EPP would likely have a minor loss of landscape aesthetics	1 = EPP would likely have a minor loss of socio-economic and community services	1 = Expected to require low levels of pesticide application to control the pest	The total expected market damage in dollar value per year as defined by the Stella bio-economic impact model.
2 = Multiple host range and moderate distribution	2 = EPP would likely have a moderate loss of landscape aesthetics	2 = EPP would likely have a moderate loss of socio-economic and community services	2 = Expected to require moderate levels of pesticide application to control the pest	
3 = Extensive host range and widespread distribution	3 = EPP would likely have a major loss of landscape aesthetics	3 = EPP would likely have a major loss of socio-economic and community services	3 = Expected to require high levels of pesticide application to control the pest	

Each column of the probability matrix was sequentially multiplied by the next to create a total probability score for each EPP. This total probability score for each EPP was then multiplied by each cell in the consequence impact matrix for that EPP, to create a final 'risk' impact matrix (**Table 32**). These risk scores were then used for aggregation with criteria weights as per the compromise programming method previously described in section (equation 1, **p. 49**).

Table 32. Final Impact Matrix Risk Scores (Consequence Impact × P{EES})

	Native Host	Environmental Health	Economic Cost ($ million)	Landscape amenity	Service amenity
Spodoptera littoralis C. Name: Cotton leaf worm	0.020	0.012	0.662	0.008	0.012
Leptinotarsa decemlineata C. Name: Colorado potato beetle	0.027	0.053	2.215	0.027	0.027
Empoasca fabae C. Name: Potato leafhopper	0.001	0.001	0.029	0.000	0.001
Bactrocera dorsali C. Name: Oriental fruit fly	0.287	0.215	0.394	0.143	0.143
Rhagoletis pomonella C. Name: Apple maggot	0.030	0.030	0.060	0.030	0.030
Parlatoria oleae C. Name: Olive scale	0.002	0.003	0.112	0.002	0.002
Zeuzera pyrina C. Name: Wood leopard moth	0.012	0.008	0.554	0.008	0.008
Thaumatotibia leucotreta C. Name: False codling moth	0.059	0.059	1.523	0.024	0.035
Indarbela dea C. Name: Bark borer	0.001	0.001	0.000	0.001	0.001
Agrotis segetum C. Name: Turnip moth	0.018	0.018	1.014	0.012	0.018

The DMCE EPP prioritisation workshop was run over two days: the first with criteria discussion, expert presentations and discussions as well as the opening of the first iteration of the decision process; and the second day, with iterations of criteria weighting, software interaction, and deliberation.

3.10.7. Results

3.10.7.1 Criteria discussion

Day one of the workshop involved a project introduction, descriptions of the process, the jury charge, and the MCAT software to be used (introduced previously in section 3.6.2, **p. 49**). The criteria brainstorming results from the surveys were provided, which had been distributed some weeks prior to jury day.

A discussion ensued concerning the fact that there was not a specific criterion for the cost to society present on the list of criteria. Up until the morning tea break, there was a discussion about including an additional criteria related to societal cost. In the subsequent discussion, it was decided to establish a criterion "Man-Made Infrastructure" to capture societal costs. Discussions on what societal cost meant to participants can be part of the deliberations on the weighting. After some discussion, all agreed that the criterion would be hereby titled "Sustainable Rural Communities" to reflect the desire for the inclusion of the impact an EPP could impose on the rural community. Additional criteria discussion arose around pesticide type and toxicity. This information was included in pest data sheets provided to each participant (again, see Appendix 2) to the best available knowledge and was considered in the environmental health criterion consequence scoring. The native host range and distribution criterion was also discussed in relation to having the capacity for one of either range or distribution to be high or low. The definition remained unchanged as the scoring knowledge of EPP consequence in relation to native hosts is not thorough enough to accommodate a more specific term.

3.10.7.2 Expert testimony presentation of EPP impact information

As discussed in section 3.3.1 (**p. 32**), decision-makers have to use diverse, complex and uncertain information when assessing investment options and make trade-offs. In our DMCE exercise in which specific EPPs needed to be ranked in order of expected impact, this was certainly apparent. Some EPPs were more of a risk when considered in relation to certain criteria, while other were not but were of significance against other criteria. We used the bio-economic spread model (detailed in section 3.9), qualitative risk scores from the literature (see data sheets contained in Appendix 2) and additional first-hand expert-knowledge for each EPP considered. Each parcel of information was presented to our group by our expert witnesses.

The first expert witness called before the jury was Dr. Shuang Liu (CSIRO Entomology/CRCNPB), a member of the ERAT project team. Dr. Liu gave an overview of the bio-economic pest simulation model housed in Stella software. The bio-economic model predicts the total expected market damage in dollar value per year to provide scoring information for our economic cost criteria. The biological model component predicts the likely spread of an EPP, while the economic section converts this to a cost. A great deal of discussion among the group followed the presentation, and questions centred on the adequacy of the figures being put up for each of the EPPs. For example, jury members could not agree that Apple Maggot would have only about $2 million damage while Olive Scale damage was estimated at $64.4 million (given that apples must be a bigger/more valuable crop than olives). As the model features an interactive and user-friendly interface, we were able to run and present different EPP arrival scenarios using participant input for scoring EPP cost. This integrated approach facilitated collective decision-making in prioritising EPP risk by both allowing participants to provide first-hand knowledge in regard to model scenario building and by the resulting model information being provided to the participants.

The next expert witness called was Dr. Abu-Baker Siddique (DAFWA/CRCNPB), who was also part of the project team. Dr. Siddique spoke on assessing EPPs in terms of gaining better information for DMCE criteria scoring. Dr. Siddique's presentation covered topics such as EPP distribution, entry, establishment, spread, damage, impact, and management. Both Siddique and Shuang's expert testimony presentations reflected impacts of an EPP if all possible control options were exercised.

After the expert presentations and proceeding discussions, the jury was asked to provide a relative weighting of the five assessment criteria to reflect each individual parties priorities (as per weighting methods). After this exercise, the participants and expert witnesses took part in discussions based on a presentation of their mean weights and the variation among them. In the deliberations which followed, participants revealed that they found it difficult to keep the criteria separate despite the knowledge that criteria were meant to be independent. This is in part because there were subtle and inevitable interactions among criteria. For example, economic damage to the industry would also relate to the socio-economic impacts to a given community that heavily relies on that industry for employment and sense of being.

3.10.7.3 Weighting rounds

Two rounds of weighting were completed on day 1 with a third and final round completed on day 2 (**Figure 24**). Economic cost was the highest mean weighted criterion at the 25-26% range while landscape amenity was weighted the lowest at 10-12% range. The involved participants did not change their preferences in any substantial manner with only minor differences in the weighting of the criteria among rounds. With 15 participants, the mean weight for a given criterion may have masked individual weighting changes.

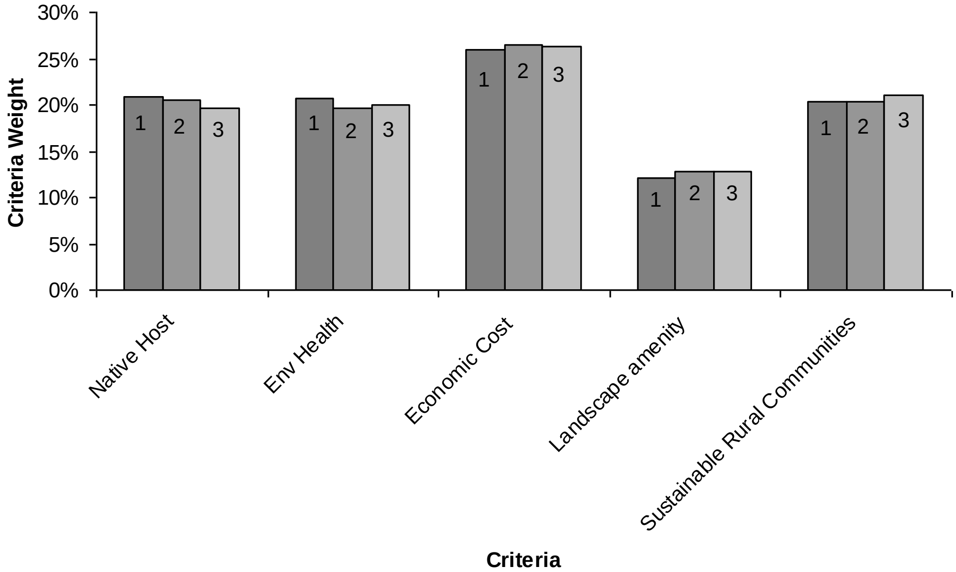

Figure 24. Change in mean criteria weights by round

After each round of weighting, the objective of the jury was to improve consensus on the weights and come to a more conclusive ranking of the options. The standard deviation around each criterion weight decreased from round 1 to round 3 with the exception of native host (**Figure 25**). Although variation levels among criteria weights were not extensive there were a few outliers and the weighting exercise was again carried out and the results presented. Each criterion was discussed, one at a time, outliers identified, and jurors asked to discuss their positions in regards to why they weighted that criterion at that level. For example, one participant weighted economic cost at a level almost twice as high as the group mean. After some discussion, that participant revealed feelings that the worst environmental or social EPP was not as high of a risk compared to the worst economic EPP. In a second round of weighting, another participant re-visited this suggestion and increased their economic cost weighting.

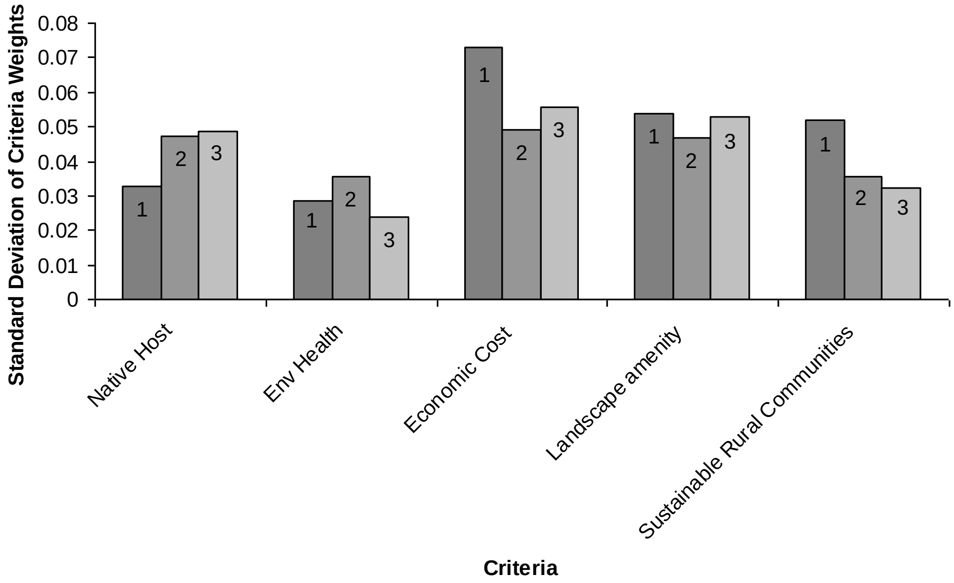

Figure 25. Change in standard deviation of criteria weights by round

After each round of weighting and the ensuing deliberation which ended as soon as no one was prepared to further alter their individual weightings, the weightings were fed into MCAT software. The resulting outcomes after the first and second weighting rounds were that the Oriental Fruit Fly was scored as having the highest risk (**Figure 26**).

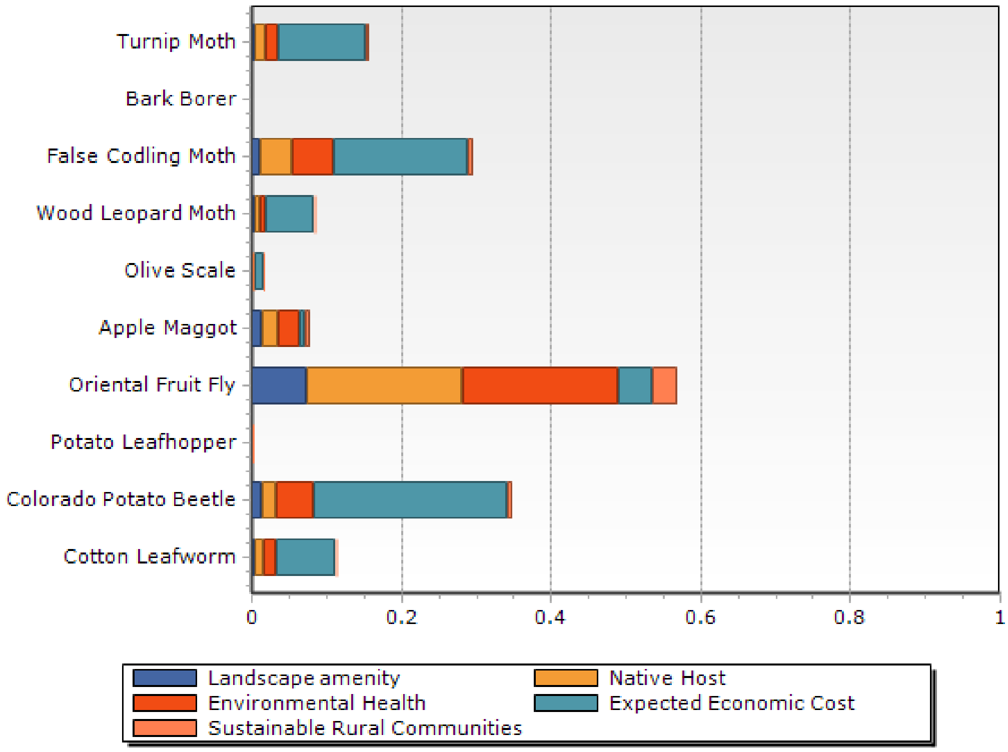

Figure 26. EPP risk rankings based on round one weights

Before we proceeded with our deliberation, we re-visited the consequence impact matrix to consider the option of removing redundant criteria for which the scores were the same for each EPP. Upon viewing the impact matrix, landscape amenity and native hosts, although not exactly the same across the board, all scored very low and could perhaps have been eliminated, but in the interests of the participants noting that this is a DMCE with only 5 criteria, we left the same criteria in the decision process. Figure 24 shows the EPP risk rankings based on the second round of weighting. The comparison between **Figure 26** and **Figure 27** shows that changes in EPP ranking across each round were generally small.

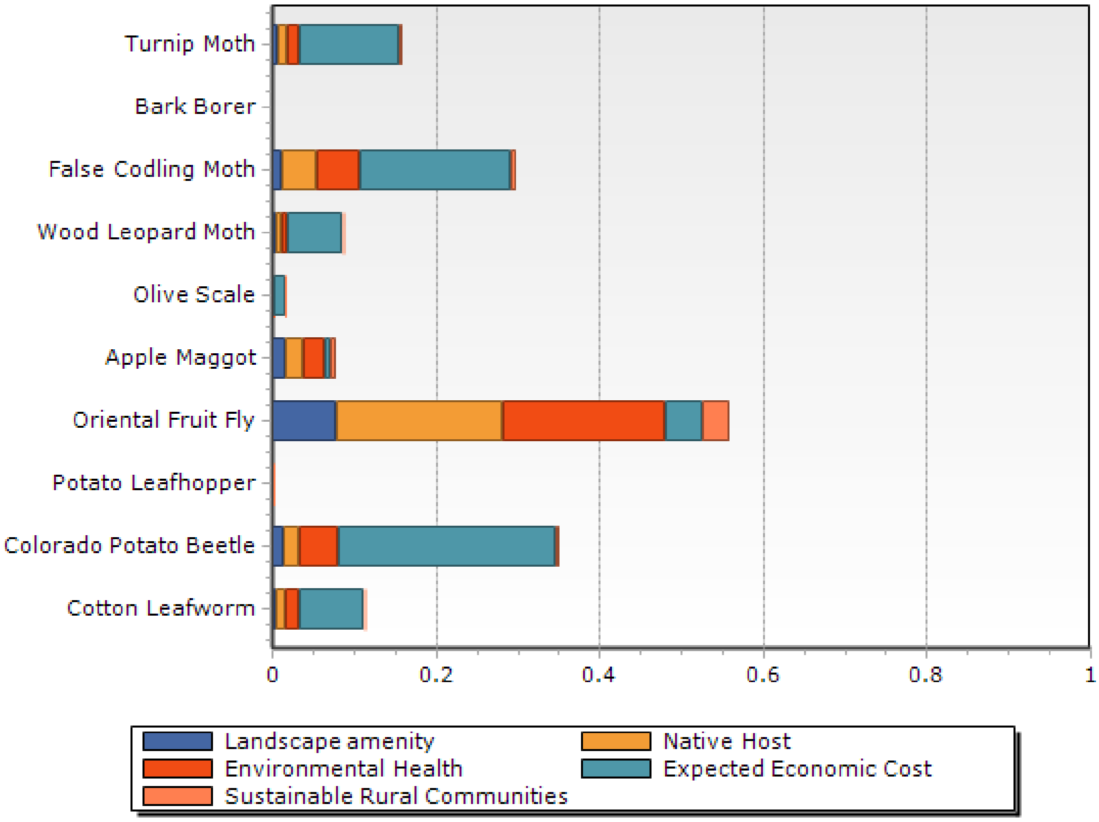

Figure 27. EPP risk rankings based on round two weights

Day two of the workshop involved the presentation of the second round of weights to the group (**Figure 24**), deliberation on these weights, a presentation of uncertainty around the criteria impact scoring, a third round of weighting based on new 'uncertain' impact scores, sensitivity analysis, and a comparison between direct and indirect EPP risk rankings. The participants found the previous day's discussion useful, particularly around the meaning of the criteria.

3.10.7.4 Further deliberation on weights

Given that there was little change in the weights between rounds one and two as well a high level of consensus, participants questioned the need for the second and third weightings. The primary objective was to gain information through further group deliberation and to assess whether the new uncertainty scoring information affected participant preferences. However, the degree of consensus amongst the group had not been anticipated, and given that the intention of the workshop was to provide a comprehensive trial of the DMCE technique the prescribed second and third weighting sessions were seen as necessary by the project team. Certainly, in the event of such an occurrence in an industry-specific DMCE directly ties to the development of future EPP management plans, there would be a strong case for these second and third weighting rounds to have be abandoned. The fact that the workshop reported here was, in essence, hypothetical (despite the EPPs and the stakeholder jury members being very much 'real'), this may have accentuated consensus forming by removing incentives to confront outlying group member preferences.

3.10.7.5 Presentation of uncertain information to the DMCE participants

Uncertainty must be considered in deliberative decision making concerning environmental risk management (Gregory 2006, Halpern et al. 2006, Georgiou 2008), as mentioned throughout this report. We attempted to express an explicit measurement of epistemic uncertainties (see section 3.1.2.3) to participants at the DMCE workshop. DMCE provides a vehicle to communicate scientific findings and associated uncertainties, and for stakeholders to provide feedback. This feedback can include up-to-date, first-hand knowledge.

However, despite the benefits of a DMCE approach, it represents a fairly 'broad brush' approach to communicating and minimising uncertainty. The project team felt additional efforts before and throughout the workshop were still required to explicitly uncover potential uncertainty and make it known to all jury members. The primary elements we employed to minimise both epistemic and linguistic uncertainty in structuring and presenting the problem:

- detailed structuring of issue with an emphasis on criteria definition and meaning
- quantitative consequence impact scores
- presentation of uncertainty around consequence impact scores by revealing potential worst-case scenario before the final round of weighting
- simple as possible scaling for consequence impact scoring.

From the outset of the DMCE workshop to prioritise EPP threats, in the problem structuring phase, we introduced uncertainty in potential EPP impact information by spending time considering suggestions about objectives and related criteria. This initial stage of problem structuring and criteria definition is extremely important and must be given adequate attention (Gregory 2006, Hajkowicz 2008). Preparation through a disaggregation of the problem helps to eliminate linguistic uncertainty and related unperceived misunderstandings, not to mention adding to the chances of success in resolving the issue at hand. As previously mentioned, we spent a large portion of workshop time in problem structuring, with criteria identification surveys and presentation, discussion, and clarification of criteria definitions to try to remove as much linguistic uncertainty as possible.

In addition to the effort in tackling linguistic uncertainty through careful problem structuring, we also dealt with epistemic uncertainty in consequence impact scores. It is important to be mindful of opportunities for the presentation of impact scores to influence how participants interpret the uncertainty, and therefore the potential for distortions in score perception. Participants suggested that although industry representatives have a tendency to be mistrustful of scientific information provided to them no matter how comprehensive it is, the information contained in our pest data sheets (Appendix 2) was better than the information most have used in the past. But, despite these favourable reactions, we considered supplementing the threat data sheets through the creation of a separate criterion that could be scored based on the level of uncertainty for specific EPPs. We decided against any kind of worst case uncertainty-related criteria in order to avoid double counting[36]. We opted instead to present an additional set of plausible consequence impact results based on more uncertain scoring information in a follow up to the initial best-guess figures.

As questions about the uncertainty around impact scores did not arise in the early deliberations we waited to present these new figures until after the first two initial weighting rounds to assess whether uncertainty made a difference to weighting and the resulting EPP ranks. We presented the uncertainty behind the impact matrix consequence scoring to provide a transparent picture of our results and the confidence that we place on their guidance. The economic cost values predicted by the Stella bio-economic impact model of section 3.8 were shown to have underlying assumptions and uncertainty. With this knowledge of uncertainty, the involved parties could gauge how much confidence they want to place in the model output for use as a reference in prioritising the EPP risks.

Examples of model assumptions presented include levels of control effort; best guess input parameter values; and a pre-set discount rate. Additional uncertain scenarios discussed revolved around an EPP spreading faster than initially thought and a more limited inspection budget than initially thought. Based on these uncertainties, we went on to reveal the 'uncertain' set of consequence scores for each EPP, which triggered a discussion on model strengths, structure and how it could be improved (i.e. is EPP detection a cause of immediate market loss? Is there a lag? Will the impact be more localised due to inter- and intra-state quarantine measures? Could the model simulate a free trade situation?). After this discussion on the uncertainty in expected EPP market damage in dollar terms and around the implications for scoring the remaining four intangible criteria, participants proceeded to the third round of weighting.

A concerted effort on the part of the project team was made to keep the presentation of consequence scores as simple as possible. We withheld information about the uncertainty in scientific knowledge and bioeconomic model outputs until after the first two rounds of weighting. We then carefully provided participants with a range of consequence impact scores that could result given the natural variation within the agri-environmental system. This was done for different parameters within the system (and the bioeconomic model designed to mimic this system) one at a time. This relatively slow form of delivery was very much in keeping with the hypothesis that "Less can be More", based on the concept that the numeracy ability ranges within a given group. For this reason, when presenting uncertainty information to participants, the simpler the information presented the better for comprehension (Gregory 2006).

Once conveyed to the stakeholder jury, the information about uncertainty surrounding EPP impact scoring did not result in a change of EPP ranking, but did alter the final risk scores of some EPPs (**Figure 28**). A given change in EPP risk in the MCAT software (introduced in section 3.6.2) following uncertainty revelation was primarily driven by revised impact

[36] Another common approach is to show uncertain impact scores that range based on potential consequences (Gregory 2006). Additional choices for the presentation of impact scores include substituting quantitative figures for diagrams, words, or visual cues. For example, using a qualitative scale such as low to high or poor to good can help participants to relate to score or uncertainty level (Cook et al. 2008).

scores accounting for uncertainty, as opposed to criteria weighting. Weighting once again remained relatively unyielding in the third round. For example, Oriental Fruit Fly was further confirmed to be the highest risk EPP based on new and higher 'uncertainty' figures for economic cost, rather than an increase in weighting for this same criterion of economic cost. In any case, DMCE provided an outlet for communicating scientific findings and related uncertainties, allow involved parties to comment, provide first-hand knowledge, and to make a collective decision by means of deliberation and consensus-building.

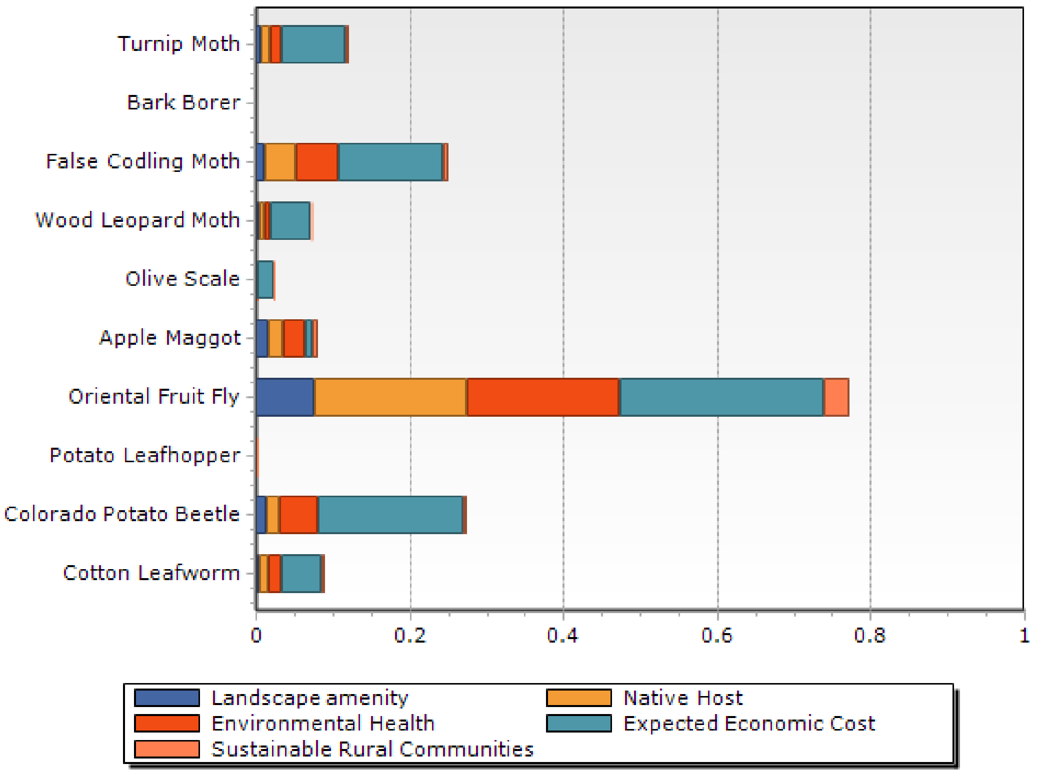

Figure 28. EPP risk rankings based on round three weights

After criteria weighting, a discussion ensued about the potential differences in weighting among the different groups in terms of professional background. Weights were grouped into the categories of grower/group representative, government, or research, development, and marketing (**Figure 29**). The mean weights among the three groups followed a consistent trend with no outliers of interest. A component of this discussion involved clarification as to how involved parties were expected to express their personal weighting preferences in regards to representing the interests of their industry or as an altruistic citizen.

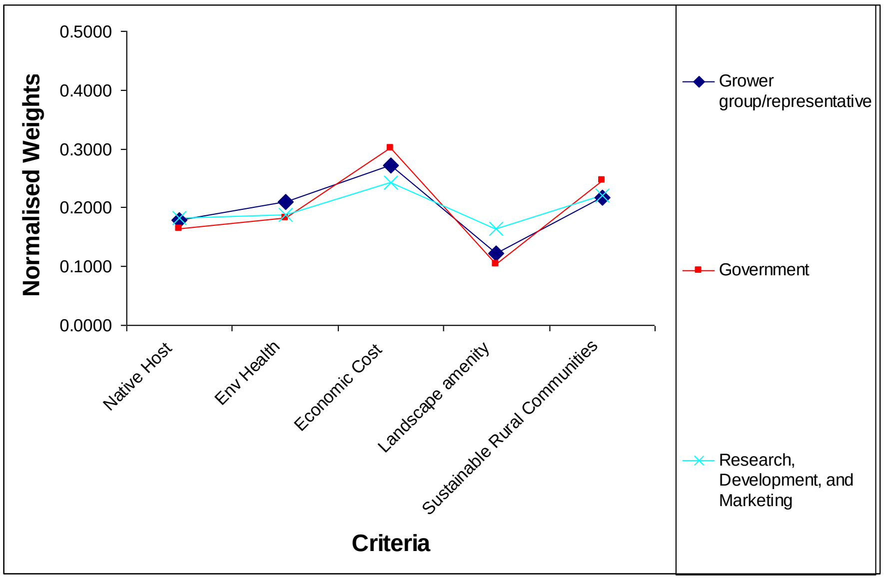

Figure 29. Final round of criteria weights grouped by participant background

Upon participant request, weights were also grouped based on gender in order to assess potential differences (**Figure 30**). The mean weights among gender groups followed a consistent trend with only native flora and fauna host criterion showing a relative difference of approximately 0.5.

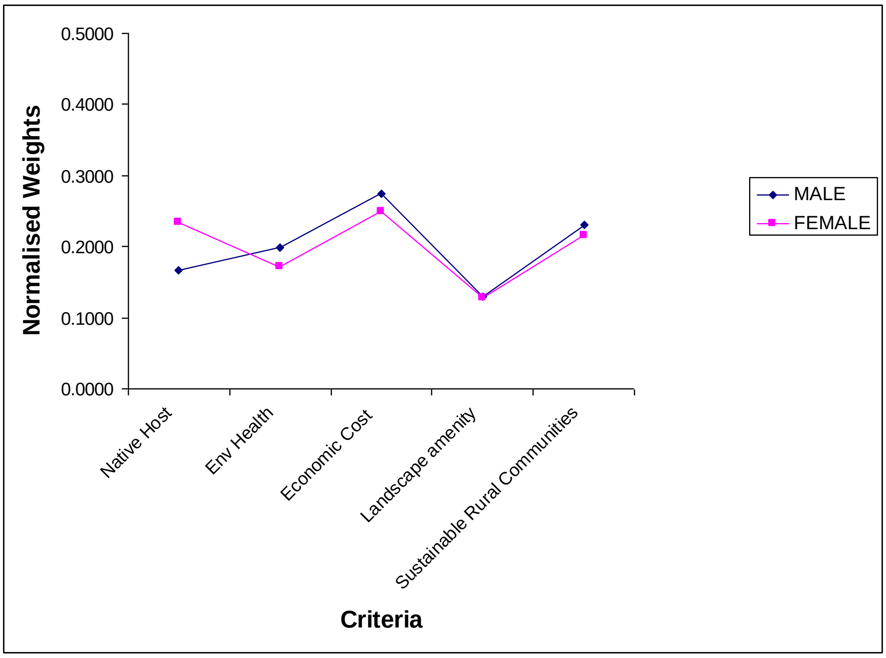

Figure 30. Final round of criteria weights grouped by participant gender

Weights were finally grouped into the work locations of urban or rural (**Figure 31**). The mean weights among the three groups followed a consistent trend with only slight differences.

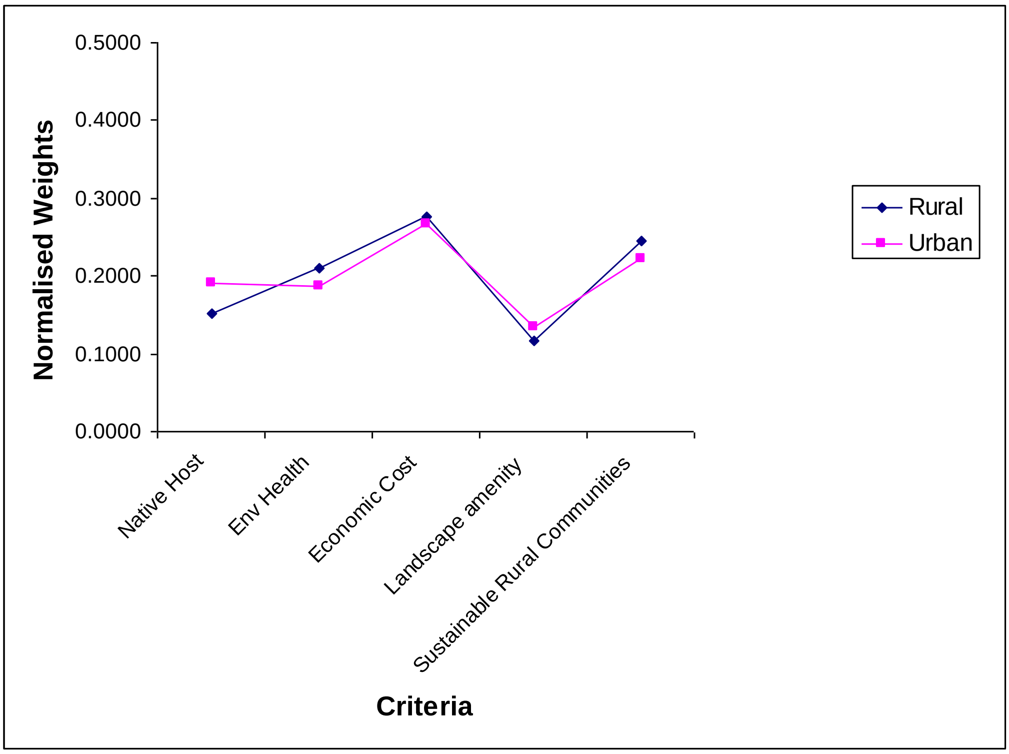

Figure 31. Final round of criteria weights grouped by participant location

3.10.7.6 Sensitivity analysis

Following the third round of weighting, a sensitivity analysis was conducted to determine where further consensus could be gained and to help participants gain a feel for the relationship between weights and rankings. The mean group weightings from round three were varied by substituting the outliers for each criterion in order to assess potential ranking changes. The first to be used (keeping all other weightings consistent with the final agreed values) was the low weight of 0.018 and high weight of 0.31 for native host; then the high outlier of 0.37 for economic cost, the 0.04 low outlier for landscape amenity, and the high outlier of 0.32 for sustainable rural communities were used. The only ranking change occurred where wood leopard moth overtook apple maggot for sensitivities using the low outliers for native host and landscape amenity, and the high outlier for economic cost. The remaining outlier sensitivities did not produce ranking changes.

An additional sensitivity analysis was then conducted based on allocating each criterion full weighting points so that participants could assess the effect that likelihood and consequence impact scores alone have on the rankings. The MCAT software (section 3.6.2) allows the original weights to be altered to the full weighting by a slide bar, providing a visual representation of the relationship between weights and impact scores.

Finally, we opened up the floor to participant requests regarding specific sensitivity tests participants were interested in performing. As this request followed the exercise of allocating full weighting units to each single criterion in turn, participants were satisfied with the impact that the varying weight levels exhibited on the rankings. Consequently, jurors did raise additional scenarios, but instead opted to re-visit some of the previous sensitive rankings. A lengthy discussion did, however, ensue regarding the influence of the weights and impact scores on the rankings which further revealed components of the DMCE aggregation method making for a more transparent and thorough understanding of the process. After completing a sensitivity analysis for each criterion in turn in an effort to work toward weighting consensus, we agreed that no further weighting was required. The important aspect to reverberate at this point is that attaining consensus on the criteria weights was not as important as the process of each person discussing their weights and the resulting information that was revealed. This discussion not only related to the main issues that were important in choosing a weight but also in minimising the linguistic uncertainty by determining the exact criteria wording to be considered. Participants found the discussion to be the most useful in comparison to the actual weighting. Although aware of the importance of DMCE, the participants were focused on the utility of the pest sheets and the bio-economic impact model suggesting that unpacking the uncertainty and gaining confidence in the science could help inform their weights.

3.10.7.7 Comparison between direct and indirect EPP risk rankings

The group mean of the system 1 (direct) EPP rankings were compared to system 2 (indirect - DMCE) rankings (**Figure 29**). System 1 and system 2 rankings were in perfect agreement for four EPPs (Cotton leaf worm, Olive scale, Bark borer, and Oriental fruit fly). Although EPP rankings displayed relatively minor discrepancies between weighting techniques on a whole, there were some notable cases. Turnip moth ranked 7th and 4th highest risk using system 1 and system 2 respectively, while both Potato leafhopper, and Apple maggot also differed by 3 ranking positions. These three EPPs, which exhibited ranking differences between system 1 and system 2, could then be used as a focal point for further discussion on why the intuitive direct approach produced different results than a structured logical DMCE framework. The discussion of the reasoning for these ranking differences could further reveal uncertainty in the results, complementing the variation around weights (recall **Figure 24**). The reasons for differing rankings were difficult to pinpoint whilst examining the group mean as each participant had their own reasons for their ranking which is why, as previously mentioned, we emailed each participant their personal graph for further consideration.

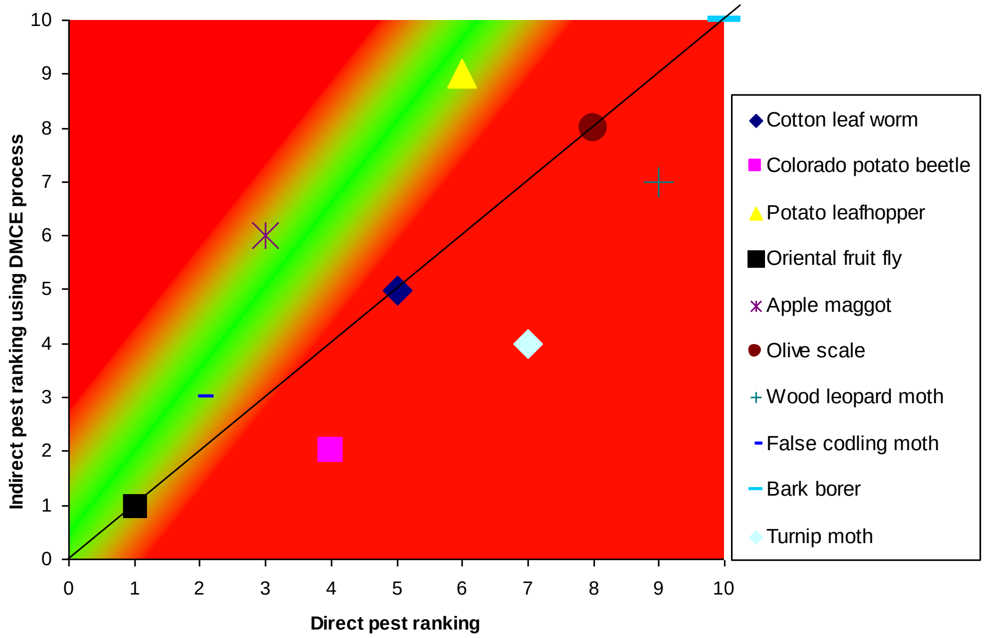

Figure 29. Group mean relative risk ranking for EPPs using the two weighting techniques

4. Implications for stakeholders

The *Enhanced Risk Analysis Tools* project was predicated on the need for a national biosecurity risk prioritisation approach. The method we have developed to satisfy this need involves the use of a quantitative bioeconomic model and a deliberative decision support technique that delivers policy outcomes. This report has outlined how the significance of EPPs for target industries can be assessed using our bioeconomic model allowing a quantitative comparison of risk and impact. It also demonstrates how the model outputs can be combined with other information about non-market EPP impacts to make prioritisation decisions on a cross-sectoral basis.

Decision makers who face demands from different government and private institutions for biosecurity support for different kinds of problems have a difficult time determining the relative importance of investment options. This is even true at a species level despite the common characteristics of introduction, spread and impact that determine the strategic importance of maintaining area freedoms. The approach we have developed provides decision-makers, be they private or government, with a means to undertake such quantitative and qualitative comparisons. We have developed and applied our species prioritisation approach to a range of horticultural industries, and in doing so demonstrated how our methodology can have future operational value if applied more generally.

Below we summarise the key findings of our research of relevance to government and industry stakeholders.

4.1. The bioeconomic modelling framework

The impact simulation model created in this project was developed as a general tool applicable to all manner of EPPs, in contrast to more specific models that may be available for individual species. We chose to adopt a stochastic approach given the large amount of uncertainty involved in predicting likely pest impacts, and our industry partners were attracted to this approach as it added a sense of realism to incursion scenarios. While this is ideal for expressing the full range of possible impacts from incursions over time, the demand for reliable data on which to assess the relative state of uncertainty about EPPs is high. We have also chosen a dynamic modelling approach in which the change in the likely impact of a new species and its control over time can be predicted. This approach is particularly useful for exploring the balance between control of an EPP and its growth and spread.

The many case studies put forward in this report clearly demonstrate the capacity of the bioeconomic model to generate useful and comparable impact predictions over significant time periods for a wide range of EPPs. While the detailed parameterisation of these case studies has been carefully carried out over the course of the project, the information from which parameter estimates are formed is constantly changing as our knowledge of EPPs and host environments increases. The case study information should therefore be seen as a snapshot reflecting the current state of knowledge. With continued information updating the information outputted by the bioeconomic can evolve over time as out information base improves.

4.2. Deliberative multi-criteria evaluation

While the quantitative results of impact simulation models are very useful in the prioritisation and management of agricultural pest risk, multi-host species that can affect environmental and social amenities can not be prioritised using these models alone. The problem is the lack of market values for assets such as biodiversity, community health and happiness.

MCDA offers an analytical approach that can be used to overcome these information constraints. It can deal with mixed sets of data (both qualitative and quantitative) and take explicit account of uncertainty (Mendoza and Martins, 2006; Wittmer et al., 2006). The particular form of MCDA that we have used in the prioritisation of EPPs, DMCE, also allows diverse groups of decision-makers to contribute to the solution of complex ranking problems through deliberative processes. Compared to MCDA without a participatory component, DMCE offers an opportunity for explicitly allowing diverse views to enter the process, for facilitating consensus-building and for initiating a dynamic process of social learning (Rauschmayer and Wittmer, 2006).

This report has demonstrated that DMCE is a flexible decision facilitation technique that provides a useful structural framework for making prioritisation decisions. It provides a context for complex information to be communicated to diverse decision making groups. Sensitivity analysis can be accommodated, adding accountability to the decision making group. However, it is important that the decision-making group clearly understands the purpose of the DMCE, definitions of the alternatives/EPPs being considered, criteria, scoring and weighting systems is group preferences are to be accurately reflected in the resultant prioritisation.

4.3. Are future societal trends going to change EPP risk substantially?

As the world becomes increasingly complex, so too do invasive species risks. Probable changes in the environment (such as climate change), the economy (through trade liberalisation) and society (urbanisation and multiculturalism) are all more likely to increase the rate of EPP arrival into Australia than they are to decrease it. From the bioeconomic model developed in this project and the sensitivity testing we have documented, it appears that future increases in government investment in control and eradication activities for EPPs once they arrive is likely to produce a net gain for society. However, such is the uncertainty about invasion processes that simply boosting government expenditure in the area of Biosecurity does not guarantee this. Indeed, the very concept of social welfare may well change with time in response to social change and requires further sociological research. It may be that over time a populace whose increasing wealth leads to greater value being placed on rural environments and biodiversity threatened by EPPs may drive a strong demand for biosecurity. On the other hand, growing cosmopolitism may steadily cause a populace to be less concerned about changes in species composition.

4.4. How can policy makers use this study?

Currently, in making decisions about non-native species problems, government and industry decision makers use a mixture of expert testimony and anecdotal evidence to form judgements about the relative importance of different biosecurity risks. Whilst practical, there are a number of factors that can lead to distortions in the decision making process and misdirection of scarce Biosecurity resources. These are include:

- Immediacy – the current EPP *crisis* is treated as a priority (i.e. political imperative);
- Institutional bias – certain taxa are prioritised because their mandated representative government agencies and institutions have historically greater power;
- Distributional issues – the disparity between winners and losers in biosecurity problems leads to inequities in response/risk management benefits;
- International commitments – Australia's international commitments to a large extent dictate their national importance, rather than their net social impacts (Waage et al. 2005).

In this project, we have come to five general conclusions that help to address some of these biases and improve policy making on EPP problems. We summarise them below as bullet points:

- Biosecurity risks are likely to increase over time meaning that more harmful species will appear in Australia.   Biosecurity will need more resources to cope with this increase in risk, but precise predictions about those risks and the costs of mitigation measures are extremely difficult to make;
- Economic models such as the bioeconomic impact simulation model we have developed can be used to compare economic importance and impact of EPPs across taxa;
- Non-market impacts of EPPs (e.g. environmental and social effects) are difficult to quantify, but can be considered along side market (e.g. agricultural and industrial) effects using MCDA methods. Where diverse mixes of community groups are concerned, deliberative processes should be used such as DMCE to facilitate complex risk management decision making;
- Biosecurity resources should be targeted at both prevention and control/eradication activities: there is no *a priori* reason to favour one over the other (Waage et al. 2005). Where the impacts of an EPP are predominantly agricultural (or industrial) an economic modelling approach such as the one put forward in this report is preferable for exploring these alternatives. Where the impacts of an EPP extend to non-market effects, a technique akin to the DMCE method we have presented is preferable.

5. Recommendations

1. **Strategies for the effective communication of risk and uncertainty in emergency plant pest prioritisation and preparedness decisions should form a part of future research proposals.**

   Although it has been identified as a component of risk analysis, risk communication is often neglected in biosecurity research. This partly explains the lack of uptake of economic information in past biosecurity risk management decisions.

2. **Traditional economic analysis should retain a significant role in resource allocation decisions, but be supplemented by communication mechanisms.**

   There are a variety of valuation techniques that can be used to elicit social and environmental values related to emergency plant pest impacts, and used in a benefit cost or cost effectiveness analysis framework. Multi-Criteria Decision Analyses should not be seen as replacement for traditional economic analyses, but as complementary.

3. **Traditional economic analyses intended for circulation and future use by diverse groups of decision-makers should be designed to be as functional and flexible as possible to cater for this diversity.**

   There is no question that EPP invasions and biosecurity generally are complicated areas of study. There is a wealth of skills and ideas that can be drawn in to shed new light on issues of risk management, data analysis and response strategies, but without an ability to interpret and understand this information it is at risk of being overlooked. By building sufficient flexibility in to tools such as the bioeconomic model presented in this report and used to conduct EPP consequence assessments, the uptake of results can be greatly enhanced. This flexibility may be in terms of interactive displays and user-friendliness, a variety of model input and output styles and formats, or the willingness of tool designers to sit down with decision-makers and explain idiosyncrasies of their particular tool work. This has the effect of enabling decision-makers to champion information like quantitative model results, and to use them to make more informed decisions and choices about EPP risk management.

4. **Deliberative multi-criteria evaluation should be considered a relevant framework for making invasive alien species prioritisation decisions and planning future biosecurity R&D investments accordingly.**

   This report has demonstrated that the deliberative multi-criteria evaluation method (DMCE) is a flexible decision facilitation technique that provides a useful structural framework for making invasive species prioritisation decisions. It provides a context for complex information to be communicated to diverse decision making groups. Sensitivity analysis and trade-offs are transparent under this framework, adding accountability to the decision making group.

5. **Efforts to simplify a deliberative multi-criteria evaluation should not be made at the expanse of disempowering participants.**

From the experience of the DMCE workshop held as part of this project, it is clear that future workshops must provide participants with a sense of ownership over scoring matrices. Our efforts to truncate the workshop process involved presenting participants with a completed impact matrix and explaining where the scientific or expert data came from in expectation that participants would accept it. Although participants could use the criteria weighting process strategically to offset scores in the impact matrix they disagreed with, having ownership of the actual scoring values would help a group to agree on, and improve the estimate. Moreover, it would enable participants to better understand the intricacies of the values. This would avoid problems related to low comprehension of impact matrix scores in regards to the origins of the values/units that each cell represented. To have adequate time and effort to work through the impact matrix scoring, we suggest that a separate meeting prior to the DMCE workshop be conducted.

A closely related issue concerns temptations for analysts to use scoring systems (particularly in the impact matrix) that aggregate and over-simplify available data. This can cause confusion amongst decision makers through a lack of familiarity with the scales used or units of measure. The purpose of the DMCE, definitions of the alternatives being considered, criteria, scoring and weighting systems should be clear and concise. Where possible, criteria should be scored against indicators in natural units that decision-makers are familiar with in their day to day lives and have little trouble visualising. These include $, tonnes, years, etc.

6. **Broad sensitivity testing exploring the trade-offs between decisions should be conducted.**

Consideration of sensitivity analysis is very important, and should not be restricted to criteria weight sensitivity tests. Participant choice of scales in measuring likelihood and consequence impact scores should also be included. For example, the impact matrix scoring using constructed scales could be transformed from normal to log.

7. **The flexibility of the deliberative multi-criteria evaluation method should not prevent it from being used with narrow, well-defined decision-making groups with relatively small numbers of discrete options to choose between.**

While complex issues involving many groups within society are certainly interesting to tackle using a flexible decision-making aid like DMCE, but it is also useful for smaller, less diverse groups who also face complex choices. For instance, issues of polyphagous EPPs and preparedness planning may be compartmentalised into individual industry groups or regions potentially affected by a pest or pests. The narrow focus of these more well defined groups could help to remove hypothetical biases potentially present within larger, more diverse decision-making groups

6. Abbreviations/glossary

ABBREVIATION	FULL TITLE
AHP	Analytical Hierarchy Process
ATC	Average Total Cost
CA	Conjoint Analysis
CABI	Centre for Agricultural Bioscience Information
CBA	Cost Benefit Analysis
CEA	Cost Effectiveness Analysis
CM	Choice Modelling
CPC	Crop Protection Compendium
CRC NPB	Cooperative Research Centre for National Plant Biosecurity
CSH	Critical Systems Heuristics
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CV	Contingent Valuation
DAFWA	Department of Agriculture and Food, Western Australia
DMCE	Deliberative Multi-Criteria Evaluation
DPI	Department of Primary Industries, Victoria
ED	Expected Damage
EPP	Emergency Plant Pest
EPPO	European and Mediterranean Plant Protection Organization
ERAT	Enhanced Risk Analysis Tools
IGP	Integrative Group Processes
HD	Hedonic Pricing
mAHP	modified Analytical Hierarchy Process
MAVT	Multi-Attribute Value Theory
MC	Marginal Cost
MCAT	Multi Criteria Analysis Tool
MCDA	Multi-Criteria Decision Analysis
NDS	Non-Dominated Set
NPV	Net Present Value
OIE	Office International des Epizooties
PHA	Plant Health Australia
SPS	Sanitary and Phyto-Sanitary

TC	Total Cost
TCM	Travel Cost Method
TR	Total Revenue
UTA	Utility Theory Additive
WTO	World Trade Organization
WTP	Willingness To Pay

7. Plain English website summary

CRC project no:	CRC10010
Project title:	Enhanced Risk Analysis Tools
Project leader:	Dr David Cook
Project team:	Mr Michael Hurley, Dr Shuang Liu, Dr Abu-Baker M. Siddique, Prof. Kim E. Lowell and Dr Art Diggle
Research outcomes:	Our research shows that multi-criteria decision analysis is an effective vehicle for the communication of results of economic analyses, technical scientific information and personal experiences to groups of decision-makers. These decision makers may be deciding on how much industry money to invest in species-specific R&D activities, government agencies forming part of the biosecurity continuum, industry and regional cooperative institutions, or local governments allocating money to pest and disease control activities. If supported by a transparent, interactive tool revealing group and individual preferences, experts capable of conveying their knowledge in a clear fashion and adequate technical information about pests, the technique we have developed is a highly effective decision-facilitation device. In a trial setting it has been successfully used to prioritise a diverse list of pests and diseases affecting different industries. An interesting finding of our research is that introducing information about uncertainties in future pest impact scenarios does not necessarily have a significant impact on pest prioritisation. While the use of quantitative models to provide effective expert testimony on the market impacts of pests proved very successful, the relative uncertainty/quality of that information appeared to have little effect on decision-maker priorities. This being the case, there may be scope to further simplify the deliberative process to make group decision facilitation more rapid.
Research implications:	The range of possible impacts society may face in the future as a result of pest and disease incursions should be taken account of when planning risk mitigation activities. For instance, industry and government R&D programs targeted towards future threats should take into account forgone opportunities to invest in other activities that could potentially produce large benefits for the community. This is particularly true of invasive species that have both cultivated and wild native hosts since an outbreak can produce both market and non-market impacts. If only the market impacts are taken into account during industry and government strategic plans, there is a danger species with environmental and social impacts may be under-funded. The implications of this research project for all members of the biosecurity continuum are that practical tools have been developed to enable both

	market and non-market impacts of pests and diseases to be accounted for when planning for the future. To be most effective they require diverse groups coming together and talk about specific threats and a willingness to understand alternative points of view and joint approaches to risk mitigation and management.
Research publications:	1. Cook, D.C. and Matheson, C. (2008) An estimate of the potential economic impact of pine pitch canker in Australia. *Australian Forestry Journal* 71(2): 107-112. 2. Hodda, M. and D. C. Cook (in press). Economic impact from unrestricted spread of Potato Cyst Nematodes in Australia. *Phytopathology*; 3. Yemshanov, D., McKenny D. W., Pedlar J. H., Koch F. H. and Cook D. (2009) Towards an integrated approach to modelling the risks and impacts of invasive forest pests. *Environmental Reviews* 17, 163-178.
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9. Appendix 1 – Bioeconomic Model Parameters

Table 33. Bioeconomic model parameters - insects

				Biological parameters																																
Number	Scientific name	English name	Host name	Probability of entry	Probability of establishment (# trees/infested tree)	Local infestation rate	Spatial infestation rate (# farms/infested tree)	Average farm size (ha)	Total area of Australian production land (ha)	Area occupied by a host (ha)	Time to maturity (year)	Cost of control ($/ha)	Cost of inspection ($/ha)	Cost of eradication ($/ha)	Inspection budget pre-1st detection ($/ha)	Inspection budget post-1st detection ($/ha)	Central control choke price ($)	Preinfest export (kg)	Preinfest production (kg/ha)	Within season multiplicaion factors (plants/plant)	Postinfest production left (%)	Postinfest export drop (%)	Preinfest domestic price ($/kg)	Domestic choke price multiplier	Supply elasticity	Demand elasticity	Export price ($/kg)	Discount rate %)	Start control threshold (%)	Control tech effectiveness (%)	Detection prob if inspected	Search efficiency	Initial time since last detection	No detect years before declared eradicated	Run length	Stochastic mode
1	*Acrobasis pyrivorella*	Pear fruit moth	Pear	0.175	0.175	5	0.02	6	4393	0.00083	6	450	40	470	60	120	282	2,705,000	29,037	0	70.0	30.00	2.7	3	0	-0.6	1.08	7	7	70	1	1	1000	3	30	1
2	*Adoretus versutus*	Rose beetle	Taro	0.175	0.175	10	0.1	2	117	30,000plant/ha	0.85	700	80	70	2,340	4,680	819	0	15000	0	80.0	20.00	2	3	0	-2	0	8	8	40	1	1	1000	3	30	0;1;2
3	*Agrotis segetum*	Turnip moth	Green tea	0.175	0.85	30	0.1	5	76	18,700 plants/ha	4	400	60	200	1,140	2,280	3,040	50,400	18000	0	80.0	2	0.6	3	0	-2	0	8	5	80	1	1	1000	3	30	0;1;2
4	*Apate monachus*	Black borer	Pear	0.175	0.5	3	0.04	6	4393	0.00083	6	400	400	470	439,300	878,600	206,471	2,705,000	29,037	0	70.0	0	2.7	3	0	-0.6	1.08	8	7	80	1	1	1000	3	30	1
5	*Aphis pomi*	Apple aphid	Apple	0.18	0.18	3	0.01	11	13,260	0.00067	6	300	40	470	110	220	517	2,705,000	20,400	0	80.0	0.00	1.19	3	0	-0.6	1.08	8	10	80	1	1	1000	3	30	1
6	*Bactrocera dorsalis*	Oriental fruit fly	Apple	0.85	0.5	50	0.5	11	13,260	0.00067	6	1,500	70	470	92,820	185,640	1,246,440	2,705,000	20,400	0	70.0	30.00	1.19	3	0	-0.6	1.08	8	7	70	1	1	1000	3	30	1
7	*Bactrocera oleae*	Olive fruit fly	Olive	0.0005005	0.5	20	0.3	10	32,000	0.004	8	400	60	200	480,000	960,000	640,000	230,000	12500	0	70.0	10.00	1.5	3	0	-2	2.2	8	7	60	1	1	1000	3	30	0;1;2
9	*Cacopsylla pyricola*	Psylla	Pear	0.175	0.175	4	0.02	6	4393	0.00083	6	300	40	470	60	120	282	2,705,000	29,037	0	80.0	10.00	2.7	3	0	-0.6	1.08	7	7	b	1	1	1000	3	30	1
10	*Carposina sasakii*	Peach fruit moth	Pear	0.5	0.5	4	0.01	6	4393	0.00083	6	450	40	470	60	120	282	2,705,000	29,037	0	70.0	10.00	2.7	3	0	-0.6	1.08	7	7	70	1	1	1000	3	30	1
12	*Delia antiqua*	Onion fly	Onion	0.85	0.5	6	1	8	4657	0.0000015	0.49	500	60	2,185	27,942	55,884	1,017,555	52,537,000	49300	500	30.0	60	0.5	3	0	-0.5	0.4	8	5	40	1	1	1000	3	30	1
13	*Dysaphis plantaginea*	Rosy apple aphid	Apple	0.85	0.85	3	0.01	6	4393	0.00083	6	360	40	470	60	120	282	2,705,000	29,037	0	50.0	25.00	2.7	3	0	-0.6	1.08	8	10	80	1	1	1000	3	30	1
14	*Empoasca fabae*	Potato leafhopper	Potato	0.025	0.5	7	0.7	30	38190	0.00001	0.33	500	20	2,185	76,380	152,760	8,344,515	28,090,000	36700	500	80.0	25.00	0.8	3	0	-1	0.55	8	5	80	1	1	1000	3	30	1
17	*Hippotion celerio*	Taro hawkmoth	Taro	0.33	0.85	20	0.2	2	117	30,000plant/ha	0.85	100	70	60	2,048	4,095	702	0	15000	0	85	0	2	3	0	-2	0	8	8	80	1	1	23	3	30	0;1;2
18	*Indarbela dea*	Bark borer	Pomegranate	0.175	0.335	2	0.03	2	200	0.004	4	600	950	68	47,500	95,000	1,350	0	20400	0	70.0	0	1.7	3	0	-4	0	8	7	80	1	1	1000	3	30	0;1;2
20	*Leptinotarsa decemlineata*	Colorado potato beetle	Potato	0.175	0.5	6	0.5	30	38190	0.00001	0.33	270	20	2,185	76,380	152,760	8,344,515	28,090,000	36700	400	80.0	25.00	0.8	3	0	-1	0.55	8	5	80	1	1	1000	3	30	1
21	*Leucoptera malifoliella*	Pear leaf blister moth	Pear	0.175	0.5	5	0.03	6	4393	0.00083	6	450	40	470	60	120	282	2,705,000	29,037	0	70.0	0.00	2.7	3	0	-0.6	1.08	7	7	70	1	1	1000	3	30	1
22	*Mamestra brassicae*	Cabbage moth	Lettuce	0.175	0.85	7	1	8	7559	0.0000125	0.15	700	30	2,185	22,677	45,354	1,651,642	1,147,000	23700	500	70.0	25	0.7	3	0	-0.5	2.7	8	5	75	1	1	1000	3	30	1
23	*Papuana huebneri*	Taro beetle	Taro	0.175	0.175	70	0.4	2	117	30,000plant/ha	0.85	600	80	70	2,340	4,680	819	0	15000	0	70.0	25.00	2	3	0	-2	0	8	8	40	1	1	1000	3	30	0;1;2
24	*Parasa lepida*	Nettle caterpillar	Green tea	0.175	0.85	40	0.04	5	76	18,700 plants/ha	4	200	170	200	3,230	6,460	2,171	0	18000	0	80.0	0	0.6	3	0	-2	0	8	8	75	1	1	1000	3	30	0;1;2
25	*Parlatoria oleae*	Olive scale	Olive	0.0005005	0.5	10	0.2	10	32,000	0.004	8	700	50	200	400,000	800,000	640,000	230,000	12500	0	80.0	10.00	1.5	3	0	-2	2.2	8	7	80	1	1	1000	3	30	0;1;2
26	*Patchiella reaumuri*	Taro root aphid	Taro	0.175	0.175	10	0.1	2	117	30,000plant/ha	0.85	500	70	60	2,048	4,095	702	0	15000	0	50	0	2	3	0	-2	0	8	8	30	1	1	1000	3	30	0;1;2
28	*Prays oleae*	Olive kernel borer	Olive	0.175	0.175	15	0.35	10	32,000	0.004	8	300	60	200	480,000	960,000	640,000	230,000	12500	0	80.0	5.00	1.5	3	0	-2	2.2	8	7	60	1	1	1000	3	30	0;1;2
29	*Psila rosae*	Carrot root fly	Carrot	0.85	0.85	6	1	17	5715	0.0000015	0.38	700	60	2,185	34,290	68,580	1,248,728	66,000,000	47500	150	30.0	60	0.55	3	0	-0.5	0.66	8	5	40	1	1	1000	3	30	1
30	*Rhagoletis pomonella*	Apple maggot	Apple	0.85	0.85	3	0.01	11	13,260	0.00067	6	1220	40	470	110	220	517	2,705,000	20,400	0	70.0	30.0	1.19	3	0	-0.6	1.08	8	7	40	1	1	1000	3	30	1
31	*Spodoptera littoralis*	Cotton leaf worm	Potato	0.175	0.5	7	0.7	30	38190	0.00001	0.33	250	20	2,185	76,380	152,760	8,344,515	28,090,000	36700	500	70.0	25.00	0.8	3	0	-1	0.55	8	5	80	1	1	1000	3	30	1
32	*Tarophagus proserpina*	Taro planthopper	Taro	0.175	0.5	10	0.1	2	117	30,000plant/ha	0.85	150	70	60	2,048	4,095	702	0	15000	0	90	0	2	0	0	-2	0	8	8	80	1	1	1000	3	30	0;1;2
33	*Thaumatotibia leucotreta*	False codling moth	Olive	0.5	0.85	3	0.03	10	32,000	0.004	8	3000	950	90	7,600,000	15,200,000	288,000	230,000	12500	0	70.0	60.0	1.5	3	0	-2	2.2	8	7	60	1	1	1000	3	30	0;1;2
34	*Trichoplusia ni*	Cabbage looper	Cauliflower	0.175	0.85	7	1	8	3210	0.00004	0.24	700	30	2,185	9,630	19,260	701,385	958,000	1500	500	70.0	20	0.8	3	0	-0.5	2.2	8	5	80	1	1	1000	3	30	1
35	*Xylosandrus compactus*	Black twig borer	Green tea	0.5	0.85	50	0.4	5	76	18,700 plants/ha	4	250	60	200	1,140	2,280	3,040	0	18000	0	80.0	20	0.6	3	0	-2	0	8	7	80	1	1	1000	3	30	0;1;2
36	*Zeuzera pyrina*	Wood leopard moth	Olive	0.35	0.4	5	0.05	10	32,000	0.004	8	700	120	270	960,000	1,920,000	864,000	230,000	12500	0	70.0	10.0	1.5	3	0	-2	2.2	8	7	70	1	1	1000	3	30	0;1;2

Table 34. Bioeconomic model parameters - fungi

				Biological parameters																																
Number	Scientific name	English name	Host name	Probability of entry	Probability of establishment (# trees/infested tree)	Local infestation rate	Spatial infestation rate (# farms/infested tree)	Average farm size (ha)	Total area of Australian production land (ha)	Area occupied by a host (ha)	Time to maturity (year)	Cost of control ($/ha)	Cost of inspection ($/ha)	Cost of eradication ($/ha)	Inspection budget pre-1st detection ($/ha)	Inspection budget post-1st detection ($/ha)	Central control choke price ($)	Preinfest export (kg)	Preinfest production (kg/ha)	Within season multiplicaion factors (plants/plant)	Postinfest production left (%)	Postinfest export drop (%)	Preinfest domestic price ($/kg)	Domestic choke price multiplier	Supply elasticity	Demand elasticity	Export price ($/kg)	Discount rate %)	Start control threshold (%)	Control tech effectiveness (%)	Detection prob if inspected	Search efficiency	Initial time since last detection	No detect years before declared eradicated	Run length	Stochastic mode
1	*Alternaria gaisen*	Black spot of Japanese pear	Pear	0.025	0.175	4	0.1	6	4393	0.00083	6	420	1200	1,000	527,160	1,054,320	878,600	2,705,000	29,037	0	80.0	0.00	2.7	3	0	-0.6	1.08	7	10	70	1	1	1000	3	30	1
2	*Botryosphaeria berengeriana f.sp.pyricola*	Blister canker	Pear	0.175	0.175	6	0.1	6	4393	0.00083	6	420	1200	1,000	527,160	1,054,320	878,600	2,705,000	29,037	0	50.0	3.00	2.7	3	0	-0.6	1.08	7	10	70	1	1	1000	3	30	1
3	*Botryosphaeria dothidea*	White rot of Apple	Apple	0.175	0.175	6	0.1	11	13,260	0.00067	6	420	1200	1,000	1,591,200	3,182,400	2,652,000	2,705,000	20,400	0	50.0	3.00	1.19	3	0	-0.6	1.08	8	10	70	1	1	1000	3	30	1
4	*Botryosphaeria dothidea*	White/Fruit rot of olive	Olive	0.175	0.175	20	0.4	10	4,600	0.004	8	600	900	460	414,000	828,000	211,600	2,700,000	12500	0	50.0	15	1	3	0	-0.5	5.8	8	7	80	1	1	1000	4	30	1
5	*Botryotis squamosa*	Onion leaf blight	Onion	0.85	0.5	7	3	8	4657	0.0000015	0.49	900	30	2,185	13,971	27,942	1,017,555	52,537,000	49300	150	60.0	10	3	3	0	-0.5	0.4	8	5	80	1	1	1000	5	30	1
6	*Ceratocystis fimbriata*	Wilt of Pomegranate	Pomegranate	0.85	0.85	4	0.05	2	200	0.002	4	1000	900	460	45,000	90,000	4,600	0	30000	0	90.00	0.00	1.7	3	0	-0.5	0	8	7	80	1	1	22	3	30	1
7	*Cladosporium allii-cepae*	Cladosporium leaf blotch	Onion	0.85	0.85	7	3	8	4657	0.0000015	0.49	300	30	2,185	13,971	27,942	1,017,555	52,537,000	49300	500	90.0	0	0.5	3	0	-0.5	0.4	8	5	80	1	1	1000	0.6	30	1
8	*Colletotrichum higginsianum*	Anthracnose	Broccoli	0.5	0.5	7	2	8	7136	0.000025	0.22	750	30	2,185	21,408	42,816	1,559,216	3,580,000	6500	700	70.0	10	1.8		0	-0.5	2.7	8	50	75	1	1	1000	3	30	1
9	*Coniella granati*	Pomegranate fruit/dry rot	Pomegranate	0.5	0.5	8	0.08	2	200	0.002	4	180	900	460	45,000	90,000	7,667	0	30000	0	70.00	30.00	1.7	3	0	-0.5	0	8	7	80	1	1	1000	3	30	1
10	*Cytospora oleina*	Olive canker/dieback	Olive	0.175	0.5	5	0.2	10	4,600	0.004	8	500	900	460	414,000	828,000	211,600	2,700,000	12500	0	75	0.0	1	3	0	-0.5	5.8	8	7	60	1	1	1000	4	30	1
11	*Gymnosporangium fuscum*	European pear rust	Pear	0.025	0.175	12	0.3	6	4393	0.00083	6	258	1200	1,000	527,160	1,054,320	878,600	2,705,000	29,037	0	80.0	0.00	2.7	3	0	-0.6	1.08	7	10	80	1	1	1000	3	30	1
12	*Gymnosporangium yamadae*	Japanese apple rust	Apple	0.025	0.175	12	0.3	11	13,260	0.00067	6	258	1200	1,000	1,591,200	3,182,400	2,652,000	2,705,000	20,400	0	80.0	0.00	1.19	3	0	-0.6	1.08	8	10	80	1	1	1000	3	30	1
13	*Monilinia fructigena*	Brown rot	Pear	0.5	0.85	6	0.1	6	4393	0.00083	6	420	1200	1,000	527,160	1,054,320	878,600	2,705,000	29,037	0	80.0	80.00	2.7	3	0	-0.6	1.08	7	10	70	1	1	1000	3	30	1
14	*Neonectria galligena*	European canker	Apple	0.85	0.85	8	0.2	11	13,260	0.00067	6	420	1200	1,000	1,591,200	3,182,400	2,652,000	2,705,000	20,400	0	70.0	50.00	1.19	3	0	-0.6	1.08	8	10	70	1	1	55	3	30	1
15	*Phoma andina*	Black blight of potato	Potato	0.175	0.5	6	1	30	38190	0.00001	0.33	400	150	2,500	572,850	1,145,700	9,547,500	28,090,000	36700	600	70.0	3.00	0.8	3	0	-1	0.55	8	10	80	1	1	1000	3	30	1
16	*Phyllosticta solitaria*	Apple blotch	Apple	0.025	0.175	4	0.1	11	13,260	0.00067	6	258	1200	1,000	1,591,200	3,182,400	2,652,000	2,705,000	20,400	0	80.0	1.00	1.19	3	0	-0.6	1.08	8	10	80	1	1	1000	3	30	1
17	*Phymatotrichopsis omnivora*	Texas root rot of olive	Olive	0.025	0.5	5	0.06	10	4,600	0.004	8	2500	900	10,500	1,035,000	2,070,000	2,415,000	2,700,000	12500	0	80.0	70.0	1	3	0	-0.5	5.8	8	7	50	1	1	1000	10	30	1
18	*Polyscytalum pustulans*	Skin spot of potato	Potato	0.5	0.5	1.5	0.1	30	38190	0.00001	0.33	300	150	2,500	572,850	1,145,700	9,547,500	28,090,000	36700	50	70.0	10.00	0.8	3	0	-1	0.55	8	0.1	50	1	1	1000	5	30	1
19	*Puccinia pittieriana*	Potato rust	Potato	0.175	0.5	10	2	30	38190	0.00001	0.33	600	150	2,500	572,850	1,145,700	9,547,500	28,090,000	36700	1000	80.0	3.00	0.8	3	0	-1	0.55	8	0.1	70	1	1	1000	3	30	1
20	*Rhizoctonia carotae*	Crater rot	Carrot	0.5	0.5	1.5	0.1	17	5715	0.0000015	0.38	400	100	2,500	57,150	114,300	1,428,750	66,000,000	47500	50	50.0	20	0.55	3	0	-0.5	0.66	8	5	60	1	1	1000	10	30	1
22	*Synchytrium endobioticum*	Potato wart disease	Potato	0.175	0.85	1.5	0.02	30	38190	0.00001	0.33	300	150	2,500	572,850	1,145,700	9,547,500	28,090,000	36700	50	20.0	15.00	0.8	3	0	-1	0.55	8	10	40	1	1	1000	40	30	1
23	*Thecaphora solani*	Potato smut	Potato	0.85	0.85	1.5	0.1	30	38190	0.00001	0.33	300	150	2,500	572,850	1,145,700	9,547,500	28,090,000	36700	50	20.0	15.00	0.8	3	0	-1	0.55	8	10	50	1	1	1000	5	30	1

Table 35. Bioeconomic model parameters - bacteria

				Biological parameters																																
Number	Scientific name	English name	Host name	Probability of entry	Probability of establishment (# trees/infested tree)	Local infestation rate	Spatial infestation rate (# farms/infested tree)	Average farm size (ha)	Total area of Australian production land (ha)	Area occupied by a host (ha)	Time to maturity (year)	Cost of control ($/ha)	Cost of inspection ($/ha)	Cost of eradication ($/ha)	Inspection budget pre-1st detection ($/ha)	Inspection budget post-1st detection ($/ha)	Central control choke price ($)	Preinfest export (kg)	Preinfest production (kg/ha)	Within season multiplicaion factors (plants/plant)	Postinfest production left (%)	Postinfest export drop (%)	Preinfest domestic price ($/kg)	Domestic choke price multiplier	Supply elasticity	Demand elasticity	Export price ($/kg)	Discount rate %)	Start control threshold (%)	Control tech effectiveness (%)	Detection prob if inspected	Search efficiency	Initial time since last detection	No detect years before declared eradicated	Run length	Stochastic mode
2	*Erwinia amylovora*	Fire blight	Apple	0.18	0.5	4	0.1	11	13,260	0.00067	6	5,500	1200	3,000	1,591,200	3,182,400	3,978,000	2,705,000	20,400	0	80.0	0.00	1.19	3	0	-0.6	1.08	8	3	40	1	1	1000	3	30	1
3	*Xanthomonas axonopodis pv. allii*	Onion bacterial blight	Onion	0.85	0.5	5	1	8	4657	0.0000015	0.49	900	30	2,185	13,971	27,942	1,017,555	52,537,000	49300	100	60.0	15	0.5	3	0	-0.5	0.4	8	5	80	1	1	1000	3	30	1
4	*Xanthomonas axonopodis pv. punicae*	Bacterial blight of Pomegranate	Pomegranate	0.85	0.5	10	0.1	2	200	0.002	4	600	900	460	45,000	90,000	9,200	0	30000	0	50.0	30.00	1.7	3	0	-0.5	0	8	7	30	1	1	1000	3	30	1

10. Appendix 2 – Threat Data Sheets

THREAT DATA

Pear fruit moth

(Acrobasis pyrivorella)

(Ref. http://www.padil.gov.au/viewPestDiagnosticImages.aspx?id=512)

CRC10010

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Pear fruit moth

(*Acrobasis pyrivorella*)

Pear fruit moth, also know as pear moth (*Acrobasis pyrivorella*). It has a number of synonyms in the literatures. Pear moth is very restricted to pear plant and is one of the destructive pests for pear industry in Russia where up to 90% crop damage reported in the literature (Shutova 1970).

Distribution: Pear moth is widely distributed in the temperate zone of Asia. Specially in Japan this pest is found in all pear growing regions. In China it occurs in a number of provinces. Similarly in Russia, it is limited to a number of provinces. The pest has not been reported in Australia, New Zealand, North America, Europe and Middle East.

Host range: Pear moth has very restricted host range that includes only pear such as *Pyrus communis* (European pear) and *Pyrus pyrifolia* (Oriental pear tree). There is no indication that the moth attacks fruit trees other than *Pyrus sp.* (Shutova, 1977).

Affected Plant Stages: Fruiting stage.

Affected Plant Parts: Fruits/pods and inflorescence.

Biology and Ecology: Pear moth overwinters as first-instar or second-instar larvae in flower buds within a thin white cocoon (Shutova, 1970; Gibanov and Sanin, 1971). The infested buds do not fall, but remain on the tree without developing. In spring, the larvae emerge and move to fresh buds. It feeds on the developing buds, flowers and fruitlets. Larvae move from fruit to fruit and a. single larva can infest and destroy two to three buds, one to three primordial flowers and up to three fruits (Shutova, 1977). The older larvae penetrate into the developing fruit around the stalk to pupate. The larvae generally enter the fruit near the calyx end or on the side of the fruit, making a prominent hole with an overhanging lip of silk and excreta. The moths lay eggs (about 120 per female) near new flower buds. The larvae hatch and penetrate the buds to form the overwintering cocoons after a week. The biology and ecology of the pest varies depending on climatic conditions. Fruits that have been infested by larvae remain black and shrivelled on the tree.

Symptoms: Fruit infested with pear moth are normally retarded in growth and turn black with a shrivelled appearance. Furthermore, the shrivelled fruits remain on the tree until the following year (Shutova, 1977). In summer, the entry holes of the pest are characteristic. They are most often placed at the calyx end or side of the fruit, with the upper side of the opening marked by an overlapping lip of accumulated excreta (Shutova, 1977). Unable to find any photo of the damage symptoms associated with this pest in literature.

Pest Movement and Dispersal: The natural spread of *A. pyrivorella* by adult flight is over relatively short distances. The main means of spread would be international trade of planting material with infested buds (Shutova, 1977). Both infested plant materials and fruits liable to carry the pest in trade/transport

Resistant plant variety: No report is available in the literatures on resistant plant variety against the pear moth.

Natural Enemies: Number of natural enemies for pear moth listed in CPC without further details of their effectiveness in the field.

Economic impact: Pear pest is considered to be one of the major pests for pear in the Far Eastern territories of Russia, *A. pyrivorella* is rated as the most serious pest of cultivated pears, and damages up to 90% of pear crops (Shutova, 1970). It is also considered to be of economic importance in Japan (Siezo, 1968).

Management: In Japan, *A. pyrivorella* is controlled by applying fenitrothion, diazinon, cyanophos or methidathion shortly before flowering and two later applications between June and August, depending on the developmental stages of the pest (Umeya, 1980). In Russia, the latest insecticidal application is recommended for mid-August (Komarova, 1984). Forecasting systems are being developed in China (Geoffrion, 1987; Feng, 1997). Biological control has not been thoroughly researched, although Meteorus colon has been reported to parasitise *A. pyrivorella* up to 57% in Russia (Komarova, 1984) and several ichneumonids in China (Xing et al., 1986). In China, fruits are individually wrapped in paper to exclude the pest. However, in certain parts of the trees the fruits remain unwrapped and serve as bait-fruits which are destroyed after infestation (Shutova, 1977).

Phytosanitary Risk: Pear pest presents a risk to all pear-growing regions in other continents. It is included in the EPPO A2 list of quarantine pests (OEPP/EPPO, 1999), though not listed as a quarantine pest by any other regional plant protection organisation. In Russia, *A. pyrivorella* is considered to be capable of survival wherever pears are grown (Shutova, 1977), and is treated as an internal quarantine pest. Measures taken against *Carposina sasakii* (EPPO/CABI, 1996a) would adequately cover *A. pyrivorella*.

Probabilities of Entry: Low - *A. pyrivorella* can enter into Australia mainly through infested plant parts (mainly buds) but under proper quarantine it has low possibility of entry into the country.

Possibility of Establishment: Low –apart from pears growing regions, the pest has low potential to establish in Australia due to its restricted host range.

Quarantine Risk: Low – because of low potential of entry and establishment of the pest. If established, the pest has also low potential to spread in other pears growing regions in Australia due to its relatively short distance flight capacity.

Economic Impact: High - based on pest biology and the damage severity reported in published literatures by *A. pyrivorella*. Unavailability of any pest resistant plant variety is also an important issue in economic impact.

Environmental Impact: Low – very restricted host capacity of *A. pyrivorella* is consider requiring less chemical application for its management i.e. less environment pollution.

Social Impact: Very low – since pear is only known fruit plant affected by *A. pyrivorella* and a proper control measure is also available. Therefore, social impact consider very low due to the presence of this pest

Pest Management cost: Low/moderate – depending on pest severity the management cost may vary. Based on literature the annual application cost for chemical control of this pest is about **$450/ha for 3 spray** (chemical cost ~$100/ha plus labor and machinery cost ~$50/ha for a single spray as suggested by Martine Combret, Development Officer, DAFWA). This cost excludes involvement of any biological control and resistant plant varieties. Effective and established control practices (both cultural and chemical) are available for *A. pyrivorella*. However, the management with cultural practice could be more expensive in case pest severity.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 15 – 25% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – due to very restricted host capacity and low dispersion possibility of *A. pyrivorella* through fruit during international trade.

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THREAT DATA

Rose beetle

(*Adoretus versutus*)

Source: http://www.discoverlife.org/20/q?search=Adoretus+versutus

CRC10010

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Rose beetle

(*Adoretus versutus*)

Adoretus versutus is one the major taro pest in the South Pacific which also attacks cocoa, cacao, coffee, rose etc. The insect known by several English names like rose beetle, Indian rose beetle, Japanese rose beetle and Fijian cane root grub. *A. versutus* is a polyphagous insect that attack many ornamental plants. No effective control measure is available to manage this pest.

Distribution: *A. versutus* is native to Indian region (Lever, 1945). The pest reported in Sri Lanka, India, Indonesia, Pakistan, Madagascar, Mauritius, Réunion, St. Helena, Seychelles, Fiji, Samoa, Tonga, Wallis Islands, Cook Islands. Not currently recorded in Australia and New Zealand.

Host range/Alternate host: *A. versutus* is a polyphagous insect that has many major (18 species) and minor (22 species) hosts. **Taro** is one of the major host and 18 taro varieties get affected by this pest (ref. CPC 2008). **Apple**, **pears**, orange, lemon, papaya are among the many minor hosts of *A. versutus.* Besides fruits and cultivated crops the pest also attacks many ornamental plants. *A. versutus* is also a pest of *Eucalyptus tereticornis* and on fresh Papaya Fruit in Fiji.

(A) **Biology of the Pest**: Adult *A. versutus* are nocturnal and feed mainly in the early hours of the night. After feeding, they hide 5-10 cm deep in the ground and disappear completely during daylight hours. If disturbed during feeding, the beetles fall to the ground. The generations are continuous. The fecundity *of A. versutus* females is not known but comparison with related beetles of similar size suggests the possibility that each female may produce about **40 eggs** (Waterhouse and Norris, 1987). Eggs lay in the soil where the **life cycle completes by about 3-months** (Waterhouse and Norris, 1987). The larvae feed on roots and decaying vegetation and sometimes on branches. Dark-brown body of the adult insect (12.8 mm long, 6.8 mm wide) covered with dense greyish-white scales dotted with brown-red hairs surrounding small blackish-brown alveoles on the wing cases. The strongly developed fore- and hind-legs are used for burrowing. Males have a smaller last sternite than females.

Symptom and Damage: Adult *A. versutus* attack leaf of both seedling and mature plant that cause defoliation. Seedlings are very vulnerable to attack because they can be defoliated rapidly and heavy defoliation leads to death of young seedling. Therefore, the insect attack in nursery is very damaging compared to negligible in mature plants.

The adults feed by perforating the leaflets, starting from the middle and without destroying the ribs. The leaflets are eaten away in very small but numerous patches, giving a skeletal appearance to the leaflet. The attacks are more numerous at the apex of the leaflets than at the base. Besides this characteristic feeding behaviour, the adult rose beetles make depressions in the border of the areas eaten, which is typical of *Adoretus spp*. and distinguishes them from the damage caused by other foliage pests. *A. versutus* feed in the early hours of the night

Fig. 1. Leaf damage caused by insect *Adoretus sp.*

Source:http://images.google.com.au/images?ndsp=20&um=1&hl=en&q=Damage+%2BA doretus&start=0&sa=N

Affected plant parts: Leaves and inflorescence.

Resistant plant variety: No resistant varieties for taro are available yet.

Pest movement and Dispersal: The infested plant materials (especially leaf) carried out by people is the most common pathway to disperse *A. versutus* in new areas. The larvae in infested nursery could also early be dispersed in new areas through soil movement.

Impact: The damage caused by *A. versutus* in taro crop is not available but the reports for other host are available in literature. For example, in Cook Island affected plants are avocados, oranges, papayas, citrus fruits, Barringtonia edulis (90% damaged), Terminalia catappa (80-90%), beans (young: 70%; mature: 30%), lychees (60-80%), Hibiscus tiliaceus (60%), ginger (20%), cashews (15%), bananas (7%), sweet potatoes (5%), white guavas (5%), pomelos (4-5%) and apples (2%) (Beaudoin, 1992). On Vitilevu island damage reached 90% on cocoa seedlings. In Tonga, damage has been observed on ginger (80%), grapevines (50%), beans (30%) vau [Hibiscus tiliaceus] (25-40%) and radishes (20%) (Beaudoin, 1992). In Fiji Vernon (1976) described serious but local damage to cocoa seedlings by A. versutus adults feeding. Lever (1945) quoted accounts of severe attack, sometimes fatal to cocoa seedlings. Fletcher (1916) reported attacks on grapes, figs, pears and plums, and Lever (1946) added aubergines, cowpeas, ginger and Hibiscus tiliaceus. Veitch (1919) recorded attack on guavas, and Veitch and Greenwood (1921) stated that the adults fed sparingly on sugarcane foliage. Putturam et al. (1976) reported attack on sorghum, the beetle feeding on the blossoms and milky grains.

Since there is no effective control measure for this pest, therefore farmers are very concern about this pest and attacks on cocoa and roses appear to cause the greatest concern (Waterhouse and Norris, 1987).

Phytosanitary risk: *A. versutus* is a quarantine pest in South Pacific regions.

(B) **Natural Enemies**: No insect natural enemies are recorded for *A. versutus* (Waterhouse and Norris, 1987).

Management: *A. versutus* management is difficult task because a considerable part of its life cycle occurs underground. The current chemical control with dieldrin spray in the soil surface is inefficient, expensive and cause environmental pollution. Similarly the cultural methods are also costly for the small growers. Maintaining a clean, weed-free plantation and buffer zone is an important step in keeping populations low. Minor damage can be tolerated.

Cultural methods: In case of cocoa cultivation, there is a tradition of building a low wall of stones or sticks around cocoa seedlings to protect them from *A. versutus*, but the cocoa is liable to be attacked as soon as it grows above the barrier (Lever, 1945; Urquhart, 1961). Such methods are labour intensive, expensive and may have the disadvantage of reducing photosynthesis and hence growth. In Malaysia, Samoa and Fiji, in cocoa the damage reduce by putting up structural barriers (such as coconut fronds or bamboo fences) around each plant, provided that those are at least as tall as the foliage. This method is effective in first year after planting, later it becomes impracticable as the plants grow taller (Entwistle, 1972). No practical measures are known to control the underground stages of *A. versutus*, but the larva's habit of emerging at night and traversing the soil surface to attack the host plant could be exploited by hand-picking. Hand-picking of adult beetles by lantern light has also been advocated (Lever, 1945).

(C) **Chemical control:** No effective chemical is available. The practice of spraying the soil surface of young cocoa plantations in Fiji with dieldrin at the time of peak adult emergence in November-December is no longer current. This practice also results in significant environmental pollution (Waterhouse and Norris, 1987; Lefeuve and Decazy, 1990).

(D) **Integrated Pest Management:** An integrated approach using coconut shading and vegetative fencing may be adopted. However, smallholders have not used chemical or agronomic control for rose beetles as the cost of chemicals and labour to erect fences and/or shading has proved too expensive.

(E) **Biological Control:** Biological control attempts against *A. versutus* were reviewed by Waterhouse and Norris (1987). Introductions of insect parasitoids have been made in Fiji, Solomon Islands, Western Samoa, Vanuatu and Mauritius, primarily against other white grub pests and one, Micromeriella marginella modesta, became established on *A. versutus* in Fiji but does not contribute to its control.

Quarantine Risk: High. *A. versutus* has multiple host range and difficult to manage in field conditions because of its eggs and larvae inhabit in soil. *A. versutus* designated as a quarantine pest in South Pacific regions.

Probabilities of Entry: Low -. Both eggs and larvae of *A. versutus* are soil inhabitant and the infected plant parts mainly leaf that are not usually associated with export.

Possibility of Establishment: Moderate – Because of multiple host capacity, the entry of *A. versutus* has good chance to find a suitable host and establish quickly under favourable climatic conditions in many parts of Australia.

Probabilities of Entry and Establishment: Low – In spite of suitable climatic conditions and divers host capacity, *A. versutus* has low chance of entry and establishment in Australia due to its low entry possibility.

Economic Impact: High – Including taro, *A. versutus* also attack and cause a significant damage to many commercial crops. The management of this pest is also very difficult that results high economic impact on the economy.

Environmental Impact: Low – Under current situation where cultural practices are the only way to keep *A. versutus* population low in the field conditions, therefore the environmental pollution from chemical application would be very negligible.

Social Impact: Moderate – Since no effective chemicals are available to control *A. versutus* in field. Therefore, many small growers would suffer by the damage severity of this pest on a number of crops. This will have negative impacts on local community.

Pest management cost: High – In absence of effective chemical controls, the cultural practice is going to be very cost effective to manage *A. versutus* in field. The cost may vary from place to place depends to labor wages, pest severity and other factors and this figure could be vary from $400 to $800/ha.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 – 30% for individual crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Medium – although *A. versutus* possess low risk of dispersion via international trade however, difficulty and ineffective pest management at field level are the main concerns in export market.

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THREAT DATA

Turnip moth

(*Agrotis segetum*)

http://www.biopix.dk/Photo.asp?Language=la&PhotoId=43329&Photo=Agrotis-segetum

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Turnip moth

(*Agrotis segetum*)

The turnip moth is a moth of the family Noctuidae. It has a number of common English and scientific names including turnip moth and *A. segetum* respectively. This pest was first described in 1775 under the name *Noctua segetum* by Denis and Schiffermuller. It is a common European species, but is also present in other parts of the world. *A. segetum* is consider a broad polyphagous insect that cause damage to many vegetable, cereals, grains and crops including tea.

Distribution: *A. segetum* is a common European species, but is also present in many of Asian, Middle East and African countires (ref CPC). This insect is not believed to be present in the United States, where its possibility of entry with imported food crops been cheked regularly. *A. segetum* is not currently recorded in Australia and New Zealand.

Host range: Including tea and coffee, *A. segetum* has very wide host range. It attacks cultivated plants belonging to more than 15 families (e.g. cotton, tomatoes, maize, grain legumes, tobacco, sunflower, sugar beet, winter cereal etc). In Russia and adjacent countries the larvae populate more than 160 plant species. In addition to cultivated host**,** *A. segetum* has number of wild host Couch-grass (*Agropyrum*), Bindweed (*Convolvulus*), plantain (*Plantago*), etc. The female lays their eggs in wild host and than attack cultivated plants.

Habitat: Areas of cultivated tea, coffee, cereal, grains legumes, and vegetable crops.

Biology and Ecology: Depending on local conditions (e.g. temperature) *A. segetum* has **1 to 2 annual generations**, sometimes, a partial third. Adults generally emerge from pupae during the day but do not become active until dusk. Mating my take place on the night of emergence or later and depending on environmental conditions each female mate 1-3 times (Gomaa, 1978) in their life. After a 3-4 day pre-ovipositional period each female lays several hundred **eggs** (**800-1200**) over about 6 days (Esbjerg, 1992). The eggs are laid one by one, occasionally in groups of 2-3 on plant residues, on the ground, and on the lower side of weed leaves adjoining soil surface or aggregating in a rosette. Development of eggs lasts 3 to 24 days depending on temperatures. Eggs are spherical shape (0.5-0.6 mm) with while colour at early stage. Larvae develop in 24-40 days, reaching 40-52 mm in length at the last 6^{th} instar. The young caterpillar first nibbles the wild plants and then attacks the neighbouring cultivated species. It feeds at night, gnawing the foliage and cutting the petioles. During the day, it conceals itself by rolling up under a lump of earth or at a slight depth in the ground. The species overwinters as a caterpillar.

The size and colour of adult moths are varied. The body length is 18-22 mm with 34-45 mm wingspan. It has dark brown fore wings with uniform and a clearer circular spot in the middle. The rear wings are white in the male and grey in the female. The periphery of the wings bears a thin black border. Females have setaceous antennae but males have comb-like antennae (figure in the cover page).

Symptoms: Leaves, stalks and stems of the affected plants show external feeding with abnormal leaf fall. In case of roots and stems both external and internal feedings are visible. The whole leaf may fall off the plant after being cut through at the base of the stalk by the larvae (fig. B).

Fig A). Attack on collar of beat   Fig B). Larva on lettuce plant

Affected plant stages: Seedling and vegetative stages.

Affected plant parts: Leaves, roots and stems

Affected Industries: Tea, coffee and other crops.

Affected time of the year: The adults appear in early summer and remain active throughout the summer period (ref. CPC).

Pest detection: In some crops (e.g. carrots), premature leaf falling caused by young larvae may indicate the presence of the pest, but by then it may not be possible to save the crop. Holes and cavities in roots and tubers are useful for mapping and assessing attacks levels. Larvae (45-50 mm) with greyish body and reddish head are visible infested plant parts.

Pest movement and Dispersal: The natural dispersal of *A. segetum* is negligible in stages other than the adult moth. The moth is a strong flier capable of flying against winds of up to 6-8 m/s (ref CPC). Plant parts not known to carry the pest in trade and transport are – Bark, Bulbs/Tubers/Corms/Rhizomes, Flowers/Inflorescences/cones/Calyx, Seedlings/Micropropagated plants, True seeds (including grain), Wood.

Natural Enemies: *A. segetum* has over 50 parasites that mainly attack on the larval stage (Alekseev 1972, Eremenko and Sem'yanov 1981). Most parasites are Hymenoptera, in particular, species in the families Braconidae and Ichneumonidae. Parasitic flies are also important parasitoids. Many of the parasitoids are not host-specific and some have a wide geographical distribution. Studies on predators, mainly beetles, have been carried out in Poland Uzbekistan, India, and Japan but the impact of the predators has not been studied. Among the pathogens viruses, bacteria, and fungi are being reported without any quantitative information (ref. CPC).

Pest impact: Including tea, *A. segetum* are capable of causing economic damage to a large number of agricultural and horticulture crops because of its wide range of host capacity. The insect larvae usually attacked seedling stage of tea and destroy the seedlings. The total damage caused by this insect is not available for tea but there are many reports on other crops. For example, 3-37% of cotton seedlings destroyed in China (Hu, 1982), and in Kazakstan 17.5% of young maize plants destroyed have been reported by Shek and Bulavskaya (1978). Neupane and Bhimsen (1971), in Nepal, estimated a loss of 33% of potatoes and a 24% weight loss caused by 7.8 larvae/m². Kay and Wheatley (1979), in the UK, found 34% of beetroots were damaged at a density of 14 larvae/m² and 17% of young lettuces were destroyed at a density of 3.5 larvae/m². However, Kay and Wheatley also found that 34 larvae/m² had no economic impact on mature lettuces. In Denmark, damage levels of 10-25% for carrots and 3-68% for beetroots are common if the larval period of *A. segetum* coincides with three to four dry, warm weeks (Esbjerg, 1985). In Germany, Cruger (1978) could find hardly any undamaged potatoes at a larval density of 200 larvae/m². Barbulescu (1973) described damage to a variety of crops in Iran as very severe at a density of 90 larvae/m² (ref. CPC). In field experiments, damage levels of up to two carrots per larva or about 50% damaged carrots at a larval density of 30-35 larvae/m² were found under very dry conditions; however, the damage level is about half of this under normal conditions (Esbjerg,1989).

Management: *A. segetum* can be managed by different control measures depending on crops, field conditions, infection severity, and availability of the techniques. Control measures include: cultivation of resistant varieties, weeding, removal of crop residues from fields, deep autumn plowing, inter-row cultivations, optimal dates of early sowing, including vetch-oat sown fallows in crop rotation, digging defensive ditches and furrows, watering, application of green poisonous baits, insecticide treatments of seeds and plantlets, release of such entomophages as Trichogramma spp., application of such bio-preparations as Lepidocide, Virin, Dendrobacillin and Bitoxibacillin. Monitoring is possible by use of sex pheromone traps.

- **Host-Plant Resistance:** Little information is available on host-plant resistance in *A. segetum*. Methanol extracts of potato tubers and wheat germ deterred oviposition (Anderson and Löfquist, 1996) and in Denmark careful weeding of onion fields is recommended as a preventive measure because the first-instar larvae cannot survive on onion plants (Esbjerg et al., 1995). For an insect as polyphagous as *A. segetum*, it is unlikely that host-plant resistance will be developed.

- **Chemical Control:** Unless persistent chemicals were used, chemical control used to be variable, however, basing the timing of treatment on the results from pheromone traps improved its efficacy. Since then, the use of synthetic **pyrethroids** directed against first-, second- and third-instar cutworms has proved to be very easy and it is highly efficient when based on information from pheromone traps (Esbjerg, 1985; Esbjerg et al., 1996).

- **Cultural Control:** Less damage occurs in the humid areas of a field (Herold, 1919). Esbjerg et al. (1995) discussed using systematic irrigation against small larvae in organic vegetable production. This has been put in practise with support for timing of irrigation by a PC-based forecasting model utilising trap catches and local weather records (Nilars and Esbjerg, 1998). It may be better not to earth up around leek plants too early because the larvae are more likely to survive in the drier and warmer top soil of the ridges. Careful weeding of onion fields may also be beneficial because the early instars of *A. segetum* cannot survive on onions.

- **Biological Control:** Many experiments on the different types of biological control carried out against *A. segetum* but there is no review of biological control for this species. Beneficial nematodes will attack and destroy cutworms in the soil. Release trichogramma wasps weekly for three consecutive weeks to parasitise cutworm eggs. Diatomaceous earth sprinkled around the base of plants is very effective. Scatter bran or corn meal mixed with Dipel Dust (*Bt-kurstaki*) and molasses on the soil surface to kill caterpillars. Eco-Bran will also kill caterpillars that feed on it. After harvest pick up garden debris and turn the soil over around plants to disturb overwintering larvae.

- **Integrated Pest Management:** Programmes combining cultural, biological and chemical control methods have been initiated in Denmark (Esbjerg et al., 1983) and the results are being put into practice in Denmark and Sweden. In Denmark these results and other later results provide the background for integrated production (IP) of carrots (Esbjerg, 1999).

Quarantine Risk: Moderate – following establishment *A. segetum* has potential to spread by natural means as adults are strong flyer and the larvae can also spared by soils and infested plant parts. The economic damage causes by this pest would be high because of its wide host range.

Probabilities of Entry: Low. *A. segetum* can enter into Australia mainly through infested vegetative plant parts and the larvae are quite visible, therefore under proper quarantine it has low possibility of entry into the country.

Possibility of Establishment: High – wide host range (both cultivated and wild plant species) of *A. segetum* makes a high possibility of finding a proper host after entry into Australia. This also support by a suitable climatic condition for the pest in many parts of the country.

Economic Impact: High - based on pest biology, multiple host rang, the nature of damage reported by *A. segetum* and the availability of effective management practices.

Environmental Impact: Low to moderate – *A. segetum* is capable of attack multiple plant species including cultivated and wild plants. However, in nature the pest has many biological enemies that are commonly used in biological control rather then fully depend on chemicals. This indicates the limited chemical applications to keep the pest population under control in field.

Social Impact: Low – although natural enemies of *A. segetum* may keep the population under control but in severe cases the management cost may rise beyond the profit level of small grower in local community. A wide host capacity of this pest is another concern of its broad impact on a number of different crops of local farmers.

Pest Management cost: Low/moderate – depending on pest severity, crops and methods used the cost may vary from $300 – 600/ha. This cost excludes involvement of any biological control and or resistant plant varieties. Effective and established control practices (both cultural and chemical) are available for *A. segetum*. However, the management with cultural practice could be more expensive in case pest severity.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 – 20% for individual crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low - *A. segetum* has limited capacity to disperse via infested plant parts (mainly vegetative) during international trade under regular quarantine process.

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THREAT DATA

Black borer

(*Apate monachus*)

Source: http://www.naturamediterraneo.com/forum/topic.asp?TOPIC_ID=36952

CRC10010

Enhanced Risk Analysis Tools

CRC PLANT biosecurity

Black borer

(*Apate monachus*)

Apate monachus is an insect pest that is also known by several English and local names and among these black borer and twig borer are very popular. *A. monachus* is a wood-boring beetle that attack wide rang of host plants but it is not usually a serious pest of growing trees. It is believe to be African origin.

Distribution: *A. monachus* is widely distributed in many African countries. It also has restricted distribution in some European countries (e.g. Cyprus, Spain, France, Greece, and Italy), Mediterranean Basin (Israel), West Indies and Cuba. In the USA the pest was accidentally introduced in Florida (Chararas and Balachowsky, 1962). *A. monachus* not currently recorded in Australia and New Zealand.

Host range/Alternate host: A. monachus has a wide host range and was recorded as a polyphagous species by Lesne (1901) and Chararas and Balachowsky (1962). Its development can be completed on a wide range of African trees and host crops. Among the major host pomegranate, mango, guava and coffee are important horticultural crop. There are many minor hosts for this pest such as apple, pear, citrus, palm, peach, grapevine, olive etc. Plant *Acacia* (wattles) is known as wild host of this beetle.

Habitat: The natural habitat of *A. monachus* is tropical and subtropical African forest.

Biology and Ecology: *A. monachus* is a wood-boring beetle, often flying during the evening and night, when it may be attracted by lights. Adults usually first bore out one short gallery, the exterior of which is a hole approximately 8-12 mm in length and 5 to 7 mm wide. This perforation leads to a second gallery, a cylindrical chamber, about 10 cm in length and 15 mm in diameter. This in turn leads to a new tunnel, 20-60 cm in length and 10-20 mm in diameter. Other methods of tunnelling include small galleries (5 to 8 mm in diameter), without the first pre-chamber. Alternatively, adults make numerous short galleries for feeding, only 7 to 10 cm in length and 15 mm in diameter (Chararas and Balachowsky, 1962). Females excavate galleries in dead wood, in which eggs are also laid. Larvae live in dead trees, excavating their own tunnels deep in the wood (Lesne, 1901, Español, 1955; Chararas and Balachowsky, 1962).

Symptoms: Adults bore deeply into the wood of living host trees while feeding (Fig. A). Tunnelling into the stems of host plants produces galleries and external holes. Damage is usually most severe on young plantations and nursery trees. Stems may be completely excavated, resulting in the death of young trees, or reduced growth of older trees.

Larvae live in the wood of dead trees and do not usually cause economic damage. Reproductions, nesting behaviour, larvae development and behaviour of the larvae have not been well characterised (Chararas and Balachowsky, 1962).

Figure A. Black borer infested tree parts.

Source: http://www.naturamediterraneo.com/forum/topic.asp?TOPIC_ID=36952

Affected plant stages: Flowering stage, fruiting stage, post-harvest and vegetative growing stage

Affected plant parts: Stems.

Affected Industries: Tree and Fruit industries

Resistant plant variety: In literatures there is no report on resistant plant species against *A. monachus*

Affected time of the year: The largest populations of *A. monachus* are most likely to occur in summer.

Detection and inspection methods: Field infestations of *A. monachus* are detected mainly by examining stem damage in suitable hosts. White, cylindrical larvae with small legs can be observed in dead wood. Bored stems may be sampled for dissection and identification of adults.

Pest movement and Dispersal: Infested plant parts mainly stem where both larvae and adult can hide and dispersed via transportation by human.

Impact: *A. monachus* is considered a pest with secondary economic impact and is not usually a serious pest of growing trees. It can be a destructive pest of coffee, but does not usually affect many trees. Crop losses caused by this species are difficult to assess, because damage is always localised, frequently occurring in several trees or a single plantation. However, 38.5% damage is reported in *Eucalyptus sp*. by this pest in Ghana. In general the pest bore into phloem and outer soft wood that makes the plant very susceptible to wind damage.

Natural Enemies: *Teretriosoma flaviclava* and *Teretriosoma sanguineum* are two known predators of *A. monachus* that both attack larvae and pupae of the pest. However, the importance of the listed natural enemies is not known. Natural enemies would not normally be expected to be important in limiting numbers of wood borers, although another *Teretriosoma* species has been shown to be a promising biological control agent of the larger grain borer (*Prostephanus truncatus*).

Management: Mostly the damage caused by *A. monachus* is localised, therefore the pest management in field conditions using cultural method is the best option compared to the chemical application.

- **Cultural control:** Planting pest-free young trees and burning infested plants is sometimes proposed, although this can be sometimes avoided by killing larvae by pushing a flexible wire, such as a bicycle spoke, into the boring (LePelley, 1968; Entwistle, 1972).

- **Chemical control:** Chemical control is difficult due to targeting and access to internal pests, as is the case with other borers. These difficulties of application are frequently compounded by unjustifiable costs and risks of environmental pollution. Luciano (1982) described the use of permethrin on an infestation of *A. monachus* on fruit trees in Italy, but concluded that preventative control was preferred.

Probabilities of Entry: Low – because the pest is easily visible in infested plant parts therefore regular quarantine measure is adequate to stop the entry during the trade or carried by passengers.

Possibility of Establishment: Moderate – because of multiple host range the pest can easily find proper host upon entry and Australia also has favorable climatic conditions for the pest.

Quarantine Risk: Very low. Because the pest is easily detectable with naked eyes and there is a low possibility of it's dispersion via trade and tourism.

Environmental Impact: Moderate – because of multiple host range that also includes native plant species (wattle). However, the effective management of *A. monachus* involves more cultural techniques rather than chemical applications that cause environmental damage.

Social Impact: Nil – *A. monachus* is a minor pest for most fruit trees and the infestation is localised that can easily be managed.

Pest Management cost: Low – because its not a serious pest and the infestation is localised i.e. easy to manage. However, no effective chemical control is available for the pest, only cultural control can keep the pest away and this might increase the management cost in severe case. No reports on biological control and pest resistant plant species. Based on pest biology and its available control measures the annual management cost of *A. monachus* is assumed to be $300 - $600/ha. This cost excludes involvement of any biological control and resistant plant varieties.

Yield loss despite control efforts: *A. monachus* is a minor pest for a number of fruit tress therefore the yield loss associated with this pest would be limited for individual crop (5 to 10%) but all together this figure would be high (above 30%) in spite of proper control measure.

Export revenue loss due to loss of Pest Freedom Status: None **-** Export losses result from entering and establishing this pest in Australia would be non-significant in case of fruit export as the dispersion of *A. monachus* mainly through timber (not fruits) where the pest inhabit and lay eggs.

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http://www.naturamediterraneo.com/forum/topic.asp?TOPIC_ID=36952

THREAT DATA

Apple aphid

(*Aphis pomi*)

Source: http://www.invasive.org/browse/detail.cfm?imgnum=1386014

CRC10010

Enhanced Risk Analysis Tools

Apple aphid

(*Aphis pomi*)

The apple aphid (*Aphis pomi*) is also known by some other scientific, English and local names. *A. pomi* probably European in origin and is pest of commercial apple orchards in USA and Europe. The primary host is apple and European pear. Unlike other harmful aphids, *A. pomi* is an autoecious species. They mainly feed on young leaf and shoots of the plant that results reduced photosynthesis.

Distribution: *A. pomi* is distributed thought Europe, Middle East and North America. Distribution of many other species similar to *A. pomi* has been recorded by Blackman and Eastop (1984). Although *A. pomi* is an important pest of apple in USA, Europe and the countries of the former USSR but the geographic distribution of this species is very restricted. *A. pomi* not currently recorded in Australia and New Zealand.

Host range/Alternate host: *A. pomi* has very restricted host range with apple (*Malus domestica*) and European pear (*Pyrus communis*) as primary hosts. In addition to primary hosts, *A. pomi* has a number of wild hosts that includes many wild apples (crab-apple, sweet crab-apple, prairie crab-apple etc.), pears and other plant species (ref. CPC).

Habitat: Mainly in commercial apple and pear orchards.

Biology and Ecology: Unlike most harmful aphids, *A. pomi* an autoecious species. It remains on apple or other Rosaceae throughout the year. The aphids feed on young tissues like young leaf and growing shoots. Aphids feed by inserting their stylets into the phloem. *A. pomi* usually infest the lower side of terminal leaves which role and undergo moderate leaf curly. They often cover the entire shoots, inflorescences by forming a thick sheath with thousands of aphids. From autumn to spring the aphid completed 10 to 15 generations.

The eggs lay in fall by wingless females after they mate with the males. Hatch occurs in the spring. The young nymphs develop into stem mothers which are wingless, pear-shaped females, bright green in colour. Stem mothers require 12-20 days to reach maturity. Adults often appear around bloom. These give birth to a generation of green viviparous (producing live young) aphids, ranging from 40-80 young per female. About three-quarters of this generation develop into winged females; the rest remain wingless. The winged forms spread colonies to other parts of the tree or other trees and orchards. About one-half of the second generation and some of the later generations may develop wings and disperse. Wingless aphids produce more offspring than alates. Aphid breeds continuously during the summer. During autumn months, they are found almost exclusively on water sprouts or terminals of young trees that are still growing. Males mate throughout their activity period, but many oviparae fail to become fertilised because of the relative scarcity of males (males are less numerous than oviparae and do not live as long).

Disease Symptoms: Colonisation of aphids (*A. pomis*) especially on the lower side of young leaf and around the growing shoots is visible (fig. below). Dense colonies reduce the greenness of apple leaves. *A. pomi* also causes the formation of pseudogalls on apple by direct feeding on the young leaves. Heavy infestation may results abnormal fruit shape, curly leaf, early leaf drop, and stunted plant growth. High densities of aphid produce honeydew that attracts fungal growth and results sooty molds on both leaf and fruits.

Fig. *Apple pomi* infested leaf

Source: http://www.invasive.org/browse/detail.cfm?imgnum=1626005

Affected plant stages: All developmental stages including seedling, flowering, fruiting, and vegetative stages of the host.

Affected plant parts: Mainly young leaves, shoots, and inflorescence. Young fruits and pods can also be infested.

Affected Industries: Apples and pears.

Pest movement and Dispersal: The natural movement of *A. pomi* is restricted by wind. The moth is not a strong flier that limits its natural spread. During trade and transportation the infested seedling and plant parts may help in pest movement from one place to other.

Host-Plant Resistance: The most resistant varieties were Ranetka Purpurovaya, Korichnoe polosatoe, Pobeda, Grushovka Moskovskaya and those of the Kitaika (Chinese Crab) type. For further information on *A. pomi* resistance varieties is referred to work by Zhuravleva (1990).

Affected time of the year: *A. pomi* cause most damage in apple orchards in the spring, when the flower buds are opening. However, it found throughout the apple growing season. The most population of the aphids occur in summer and autumn.

Natural Enemies: *A. pomi* has many different types of natural enemies (Pathogen, Parasitoids and Predators) that attack different developmental stage of the pest (e.g. eggs, larvae, pupae). Parasite, Trioxys sp. used in apple orchards against *A. pomi* in Quebec, Canada and Netherlands (Evenhuis, 1963). In Europe, Adalia bipunctata is often the most numerous predators on apple trees, and is responsible for significantly reducing aphid numbers. Natural enemy complexes in apple orchards have also been described in Italy (Pasqualini et al., 1982), Turkey (Erol and Yasar, 1996), and in the far east of Russia (Aksyutova and Gul'dyaeva, 1977). Syrphids found to be important predators on apple between May and September in southern France (Lyon and Tiefenau 1974). The dipteran *Aphidoletes aphidimyza* was reported as the most important predator on apples in a study in Nova Scotia, Canada (Stewart and Walde, 1997).

Impact: *A. pomi* is an important pest of apples in the USA, throughout Europe and the countries of the former USSR. The aphids found in the orchards throughout the fruit growing season but the most damage causes in the spring, when the flower buds are opening. The aphids attack feed on young leaf and growing shoots of the tree. These results reduced photosynthesis, stunted plant growth and finally fewer yields. Heavy infestations deform the fruit shapes and develop sooty moulds that reduce the market value of the fruits. Damage is more severe on nursery stock and seedlings. Therefore, the impact of *A. pomi* on apple and pear industries is significant.

Management: *A. pomi* managed by different ways depending on it's severity, field conditions, and availability of the techniques. Among the different techniques the following are very few used by growers.

Chemical control: Number of chemicals is effective to control *A. pomi* and chemical sprays used mainly against adult stages of *A. pomi*. For example, 1 to 2 % application of insecticidal soap or summer horticultural oil can provide effective control of these aphids. Pirimicarb is often used to control *A. pomi* within IPM programmes in apple orchards. Similarly, Oxydemeton-methyl and parathion-methyl are also found to be effective. Synthetic pyrethroids, including permethrin, fenvalerate and flucythrinate have also been recommended against *A. pomi*. Airblast sprayers are more effective than boom sprayers for *A. pomi* control when vertical top growth (watersprouts) had grown to 0.7-1 m (Hogmire *et al*. 1991). *A. pomi* is resistant to many commonly used pesticides, including parathion and diazinon, which were standard treatments during the 1960s.

Biological Control: *A. pomi* has number of different types of natural enemies (Pathogen, Parasitoids and Predators) that attack different developmental stage of the pest (e.g. eggs, larvae, pupae). Green lacewin, chrysopid (Chrysoperla carnea) used to control *A. pomi* on dwarf apple in Ontario, Canada (Hagley, 1989). As biological agents different species of pathogenic fungi against *A. pomi* is described by Chudare (1988). Preparations of *Entomophthora thaxteriana* and *E. virulenta* were effective against *A. pomi* (ref. CPC, 2008).

Resistant variety: *A. pomi* attack can be controlled by growing resistant plant varieties that are available. The most resistant varieties were Ranetka Purpurovaya, Korichnoe polosatoe, Pobeda, Grushovka Moskovskaya and those of the Kitaika (Chinese Crab) type (ref. CPC, 2008).

Probabilities of Entry: Low – because the pest is easily visible in infested plant parts therefore regular quarantine measure is adequate to stop the entry during the trade or carried by passengers.

Possibility of Establishment: Low – because of restricted host range the pest is unlikely to find host readily upon entry, although Australia has favorable climatic conditions for the pest.

Quarantine Risk: Low – because the pest is readily detectable in the infested plant parts during trade.

Environmental Impact: Low – because of restricted host range, available resistant plant varieties, biological control, and effective chemical measures.

Social Impact: Nil – the pest is easily manageable through available control measures including biological and pest resistant plant varieties as described in the literatures. Therefore the local community depending on apple industry would not be affected following attack by this pest.

Pest Management cost: Low – because of available insecticides for chemical control, natural enemies for biological control, and resistant plant varieties for the pest. Moreover, in literatures there is available information on control measures of this pest. Based on literature the annual application cost for chemical control of this pest is about **$300/ha for 2 spray** (chemical cost ~$100/ha plus labor and machinery cost ~$50/ha for a single spray as suggested by Martine Combret, Development Officer, DAFWA). This cost excludes involvement of any biological control and resistant plant varieties.

Yield loss despite control efforts: Based on pest biology and its impact on the host plant the total yield loss assumed to be between 15 – 25% in spite of proper control measure.

Export revenue loss due to loss of Pest Freedom Status: None - Export losses result from entering and establishing this pest in Australia would be at non-significant level because of its limited host range and very low possibility of pest dispersion through export.

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THREAT DATA

Oriental fruit fly

(*Bactrocera dorsalis*)

http://en.wikipedia.org/wiki/Image:Bactrocera_dorsalis.jpg

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Oriental fruit fly

(*Bactrocera dorsalis*)

Oriental fruit fly (*B. dorsalis)* is a tropical species and widespread in tropical Asia. It's unable to survive the winter in the EPPO region. Oriental fruit fly attacks over 300 cultivated and wild fruits and it is one of the most destructive fruit fly pests of East Asia and Pacific.

Distribution: *B. dorsalis* is widely distributed in many Asian countries such as Bangladesh, India, Sri Lanka, Nepal, Pakistan, China, Japan etc. The distribution in USA is restricted in California, Florida and Hawaii. Absent in European countries probably because of cold temperature. *B. dorsalis* is not yet recorded in Australia and New Zealand.

Host range/Alternate host: Including apple and pears the oriental fruit fly has been recorded from more than 150 kinds of fruit and vegetables, including citrus, guava, mango, papaya, avocado, banana, loquat, tomato, surinam cherry, passion fruit, persimmon, pineapple, peach, apricot, fig, and coffee. Avocado, mango, and papaya are the most commonly attacked. There are about 117 host species in 76 genera and 37 families that are porn to attack by this pest (Allwoood *et al,* 1999) i.e. the pest apparently breed in all fleshy fruits.

Habitat: Areas of both cultivated and wild fruits.

Biology and Ecology: Development from egg to adult under summer conditions requires about 16 days. The mature larva emerges from the fruit, drops to the ground, and forms a tan to dark brown puparium. Pupation occurs in the soil. About nine days are required for attainment of sexual maturity after the adult fly emerges. The developmental periods may be extended considerably by cool weather. Under optimum conditions, a female can lay more than 3,000 eggs during her lifetime, but under field conditions from 1,200 to 1,500 eggs per female is considered to be the usual production. Apparently, ripe fruit are preferred for oviposition, but immature ones may be attacked also.

Symptoms: The flies attack fruit at different stages of maturity and the infested fruits drop off prematurely. Fruit attack by oriental fruit fly usually shows signs of oviposition punctures. Following oviposition there may be some necrosis around the puncture mark ('sting') as showed in figure A. This is followed by decomposition of the fruit due to microbial infection. Fruit with high sugar content, such as peaches, will exude a sugary liquid, which usually solidifies adjacent to the oviposition site. Larvae bore through matured fruit and cause fruit to rot (fig. B). Ripe fruit are more susceptible to attack then unripened and immature one.


Figure A. Infested fruit with sting   Figure B. Cut fruit with larva

Affected plant stages: Fruiting stage and post-harvest

Affected plant parts: Mainly fruits

Affected Industries: Fruit industries

Resistant plant variety: No reports on resistant varieties of this plant species for *B. dorsalis*.

Affected time of the year: The largest populations of *B. dorsalis* occur in summer when there are more fruits on most trees.

Detection and inspection methods: The adult oriental fruit fly, which is noticeably larger than a house fly, has a body length of about 8.0 mm; the wing is about 7.3 mm in length and is mostly hyaline. The color of the fly is very variable, but there are prominent yellow and dark brown to black markings on the thorax. Generally, the abdomen has two horizontal black stripes and a longitudinal median stripe extending from the base of the third segment to the apex of the abdomen. These markings may form a T-shaped pattern, but the pattern varies considerably. The ovipositor is very slender and sharply pointed (fig. in the cover page).

Fruits should be inspected for puncture marks and any associated necrosis. Suspect fruits should be cut open and checked for larvae, although larval identification is difficult. Other signs as described under the symptoms may also help in initial detection. A grid of methyl eugenol and cue lure traps, at least in high-risk areas can be used to detect the flies. Traps are usually placed in fruit trees at a height of about 2 m above ground.

Pest movement and Dispersal: Oriental fruit flies are good fliers and marked sterile males have been recovered up to 24 miles away from their release point and they are very transient throughout their life (Steiner, 1957). Many *Bactrocera* spp. can fly 50-100 km (Fletcher, 1989). Adult flight and the transport of infested fruits are the main means of movement and dispersal to the uninfested areas. The eggs/larvae, borne internally in the infested fruits (visible to naked eye), can be dispersed in distanced area during the trade and by traveller. The insect pupae can also be dispatched through infested soil, gravel, water etc.

Disease Impact: Oriental fruit fly is considered one of the most devastating pests of fruit in areas where it occurs. *B. dorsalis* is a very serious pest of a wide variety of fruits and vegetables throughout its range and damage levels can be anything up to 100% of unprotected fruit.

Different developmental stages of fruit preferably ripen stage, are infested this pest and this cause severer economic loss by reducing the market value of the fruit. The microbial (bacteria, fungi, virus etc.) infection through the injury caused by the pest plays a significant role in total fruit damage by this pest. The impact of *B. dorsalis* is considered to be very high due to its high reproductive potential (up to 800 eggs), high biotic potential (short life cycle), rapid dispersible ability and wide host range including many of the host present in Australia. In Hawaii, the pest found in more than 125 kinds of hosts and similarly it is one of the most destructive fruit fly pests of East Asia and the Pacific. In West Pakistan 50 to 80% infestation by this pest has been recorded in pear, peach, apricot, fig and other fruits.

Natural Enemies: Thirty-two species and varieties of natural enemies to fruit flies were introduced to Hawaii between 1947 and 1952 to control the fruit flies (Bess, *et. al*., 1961). Of these natural enemies, one predator and 13 parasites were specific for the oriental fruit fly (van den Bosch, *et. al.*, 1951). These parasites lay their eggs in the eggs or maggots of fruit flies and emerge in the pupal stage. Only three, *Opius longicaudatus* var. *malaiaensis* (Fullaway), *O. vandenboschi* (Fullaway), and *O. oophilus* (Fullaway), have become abundantly established (Hardy and Delfinado, 1980). These parasites are primarily effective on the oriental and Mediterranean fruit flies in cultivated crops. *O. longicaudatus* is a parasite of the second and third instar fruit fly larvae; *O. vandenboschi* is a parasite of the first instar fruit larvae; and *O. oophilus* is an egg-larval parasite (van den Bosch and Haramoto, 1953). *O. longicaudatus* females are commonly seen on over-ripe fruits on the ground and ripe fruits on the trees where *O. oophilus* females are primarily associated with fruits on the trees (van den Bosch, *et. al*., 1951).

The pathogen, *Nosema tephritidae* (Fujii and Tamashiro), a microspordian ingested by mouth, also attacks this fly (Fujii and Tamashiro, 1972). Diseased larvae and pupae appear normal externally (Fujii and Tamashiro, 1972). Symptoms are not easily detected until the adult stage when infected individuals are sluggish, have dropping wings and distended abdomen, and poor to no flying ability. Death primarily occurs during late pupation. This pathogen also affects the melon fly, *Bactrocera cucurbitae*, and the Mediterranean fruit fly, *Ceratitis capitata* (Fujii and Tamashiro, 1972).

Management: In conjunction with the post-harvest quarantine treatments, it is helpful to apply pre-harvest management practices to reduce fruit fly populations. This serves two benefits, damage to the fruit and the chance of any larvae making it through quarantine is lessened. Since the discovery of the oriental fruit fly in Hawaii a number of methods have been employed in attempts to reduce or prevent damage by this pest. They include: 1) mechanical control, 2) cultural control, 3) biological control, 4) post-harvest quarantine treatments and 5) chemical control.

- **Mechanical control:** Mechanical methods of controlling the oriental fruit fly include the use of protective coverings on the fruit and the destruction of adults by use of traps. Shrubs within 100 yards of larval hosts may be used advantageously in placing traps. The use of protective coverings is more effective and costly than the use of traps.

- **Cultural control:** There are three principal cultural methods that may be used for controlling this pest. These methods are: 1) field sanitation, 2) trap crops and 3) resistant varieties.

  Of utmost importance and effectiveness is field sanitation. When detected, it is important to gather all fallen and infested host fruits, and destroy them (Liquido, 1993). This practice reduces reinfestation pressure. Crops should be plowed and disked under as soon as harvest has been completed. Liquido (1990) reported that papaya fruits left on the ground serve as a major breeding site and reservoir of resident melon fly populations. Pre-harvest control measures such as field sanitation could enhance the quality of marketable fruit by allowing the use of less damaging schedules of post harvest quarantine treatments. For example, vapor heat, dry heat, hot water double dip or a combination of these treatments) could be applied at lower kill temperatures or shorter treatment durations (Liquido, 1990; Liquido, *et. al*., 1989; Liquido and Cunnigham, 1990).

  Biological control: Biological control has been tried against *B. dorsalis sensu lato*, but introduced parasitoids have had little impact (Wharton, 1989). Male annihilation, utilising the attraction of males to methyl eugenol was used to eradicate *B. dorsalis* from the northern Ryukyu Islands, Japan (Cunningham, 1989b). The sterile insect technique (SIT), requiring the release of millions of sterile flies into the wild population so that there is a strong likelihood of wild females mating with sterile males (Gilmore, 1989), was used to eradicate *B. dorsalis* from the Ogasawara Islands, Japan (Shiga, 1989).

- **Post-Harvest quarantine control:** The current quarantine treatment for papaya grown in Hawaii for distribution to the US mainland requires careful fruit selection and a two-stage hot- water immersion treatment called the "double dip" method (APHIS, 1988; Liquido and Cunningham, 1990). The double dip method involves the treatment of less than quarter-ripe fruits for an initial immersion for 30 minutes in 107.6ûF (42ûC) water followed immediately by a second hot water immersion at 120.2ûF (49ûC) for 20 minutes (Liquido and Cunningham, 1990).

  On bananas, Armstrong (1983) states that quarantine treatments would not be necessary for export to the US mainland or elsewhere if only mature green fruit is harvested and only bananas in early ripeness stages are processed and packaged for market.

- **Chemical control:** The chemicals used for oriental fruit fly control have been used as 1) toxicants in baits and 2) sprays.

  Insecticide bait sprays are applied either to the crops to be protected, to the plants with which the adults are closely associated, or to both.

  Proteinaceous liquid attractants in insecticide sprays is a recommended method of controlling adult Oriental fruit fly populations in the vicinity of crops. The bait insecticide sprays are applied to broad leaf plants that serve as refugia for Oriental fruit fly adults. Baits serve to encourage the adults (especially females) to feed on the spray residue and can provide good rates of kill. To be effective, bait-insecticide sprays must be used in combination with good sanitation practices. These practices include destruction of unmarketable fruit on every harvest date, and destruction of crop residues immediately after economic harvest has been completed. Bait sprays work on the principle that both male and female tephritids are strongly attracted to a protein source from which ammonia emanates. Bait sprays have the advantage over cover sprays in that they can be applied as a spot treatment so that the flies are attracted to the insecticide and there is minimal impact on natural enemies.

Larvae are difficult to chemically control since they are protected within the fruit (Tamashiro and Sherman, 1955). However, with correct timing, the last larval stage may be targeted when it leaves the fruit and drops to the ground to pupate with soil toxicants.

The use of chemicals for the control of fruit flies on avocado can be reduced by combining chemical treatments with a cold storage period (at 46º and 55ºF) of 5 days after harvest to kill fruit fly eggs and some larvae (Manoto and Mitchell, 1976). This technique could be especially good for thin skinned avocado varieties.

Quarantine Risk: Very high - because it's an indigenous to Asia that has high potential to establish enormous population in various others tropical areas like WA, Australia.

Probabilities of Entry: High - through a wide range of infested fruits carried by tourist, regular passengers and also via trade unless strict quarantine and phytosanitary restriction are applied on export fruits from the countries where this pest is established.

Possibility of Establishment: Moderate/high - specially in Western Australia because of favorable climatic conditions along with a wide range of suitable host of this pest.

Environmental Impact: Low – minor environmental impact is to be expected since fruit trees are the main host of *B. dorsalis* and most unlikely the native plants of Australia would be affected by this insect. However, indirect environmental impact may come from the insecticides use to control the pest.

Social Impact: High - impact on backyard fruit trees to be expected and this will results negative impact on socio-economic condition of the society.

Pest Management cost: High **-** since the fly can persist throughout the season therefore, the chemical spray should be carried out at every **6-7 days interval** from the early season till harvesting time. Assume it's a minimum of **12-15 times** per season. The effective chemicals for the fruit fly are Dimethoate and Fenthion (ref. pest advisory leaflet no. 40, 2001). The tentative cost is $70-80/ha (http://www.oktreefruit.com/Newsletters/costcomparison06.pdf). In addition, another $100/ha is the application for a single spray. The total cost would be $170 -180/ha for a single spray and it needs at least **12 -15 spray** i.e. **$2040-2700** for each year. Depending on the other factors (e.g. rain) the total cost might be higher.

Yield loss despite control efforts: Despite incorporating various control measures including bait spray into normal management practise, it is expected that a certain amount of loss will still occur through the effects of *B. dorsalis.* In literatures, there are no concrete figures on the yield loss despite of control efforts. However, based on biological nature of the pest and damage intensity on host, **5 to 20** per cent yield loss is expected under all control measures. Due to most favourable climatic conditions in WA, it is assumed that yield loss would be in the upper range compared to the other states in Australia.

Export revenue loss due to loss of Pest Freedom Status: Export losses result from *B. dorsalis* entering and becoming established in Australia would be at significant level.

Australia's big fruit industries export various kinds of fruits that are susceptible to this pest. Therefore, the risk associated with the market loss is considered high. *B. dorsalis* causes damage to wide range of fruits that's price range is variable. This makes it difficult to predicting market losses that's highly subjective. It is conceivable that it may be in the order of 25%, but this is a highly subjective estimate. Hence, a variable estimate was assumed using a pert distribution with a minimum value of 0 per cent, a maximum value of 50 per cent, and a most-likely value of **25** per cent.

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THREAT DATA

Olive fruit fly

(*Bactrocera oleae*)

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Olive fruit fly

(*Bactrocera oleae*)

Olive fruit fly is an insect with scientific name *Bactrocera oleae*, is a serious pest of olives in most of the olive growing regions. The fly lives all of its life stages solely in the olive fruit i.e. it can reproduce only in olives. Olive fruit fly poses a serious threat to both table olive and olive oil industries. *B. oleae* is a native of eastern Africa and consider the most damaging pest of olives in southern Europe, North Africa, and the Middle East.

Distribution: Mediterranean basin, northern, eastern and southern Africa, Canary, Islands, western Asia, India, and apparently wherever olives (the genus *Olea*) cultivated in the Eastern Hemisphere. In the western Hemisphere, it's a serious pest in California and moved there via Mexico. Not currently recorded in Australia and New Zealand.

Host range/Alternate host: It has very narrow host range and being restricted to olives (*Olea europaea subsp. europaea*) only. In Europe, it attacks cultivated olives but in Africa it is associated with wild olives. The adults fly congregate in various plants (e.g. orange, lemon, grapefruit, tangerine, calomondin, cherry, plum, avocado, loquat, nectarine and Surinam cherry trees) for food or refuge.

Habitat: Areas of both cultivated and wild olives

Life cycle and biology of the Pest: Depending on local conditions (e.g. temperature) the olive fruit fly has **2 to 5** reproductive cycle in a year. It overwinters either as an adult or a pupa in the soil or in fallen fruit. In the beginning of summer, new adults start to emerge from overwintered pupae (Freidberg and Kugler, 1989). The females laid eggs below the fruit skin of mature olive when the pits begin to harden, this often create a dimple or brown spot. The legless larva (maggot) develops from the egg, feeds upon the fruit tissues and causing the fruit to drop off the tree. In summer the egg, larval, and pupal stages last 2 to 4, 10 to 14 and about 10 days respectively (Clausen 1978; Mazomenos 1989). Under favourable conditions, an each female fly may produce 10 to 40 eggs per day with **200 to 500** eggs in her lifetime. Multiple generations occur throughout summers and fall, optimum temperature for this is 68°F to 86°F. The activity threshold for the adult fly is 60°F and below this temperature they are not very active. Hot (95° to 105°F) and dry conditions reduce the fruit fly population. The larva (maggots) can experience relatively high mortality during hot and dry weather, therefore the population densities are higher in cool and humid coastal areas compared to hot and dry inland areas.

Disease Symptoms: The ovipositor scar where egg is laid is often the first evidence of infestation (fig. A). Puncture marks and exit holes may be observed. The larva feed on the olive flesh, leaving brown tracks and tunnel. Brown lines (tunnels) and maggots are visible after cutting the infested fruit. The damaged fruit is susceptible to rot and drop prematurely which is useless as a table fruit.

Figure A. Infested olive with spot Figure B. Cut olive with young maggot

Affected plant stages: Fruiting stage

Affected plant parts: Olive fruits only. When fruit pit begins to harden it gives off chemicals which trigger the development of eggs in the female fly.

Affected Industries: Olive

Susceptible plant variety: In Europe, large size of fruit with a high water content, which describes most of the table olive varieties, are most vulnerable to attack by this fly. The thickness and fragileness of the olive fruit skin are also related to the susceptibility. The fruit with fragile skin is easier to puncture by female fly with her ovipositor to laid eggs under the skin. Preliminary studies by Zalom, Burrack and Kreuger reveled that fly has definite variety preferences. This could be important for the oil producers who have multiple varieties to select for plantings. According to the above investigator following is the table showing percent of olive infested. The results are based on laboratory test only.

Variety	**Attack rate (%)**
Sevillano	80-90
Manzanillo	18-30
Mission	69-81
Frantoio	13-15
Leccino	15-44
Arbequina	3-7

Koroneiki	4-10

Affected time of the year: The largest populations of the fly occur in the fall when there are olives on most trees.

Pest identification: Adult olive fruit fly is approximately 4-5 mm in length, reddish-brown in color with large eyes and small antennae. The head, thorax, and abdomen are brown with dark marks. Several white or yellow patches found on the top and sides of the thorax. The wings are clear with a small dark spot near the tip and can be distinguished from those of other fruit flies (e.g. walnut husk fly) that have color wing bands or patterns. The female (figure in the cover page) have dark colored pointed ovipositor at the end of the abdomen, used for pierce fruit before laying eggs under fruit skin. Larvae are yellowish white, legless with pointed heads. The young larvae are hard to see but the mature one can be visible inside the fruit. The larval stage is spent entirely within the fruit.

Pest movement and Dispersal: The flies can travel several miles (2-3 miles) in search of olives in which to lay their eggs. Some species of *Bactrocera* can fly even 50-100 km (Fletcher, 1989). Eggs and larva (visible to naked eye) can be carried out by the fruit during trade/transportation.

Detection and Inspection Methods: In areas where the olive fruit fly is not well established, the adult fly population are being monitored with yellow sticky traps containing a sex pheromone (spiroketa) and /or ammonium carbonate, ammonium bicarbonate, or diammonium phosphate bait. Male fly get attracted by sex hormone and the female one get attracted by ammonium volatile. Both sexes are attracted to yellow color of the trap and are captured on the sticky trap surface (ref. CPC).

Disease Impact: The olive fruit fly is considered the most devastating insect pest of olives in the Mediterranean region (Fimiani 1989). In USA, the rapid invasion of California by this pest poses a severe economic threat for the state's commercial olive growers. The larvae of the olive fruit fly feed inside the fruit, destroying the pulp and allowing the secondary infection of bacteria and fungi that rot the fruit and greatly increase the free acid level (acidity) of the oil and also lower oil quality. Feeding damage destroys the value of table fruit and in severe cases it causes premature fruit drop. In olive growing regions where olive fruit fly is well established the losses up to100% for table cultivar and 80% for oil values because of it's lower quantity and quality. For the table olive growers minor marks left on the fruits due to the infestation lead to rejection of entire crop. But in case of oil production some infestation can be tolerated as long as fruits are not rotten due to secondary infection. For commercial table fruit orchards in Europe, the damage threshold is 1%, but California table fruit processors have zero tolerance for olive fruit fly damage. Similarly, damage threshold level for oil production in Europe is 10% but research in Spain showed that high quality extra virgin olive oil can be produced even with 100% of the fruit showing stings, as long as the fruit was not rotten. The real problem for oil producers is when larval feeding introduces fruit rotting organisms that create off flavors as well as early fruit drop. Some European districts cannot grow table olives because control of olive fruit fly is not economical. The expense of treatments and the likely crop damage have the potential for eliminating olive culture in home orchards or as a viable commercial industry in California. In Mediterranean countries, especially in Greece and Italy where large commercial production occurs, reported 30% crop loss due to this fly.

Management: The olive fruit fly is managed by different ways depending on it's severity, field conditions, and availability of the techniques. In the Eastern Hemisphere, insecticides are used in bait-sprays or as sprays from the air to control the olive fruit fly. In California, management depends on bait sprays, trapping of adults flies, harvest timing, fruit sanitation after harvest, and biological control (Van Steenwky *et al.* 2003). Among the different techniques the following are very few used by olive growers

- **Regulatory control** – the plant quarantine risk posed by *B. oleae* is very low and therefore, normal anti-fruit fly regulations will seldom be essential.

- **Physical control -** Remove old fruit remaining on trees following harvest and destroy all fruit that are on the ground by either burying at least 12 inches deep, or taking to the landfill. Extremely high fly populations can occur in fruited varieties of landscape trees and in unmaintained ornamental situations. These can be a significant source for invasion of commercial groves. An area-wide approach is needed to reduce olive fly densities where commercial plantings are near ornamental or unmaintained trees.

- **Mechanical control** – using different kind of traps in monitor the fly populations. McPhail or yellow sticky traps, mass traps are commonly used one in a small field or backyard plants for control measure. In California, mass trapping reduced crop damage levels to ~30%, compared to almost 90% in untreated controls. Several types of traps are being used for disease management but the technique is time consuming, cost effective and not suitable for commercial cultivation.

- **Chemical control:** A bait containing the biologically produced insecticide spinosad know as GF-120 NF Naturalyte is proving to be effective when applied frequently throughout the period of pit hardening to harvest. It is available from Dow AgroSciences. The combination bait and insecticide is sprayed at a rate of 1 part to between 1.5 and 4 parts water and applied at a rate of one ounce per tree. The bait is sprayed only on a portion of the tree. Prevent fruiting on landscape trees in spring by using a chemical like "Fruit Stop" or destroy fruit on the ground in fall to reduce this invasion pathway. The 'Fruit Stop' application rate is 4 fl oz/10 gal water with 0.5 -1 fl oz of nonionic wetting agent to each 10 gal of spray mix. A number of review articles on chemical control of this pest are available (Roessler 1989, Jervis and Kidd, 1993 and Delrio, 1995).

- **Biological Control -** olive fruit fly is attacked by a number of parasitic wasps (Clausen 1978, Ranaldi and Santoni 1987) but the parasites do not provide acceptable control in commercial situation. At this time there are not biological control agents of this fly commercially available for release. Preliminary releases of *P. concolor,* a parasite that can be raised in culture and has been released for other fruit flies including the Mediterranean fruit fly, have been attempted in California with limited success to date.

- **Cultural Control -** using the less susceptible or resistant olive variety is good way to control crop damage. But currently there is no such kind of crop variety for the growers in the market yet. The scientists are working in this aspect of control crop management.

Monitoring and Treatment Decisions: Surveying fruit for infestation can give some indication of the severity of an infestation. Looking for maggots infesting fruit that has fallen from trees in late winter and spring is useful as it will give some indication of overwintering olive fly densities. Adult fruit flies can be monitored with McPhail traps or with yellow sticky traps. McPhail traps have proven to be more effective than yellow sticky traps in catching larger numbers of olive fruit flies and catching them earlier in the season. White and Elson-Harris (1994) described suitable traps for this pest.

Quarantine Risk: Low – low potential of entry and establishment of *B oleae* in Australia and its readily visible eggs and larvae in infested fruit make the pest low risk in quarantine issue.

Probabilities of Entry: Low – the possible pathway of entry of *B oleae* is mainly through infested fruits during the trade, but the pest eggs and larvae are readily detectable by naked eyes. Therefore, under proper quarantine it has low possibility of entry into the country.

Possibility of Establishment: Low –apart from olive growing regions, *B oleae* has low potential to establish in Australia due to its selective host range.

Probabilities of Entry and Establishment: Extremely low – *B oleae* with very restricted host (olive mainly) is unlikely to find suitable following the entry in Australia, although Australian climatic conditions are in favour of *B oleae.*

Economic Impact: Moderate to High - based on pest biology and the damage severity reported in published literatures by *B oleae.* Limited pest resistant plant variety is also an important issue in economic impact.

Environmental Impact: Low – because the management of *B oleae* is assumed to require less chemical application compared to the pest with multi-host. Less chemical application will limit the environmental pollution.

Social Impact: Very low – since olive is only known fruit plant affected by *B oleae* and a proper control measure is also available. Therefore, very low social impact is considered due to the presence of this pest.

Pest Management cost: Low/moderate – depending on pest severity the management cost may vary from **$300 to 600/ha**. This cost excludes involvement of any biological control and or resistant plant varieties. Effective and established control practices (both cultural and chemical) are available for *B oleae*. However, the management with cultural practice could be more expensive in case pest severity.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 15 – 30% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – due to very selective in host and low dispersion possibility of *B oleae* through fruit during international trade.

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THREAT DATA

Cabbage looper

(*Trichoplusia ni*)

Ref. http://www.hantsmoths.org.uk/images/DSCN1026_ni_moth_sherbornestjohn-12-06-06.jpg

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Cabbage looper

(*Trichoplusia ni*)

Cabbage looper (*T. ni*), is also know by many other English names like 'lettuce pooer' 'ni moth' 'silver vi moth' etc. is serious economic pest of cabbage and many other related vegetables, particularly in the USA and Europe. The moth larvae feed on leaves at night. The adult moth is brown with a white spot on each wing, it's a stronger flyer and can migrate considerable distances. Cabbage looper is not reported in Oceania yet.

Distribution: Cabbage looper is native to the USA and found throughout Canada, Mexico and USA wherever host plant crucifers are cultivated. The pest has also been reported in many Asian, European and African countries, In the UK and northern Europe cabbage looper is a sporadic migrant only. The pest has not been reported in Australia yet.

Host range: Including both cultivated and wild host, cabbage looper has a wide host range. Members of crucifer family like cabbage, cauliflower, broccoli etc. are considered as major host. Outside the crucifers members the pest also cause damage to potato, lettuce, onion, carrot, spinach, parsley, tomato, cucumber etc and consider as minor hosts of the pest. Among the wild host Acacia (wattle), Brassica (mustard), tobacco etc are important. *T. ni* is listed as feeding on over 160 species of plants in 36 families but cultivated crucifers are preferred (Sutherland and Greene 1984).

Affected Plant Stages: Vegetative growing stage

Affected Plant Parts: Leaves and whole plant.

Biology and Ecology: The cabbage looper moths are nocturnal and rarely seen during daylight hours. Adults are attracted to light at night. The adult insect is highly dispersive and a strong flier that can fly up to 200 km. There is no diapause present in this insect, and although it is capable of spending considerable time as a pupa, it does not tolerate prolonged cold weather. It reinvades most of the United States and all of Canada annually after overwintering in southern latitudes. Cabbage loopers overwinter as pupae attached to host plants and other nearby objects. The adults emerge in the spring and female moths lay several hundred eggs (200 – 300) singly on the upper surfaces of host plant leaves over a 10-12 day period. Larvae hatch from the eggs 3 to 6 days after being laid. They immediately begin feeding in the underside of the leaf producing small holes. Larval development may be completed in two weeks if weather is favorable and the cabbage looper can have 3-4 generations per year. The larvae feed for 2-4 weeks and a generation is usually completed in about 35 days.

Damaged Symptoms: Cabbage loopers are leaf feeder and daily it can consume three times of leaf material in their wet. Young larvae feed between veins on the underside of the lower leaves. Large larvae make ragged holes in the foliage and move to the center of the plant. Infested leaf left with a net-like appearance. Large loopers can also burrow through 3 to 6 layers of tightly wrapped head leaves in cabbage. Plants can be severely defoliated and stunted, producing no heads or becoming unfit for consumption. Large amounts of dark green pellets excreted by the feeding looper may stain cauliflower heads. The presence of cabbage looper larvae in broccoli heads renders them unmarketable.

Average population densities of 0.3 larvae per plant justify control (Kirby and Slosser 1984).

Fig. Damaged symptoms by Cabbage looper

Ref. http://www3.telus.net/conrad/insects/cabloop.html

Movement and Dispersal: The potential for natural spread of cabbage looper is high as the adult are highly dispersive and a strong flier that can fly up to 200 km. Infested plants leaf, soil gravel, field tools etc. can play role in pest dispersion both locally and distance. Trading of infested vegetables would be the main means of spread as the larvae and eggs can easily be missed in quarantine.

Resistant plant variety: No report is available in the literatures on resistant commercial variety against this pest.

Natural Enemies: The cabbage looper is attacked by numerous natural enemies, and the effectiveness of each seems to vary greatly. Most studies note the effectiveness of wasp and tachinid parasitoids, and a nuclear polyhedrosis virus (NPV). Predation has not been well studied except in cotton. The natural enemies of cabbage looper in the USA were reviewed by Waterhouse (1998).

Economic impact: Although seedlings are occasionally damaged, most injury occurs after heading. Young plants between seedling stage and heading can tolerate substantial leaf damage without loss of yield. However, cabbage looper populations can cause both severe yield and quality losses, especially under dry conditions. In case of severely infestations cabbage, no heads may be marketable at the end of the season. Wide host capacity of this pest will have significant economic impact on agriculture, although there is no exact figure on the losses is being reported in literature for any host crop.

Management: Inspect weekly to determine if a 5% infestation threshold has been reached and, if so, treat with an effective insecticide spray. The cabbage looper may be managed by spraying or dusting with a residual insecticide or with *Bacillus thuringiensis* (apply weekly). Plant stalks remaining after the crop has been harvested should be destroyed and the field plowed. It may also be helpful to remove weeds on which the first generation of larvae can develop, e.g., shepherd's purse, wild mustard and peppergrass.

Natural enemies of the cabbage looper also contribute to its control. These include a polyhedral virus and four species of parasitic insects. On cabbage, broccoli, cauliflower, Brussel sprouts, and collards in home gardens, use Dibrom 60 EC (naled) at a rate of 2 teaspoons of formulation/gallon of spray is reported to be effective.

Control is not often needed because of the abundance of natural enemies, so regular monitoring of natural enemies is also important. Treatment thresholds vary depending on the crop and location and growers. Normally, spraying should not occur when there is less than one larva per five plants.

Probabilities of Entry: Low – Cabbage looper host leaves and readily visible with naked eyes. Therefore, the pest has low possibility of entering into Australia under proper quarantine.

Possibility of Establishment: High – Cabbage looper has a wide host range capacity that makes it easy to find suitable host following enter into Australia where environmental factors are also in favor of this pest.

Quarantine Risk: Low to Moderate – Cabbage looper is a strong flier, therefore, following establishment the pest has high potential to spread locally and also nationally mainly by infested vegetables and agricultural tools under non-restricted interested trading.

Economic Impact: Moderate to high – the pest biology, wide host rang capacity, damage severity, and the available management practices for cabbage looper indicate moderate to high impact on the economy following its successful establishment in Australia.

Environmental Impact: Low – although cabbage looper has a wide host range capacity but there are many natural enemies for this pest that keep the insect populations under control in nature. Therefore, the pest management requires minimum chemicals and low environmental impact through chemical pollution is anticipated.

Social Impact: Low – although cabbage looper can attack multiple vegetable crops but the growers can reduce the damage level by several cultural practices as the pest is easy to detect in the field and take proper management actions. .

Pest Management cost: Low/moderate – depending on pest severity the management cost may vary from $350 -1050/ha. Based on 7 spary/season the cost is calculated about $700/ha. This cost excludes involvement of any biological control and or resistant plant varieties. Control is not often needed because of the abundance of natural enemies that keep the insect population density below threshold level in the field.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 to 20% for crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Moderate – The cabbage looper has the capacity to survive in infested crops and disperse during non-restricted trade. This may concern to export market.

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THREAT DATA

Cabbage moth

(*Mamestra brassicae*)

Enhanced Risk Analysis Tools

Ref. http://www.inra.fr/hyppz/IMAGES/7032160.jpg

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Cabbage moth

(*Mamestra brassicae*)

Cabbage moth (*M. brassicae*), is also know by other English names like 'cabbage armyworm' and many other scientific names. The larval stage of cabbage moth causes serious damage on a number of vegetable crops and brassica hosts are the preferred one among others. The insect also attack some ornamental and woody plants such as sallows and oaks. The infestation could reach up to 98% and most of the infested crops are not marketable. Cabbage moth widely distributed in many European and Asian countries but not reported in America and Oceania yet.

Distribution: Cabbage moth is present throughout the Palaearctic region from Europe to Japan and subtropical Asia but not present in America or Oceania (APPPC, 1987; Zhang, 1994). The species is abundant all over Denmark, and in southern Scandinavia and Finland (Skou, 1991). In Turkey and Germany cabbage moth is a serious pest of cabbage (Saban et al. 2006).

Host range: Cabbage moth larvae are extremely polyphagous and in total, they eat plants of more than 70 species of 22 families, including Onion, cabbage, cauliflower, lettuce, potato, tomato, tobacco, pea, common bean, maize, carrots etc.; they also occupy fruiters (apple, pear, and peach trees), ornamental and forest plants (e.g. oak). But the hosts belong to Brassicaceae and Chenopodiaceae family are among the most preferred.

Affected Plant Stages: Mainly vegetative stage but flowering and fruiting stages also get affected.

Affected Plant Parts: Primarily leaves but stem, root, growing point, fruits and whole plant could be affected.

Biology and Ecology: Larvae of cabbage moth are nocturnal and rarely seen during daylight hours. Adults are attracted to light at night. The adult moths emerge from pupae in the soil. Shortly after emergence the moths mate, and the females deposit their eggs in regular batches of up to 70-80 eggs, mainly on the undersides of leaves. Number of eggs laid by individual female varies from **600 to 2700** depending on many factors. The eggs normally hatch in 6-14 days, and the larvae immediately start to feed on the leaves. Female lifespan 2-3 weeks. Young larvae feed gregariously. In white cabbage field the larvae started to spread all over the host plant within a few hours after hatching (Johansen 1997). After 1-2 days they were found on the nearest neighbouring plants and rows, and they continued to disperse radially from the original infested plant throughout the larval stage. Young larvae feed mainly on the external leaves and gradually they move into the heart of the plants. Nearly full-grown larvae are often concealed in the soil during daytime and enter the plants to feed at night. Larval development normally takes 4-7 weeks. Mature larvae leave the plants to pupate in thin cocoons in the soil at a depth of about 3-5 cm (Rygg and Kjos, 1975). Depending on climate, the insect develops **1-3 generations** per year. Hibernation and aestivation take place in the pupal stage.The species is nocturnal in habit and emergence from pupae, flight, mating activity, egg deposition and feeding mostly take place during the dark period. Cabbage moth is a hygrophilous species, found more often in areas with high humidity, especially in river flood plains. For oviposition, the moths require additional feeding on flowers. Therefore, the limiting factors of species distribution include low air humidity and the absence of flowering nectariferous plants. Wintering pupae are capable of withstanding long flooding. Entomophages (predators and parasites) and diseases limit pest numbers.

Damaged Symptoms: Young larvae of cabbage moth usually feed on underside of the external leaves. Larvae make ragged holes in the foliage and move to the centre of the plant. As the larvae grow older, the feeding holes become larger. Infested leaf left with a net-like appearance. Large amount of dark green larval faeces are quite visible on the infested leaves and this faeces initiate bacterial and fungal infection on the leaf. In cauliflower and broccoli, the larvae also feed on the inflorescence where they chew more or less deep holes. Small larvae live well hidden between the flower stems and may pass sorting procedures, contaminating processed products. Soyabean leaves may be completely skeletonised. The feeding may destroy young buds, leading to distorted growth. The larvae bore into the pods and feed on the seeds.

The larvae feed on leaves, buds and petals in ornamentals such as Dahlia, Chrysanthemum and Rosa, and they may bore into the fruits in fruiting crops such as tomato.

Fig. Cauliflower damage by Cabbage moth (*M. brassicae*)

Ref. http://www.inra.fr/hyppz/RAVAGEUR/6mambra.htm

Movement and Dispersal: The potential for natural spread of cabbage moth is high as the adult insects are highly dispersive and a strong. Infested plants leaf, soil gravel, field tools etc. can play role in pest dispersion both locally and distance. Trading of infested vegetables would be the main means of spread as the larvae and eggs can easily be missed in quarantine.

Resistant plant variety: An Australian cauliflower line has been found to be resistant to infestation of *M. brassicae* in The Netherlands (Finch and Thompson, 1992). Red cabbage has been found to be less infested with larvae than white cabbage and Savoy cabbage.

Natural Enemies: The cabbage moth is attacked by numerous natural enemies like Trichogramma (parasitoids), Chrysoperla (predator) and Erynnia nitida (entomopathogenic fungus). But none of these have any great impact on suppressing the insect population density in the field (Carl et al. 1986).

Economic impact: Cabbage moth has wide host range with more than one generation of reproductive capacity that play significant role in crop damage. More than 70 plant species of 22 families can be affected by this insect. In cabbage crops in Germany, cabbage moth is a main pest with regular occurrence. In field 27-98% of the plants in different cabbage crops were reported infested (Hommes, 1983). Larval infestation of cabbage in Moldavia found to harvest losses of 8-80 %. In case of white cabbage in Norway, weight losses due to larval damage were 10-13% (Rygg and Kjos, 1975). In Turkey average of 38.1% infestation were noted in the cabbage field and infested cabbage with larval faeces were non-marketable (Saban et al 2006).

Management: Control measures include autumn plowing, inter-row cultivation of tilled cultures, eradication of weeds, release of Trichogramma in the beginning of moth flight and repeatedly for 7-8 days, and insecticide treatments of plants during the period of caterpillars hatching.

Control of cabbage moth is very often based on insecticides. Depending on number of generations produced by the insect, 1 or 2 spray treatment may be sufficient to control the larvae. To be effective, insecticides must be applied when the larvae are small. Narrow-spectrum insecticides should be chosen when possible to preserve and encourage the build-up of natural enemies. Chemicals in use are within the groups of organophosphates, pyrethroids, carbamates, organochlorines and insect growth regulators. In Belgium, insecticides are often applied to Brussels sprouts every 2-3 weeks to control cabbage moth larvae (Van de Steene, 1994). Insecticides currently

Probabilities of Entry: Low – Cabbage moth associated with the host leaves and readily visible with naked eyes. Therefore, the pest has low possibility of entering into Australia under proper quarantine.

Possibility of Establishment: High – Cabbage moth has a wide host range capacity that makes it easy to find suitable host following enter into Australia where environmental factors are also in favor of this pest.

Quarantine Risk: Low to Moderate – Cabbage moth capable of flying and have more then one generations in a year, therefore, following establishment the pest has high potential to spread locally and also nationally mainly by infested vegetables and agricultural tools under non-restricted interested trading.

Economic Impact: Moderate to high – the pest biology, wide host rang capacity, damage severity, and the available management practices for cabbage moth indicate moderate to high impact on the economy following its successful establishment in Australia.

Environmental Impact: Low – although cabbage moth has a wide host range capacity but there are many natural enemies for this pest that keep the insect populations density low in some extent in nature. Therefore, the pest management requires minimum chemicals and low environmental impact through chemical pollution is anticipated.

Social Impact: Low – although cabbage moth can attack multiple vegetable crops but the growers can reduce the damage level by several cultural practices as the pest is easy to detect in the field and take proper management actions. .

Pest Management cost: Low/moderate – depending on pest severity the management cost may vary from $350 -1050/ha. Based on 7 spary/season the cost is calculated about $700/ha. This cost excludes involvement of any biological control and or resistant plant varieties. Control is not often needed because of the abundance of natural enemies that keep the insect population density below threshold level in the field.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 to 20% for crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Moderate – The cabbage moth has the capacity to survive in infested crops and disperse during non-restricted trade. This may concern to export market.

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THREAT DATA

Psylla

(*Cacopsylla pyricola*)

Enhanced Risk Analysis Tools

(Ref. http://www.gslong.com/PestofMonth.htm)

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Psylla

(*Cacopsylla pyricola*)

Pear psylla (PP), *Cacopsylla pyricola*, is the most important insect pest of pear in all pear-growing regions. The insect is the primary pest for pears in North America and accidentally introduced from Europe into Connecticut, U.S.A. in about 1832. It can be a limiting factor in pear production by causing stunting growth, defoliation, and even killing trees. PP can be found in other hosts such as neighboring cherry or apple orchards, especially in fall and early winter and they cannot complete their lifecycle or reproduce outside of a pear orchard.

Distribution: PP is widely distributed in Europe. Following it's introduction to USA from Europe it has been a major pear pest in USA and Canada (Hodkinson, 1984). PP in Iran is confirmed, where it may have been introduced. The pest also has limited distribution is in Asia including China and Japan. The pest is unknown in Australia, New Zealand and Oceania.

Host Range: Under natural conditions PP is probably restricted to pear (*Pyrus communis*) only. In experimental plantations it has also been found on *Pyrus ussuriensis* and other *Pyrus* spp. and their hybrids with *P. communis.* However, these are less attractive to PP than *P. communis* (Harris, 1973, 1975).

Affected Plant Stages: Flowering stage, fruiting stage, post-harvest and vegetative growing stage.

Affected Plant Parts: Fruits/pods, leaves and stems.

Biology and Ecology: Adults PP overwinter in or near pear orchards. Few adults are mated before overwintering. In early spring adults return to the trees, mate and begin ovipositing in crevices on fruit spurs and on young leaves as they unfold. One female PP may deposit up to 500 eggs during their life. There are three to four generations of the PP per year. One generation is completed in two to three weeks. Females of the later generations will deposit most of the eggs along the leaf midribs. Most oviposition (by summer) adults occurs near leaf midveins; egg survival is also highest near midveins. As nymphs develop, they become engulfed in a droplet of accumulating honeydew. Such droplets may contain the shed skins of the preceding instars. PP serves as the vector for the mycoplasma-like organism causing pear decline when European scions are grown on Asian rootstocks. Recent research at USDA indicates that a transgenic pear line (developed for resistance to fire blight) may be less suitable as a host for PP.

Symptoms: The PP secretes large amounts of honeydew, which runs down over foliage and fruit and in which a sooty fungus grows (fig. left). This causes the skin of the fruit to become blackened and scarred and the foliage to develop brown spots (fig. right). Heavy infestations may cause partial to complete defoliation of trees, reducing vitality and preventing the formation of fruit buds. Return bloom and fruit set are often reduced the following season. Overall tree growth can be stopped or stunted with heavy psylla injury. These combined effects are often termed "psylla shock." There is also limited evidence that psylla inject some type of toxin into the tree, causing a disease known as pear decline. In addition, PP have been implicated in the transmission of fire blight.

Fig. Psylla Infested leaves, stems and fruits.

Source: http://www.agf.gov.bc.ca/cropprot/tfipm/pearpsylla.htm

Movement and Dispersal: The most common way for psyllid to move long distances is with infested fruits and plant parts.

Phytosanitary Risk: Moderate - overwintering adults are long-lived and may be transported together with the pear (or other goods) over long distances. There is a risk of introducing the species and phytosanitary measures are recommended (ref. CPC).

Natural Enemies: The literature on the entomophagous fauna of PP in Europe is summarised by Lyoussoufi et al. (1994a). Detailed distributions are not given because the natural enemies are widespread and have been recorded from one or more of the three *Cacopsylla* species in all countries where studies have been made. There do not appear to be any important differences in host preference. A list of natural enemies found in Canada is included in Canada Agriculture (1971).

Impact: Moderate - The PP can cause three forms of damage. The most common is a result of the honeydew produced by the nymphs. Psylla feed by sucking juice, called phloem, from the pear tree. While feeding, the nymph produces honeydew which forms into a droplet. The honeydew produced can drip or run onto fruit causing a dark russet spot or streak. This result in fruit marking and can downgrade the quality of the fruit. In large numbers psylla can stunt or defoliate trees and cause fruit to drop. These symptoms, called psylla shock, are caused by saliva injected into the tree by the feeding nymphs. Psylla can also transmit a disease, called pear decline, through their saliva. Pear decline damages sieve tubes in the phloem and translocates to the roots and results in root starvation. Pear decline can eventually result in tree death, however the severity of the disease depends on the origin of the rootstock. Psylla shock and pear decline are usually not a concern in commercial orchards, as control measures to reduce psylla russett keep populations in check.

MANAGEMENT OPTIONS:

Monitoring: Growers should monitor for the presence of PP using their most sensitive pear variety (i.e., Bartlett). To sample for PP nymphs in the early season, examine at least 10 leaves (five spur and five recently expanded shoot leaves) per tree on a minimum of five trees per block. The action threshold at this time is 0.5 nymphs per leaf. For the summer generations again examine at least 10 leaves (recently expanded shoot leaves) per tree on a minimum of five trees per block. The action threshold now is 1.5 nymphs per leaf. When the psylla population is primarily in the adult stage, examine the leaves for the presence of adult activity and egg laying.

Cultural management: Several cultural control practices will reduce psylla populations and dependence on insecticidal control. First minimise heavy pruning, which encourages the proliferation of terminal shoot growth. An overabundance of terminals provides more feeding sites for the psylla. Second, pear trees should receive the minimum amount of nitrogen fertilisation necessary for proper tree and fruit growth. Overfertilisation can cause extended terminal growth and delay hardening off, allowing optimal feeding conditions for the psylla. Third, and most important, is to remove water sprouts during early/mid summer. Because water sprouts provide one of the only sources of succulent leaves at this time of the year, this technique can eliminate a large portion of the psylla population.

Biological Control: Biological control has been attempted in North America. *Prionomitus mitratus* was imported from Switzerland and released in British Colombia, Canada, during 1963 and recovered, but it was discovered that it had already been present in Canada and the USA before its introduction. European *Anthocoris* spp. were also released in British Colombia at that time, but only *A. nemoralis* became established. An unsuccessful attempt was also made to transfer a native species, *A. melanocerus*, from British Colombia to Ontario. It was concluded that further studies were required on the extensive complex of native predators with a view to enhancing their impact, before any additional importations were considered (Canada Agriculture, 1971). *P. mitratus* and *Trechnites psyllae* were imported into the USA and released in California in 1965, but there are no reports of the outcome (Clausen, 1978). Subsequently, coccinellid predators from various countries have been released in Washington, but only one, *Harmonia axyridis* from Japan, is known to have become established (Dreistadt et al., 1995).

Chemical Control: Dormant oil may be applied when eggs begin to appear in spring. Various insectides are registered for control. Horticultural spray oil may be applied. This is more highly refined than dormant oil and should not be confused. Also, a lower rate is used, 1 qt/100 gal, rather than the 2 gal / 100 gal recommended in dormant sprays. Horticultural spray oil is recommended to be included with avermectin sprays (http://www.virginiafruit.ento.vt.edu/psylla.html).

According to Burts (1970) the only satisfactory control of PP in Washington was to spray insecticides. Pure chemical control, however, is problematic as predator populations are often adversely affected, and psyllid populations develop resistence (Riedl et al., 1981; Harries and Wege, 1997). Chemical control is usually applied together with other methods, and the products are often relatively specific. Some of the substances which have been used include: growth regulator fenoxycarb (Burts and Beers, 1994); feeding and oviposition deterrents sprayed onto host leaves (Horton et al., 1995); broad spectrum pyrethroid insecticides (Solomon et al., 1989); and avermectin B1 (abamectin) (Etienne et al., 1992).

Resistant plant variety: PP has the potential to adapt significantly to pear cultivars (Puterka, 1997). But there are some cultivars resistant to psyllids have been reported by Hunter (1994) and Djouvinov *et al.* (1994).

Integrated Pest Management: Solomon and Morgan (1994) discuss the use of broad spectrum and selective pesticides in orchards in the UK. The broad spectrum insecticide should be applied following the return of overwintered pear psyllids to the orchards when anthocorid predator populations are still small. Selective pesticides are toxic to larvae but not adults of pear psyllids and should be applied when the majority of psyllids are in the susceptible stage.

Probabilities of Entry: Low - because the pest can enter into Australia through mainly infected fruits and plant parts in case of poor quarantine.

Possibility of Establishment: Low – as the pest has a narrow host range and unlikely to find a suitable host at the right stage in its life cycle.

Economic Impact: Medium to high - based on pest biology, the damage caused by the pest and its available management practices.

Quarantine Risk: Low - The plant quarantine risk posed by psyllid is low. Once established, the insect has high potential to establish in various pear growing regions in Australia by natural spreading e.g. flight, wind etc.

Environmental Impact: Low – because of restricted host range, available resistant plant varieties, and effective control measures both cultural and chemical.

Social Impact: Nil – effective control measures will keep psyllid population under control and have positive impact on local industries as well as in small growers. Therefore, presence of this pest would not have any negative impact on the local community depending on pear industry.

Pest Management cost: Low/moderate – depending on pest severity the management cost may vary. Based on literature the annual application cost for chemical control of this pest is about **$300/ha for 2 spray** (chemical cost ~$100/ha plus labor and machinery cost ~$50/ha for a single spray as suggested by Martine Combret, Development Officer, DAFWA). This cost excludes involvement of any biological control and resistant plant varieties. Effective and established control practices (both cultural and chemical) are available for *C. pyricola*. However, the management with cultural practice could be more expensive in case pest severity.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 15 – 30% even under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: None **-** Export losses result from entering and establishing this pest in Australia would be at non-significant level because of its limited host range and very low possibility of pest spread through export, specially in case of fruit.

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THREAT DATA

Peach fruit moth

(*Carposina sasakii*)

(Ref. http://www.jpmoth.org/Carposinidae/Carposina_sasakii.html)

CRC10010

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Peach fruit moth

(*Carposina sasakii*)

Carposina sasakii, common English name 'Peach fruit moth or Peach fruit borer, is major insect pest of fruit trees in Korea (Kim et al., 2000), and is very difficult to control because larvae bore into fruits.

Distribution: *C. sasakii* is manly distributed in Chian, Japan, Korea and small part of Russia also. It's presence in Canada is being reported but it may be different species. Otherwise the pest is not known in USA, Europe, Australia and New Zealand.

Host range: Including apples, pears, peaches, apricots and plums *C. sasakii* has wide rang of cultivated and wild host.

Affected Plant Stages: Flowering stage.

Affected Plant Parts: Fruits/pods and seeds.

Biology and Ecology: *C. sasakii* overwinters as hibernating larvae in cocoons in the soil as well as in fruit at storage conditions (Shutova, 1970). The larvae pupate in the spring in fresh cocoons on the surface of the soil and the moths emerge about 12 days later. The female lay eggs on each fruit usually near the calyx and up to 13 larvae have been recorded in a single pear (Yago and Ishikawa, 1936). One female can carry up to 300 eggs (Ohira, 1989) but lays an average of about 100 eggs (Gibanov & Sanin, 1971). Usually the pest has one generation per year in temperate countries but under warmer conditions it might complete a full or partial second generation (Chang et al. 1977). The young larvae bore into the fruit, usually near the calyx, but reject the skin. Later, they may move from one fruit to another. Susceptibility to penetration by the young larvae varies with growth stage, species and cultivar of fruit. Susceptibility of fruit penetration varies from developmental stages of fruit as well as fruit varieties. Larval developmental rate also influence by these factors, in addition to temperature (Gibanov and Sanin, 1971; Chang et al., 1977).

Symptoms: Several eggs are visible usually near the calyx. The larvae tunnel the fruit, feeding on the fleshy parts as well as on seeds but rejecting the skin. Up to 13 larvae found in each fruit. Infested pears turn yellow, apples exude gum and apricots ripen unevenly (Gibanov & Sanin, 1971).


Fig. *C. sasakii* on healthy fruit (left), larvae inside the infested fruit (right).

Source: http://www.fruit.affrc.go.jp/kajunoheya/apdb/lepA-M/C_sasak1.htm

Movement and Dispersal: The potential for natural spread of *C. sasakii* is very low as it can only fly very short distances. International trade would be the main means of spread through infected plant materials including seeds (Shutova, 1971). Larvae are able to survive long periods in stored fruits and USDA inspectors find almost every year on raw fruit from Japan and Korea.

Phytosanitary Risk: *C. sasakii* is an A2 quarantine pest for EPPO (OEPP/EPPO, 1999) and for COSAVE. In Russia it's an internal quarantine pest. The risk of introduction of *C. sasakii* exists mainly in pear growing regions. The most likely pathway for introduction is through imported fruits.

Resistant plant variety: No report is available in the literatures on resistant plant variety against this pest.

Natural Enemies: Number of pathogens and parasitoids are listed in the literatures without mentioning their success in *C. sasakii* control under field conditions.

Economic impact: *C. sasakii* is primarily a pest of pome fruits. It is considered one of the most important pests of these fruits in the Far East. In Japan, Korea Republic and China, it may cause heavy losses of apples if not controlled (USDA, 1958). For example, Hwang *et al.* (1958) reported about one third of apple losses in Liaoning province. Compare to apple (40-100%), apricots and plums damage could more severe in pears such as 100% in some cases (Sytenko, 1960; Pavlova, 1970; Gibanov and Sanin, 1971).

Control: *C. sasakii* can be successfully achieved by applying either fenitrothion, parathion, fenvalerate or deltamethrin at the oviposition peaks of the first and second generations, in combination with the mechanical removal of fallen fruit (Huan *et al.*, 1987).

In case of biological control, a few record of parasites. *Anilastus* sp. (Hymenoptera: Ichneumonidae) was raised from infested apples in Japan (Pschorn-Walcher, 1964). A fungus, *Isaria fumosorosea*, has been advocated for control (Sekiguchi, 1960). More recently, *Metarhizium anisopliae* has been reported most effective in a comparative study (Yaginuma & Takagi, 1987).

Probabilities of Entry: Low to moderate. *C. sasakii* can enter into Australia mainly through infested plant fruits but under proper quarantine it has low possibility of entry into the country.

Possibility of Establishment: Moderate - because of available host (pears, apple, plums, peaches, apricots etc.) and suitable climates the pest has moderate chance to establish in Australia.

Quarantine Risk: Low – following establishment the pest has low potential to spread by natural means as it can only fly very short distances.

Economic Impact: High - based on pest biology, multiple host rang, damage reported by *C. sasakii* and the effective management practices availability.

Environmental Impact: Low to moderate – because *C. sasakii* has multiple host range including both cultivated (mainly fruit) and wild host. In pest management, limited biological control plus absence of pest resistant plant varieties encourage more chemicals applications that cause environmental pollution.

Social Impact: Low – although effective control measures will keep *C. sasakii* population under control but in severe cases the management cost may rise beyond the profit level. The pest is also capable of infect multiple fruits. Hence, there is a chance of a negative impact of *C. sasakii* on both local industries as well as in small growers depending on damage severity.

Pest Management cost: Low/moderate – depending on pest severity the management cost may vary. Based on literature the annual application cost for chemical control of this pest is about **$450/ha for 3 spray** (chemical cost ~$100/ha plus labor and machinery cost ~$50/ha for a single spray as suggested by Martine Combret, Development Officer, DAFWA). At least 3 or even more spray in a season is required. This cost excludes involvement of any biological control and resistant plant varieties. Effective and established control practices (both cultural and chemical) are available for *C. sasakii*. However, the management with cultural practice could be more expensive in case pest severity.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 15 – 30% for individual crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Moderate - due to *C. sasakii* capacity to disperse via infested fruits and seeds during international trade. Larvae of *C. sasakii* are also able to survive long periods in stored fruits.

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THREAT DATA

Carrot root fly

(*Psila rosae*)

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Ref. http://www.umassvegetable.org/soil_crop_pest_mgt/insect_mgt/images/CarrotRustFly.jpg

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Carrot root fly

(*Psila rosae*)

Carrot root fly (CRF) is also known by carrot rust fly (*Psila rosae*). It's a serious pest for carrot and other related vegetable crops. The fly attack both seedling and mature plants that cause significant economic loss. It's difficult to control CRF due to its wide host range. Therefore, the preventive measure is encouraged for the grower. CRF is most likely native to Europe where it is widely distributed but the pest is not reported in Australia yet.

Distribution: Carrot root fly is widespread in Europe and most likely originated there. The pest is also reported in most part of North America. From Europe, CRF spread across the northern hemisphere, including Canada and USA and has also been introduced to New Zealand (CAB International 2005). Australia is free of CRF.

Host range: Including both cultivated and wild carrots (*Daucus sp.*) CRF has many other hosts belong to Umbelliferae family. In absence of these hosts, the CRF larvae may also feed on other plant species such as cabbage, lettuce, potato, beet and endive.

Affected Plant Stages: Seedling and vegetative stages

Affected Plant Parts: Roots, leaves and whole plant.

Biology and Ecology: Adult flies emerge from overwintering cocoons in spring, and females lay their eggs on or near the crowns of young carrots. The eggs hatch after about ten days, and the maggots feed for up to 7 weeks before pupating in the soil. The length of the life-cycle is temperature dependant. Depending on climatic conditions there can be 1 to 3 generations per year. Adults can be found on foliage around host plants. Each female lays between 5 and 167 eggs into cracks in the soil. Larvae emerge after 7 days and can move up to 60cm through soil, feeding on roots. Second generation larvae burrow into the tap root and produce a mine. Mature larva forms a puparium in soil and overwintering in host roots (CAB International 2005).

Symptoms: CRF attack both seedling and mature carrot plants throught out the growing season. Infested carrot field shows plants with radish foliage and blank patches due to seedling death. The larvae on feed on apices of tap roots that result seedling to die. Infected mature plants exhibit stunted growth with radish foliage and distorted carrot. The surface of the infested carrots (tap root) showing irregular brown feeding channels, where the larvae might be visible occasionally. The feeding channels allow secondary infections by other soil borne pest. In case of other hosts, the symptoms are very much similar to carrot with very little changes.

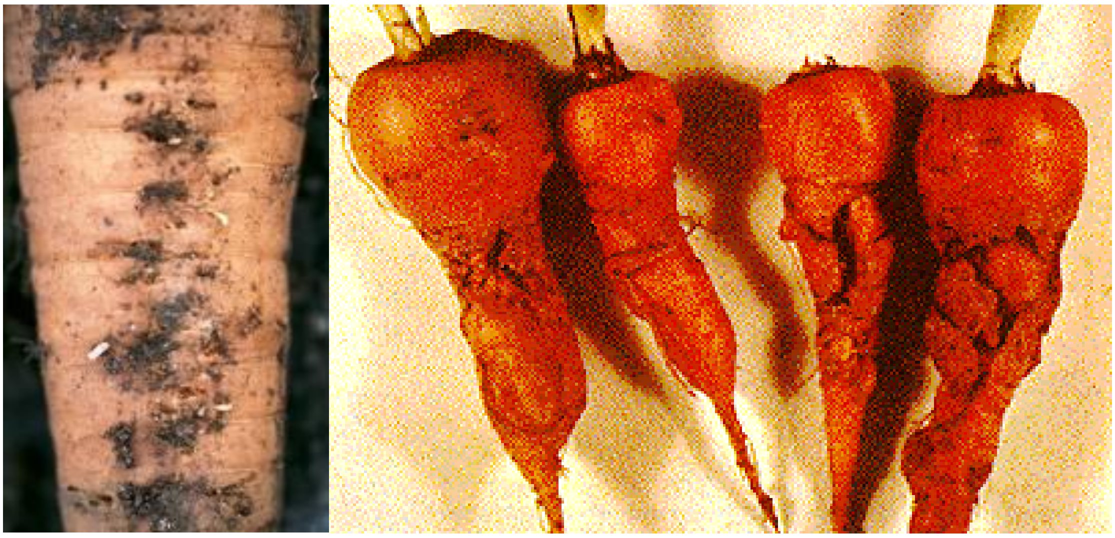

Fig. Symptoms cause by carrot root fly (CRF). Infested carrots show brown feeding channels with white larvae (right) and distorted shape (left).

Ref. http://www.insectimages.org/images/384x256/1243119.jpg
http://www3.telus.net/conrad/insects/crf.html

Movement and Dispersal: The potential for natural spread of CRF is low as it is a weak flier but strong wind may help in spread far. However, infested carrots, soil gravel, water etc. can play major role in pest dispersion both locally and distance. Trading of carrot would be the main means of spread as the larvae can survive inside and easily be missed in quarantine.

Resistant plant variety: No report is available in the literatures on resistant commercial variety against this pest.

Natural Enemies: Number of parasites and predators are listed in the literatures without mentioning their success in controlling CRF under field conditions.

Economic impact: CRF is on one the primary and serious pests of carrot in Europe and 60% damage of untreated carrots has been reported in England (Coppock et al. 1975). Toms (1972) reported 30% of carrots being unsaleable obtained from an average infested field. CRF attack persists throughout the season from seedling to harvesting stage. Therefore, the economic damage is severe compared to other pest.

Management: Preventive measure is more effective than the currently available control measures. Currently available pesticides are unlikely to provide acceptable control of large populations, so cultural methods for managing local populations are important for the growers. Since the fly is relatively weak flyers, populations tend to be localised. Flies probably travel less than 1000 yards in search of egg laying sites. Isolation of crops from previous years' fields can significantly reduce carrot fly risk. Delayed spring seeding of carrots also reduces the severity of rust fly attack.

Removing heavily infested plants quickly from the field helps in eliminating source of next year's rust fly population. Early fall harvesting and storage of carrots in pits and root cellars rather than in the ground help minimise fall infestations caused by late second and early third generation maggots.

Probabilities of Entry: High. CRF can enter into Australia mainly through infested carrot but under proper quarantine it has low possibility of entry into the country. However, risk analysis for CRF by Plant Health Australia (PHA) predicted high entry potential in the country, although CRF not a seed-borne pest.

Possibility of Establishment: High – CRF posses a wide host range including cultivated, native and some weed species of Apiaceae. Suitable climatic conditions in some parts of Australia are in favor to establish the pest in this country. Plant Health Australia also predicted high potential of establishment for this pest in Australia.

Quarantine Risk: Low to Moderate – following establishment the pest has some potential to spread locally and nationally mainly by infested soil, agricultural tools, and carrots. CRF has a history of introduced into North-America and New-Zealand from Europe. Therefore, CRF has a considerable quarantine risk as the pest can easily be carried as a larva in root crops.

Economic Impact: High – the pest biology, wide host rang, damage severity, and the difficulty with currently available chemical control of CRF indicate it's high economic impact following its successful establishment in Australia. Plant Health Australia also predicted the same.

Environmental Impact: Low/Moderate – wide host range including native plants, the crop damage severity, and lack of effective control measures may influence the grower to use some non-specific pesticides in pest management that might pollute the environment in some extend

Social Impact: Moderate – CRF is a serious pest of carrot and other related crops and currently there is not effective chemical control for this pest. Therefore, the pest can bring severe crop damage for both commercial and small growers. Hence, there is a chance of a negative social impact of this fly on both local industries as well as in small growers depending on damage severity.

Pest Management cost: Low/moderate – depending on pest severity the management cost may vary from $350 t0 1050/ha. Based on 7 spary/season the cost is calculated $ about $700/ha (ref. Project Manager, Potato, DAFWA).This cost excludes involvement of any biological control and or resistant plant varieties. CRF management mainly depends on cultural practices because the current chemical spry is not effective. However, the management with cultural practice could be very expensive or even impossible in case pest severity.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 15 to 30% for crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Moderate – The CRF has the capacity to survive in infested carrot and disperse during international trade. This may concern to export market.

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THREAT DATA

Rosy apple aphid

(*Dysaphis plantaginea*)

(Ref. http://www.invasive.org/browse/detail.cfm?imgnum=1326213)

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Rosy apple aphid

(*Dysaphis plantaginea*)

Rosy apple aphid, (RAA) *Dysaphis plantaginea*, is one of several species of aphids that infest commercial apple orchards and backyard apple trees. It is the most destructive of the aphid species that feed on apple trees; other aphids found on apple are green apple aphid. RAA feeds on pear and hawthorn as well as apple. Because rosy apple aphid does not occurs in most orchard in most years. It is important to determine each spring whether or not this pest is present in individual orchards. RAA has been a major pest of apple trees in North America since the end of the 19th century. It is the most serious of the five aphid species attacking apple, causing leaf, fruit and systemic root damage. In severe outbreaks, up to 50 percent of the fruit have been injured.

Distribution: *D. plantaginea* is widespread throughout Europe - from the Scandinavian Peninsula to the Mediterranean Sea, including the UK and the southern islands (Sicily, Sardinia, Corsica, Cyprus), and the Canary Islands and Azores. The aphid is found in North Africa, Middle East, Caspian region, India and some Southeast Asian countries - Taiwan, Korea, Japan. *D. plantaginea* has been a major pest on apple trees in North America since the end of the nineteenth century and now is widespread in the USA and southern Canada. The pest is unknown in Australia, New Zealand and Oceania, and Central and South America (CIE, 1981; Hogmire and Beavers, 1998; Fauna Europaea, 2005).

Host range: RAA is harmful only to apple (*Malus domestica*). Its secondary host plant is plantain (*Plantago* spp.), especially *P. lanceolata*, also known as ribgrass. Other hosts are *P. major* and *P. rugelii* (Baronio et al., 1989; UC, 2002; HYPPZ, 2005). The species colonises almond in Turkey (Bodenheimer and Swirski, 1957). Some authors reported other hosts - pear (Theobald, 1916 and Swaim, 1919, quoted by Shaposhnikov, 1955) and Sorbus aucuparia (Nevskii, 1951), but probably they had observed other aphids (Grigorov, 1980). According to Sechser and Reber (1999), around an apple orchard in Switzerland characterised by minimum insecticide input Viburnum opulus was most infested by RAA, followed by *Acer pseudoplanatus*, Euonymus europaeus, hazelnuts and *Picea abies*; *Ligustrum vulgare* was least infested. This information is not confirmed from other authors and there is doubt about the correct identification of the aphid (ref. CPC).

Affected Plant Stages: Flowering stage, fruiting stage and vegetative growing stage.

Affected Plant Parts: Fruits/pods, leaves and stems.

Biology and Ecology: RAA overwinters in the egg stage. In the fall, oval yellow eggs about 0.5 mm long are laid in crevices in the bark of larger branches. Eggs begin to darken, and after one to two weeks, they become shiny black and are impossible to differentiate from those of green apple aphid and apple grain aphid. In the spring, eggs hatch for about two weeks while the buds are in the silver-tip to half-inch green stage. Newly hatched nymphs feed on expanding buds and undergo five molts until they mature into wingless adult females that give birth to live young without being fertilised by males. Each female produces an average of 185 offspring, which can lead to rapid buildup of large populations. Nymphs cluster around each mother to the extent that infested leaves may be covered by more than one layer of aphids.

One generation is completed in two to three weeks. Adult aphids in a colony are generally wingless until crowded conditions induce the formation of winged individuals that can disperse to new hosts. The winged aphids often fly to a different plant species which is called the secondary host. RAA may remain on apple throughout the summer, but usually moves to narrow-leaf plantain or dock in early-summer. By late-July, most of RAA have left the apple trees.

Reproduction without mating continues on secondary hosts (plantain, dock) until late-summer or autumn when winged forms develop and return to the primary host (apple). Here a generation is produced that will develop into sexual adult males and females; these mate, then the females deposit overwintering eggs on the primary hosts.

Symptoms: This is potentially the most damaging aphid species on apples. RAA cluster on leaves of fruit spurs and growing shoots where they cause severe leaf curling (fing.1). Fruits on heavily infested fruit spurs fail to properly develop and become misshapen (fig. 2).

Fig.1.Leaf curling and distortion caused by rosy apple aphid. Fig. 2. Fruit and leaves distorted by rosy apple aphid (ref.http://www.ipm.ucdavis.edu/PMG/r4301511.html)

Plant parts liable to carry the pest in trade/transport

- Bark: Eggs; borne externally; visible under light microscope.

- Leaves: Nymphs, Adults; borne externally; visible to naked eye.

- Seedlings/Micropropagated Plants: Eggs, Nymphs, Adults; borne externally; visible to naked eye.

- Stems (above Ground)/Shoots/Trunks/Branches: Eggs; borne externally; visible under light microscope.

Phytosanitary Risk: The risk of introduction of RAA exists mainly in regions where new apple orchards will be created. The most likely pathway for introduction is through nursery stock.

Pest movement and Dispersal: Natural dispersal (non-biotic). RAA can fly a short distance and it is possible that the pest can spread slowly to new areas where apples are grown. Agricultural practices and the most common way for RAA to move long distances is with infested seedlings.

Economic impact: RAA has been a major pest on apple trees in North America since the end of the nineteenth century. It is the most serious of the five aphid species attacking apple, causing leaf, fruit and systemic root damage. In severe outbreaks, up to 50% of the fruit have been injured. The aphids remove plant juices from the leaves, causing severe curling and abscission, and twisting of growing shoots. One nymph feeding for 24 hours is sufficient to cause the leaf to be curled when it unfolds. The aphids excrete large quantities of honeydew, which provides a substrate for a black sooty fungus which can affect fruit finish. However, the most serious effects results from the translocation of saliva from the leaves to the fruit. This causes the apples to remain small and deformed and renders them unmarketable. Systemic effects of the toxic saliva include reduced growth of roots and other woody tissue. This can have an important impact on young trees as they develop a mature bearing structure (Hogmire and Beavers, 1998). Feeding by RAA on 22-53% leaves of the tree significantly reduced accumulation of dry weight in all portions of the trees during the first season's growth. At the 10-leaf stage of the second season, dry weights of trees infested with RAA during the previous year were still significantly lower than those of control trees (Varn and Pfeiffer, 1989).

In Spain, RAA affected up to 37-54% of the terminals in the observed orchards (Minarro and Dapena, 2001). In Poland decreased seedling weight (one-year-old apple seedlings) by 35.9-48.8%. The fruits on the infested shoots suffered reductions in diameter of approximately 22-28% and weight reductions of approximately 30-53% (Wilkaniec, 1993; Wilkaniec, 1998). Due to aphid feeding, the commercial yield of fruits (Primula variety) was reduced to 5.2%, in comparison with a commercial yield of 66.6% from un-infested trees. Aphid feeding did not cause significant change in blushing of fruits (Wilkaniec and Trzcinski, 1997). Increasing fruit number and aphid densities increased the reduction in fruit growth rates (Berardinis et al., 1994).

MANAGEMENT OPTIONS: Research at the Penn State Fruit Research and Extension Center demonstrated that an insecticide application at the green tip to half-inch green stage provided optimum control of RAA. A second application is recommended before bloom if an average of at least one infested leaf cluster per tree is found at the prepink to pink stage of apple development. The presence of this insect after bloom will result in fruit injury. Therefore, an insecticide should be applied at petal fall if any live colonies are found in order to minimise additional injury.

Delayed Dormant Oil: The green apple aphid, apple-grain aphid and rosy apple aphid overwinter as eggs on twigs and bark crevices of apple trees. A delated dormant oil application between green-tip and half-inch green controls newly hatched aphids. Failure to use a properly timed delayed dormant oil application may require additional in season treatments. These in season treatments are usually more expensive and disrupt beneficial insects that control secondary pests.

Chemical Control: Number of chemicals are effective in controlling this pest e.g. Lorsban 4E, Supracide2E, Pounce3.2EC, Ambush 2E, Asana XL 0.66EC, Sperior oil and Esteem 0.86EC(http://www.caf.wvu.edu/kearneysville/pest_desctriptions/control/RAAControl.htm) In general 2 spray are required in one season and good control depends on proper timing of insecticide applications. Overwintering aphid eggs can be targeted with a delayed dormant spray to prevent early damage to fruit or expanding leaves, although a spray at the pink bud stage, after eggs have hatched, is usually more effective for control of rosy apple aphid.

Good control depends on choosing a material that will kill aphids but will not kill natural enemies. Systemic insecticides such as dimethoate are more effective than contact materials. After the leaves begin to curl, contact insecticides usually do not provide adequate control unless applied with large volumes of water to thoroughly cover the curled leaves. Keep in mind that use of most broad-spectrum insecticides encourages aphid outbreaks by killing predators and parasitoids.

A 1 to 2 % application of insecticidal soap or summer horticultural oil can provide effective control of these aphids. Use the monitoring and economic thresholds and apply these as necessary. Neither of these will provide any residual control, so thorough coverage is essential. Control of rosy apple aphid after the leaves have curled may be difficult. While effective control can be obtained with a 1 to 2% summer horticultural oil treatment, caution is advised as these may be incompatible with some other pesticides (particularly sulfur containing products), are phytotoxic at higher temperatures (above 100ºF and high humidity) and at high concentrations (>2%), and may affect fruit finish on some varieties.

Natural Control: Small parasitic wasps attack RAA; they lay their eggs in aphids by stinging with their ovipositor (egg-laying organ). The wasp egg hatches within the aphid and the young wasp larva consumes the aphid. Parasitised aphids turn brown or black. In time, the wasp larvae emerge as adults from the aphids, leaving behind empty aphid skins. These skins, called "aphid mummies," can be found attached to leaves.

Other natural enemies of apple aphids include predators such as hover fly larvae (white legless maggots), lacewing larvae, lady beetle larvae, lady beetle adults, and gall-midge larvae (orange maggots). These predators feed on many different aphid species in addition to other insect pests. A cool, wet spring favors aphid development because these conditions are unfavorable for the aphid's natural enemies.

Phytosanitary Risk: The risk of introduction of RAA exists mainly in regions where new apple orchards will be created. The most likely pathway for introduction is through nursery stock.

Quarantine Risk: Low – because seedlings are major carrier and the pest can be readily visible in infested parts. Moreover, unlike fruits the seedlings are rarely carried by tourist during the travel.

Probabilities of Entry: High – the pest associated with leaves, stems and fruits, therefore there is high risk of entry as suggested in Plant Health Australia.

Possibility of Establishment: High – multiple hosts and their cultivations in Australia along with suitable climate makes it easy to establish this pest (ref. Plant Health Australia).

Economic Impact: High – Based on damage causes in USA, Spain, Poland and some other countries it consider a serious pest (apple in particular) with its difficult management practice.

Environmental Impact: Nil - since apple is the main host of RAA and unless other native plants become the host, no environmental impact is to be expected by this insect.

Social Impact: High - impact on backyard fruit trees to be expected and this will results negative impact on socio-economic condition of the society.

Pest Management cost: Moderate – number of chemical are effective in controlling this pest and generally at least 2 sprays are needed per season. Assume this must be applied a minimum of two times per season. The tentative amount of common insecticide (Superior Oil 70) needed 60L/ha and tentative cost is $ 130.0/ha (http://www.oktreefruit.com/Newsletters/costcomparison06.pdf.). In addition, labor and equipment costs of $50/ha are assumed. Therefore, single spray would cost **$180/ha**). Usually at least two spay in a season is recommended in the literature. Depending on the other factors (e.g. rain) the total cost might be different.

Yield loss despite control efforts: In literatures, there are no concrete figures on the yield loss despite of control efforts. In case of severe outbreaks up to 50% of the fruit have been injured by this pest in USA (http://www.caf.wvu.edu/kearneysville/pest_month/rosy_apple _aphid.htm). Based on biological nature of the pest and damage intensity on host, 5 to 20 per cent yield loss is expected under all control measures. Due to warm climatic conditions in Australia, it is assumed that yield loss would be in the upper range compared to the other cold-climate countries.

Export revenue loss due to loss of Pest Freedom Status: Export losses result from RAA entering and becoming established in Australia would be at significant level. Australia's big fruit industries export various kinds of fruits (specially apple) that are susceptible to this pest. Therefore, the risk associated with the market loss is considered high. In addition to apple, RAA might a new host in Australia and cause significant damage that is unknown. This makes it difficult to predicting market losses that's highly subjective. It is conceivable that it may be in the order of 25%, but this is a highly subjective estimate. Hence, a variable estimate was assumed using a pert distribution with a minimum value of 0 per cent, a maximum value of 50 per cent, and a most-likely value of 25 per cent.

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THREAT DATA

Potato leafhopper

(*Empoasca fabae*)

Source: http://ipcm.wisc.edu/WCMNews/tabid/53/EntryID/307/Default.aspx

CRC10010

Enhanced Risk Analysis Tools

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Potato leafhopper

(*Empoasca fabae*)

The potato leafhopper (PLH) is a member of the insect order Homoptera and family Cicadellidae. Adult PLH adult is a pale green-brown, wedge-shaped, winged insect about 3-4 mm in length with piercing and sucking mouthparts. PLH is a native species to USA but is unable to survive northern winters, and adults migrate into the Midwest each spring. This insect has been noted on more than 200 host plants that includes both crop and ornamental plants.

Distribution: PLH is widely distributed throughout the US mid-west and southern Canada. Among entomologists, the PLH ranks third as the most important insect pest in North America, after the Colorado potato beetle and green peach aphid.

Host range/Alternate host: PLH feeds on more than 200 (Lamp et al., 1994) cultivated and wild plants, including bean, potato, alfalfa, soybean, and peanut. In North Carolina, peanuts are more seriously affected by this pest than are forage and pasture crops.

Biology and Ecology: PLH has explosive population growth with 3-5 generation per year depending on temperature. Adults are able to fly hundreds of miles nonstop during this migration, which is wind-assisted, and adult potato leafhoppers also tend to be very dispersive locally throughout the summer. Leafhoppers will stay in crop fields until killed by fall frosts. Leafhoppers typically overwinter as adults but it can not survive in hard winter. Adults emerge in the spring, mate and lay eggs inside the veins on the underside of infested plants.

The female leafhopper lives about 30 days and after maturity lays 1-6 eggs daily and about 200 eggs per adult in life. Eggs hatch in 8 -10 days, forming the first of several nymphal stages. Nymphal stages are short and within 12 -15 days of hatching the nymphs will become adults. Nymphs move backwards and sideways in a crab-like fashion and cannot move from field to field.

Symptoms and damages: Potato leafhopper (both adult and nymphs) cause feeding injury to potato plants. They feed on the underside of leaflets. Injury starts with a yellowing along leaflet margins with a slight rolling. This slight injury is soon followed by a gradual browning starting at the leaflet's tip and margin referred to as "hopperburn", and extending basipetally until the leaflet is all dead and desiccated. The browning is due to cellular death or necrosis. Defoliation will occur. The damage reduces forage yield and quality in several ways. Damaged plants may be stunted, with heavily infested fields experiencing as much as a 50% yield reduction. Damage also results in substantially lower protein levels. No effects on tuber quality have been reported by potato leafhopper. PLH may play role in transmitting some viral diseases.

 

Fig: Severely damaged plants are stunted and chlorotic. Leafhopper burn appears as yellow wedge-shaped areas on the tips of leaflets (left) and leaf margin with inward roll (right). (photo sources: North Central Extension Publication NCR547 and Penn State – College of Ag Sciences).

Affected plant stages: Seeling to vegetative stages

Affected plant parts: Leaves

Affected Industries: Crop industries, specially potato and legumes

Resistant plant variety: Little information is available on varietal tolerance to PLH. However, Tendercrop cultivars are less susceptible to damage than Blue Lake cultivars (Bennett *et al.* 2007).

http://www.vegedge.umn.edu/vegpest/plh.htm

Affected time of the year: The largest populations of PLH occur in summer.

Detection and inspection methods: Field infestations of PLH are detected mainly by examining leaf in suitable hosts. The infected plant shows stunted growth with yellow leaf similar to viral symptoms. But quite visible PLH under the leaf surface differentiate the PLH infestation from viral one.

Pest movement and Dispersal: Adult PLH are able to fly hundreds of Km nonstop with wind assisted during the migration. Infested plant part is mainly leaf where both larvae and adult can hide and dispersed via transportation by human.

Natural Enemies: PLH have few effective natural enemies. Natural enemies can be integrated into farming systems at several levels. The most basic level is to understand and utilise the benefits of natural control to your advantage. An important example in the Midwest is the impact of Erynia radicans. This fungus is present throughout the upper Midwest. When a leafhopper becomes infected it will die in 2-3 days. As the disease spreads though the population, leafhopper numbers can drop rapidly. In Michigan, USA, outbreaks of this disease (epizootics) have occurred every year since 1989. Typically they occur in late July or August in conjunction with a cool, wet period. Producers watch for these epizootics in both dry beans and lucerne, and frequently find no need for further insecticide applications after epizootics occur (Wraight et al., 1990). Successful biological control agents, both insect parasitoids and microbial pathogens, are currently helping to reduce populations of other major lucerne pests to well below economic thresholds in many areas (Hower and Flinn, 1986).

Impact: What makes PLH especially dangerous is that early symptoms are very subtle and can easily be missed. Another concern is that once the leafhoppers arrive, they continue to feed and reproduce until killed by fall frosts. PLH has long been recognised as a pest of potato, but its destructiveness was only fully appreciated with the introduction of modern synthetic insecticides. In Minnesota, USA, annual losses to potato (including control costs) have been estimated at $US 7 million, roughly 10% of the production value (Noetzel et al., 1985). Earlier investigators reported a strongly negative curvilinear yield response with increasing densities of the leafhopper. However, because it takes so few leafhoppers to cause economic damage, the relationship between yield loss and leafhopper numbers is directly linear (Radcliffe and Johnson, 1994). In south western Ontario, Canada, average losses of 64% for potatoes on mineral soil and 85% for potatoes on organic soil due to *E. fabae* were recorded (Tolman et al., 1986). PLH is a serious pest of potato in some parts of India. Maximum pest population and hopper burn were observed on variety Kufri Chandramukhi and Kufri Bahar and minimum on Kurfri Sindhuri. Early planted crops suffered the maximum hopper burn (Verma et al., 1994).

Management: Monitoring fields for populations and correctly identifying the leafhopper is essential to good management. There are many leafhoppers that do not damage potato. A threshold for treatment has been established for potato leafhopper as one nymph per 10 leaves.

Biological Control: A naturally occurring fungal pathogen helps reduce the populations of the potato leafhopper under cool, moist conditions. Predators and parasites appear to play only a minor role in regulating this pest.

Cultural Control: Cutting of forages is an effective method for reducing leafhopper damage. Adult leafhoppers will leave the fields when it is cut. The wingless nymphs will remain behind, but without foliage to feed on they quickly die. If a field is at or above threshold and is mature, cutting is the preferred control measure. Keeping the weeds out in and around the fields also helps in managing the insect.

Resistant Varieties: There are alfalfa varieties on the market that are tolerant to leafhopper feeding or deter leafhopper feeding because of inflorescence (or leaf hairs) on the plant leaves. These varieties are currently being field tested as research trials in USA.

Chemical Control: An insecticide treatment is justified when leafhoppers exceed thresholds and the crop is not yet mature enough for harvest. Many insecticides will kill leafhoppers. At planting, Admire, Platinum, Thimet and Disyston are common. Foliar treatments include Actara, Asana, Ambush/Pounce, Baythroid, Dimethoate (formerly Cygon, also used for false chinch bug), Furadan, Monitor (also used against aphids), Provado, and Thiodan. For gardening, Sevin is recommended. With systemic insecticides, 10 gallons of spray is sufficient for effective control. With non-systemic insecticides, a minimum of 10 gallons of spray per acre in small plants (less than about 6 inches tall) and 20 gallons per acre in taller plants should be applied (http://www.canr.msu.edu/vanburen/plh.htm). .

Quarantine Risk: Low to moderate - because the pest is easily detectable with naked eyes and there is a low possibility of it's dispersion via trade and tourism since vegetative parts of the host (leaf not potato tuber) are responsible to carry out the pest. However, PLH could be a serious pest at regional level because of its wide host range.

Possibility of Entry: Very low – infested plant part is mainly leaf where both larvae and adult can hide and dispersed via transportation by human only. Therefore, during potato tuber trade the chance of entry of this pest is very low.

Probabilities of Establishment: High – both wide host range capacity and suitable climatic conditions in Australia for PLH provide a great opportunity to establish upon its successful arrival in the country.

Economic Impact: High – presence of PLH in Australia has the potential to reduce potato yields with its extensive reproduction capacity as reported in USA. Beside potato PHL is also capable of causing significant damage to others agricultural crops.

Environmental Impact: Very Low – in pest management, the applied chemicals in the field will cause environmental pollution that imbalance the ecosystem. In addition, PLH might find some native plants as host.

Social Impact: Moderate - since, PLH is capable of infecting various agricultural crops that are valuable to the local farmers; therefore, crop damage by this pest will bring a negative economic impact in the infested region. Higher cost involves in disease management may also discourage the small growers to continue in future.

Pest management cost: The total production cost increases are to be expected from the chemical application in order to control PLH in the field. Although, there are some biological agents that can keep the PLH population in some extent but still requires chemical treatment. The insecticides 'Sevin' is fond to be most effective chemical for PLH and the effective dose is 10 gallon/acre i.e. 94L/ha. Based on website information http://www.shopping.com/xDN-garden-sevin_insecticide the cost has been calculated $200/ha. In addition, the application cost would ~$50/ha for a single spray. Depending on weather conditions it might need 1-2 spray in a season. The total cost would be $250x2 = **$500/ha** in case of 2 spray.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on host like potato the total loss assumed to be between 10 - 15% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – export markets may suffer from PLH entering and becoming established in Australia. PLH has short life cycle, sensitive to cold and plant leaf is the affected part only. Based on these biological natures of PHL, there is low possibility of spreading through agricultural commodities during the trade. Therefore, the presence of this insect may not have significant impact on our export markets. It is very difficult to estimate exact export revenue loss associated this pest, but may be expected to be in the range of **5 -10 per cent**.

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THREAT DATA

Granulate cutworm

(*Feltia subterranea*)

Source: http://bugguide.net/node/view/99477

CRC10010

Enhanced Risk Analysis Tools

Granulate cutworm

(*Feltia subterranea*)

Feltia subterranea is an insect pest that is also known by several English and local names and among these granulate cutworm and cutworm are very popular. *F. subterranea* general feeders and attack a wide range of crop plants. The larvae feed on the foliage of young seedling and cut off the seedling near the ground that causes significant crop damage.

Distribution: The distribution note of *F. subterranea* reveals that this pest is restricted in different states of North America, (Bermuda, Mexico and USA), Central America and South America. In USA, *F. subterranea* is a threat for tobacco plant and it's also a primary pest of peanut in Georgia. Cutworms are a sporadic problem in both the Midwest and South of USA. *F. subterranea* currently not recorded in Australia and New Zealand.

Host range/Alternate host: *F. subterranea* feed on a wide range of host plant that includes 61 hosts of economic importance. Among these plants potato, sweet potato, tomato, tobacco, onion, eggplant, cabbage, bean, beet, Brussels sprouts, alfalfa, turnip, pea, cauliflower, clover, wheat etc.

Biology and Ecology: *F. subterranea* over winter as larvae or pupae under the soil surface. In the spring, the moth emerges and lay eggs. Each female moth laid an average of 325 eggs which hatches soon after 3-5 days. Within 5-7 weeks the larvae develop. These caterpillars feed at night and hide during the daytime under the plant debris near the soil of the infested plants. Mature larvae develop into pupate below soil surface (5 to 15 cm) and pupate stage lasts about 2 weeks or longer depending on the temperature. The number of generations per year varied (2-5) from location to location. In US, there are 5 to 6 generations per year in Louisiana but 2-3 in North Carolina.

Symptoms: *F. subterranea* larvae feed at night on foliage of the seedling mainly. It attacks the seedling and cut off near the ground level (Fig. A). Most of the plant is not consumed, merely being eaten enough to cause it to fall over. Damage often occurs in wet spots within a field or around field margins with a lot of vegetation. In daytime the larvae hide in holes, under debris or under hatches near soil surface.

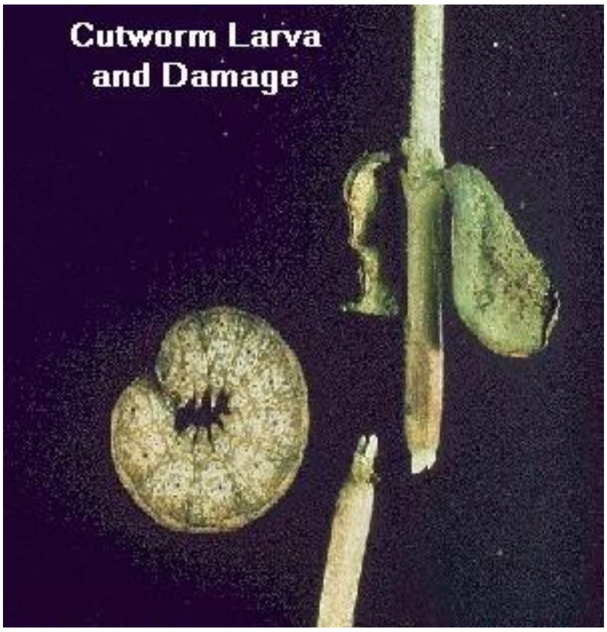

Figure A. Cutworm larva and the damaged seedling..

Source: http://web1.msue.msu.edu/imp/mods1/visuals/soyb0023.jpg

Affected plant stages: Mainly seedling stage

Affected plant parts: Vegetative parts, mainly young leaves.

Affected Industries: Horticultural industries

Susceptible plant variety: In literatures there is no report on the susceptible or resistant varieties of plant species against *F. subterranea.*

Affected time of the year: The larval stage is the most damaging and largest larval populations of *F. subterranea* are most likely to occur in spring.

Detection and inspection methods: *F. subterranea* in the field *is* detected mainly by examining seedling damage (just above the ground) in suitable hosts. The caterpillar (Fig. A) with dark brown to gray and pale longitudinal strips can be visible just beneath the soil surface or debris in the infested areas.

Pest movement and Dispersal: Infested plant parts mainly leaf where the adult lay eggs and the infested soil with larvae help in pest movement into a new area via human transportation.

Impact: Generally, *F. subterranea* is not considered a serious pest because the seedling damage cause by this pest can be compensates by rigours growth of the next seedlings. If required, replanting also minimise the crop yield. A single larva can cut off several plants before completing its life cycle. Sometimes, the infested field with thin seedling population encourage weed production that ultimately impact on total yield. Occasionally, the larvae also feed on mature leaves after climbing to the top of the plant. The infested plant becomes less productive due its low photosynthetic areas. Report from USA, the crop loss attributed by this pest varied from 0.02 to 0.09% in the passed five years (ref. no. 9).

Natural Enemies: *Encarsia porteri* (attack insect eggs) and *Telnomus remus* are the only two parasitoids are reported in the literature (ref. CPC) for *F. subterranea.* No successful work on biological control of this pest is available in the literature.

Management: Mostly the damage caused by *F. subterranea* is localised, therefore the pest management in field conditions using cultural method is the best option compared to the chemical application.

- **Cultural control:** Planting in pest-free area and maintaining this by removing leaves with eggs and killing larvae in the soil manually, although these can be time consuming and boring. This technique are feasible at the initial stage where infestation rate in very low but not applicable in severe case. Classical conventional tillage system is excellent cultural control of this pest.

- **Chemical control:** *F. subterranea* is not a problem in the field where the previous vegetations were destroyed several weeks before planting, either by tillage or by chemical. The insect usually first appears in low and wet areas of the field. Fields with leguminious and other broadleaf plants area at high risk of *F. subterranean.* Insecticides recommended for cutworm control are listed below. Single application is usually sufficient because of high susceptibility of cutworms to these insecticides. Treatment is recommended when cutworm infestations threaten to reduce plant population below an acceptable level (approximately 35,000 plants per acre).

Insecticides Recommended for Control of Cutworms

Insecticide	Trade Name	Lbs ai/acre
Acephate	Orthene (generics)	0.8
Cyfluthrin	Baythroid	0.0125
Cyhalothrin	Karate	0.02 to 0.03
Cypermethrin	Ammo	0.025
Deltamethrin	Decis	0.013 to 0.019
Esfenvalerate	Asana	0.03
Tralomethrin	Scout X-tra	0.016 to 0.02
Zetamethrin	Fury	0.016 to 0.024

Source: Cotton Insect Control Guide, 2002, Publication 343, Mississippi State University Extension Service.

Probability of entry: Low. The pest is easily detectable with naked eyes and there is a low possibility of its dispersion via trade and tourism.

Possibility of Establishment: High – the pest has a wide host range (mostly cultivated plant species) that makes a good chance of finding a proper host after successful entry into Australia. This also support by a suitable climatic condition for the pest in many parts of the country.

Economic Impact: High - based on pest biology, generally *F. subterranea* is not considered a serious pest because the seedling damage cause by this pest can be compensates by rigours growth of the next seedlings.

Environmental Impact: Very low - no significant environmental effect from chemical application unless *F. subterranea* finds some native plants as host. This indicates the limited chemical applications to keep the pest population under control in field.

Social Impact: Very low - since, *F. subterranean* management practices are less complex and inexpensive compared to others that indicates no impact on socio-economic by this pest.

Pest Management cost: Low – the total production cost increases are to be expected from the chemical applications in order to control *F. subterranea* in the field. *F. subterranen* not consider a serious pest because it mainly attacks seedlings that can be minimised by rigours growth of the next seedlings in densely planted area. The growers still need to maintain proper management procedures and use some insecticides in severe cases. The cutworms are relatively susceptible to some chemical available in the market. Therefore, a single application is usually sufficient for effective control. Depending on chemicals the price are variable. However, based on '*Farm Budget Guide 2001*' it may assume that minimum cost would be around $90-110/ha for a single application. In addition, vehicle, equipment and labour costs would be another $50/ha (labour = $20/hr, tractor and other spray costs include fuel, oil, maintenance = $30/ha, time requires for spray = 1hr/ha). The total cost assumed to be $140-160/ha.

Yield loss despite control efforts: Based on biology of the pest and available control measures minor yield loss (0.02 to 0.09%) can be expected even under proper management systems. Moreover, it's an exotic pest therefore the loss may become higher in first few years until grower gets familiar with proper management procedures and effective chemicals.

Export revenue loss due to loss of Pest Freedom Status: Nil - The effects on export markets would be very little following entry and establishment of *F. subterranea* in Australia. This insect has short life cycle, sensitive to cold, and mainly attack seedlings. Therefore, the biology of the pest indicates that there is a low possibility of it's spreading through agricultural commodities during the trade. This indicates, the presence of *F. subterranea* may not have any impact on our export markets.

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THREAT DATA

Taro hawkmoth

(*Hippotion celerio*)

Source: http://www-staff.it.uts.edu.au/~don/larvae/sphi/celerioz.jpg

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Taro hawkmoth

(*Hippotion celerio*)

Taro hawkmoth (*H. celerio*) is a leaf feeding insect and widely recorded in many parts of the world. The insect attack many host in different regions that includes both cultivated and wild plants. Taro hawkmoth is one of the major pests of taro plant.

Distribution: Taro hawkmoth is widely distributed in Asia, Europe and African regions. It is a major pest of taro (*Colocasia esculenta*) throughout the pacific region. Based on the information in CPC (2008) the insect was reported in Australia in 1986 without further details (Hamilton & Toffonlon, 1986).

Host range: Taro hawkmoth larvae attack a wide range of plants and in the tropics this is a serious pest of taro (*Colocasia esculenta*), sweet potato (*Ipomoea batatas*); tobacco and grape vines (Clausen (1977). The insect also feeds on several wild plants including *Anchomanes difformis*, Arum, Beta, Boerhavia, Caladium, Cissus, Convolvulus, Cryptocoryne, Gossypium, Sorghum, Spermacoce and Zea mays (Sevastopulo 1984).

Life cycle and biology of the Pest: The female taro hawkmoth lays eggs singly on the upper or lower surface of the leaves and stems of the host plant with average **302 eggs per female** in tobacco plant (Madden & Chamberlin, 1954). Eggs hatch in 3-5 days (5-10 days in cooler climates). On hatching, the young larva immediately consumes its eggshell, then moves off to find a resting place on the lower surface of a leaf. In younger larvae, the long dark horn is waved up and down as the larva moves, but as the larva grows the horn becomes smaller and immobile. As with most larvae exhibiting anterior eye-spots, the head is retracted when the larva is alarmed, expanding two large eye-spots on the first abdominal segment. The larva gradually darkening as it approaches maturity. The pupa is formed in a loosely spun brown cocoon, either on the ground amongst litter, or just below the surface of the soil. The adult lifespan is 29-35 days for females and 28-35 days for males (Diongzon, 1981). The taro hornworm has **3-5 generations** per year. The detail biology of the taro hawkmoth has been described from both laboratory and field observations in the literatures by many scientists (Diongzon 1981, Pinney 1962, Carcasson 1967, Skaifee 1979 and Pittaway 1993).

Taro hawkmoth prefer semi-arid and arid environments, it is more likely to be found during the drier seasons than during the rains. However, it can be found in many climatic regions.

Symptoms/damage: Damage caused by taro hawkmoth is obvious in the infested plant leaf. The leaf is marked with various (small to large) holes and appears as ragged leaf (fig. 1). The caterpillars are gigantic feeders and the high number of caterpillars can cause severe defoliation of taro plant. The insect also feed on young succulent stems and shoots, and on sweet potato vines.

Figure 1. Taro leaves with larvae. Source: http://www.padil.gov.au/viewPest.aspx?id=410

Affected plant stages: Vegetative growing stage.

Affected plant parts: Growing points, leaves and stems.

Resistant plant variety: In literature no information is available on resistant/susceptible taro plant variety against taro hawkmoth.

Pest movement and Dispersal: As taro hawkmoth makes a large hole in the infested leaf therefore the larvae can easily be spotted. Both eggs and larva (visible by naked eyes) can be carried out by leaves during trade/transportation.

Affected time of the year: Usually throughout the year, depending on the regions.

Impact: The taro hornworm is a serious pest of taro and sweet potato crops cultivated throughout the humid tropics, especially in the Pacific Islands. High infestation levels result in severe defoliation (Copr, 1978) that has negative impact on the production. In case of pest severity the farmers use various chemicals that pollute the environment. Actual damage caused by this pest in taro production is missing in the literature. However, in New South Wales, Australia, this species is listed as one of 12 important arthropod pests of sweet potatoes (Hamilton and Toffolon, 1986). In the Philippines, it is reported to be a minor pest on cultivated legumes. Besides, taro and sweet potatoes the insect also feed on various ornamental plants, tobacco and grape vines. Therefore, taro hornworm will also have negative impact on these plant species.

Management: Taro hornworm larva is big in size (80-90 mm) and easily visible in naked eyes therefore it's easy to manage physically (handpicking) in case of small field. In case of high infestation, carbaryl has proved very effective. Other chemical insecticides which have given a good level of control are azinphos-methyl, fenitrothion, trichlorfon and fenthion. Present recommendations in Pacific island countries include: indoxacarb (e.g. Steward), spinosad (e.g. Success), Bt (e.g. Delfin, Thuricide, Dipel) and imidacloprid (e.g. Confidor, Mustang). All were applied as foliar sprays. In case of biological control, few parasites and predators are mentioned in the literature without the effectiveness in the field. For example, *Trichogramma chilonis,* a parasite that attack eggs, is used in Marianas. Other parasite such as *Palexorista sp.* found in Solomons, also used in the Pacific region. Predaceous shield bugs and toad have also been observed feeding on larvae of taro hornworm. Odindo (1992) reported various biological agents that have potential in biological control of taro hornworm. These include the bacterium *Bacillus thuringiensis* and the fungus *Metarhizium anisopliae*. *A parasitoid*, *Snellenius hippotionus*, was isolated from this species in Papua New Guinea and could possibly be used in other parts of the tropics.

Quarantine Risk: Moderate. Although it's easily to spot eggs, larvae and adults of taro hornworm in the infested plant parts but it's wide host range (cultivate, ornamental and wild plant species) is an quarantine issue after establishment in Australia. Multiple host capacity enhances spreading of the pest locally but reduces the success of its eradication process.

Probabilities of Entry: Low/moderate -. Although taro hornworm has multiple host range but the pest is mainly associated with vegetative plant part (mainly leaf) and the international trade usually involve with fruits of the host plants. Therefore, taro hornworm has low possibility of entry via international trade and tourist under normal quarantine procedure.

Possibility of Establishment: High – Multiple host rang and favourable climatic conditions in many parts of Australia provide high possibility of establishment for taro hornworm after entry.

Probabilities of Entry and Establishment: Low/moderate – suitable climatic conditions, a multiple host range, and low possibility of entry of taro hornworm are the main deciding factors in this issue.

Economic Impact: Moderate - Big appetite, high fecundity (over 300 eggs/female), and a wide host range of taro hornworm play important roles in the damage cause by the pest.

Environmental Impact: Moderate – Limited parasite and predators in nature for biological control of taro hornworm results grower dependency on chemical application in its management that pollute the environment and more chemical applications are required in case of wide host range of the pest.

Social Impact: Low – depending on host and infestation severity, taro hornworm may cause little negative impact on local industries. For example, taro hornworm mainly eats leaf that reduces the yield rather destroying the total production. But available chemicals in the market help the local farmers to keep in the pest population under control in the field.

Pest management cost: Low/moderate – depending on pest severity and other factors the management cost may vary from $100 - $200/ha. This cost excludes involvement of any biological control and or resistant plant varieties. Effective and established control practices (both cultural and chemical) are available for taro hornworm. However, the management with cultural practice could be more expensive in case pest severity.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on different host plant the total yield loss assumed to be between 10 – 15% for individual crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – taro hornworm possess low possibility of dispersion via international trade because the pest is mainly associated with vegetative plant parts (leaf) that are usually not involve in export.

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http://www.padil.gov.au/viewPest.aspx?id=410

THREAT DATA

Bark borer

Indarbela dea

Adult male of *I dea*

Source: http://www.cabicompendium.org/cpc

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Bark borer

(*Indarbela dea*)

I. dea is an insect with common English name bark borer. It attacks many species that are mainly tree plants. The larval stage of the insect causes the damage by forming a number of tunnels in both trunks and branches of tree. The infested plants suffer from nutrient deficiency that results less yield.

Distribution: The insect *I. dea* had restricted distribution in a number of provinces in China, a few places in India and Vietnam. Australia and New Zealand .are currently free from this pest.

Host range: Including pomegranate (*Punica granatum*), *I. dea* attacks a wide range of host plants in China covering 42 species of 24 families (Chien, 1964). *Acacia confusa* (Taiwan acacia), *Albizia julibrissin* (silk tree), *Albizia lebbeck* (Indian siris), *Artocarpus heterophyllus* (jackfruit), *Casuarina equisetifolia* (casuarina), *Dimocarpus longan* (longan tree), *Leucaena leucocephala* (leucaena), *Litchi chinensis* (lichi), (pomegranate), *Salix babylonica* (weeping willow), *Salix matsudana* (Peking willow) among the other host plants of this pest. In India, tea and mango plants also get infested by this pest (Du, 1932; Indian Tea Association, 1938).

Habitat: Areas of both cultivated and wild host trees including pomegranate

Life cycle and biology of the Pest: In Southern China, *I. dea* could have only one reproductive cycle in a year that includes different developmental stages like egg, larvae, pupae, and adult. Adults appear in summer and each female lays more than **350 eggs** in a number of batches (5-13) in her lifetime. The eggs are laid on the bark of trees with a stem and egg development takes 12-19 days, with an average of 16 days. The eggs hatch into larvae and the developing period is 286-343 days, the average is 316 days (i.e. **one generation/year**). The larvae bore a tunnel and hide in it during the daytime and bite the phloem tissue of the host tree at night. It takes 2-4 hours for the newborn larvae to spread; the larvae live on the base of branches or scars. They form a mine covered with excrement and scraps of bark, then enter the trunk by puncturing a hole and making a tunnel, where they hide. Final-instar larvae cover the exit hole with silk and overwinter. Overwintering larvae may come out to feed at night when temperatures are above 15°C. (ref. CPC).

Symptoms: The tunnels produced on the bark by developing larvae are often the first evidence of infestation. The area of bark damage caused by each larva feeding may be observed. The larvae bore into the stem and branches of host plants, forming a tunnel, and eat the bark of the host tree. One larva can eat 54-93cm² bark in a lifetime.

Affected plant stages: Vegetative growing stages

Affected plant parts: Stems.

Affected Industries: Pomegranate, Tea, mangoes, orange etc.

Susceptible plant variety: Limited information is available in the literature on susceptible and resistant plant varies for *I. dea*.

Pest movement and Dispersal: The adult *I. dea* are not capable of flying distance but their eggs and larva inside the stems can be carried out by human in distance that helps in pest dispersion in new areas.

Detection and Inspection Methods: Both larvae and adults of *I. dea* are big enough (20-30 mm long) to be seen by naked eyes inside the stem where they make several tunnels (10-30 cm long). Infestations of *I. dea* are detected by the presence of black-brown excrement and scraps of larvae on the bark of host trees; the larvae may be found hiding in tunnels within the tree (ref. CPC).

Impact: *I. dea* is an important pest of litchi, Dimocarpus longan and other trees. More than 20 species of subtropical and tropical plants are hosts of *I. dea*. Up to 70% of trees in an orchard may be damaged in some areas. The larvae bore into the trunks and branches forming a number of tunnels; they also damage the bark at night thus affecting the transport of water and nutrients. Trees are weakened, resulting in reduced production and quality. However, tree losses caused by this pest are difficult to assess (ref. CPC).

Management: *I. dea* manage by different ways depending on its severity, field conditions, and availability of the techniques. Among the different techniques the following are very few used by growers as described in CPC.

Cultural Control: When pruning branches of host trees, the sawing area must be smooth and the amount of wood shavings produced should be minimised. Cuts should be avoided as far as possible. Lime and lotion should be smeared on cuts. Other fruit trees surrounding the affected trees should also be subject to control because *I. dea* can damage a range of host plants.

Chemical Control: Spraying dichlorvos in the evening onto the opening of each tunnel, and on the visible excrement of *I. dea*, was >90% effective (Xu, 1983). **Dichlorvos** was also highly effective (>95%) when injected into the tunnels using a syringe (Xu, 1983). Plugging the exit holes of the tunnels with an insecticide bolus containing mainly zinc phosphide, gave 100% control of *I. dea* (Luo, 1995). A fumigant of zinc phosphide applied to each tunnel in a plug or as a paste was >95% effective (Xu, 1995).

Biological Control: Many larvae and pupae of *I. dea* are parasitised by the fungus *Beauveria bassiana* (Chien, 1964). Injecting or spraying a suspension of the entomopathogenic nematode, *Steinernema carpocapsae*, into the tunnels of *I. dea* controlled the pest by >95% in a range of host plants in Guangdong province, China (Xu and Yang, 1992).

Integrated Pest Management: The application of the entomopathogenic nematode *S. carpocapsae*, along with an insecticide plug, controlled *I. dea* by 90-95% in China (JL Xu, Guangdong Institute of Entomology, Guangzhou, China, personal communication, 1995).

Quarantine Risk: Low. - bark borer unable to fly long distance but internal inhabitant larvae (visible with naked eyes) spread by human through infested plant parts. .

Probabilities of Entry: Low - moderate. Although eggs and larvae of *bark borer* are quite visible and live side the trunk of infested plant but its diverse host capacity may attribute in escaping of normal quarantine during trade.

Possibility of Establishment: Moderate – due to diverse host capacity bark borer has potential to find a suitable host following entry. Many areas of Australia have favourable climatic conditions for this pest.

Probabilities of Entry and Establishment: Low to moderate – suitable climatic conditions, a multiple host capacity and low to moderate possibility of entry of bark borer has low to moderate chance of entry and establishment in Australia.

Economic Impact: Moderate – it is hard to assess the economic impact by bark borer because of its indirect effect on crop/fruit production. The insect mainly attack stem that reduce the production and sometime the infected plant may even die in early stage. However, this impact assessment was done based on the pest biology and the damage severity in various plant species reported in the literatures. Availability of resistant plant variety and other control measure are also important issues in economic impact.

Environmental Impact: Moderate – chemical control of bark borer requires more chemical application (live inside trunk) due to its complex biology and diverse host capacity. Excessive chemical applications lead to environmental pollution. In addition to this, the pest may attack some native plants and destroy them slowly that will cause a negative impact on environment.

Social Impact: Low – this assessment was carried out based on pest biology, the damage severity by the pest and the available management practices for bark borer in field conditions.

Pest management cost: Low/moderate – depending on pest severity and the available control measures the cost may vary from **$300 to $700/ha**. This cost excludes involvement of any biological control and or resistant plant varieties. Effective and established control practices (both cultural and chemical) are available for bark borer. However, the management with cultural practice could be more expensive in case pest severity. However, the cost/ha also vary from crop to crop depending on number of spray. For examples, in case of tea and pomegranate the costs were calculated about $400 and $600/ha respectively.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 – 20% for individual crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – because of low dispersion possibility of bark borer (usually through infested timber) during international trade.

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THREAT DATA

Colorado potato beetle

(*Leptinotarsa decemlineata*)

Sources: http://www.inra.fr/internet/Produits/HYPPZ/IMAGES/7032040.jpg

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Colorado potato beetle

(*Leptinotarsa decemlineata*)

Leptinotarsa decemlineata is a serious potato insect pest that is also known by several English and local names and among these Colorado potato beetle (CPB), Colorado beetle very popular name. CPB is mainly feed on leaf but can also attack newly growing parts of the plant. CPB has quick capacity of developing resistance against most of insecticides and that's makes it difficult to control in field condition. The origin of CBP is not clear but Colorado and Mexico consider as part of its native places.

Distribution: CPB is widely distributed in many European and North American countries. It has restricted distribution in a few Asian countries that includes China, Kazakhstan, Tajikistan and Turkey but absent in Japan. CPB has not yet recorded in Australia, New Zealand and Africa.

Host range/Alternate host: Including potato plant many other members of Solanaceous family like eggplant, tomato, pepper, tobacco etc. are the primary hosts. Some of the wild member of this family including *Datura, Lycium, Physalis spp.* serve as secondary host for serious this pest. .

Biology and Ecology: Overwinter adult CPBs emerge from the ground in spring or early summer. CPB females are very prolific and can lay as many as 1000 eggs depending on geographic location and host. The eggs are laid under in cluster form underside of the host leaf. The eggs hatches after 4-15 days into larvae and the larvae feed on leaves. The larvae go through different developmental stages and turn into a prepupae which is inactive and immobile. The prepupae drop to the soil and burrow to a depth of several inches and turn into pupae. Depending on climatic condition, the adult may emerges in a few weeks and continue the life cycle. The insect lifespan is **1-2 years** with **1-2 generation.** A second generation sometimes incomplete in temperate and meridian zones. In cold areas, CPB can not complete full generation therefore it's unable to establish permanently in these areas. In warm areas, CPB might be active throughout the year.

Symptoms: Both adult and larvae of CPB feed on leaves and causes full or partial defoliation of the plant (Fig A) depending on the insect population on the infected plant. The insect also attack newly growing areas and young tubers exposed at the soil surface. Heavily infested plant shows black and sticky excrement of insect on its both leaves and stem. Fully grown orange colour larvae are quite visible with naked eyes in the infested plant leaf (Fig. B).

Figure A. Partially defoliated plant due to CPB attack

Figure B. Fully grown larvae on a potato leaf

Source: http://www.inra.fr/internet/Produits/HYPPZ/RAVAGEUR/6lepdec.htm#ima

Affected plant stages: Vegetative, Flowering and fruiting stage.

Affected plant parts: Mostly leaves but also newly growing buds and young tubers exposed at the soil surface.

Affected Industries: Potato and other vegetable industries of Solanceae family members.

Resistant plant variety: Potato breeding lines with resistance to CPB have been released (Plaisted et al., 1992; Lorenzen and Balbyshev, 1997). Other potentially valuable mechanisms of resistance have been identified as well (Balbyshev and Lorenzen, 1997).

Affected time of the year: The largest populations of CPB are most likely to occur in spring depending on the weather conditions in growing areas.

Detection and inspection methods: Field infestations of CPB are detected mainly by examining symptoms in the host plant. Due to the large size both adult and larvae are visible on the leaf by naked eyes. The adult's (~10 mm) are oval shape with several black strips and spots on wings and head respectively. Orange-yellow eggs in cluster (10-30) are quite visible underside of the leaves.

Pest movement and Dispersal: Wind-borne migration is the main means of natural spread of CPB, specially of the spring generation. Short range dispersal (up to several meters) may occur by walking of adult CPB. During the trade, both adult and larvae can be transported via potato plants, tubers and packaging materials. Fresh vegetables (of non-host crops) grown on land harbouring overwintered beetles are a common means of transport in international trade (Bartlett, 1980).

Disease Impact: CPB is considered one of the serious pests of potato. Often the pest can also cause damage to eggplant, tomato, pepper, tobacco, and other members of Solanaceae family. Both adult and larvae of the insect attack leaf, growing parts of plant, and sometime young tubers exposed at the ground level. High insect population can defoliate and kill plants. Severe yield loss occurs if the host get infested within 2 weeks of flowering. But infestation before harvest or very early stage of host growth has little effect on yield. Damage often occurs in isolated spots throughout the field.

Natural Enemies: Numerous predatory and parasitic species are known to attack both larvae and pupae of CPB. However, their impact in field condition is not satisfactory. Therefore, till now there is no effective biological control measure for CPB.

Management: Mostly the damage caused by larval stages of CPB feeding on leaves. The adult CPB become resistance to many insecticides quickly, therefore the pest management in field conditions using physical and cultural method are the best option compared to the chemical application.

- **Physical and Cultural control:** Hand-picking can effectively control the CPB in small area. Inspecting potato field 1 or 2 times per week, removal and kill CPB is also feasible only for small areas. Crop rotation can also be effective control measure for CPB if there is no other infested field within at least 0.5 km. Because 50-75% of overwintered beetles disperse into a nearby potato crop by walking. By plant early maturing cultivars and shifting planting date also result better results.

- **Biological control:** In literatures are many work on biological control of CPB using different fungi, bacteria, virus and nematodes under both glasshouse and field conditions (Schroder and Athanas 1989, Schroder et al.1985, Ayleshina 1978, Lipa 1985, Zehnder and Gelernter 1989, Ferro and Lyon 1991, Zehnder et al.1992, Dubois and Jossi 1993, Korol' et al.1994, Ferro, 2000). However, still there is no effective and feasible biological control measure against this pest.

- **Transgenic plant:** Transgenic potatoes expressing the gene (Cry3A delta –endotoxin) from *B. thuringiensis* subsp. *Tenebrionis* were approved for commercial use in the USA in 1995. The transgenic potato varieties are highly toxic to CPB (Perlak et al., 1993; Wierenga et al., 1996) and provide excellent control of the beetle. However, planting of these transgenic potato varieties declined dramatically by 2000 due to concern over consumer resistance to purchasing transgenic potatoes and products made from them.

- **Chemical control:** Chemical control of CPB is difficult due to it's resistance over a wide range of insecticides. However, alternate application between different classes of insecticides for the first and second generation larvae is more effective. Following are the major classes of fungicides against CPB.

    - Pyrethrins: Most effective at cool temperatures.
    - Rotenone: May be sold alone or in a mixture with pyrethrins or methoxychlor
    - Organo-chlorines: Example is methoxychlor

- Carbamates: Example is carbaryl (Sevin). Sevin no longer effective for Colorado potato beetle in certain areas.

Quarantine Risk: Moderate - because the pest is easily detectable with naked eyes and there is a low possibility of it's dispersion via trade and tourism under proper quarantine method. CPB might be a serous pest a regional level.

Possibility of Entry: Moderate – During the trade, both adult and larvae of CPB can be transported via potato plants, tubers and packaging materials. Fresh vegetables (of non-host crops) grown on land harbouring overwintered beetles are a common means of transport in international trade (Bartlett, 1980).

Probabilities of Establishment: Moderate– In spite of suitable climatic conditions in some part of Australia the restricted host capacity of CPB reduces the chance of its establishment in Australia.

Economic Impact: High – presence of CPB in Australia has the potential to reduce both tuber yields and export market of Australian seed potatoes. Including potato CPB also causes significant damage to others crop like tomato, eggplant, tobacco etc.

Environmental Impact: Low – Environmental impact is considered low based on the current available information. However, apart from cultivated plant species if there are other wild host species belong to the same family of Solanaceae are present in Australia that can be attacked by CPB and bring good impact environment. CPB control using various chemical will have some negative impact on the existing ecosystem that ultimately will impact on the environment.

Social Impact: Low – Increased production cost associated with insecticides application may increase the market price of the crop unless the pest severity is low or the grower find some other control measure.

Pest management cost: Production cost increases are to be expected to result from the need for additional chemical treatments four times per season. CPB develop resistant quickly against any new chemical. Therefore, more than one chemical and/or higher chemical dosages may required to control this pest. Since the pest can persist through out the season therefore, at least 2 times chemical treatments are required in a season. Based on some effective insecticides and their prices, chemical cost is assumed to be ~$70-80/ha and the application cost ~$50/ha per spray (base on Farm Budget Guide 2001). The total cost would be 2 times of single spray i.e. **$240 - 300/ha**. (ref. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex11110) Depending on the other factors (e.g. rain) the total cost might be different.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on host like potato the total loss assumed to be between 5 - 20% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Moderate – Export losses may result from CPB entering and becoming established in Australia, especially the potato industry. Australia export potato about 92% of its production in various countries and this export market would be affected if CPB is established in Australia. Similar to potato, tomato export market will suffer by this pest. Although total export earning would not be lost because the producers may find some other import countries with lower price. It is very difficult to estimate exact export revenue loss associated this pest, but may be expected to be in the range of **10-30 per cent**.

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THREAT DATA

Pear leaf blister moth

(*Leucoptera malifoliella*)

(Ref. http://www.insectimages.org/browse/detail.cfm?imgnum=2102094)

CRC10010

Enhanced Risk Analysis Tools

Pear leaf blister moth

(*Leucoptera malifoliella*)

Pear leaf blister moth (PLBM), *Leucoptera malifoliella*, is destructive pest of pear, apple, cherry, quince and birch. The pest mainly attack leaf and it is also know by 'apple leaf miner' and some other common names in the literatures. *L. malifoliella* occurs in temperate zones of Eurasia.

Distribution: *L. malifoliella* is widespread in whole of Europe, even in the most northern countries like Turkey, the former USSR, the area around the Caspian Sea, the Middle East, central Asia, western Siberia and east through northern China (Ivanov, 1976; Gulii and Pamuzak, 1992; CERIS, 2004; CFIA, 2005a; EPPO, 2005; Jonko, 2005). The pest is unknown in North America, Australia, New Zealand and Oceania

Host range: The major host are *Pyrus* (pears), *Pyrus communis* (European pear)*Cydonia oblonga* (quince), *Malus domestica* (apple) and *Prunus avium* (sweet cherry). It also attacks deciduous forests and shade trees such as flowering quinces (Chaenomeles sp.), Cotoneaster sp., birch, wild apple (Malus sylvestris), blackthorn, wild pear (*Pyrus communis*) and fragrant pear (*Pyrus sp*. nr. communis), Chinese white pear (*Pyrus bretschneideri*), witch-wood (*Sorbus aucuparia*) and alder. The most important wild host is hawthorn, Crataegus sp. (Grigorov, 1976; Gulii and Pamuzak, 1992; Garland, 1995; Tomov and Trenchev, 2001; Andreev, 2005; HYPP, 2005; Ellis, 2005; CFIA, 2005a) (ref. CPC).

Affected Plant Stages: All stages

Affected Plant Parts: Mainly leaves but may also found on fruits.

Biology and Ecology: *L. malifoliella* is a multivoltine, lyonetiid species, with between one and five generations per growing season in Europe, depending on geographical location. Four generations per year have been reported in Iran (Beheshti, 1989). One generation took an average of 26 days at 28°C, 36 days at 23°C and 50 days at 18°C (Saringer et al., 1985). Female deposit eggs singly on the undersides of leaves. Over 350 eggs can be found on a single leaf when the population density is very high. Females from overwintered (April-May) and late-summer (August-September) generations lay an average of 25-30 eggs, whereas females from summer generations (June-July-August) lay 45-50 eggs. The adults live for 4-7 days (Ivanov, 1976). Adult moth wingspan 6 to 7 mm, fore wings greyish-white, shiny with a brownish stripe on the proximal half, surrounded by coppery zones, black and white. Hind wings pale grey and fringed. Larva: 4 mm long, yellowish to pale brown, head brown, very small, bevelled, sunk into the thorax moth lays eggs on the underside of leaves. The caterpillar lives as a leaf miner; the concentric galleries, diameter 5 to 6 mm, form whitish then brown spots, in which owing to leaf transparency, the frass is visible, grouped in darker concentric circles .On completion of growth, the caterpillar leaves the gallery and spins a cocoon on the surface of the leaf (1st generation) or in cracks in the bark on the underside of branches (2nd overwintering generation). Pupa: formed after 2 days, its development lasts 8 days for the summer generation (Source: inra.fr).

Symptoms and damage: The larvae make spiral mines on the leaves of the apple, pear, quince, cherry and morello. By high injury, the damaged leaves transpirate intensively, decrease their assimilation activity and drop off prematurely (Radoslav *et al.,* 2001). The species develops three-four generations annually and overwinter as a pupa in a white cocoon on the trunk and skeleton branches of the fruit trees. During the spring, the moths' flight begins in April, when the average daily temperature reaches 12.8°C (Ivanov, 1976; Tomov, 1998).In case of severe infestation, the leaf surface is severely damaged by the presence of mines and photosynthesis is badly affected (source: http://www.russellipm-agriculture.com/insect.php?insect_id=55). *L. malifoliella* is a multivoltine, lyonetiid species, with between one and five generations per growing season in Europe, depending on geographical location.

Fig. Damaged caused by *Leucoptera malifoliella (source:* http://www.russellipm-agriculture.com/insect.php?insect_id=55)

Means of Movement and Dispersal: The most likely pathway for introduction of *L. malifoliella* is through international trade of apples and pears from Europe and Asia. Inspections are difficult due to the small size of the pest (3 mm) and its covert location, usually within the calyx. Other potential pathways of introduction include nursery stock or scion material (CPC). Fruit is mainly known plant part liable to carry the pest in trade/transport

Resistant plant variety: No report is available in the literatures on resistant plant variety against *L. malifoliella.*

Natural Enemies: A list of natural enemies (both parasitoids and predators) of *L. malifoliella* on apple, pear and peach has been reported in different countries and most of these enemies attack larvae of the insect but their success in controlling *L. malifoliella* under field conditions is not at significant level (more details information in CPC).

Economic impact: Extremely high populations of *L. malifoliella* can be dangerous, for example, under favourable biotic and abiotic conditions in regions with large apple, pear or quince the pest can be very destructive. Outbreaks of *L. malifoliella* are thought to be caused by the application of insecticides against other pests (Ivanov, 1976), as happened in Slovenia during the periods 1968-1978, 1981-1988, 1992-1995 and since 2000 (Matis, 2004).

The pest can cause yield loss due to leaf loss that leads to a decrease in fruit size and quality. Heavy leaf loss also has an adverse effect on fruit quality components. Heavy leaf losses also influence blossom bud differentiation in the blossom set of the following year. Both the number of inflorescences and the number of blossoms per inflorescence are reduced. For *L. malifoliella*, a mean mine size of 0.96 cm² was recorded, which corresponds to a 4.2% loss of leaf area Baufeld and Freier, 1991, 1992). The reduction in apple production caused by leaf-mining moths was calculated as 4.6-23.4% (Ivanov, 1975). The pupation of larvae on the fruits and the presence of cocoons reduces the commercial value of apples and creates export quarantine problems (Blanc, 1983) (ref. CPC).

Management (ref. CPC): *L. malifoliella* on fruit trees are difficult to control for various reasons, including their covert way of life, which makes them difficult to reach with sprays. The population density of *L. malifoliella* increases in orchards when chemical pesticides (organophosphates, carbamates, etc.) are applied without skill, as the pesticides can kill almost all of the natural regulators of the pest. In Bulgaria, more than 75% of larvae are parasitised in nontreated orchards, whereas in treated orchards, between 2 and 28% of caterpillars are affected by parasites (Ivanov, 1976; Ivanov et al., 1982). Similar results were obtained in Germany (Vogt, 1997) and in Hungary (Balazs, 1997). The following control measures are available in the literature.

Cultural Control: Observations in Hungarian apple orchards with L. malifoliella and Panonychus ulmi found that weak pruning techniques were correlated with a higher level of pest damage than strong pruning techniques, especially in organic growing systems. Techniques should be carefully chosen because shoots grow faster and more vigorously after strong pruning, and this supports better preservation of trees, because of the reduced susceptibility to pests and diseases (Holb et al., 2001).

Mechanical Control: The population density of the overwintered generation can be reduced by scraping and removing old, loose bark, along with the cocoons of the pupae (Ivanov, 1976).

Chemical Control: For successful chemical control against *L. malifoliella*, the phenological development of the pest must be followed and sensitive stages identified. These sensitive stages depend on the life cycle of the pest and on the mode of action of the applied pesticides. The most appropriate times for chemical control are the period of active flight and egg laying, until the beginning of egg hatching; and the period of hatching and larval injury, until the formation of small mines. Insect growth regulators (chitin-synthesis inhibitors, juvenoids, ecdisoids) are used during the first period and contact insecticides from different groups can be used during the second period (Ivanov et al., 1982; Andreev et al., 2001). Winter spraying against pupae is possible in March, but this is not sufficient to reduce summer treatment. Mineral oils, applied alone or in combination with organophosphates, are 25-60% effective (Ivanov, 1976). Control of adult moths is not satisfactory because they fly for long periods of time (Ivanov, 1976). Several sprays with highly persistent insecticides are required, which can kill natural regulators of the pest. However, treatment of adults with compounds containing pyrethroids gave good results when applied at the beginning of mass swarming and at peak swarming in apple and cherry orchards in Hungary (Penzes, 1985). The larvae have to be controlled by sprays applied immediately after hatching and before they have entered the leaves. Some insecticides, which penetrate the leaf tissue, are efficient against young larvae, when the mines are up to 3 mm, but chemical control is not effective when the mines are larger than 5-6 mm. A long list of organophosphates, pyrethroids, carbamates, etc. is reported to control L. malifoliella. The list begins with DDT and methyl-parathion, which were used in the middle of the twentieth century, it continues with trichlorphon, dichlorvos, tetrachlorvinphos, endosulfan, phosalone, methomil, chlorpyrifos, dimetoate, deltamethrin, cypermethrin, etc. (many of these insecticides are still in use) and ends with the new generation of neonicotinoid insecticides such as acetamiprid, imidacloprid, thiacloprid and thiamethoxam. Pesticides with high toxicity and long persistence are no longer permitted. Single spraying is not effective as the first generation of L. malifoliella has a long flight period. At least two treatments are required in cases of heavy infestation Ivanov, 1976, 1978, 1980; Maciesiak, 1999; Maciesiak and Olszak, 2002; Miklavc, 2003; NSPP, 2005). Insect growth regulators have a good ovicidal effect on 1-day-old eggs and the most effective chemical control against L. malifoliella is achieved with treatment at the start of oviposition. Juvenoids, ecdisoids, inhibitors of premature drop and chitin synthesis inhibitors such as triflumuron, teflubenzuron, tebufenozide, spinosad, methoxyfenozide and hexaflumuron may be used (Velcheva, 1986; Vogt, 1997; Maciesiak, 1999; Maciesiak and Olszak, 2002; Miklavc, 2003; Enzsoly and Kuroli, 2003). A loss in efficacy of diflubenzuron against L. malifoliella was reported in 11 apple orchards in the province of Bologna, Italy (Faccioli et al., 1990). Temperatures above 26°C and air humidity below 50% reduced the effectiveness of preparations based on active ingredients including endosulfan, trichlorfon, diflubenzuron and cypermethrin by 20-40%, when used against L. malifoliella (Marinkov, 1986). The population dynamics of L. malifoliella were influenced by insecticides used against the European cherry fruit fly (Rhagoletis cerasi), San Jose scale (Diaspidiotus perniciosus) and cherry bark tortrix moth (Enarmonia formosana) in Hungarian sour cherry orchards (Balazs and Jenser, 2004).

Host-Plant Resistance: Cravedi and Roversi (1985) investigated the relative susceptibility of 15 varieties of apple tree to L. malifoliella in Cremona, Italy. The number of eggs per leaf was in inverse ratio to the hairiness of the lower surface of the leaves. However, yield did not differ significantly between varieties that were more or less heavily affected.

Biological Control: Draganova and Tomov (1998) investigated the virulence of a strain of Beauveria bassiana against larvae of L. malifoliella. Twenty percent of larvae treated with conidia and 26.67% of larvae treated with blastospores died by mycosis before making a cocoon, whereas 56.67 and 50%, respectively, died by mycosis after making a cocoon. Rovesti and Deseo (1991) reported that seed kernel extract of Neem (Azadirachta indica) was most effective at a low dose (1.25 g/L) producing 80-100% mortality of L. malifoliella larvae. The growth of hatched larvae was disrupted and no pupation occurred. Neem leaf extract gave 80% mortality. However, these results were not confirmed in another investigation in Italy (Pasqualini et al., 1998), where the author established a low efficiency of Neem extract against *L. malifoliella*.

Integrated Crop Management: *L. malifoliella* is an important pest in apple IPM systems (Briolini, 1975; Pelov et al., 1996; Jenser et al., 1999) and the population density of the pest must be considered. Chemical control is only used when the population density exceeds the economic threshold (Ivanov et al., 1982). According to the principles of IPM, the pesticides used must be the least hazardous to humans, livestock and beneficial entomofauna whilst providing effective control of the pests; for example, insect growth regulators and some contact insecticides (Dulic and Injac, 1982; Pelov et al., 1996; Vogt, 1997). The number of parasitoids (predominantly Chrysocharis pentheus, Neochrysocharis formosa, Pholetesor bicolor, Sympiesis sericeicornis, S. gordius and Pnigalio pectinicornis) and parasitised leaf miner larvae were higher on an apple IPM farm than in a conventionally managed farm in Hungary. In Hungary, Fekete et al. (2004) investigated the importance of flowering herbaceous plants in IPM of apple. In a comparison of different IPM plots, the population of L. malifoliella was lower in a plot of sowed herbaceous plants, and more parasites were found in the larvae. L. malifoliella was found in IPM systems for sour cherry orchards in Hungary (Jenser et al., 2001).

Phytosanitary Risk: The most likely pathway for the introduction of *L. malifoliella* is through commercial shipment of apples from Europe and Asia. Inspections are difficult due to the small size (3 mm) of the pest and its location, usually within the calyx. Other potential pathways include nursery stock or scion material (CERIS, 2004). *L. malifoliella* is a quarantine pest for Canada (CFIA, 2005b) and the USA (USDA, 2005) (CPC).

Quarantine Risk: Low. The plant quarantine risk posed by *L. malifoliella* is low. Once established, RAA has moderate potential to establish in various pears, apple growing regions in Australia by natural spreading e.g. flight, wind etc.

Probabilities of Entry: Low. Under quarantine procedure, *L. malifoliella* has low potential to enter into Australia through infested plant materials.

Possibility of Establishment: Moderate. *L. malifoliella* has moderate potential to establish in Australia because of available host (pears, apple, apricots etc.) in Australia.

Management Cost: Effective chemicals to control aphid are available and not costly. Single spray may cost about $150/ha ($100.00 for chemicals and $50.00 for labour and machine). In one season at least 3-spray are required for this pest (Source - Martine Combret/Development officer/DAFWA/Bunbury).

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THREAT DATA

Onion fly

(*Delia antiqua*)

Enhanced Risk Analysis Tools

(Ref. http://www.inra.fr/hyppz/RAVAGEUR/6delant.htm)

CRC10010

Enhanced Risk Analysis Tools

Onion fly

(*Delia antiqua*)

Delia antique/Hylemya antiqua, common English names 'onion fly' or 'onion maggot', is serious insect pest of both cultivated and wild onion in North America. Onion fly is very similar to housefly. The fly causes significant economic damage for the onion grower and difficult to control as the larvae feeds inside the bulb. Onion fly is not reported in Oceania yet.

Distribution: Onion fly is widespread in Europe, Asia and in most part of North America. The pest may occasionally imported into some countries but not able to establish there such as Colombia, Brazil and Hawaii. The onion fly in USA and Canada is most likely introduced from Europe in the first half of the 19th Century (Griffiths 1993). The pest is not reported in Australia and New Zealand.

Host range: Major host is cultivated onion (*Allium cepa*) but the pest is also associated with wild and other *Allium* species such as *A. porrum* (leek). *A. sativum* (garlic) and *A. schoenoprasum* (chives).

Affected Plant Stages: Seedling, Vegetative and post-harvest stages

Affected Plant Parts: Leaves, roots and stems.

Biology and Ecology: Onion fly can be found in small garden and commercial growing areas wherever the host plats *Allium* sp. are cultivated. In USA, depending on temperature the fly usually has 2-3 generations/year. It lays eggs near the base of host plant or in the soil around the host plant. The eggs hatch after three days and larvae enter susceptible plants by tunnelling into the base. The larvae feed inside the bulb or lower part of the seedlings. The larvae moves from one seedling to other and kill the seedlings in a patchy form in the field. In older plants they feed in the bulb, and work upwards. It takes three weeks for the maggot-like larvae to reach full size (8mm long). Then they burrow about 75mm into the soil and pupate. The chestnut-brown pupae hatch into the second generation of flies about 17 days later. There are up to two more generations in July and, to a much lesser extent, in August and September. The last generation overwinters in the soil as pupae. Onions sown in August for overwintering are especially vulnerable to later generations. A single female usually lays 40 to 50 eggs in field conditions. Adults generally live 18 to 25 days and the complete life cycle (egg to adult) takes 42 to 56 days depending on temperature.

The larvae moves from one seedling to other and kill the seedlings in a patchy form in the field. In older plants they feed in the bulb, and work upwards. Eventually, the lower part of the bulb is so damaged that the resulting pale, wilting foliage is easily pulled off. The flies are active in summer and overwinter as pupae in the soil.

The outer leaves tend to fall to the ground, while the inner leaves remain vertical, but are soft and no longer crisp. When you look closely at the bulb it is rotting, smelly and can have as many as 30 maggots in it. Even lightly affected plants are unfit for harvesting.

Symptoms: Affected young plants turn yellowish brown, dry up, wilt and eventually die (figure below on centre), leave and stems of more established plants become soft and rotten. Affected seedlings tend to die in several patches in the row (figure below on left). The affected bulbs also rot in storage. The larvae of the onion fly bore into onion bulbs (figure below on right) that results rotten and smelly bulb with as many as 30 maggots in it, unfit for harvesting. Attacks are most severe in early to mid summer. Symptoms of onion fly may be confused with stem nematodes or onion white rot. The second generation onion maggot feeding on developing bulbs typically results in distorted growth accompanied by rotting tissue. Feeding by third generation maggots on late season onion bulbs results may result in an unusable crop.

Fig. *Onion fly infested field* – Thinned out seedlings (left), wilted seedling (centre), and split bulb with larvae inside (right).

Sources:http://www.inra.fr/hyppz/RAVAGEUR/6delant.htm
http://www.ipm.ucdavis.edu/PMG/r584300211.html

Movement and Dispersal: The potential for natural spread of onion fly is low as it can only fly very short distances. However, infested plants leaf, onion bulb, soil gravel, water etc. can play major role in pest dispersion both locally and distance. Trading of onion would be the main means of spread as the larvae can survive inside the bulb (Hill 1987) and easily be missed in quarantine.

Resistant plant variety: No report is available in the literatures on resistant commercial variety against this pest.

Natural Enemies: Number of parasites and predators are listed in the literatures without mentioning their success in onion fly control under field conditions.

Economic impact: Onion fly is on one the primary and serious pests of onion in USA and some other countries. This fly can cause damage from seedling stage to storage conditions and therefore it has more economic impact then any other onion pest. The infestation and damage cause by onion fly varies depending on temperature and geographic location. For example, 80-90% infestation reported in Iran, 15- 62% in Romania, and 25 – 84% with about 50% yield loss in Poland (Szwejda 1982). In Michigan (USA) first generation of the larvae caused twice as much as damage by 2nd generation but no figure is being reported in literature.

Management: Where onion flies are a recurring problem covering the crop immediately after sowing or planting with insect-proof mesh to protect against the early generation is worthwhile. Infested plants with larvae and should be carefully removed and burned. Use a crop rotation and cultivate the soil in winter to expose pupae to natural predators.

Chemical spry or dusting is not effective in control onion fly infestation. However, seed dressing with Oftanol T (50g/kg of onion seed) reported to be economically effective in controlling this pest in Poland (Narkiewicz-Jodko).

In case of biological control, there are a variety of natural enemies that collectively help reduce populations of onion fly maggot larvae and adults. For example, predatory flies and birds consume the onion fly. Parasitic wasps can be found early in the season attacking first generation maggots. Parasitic fungus *Entomopthora muscae* can also infect large numbers of the adult onion fly. Similarly some beneficial nematodes are affective for killing the onion fly maggots.

Probabilities of Entry: Low to moderate - Onion fly can enter into Australia mainly through infested bulb but under proper quarantine it has low possibility of entry into the country. However, Plant Health Australia (PHA) reported as high potential of entry of this pest in Australia.

Possibility of Establishment: Low to Moderate – Onion fly has restricted host range (mainly *Allium* species) but suitable climatic conditions in some parts of Australia are in favor to establish the pest in this country.

Quarantine Risk: Low to Moderate – following establishment the pest has some potential to spread locally and nationally mainly by infested soil, agricultural tools, and bulbs.

Economic Impact: Low – the pest biology, restricted host rang, damage severity, and the available management practices for onion fly indicate low impact following its successful establishment in Australia. PHA refer high economic impact by this pest.

Environmental Impact: Negligible – because of restricted host range and cultural-based management practice for onion fly will limit chemical applications. Therefore, negligible environmental impact through chemical pollution is anticipated.

Social Impact: Low – although onion fly has restricted host range but it can bring severe damage to commercially grown onion farmers as there are no effective spray to manage this insect. Hence, there is a chance of a negative social impact of this fly on both local industries as well as in small growers depending on damage severity.

Pest Management cost: Low/moderate – depending on pest severity the management cost may vary from $250 to $750/ha. Based on 5 spary/season the cost is calculated about $500/ha (ref. Project Manager, Potato, DAFWA). Chemical spray is not effective in case of onion fly but seed dressing reported to be economically effective (ref. Pest data sheet).This cost excludes involvement of any biological control and or resistant plant varieties. Onion fly management mainly depends on cultural practices because the current chemical spry is not economically viable for the growers. However, the management with cultural practice could be very expensive or even impossible in case pest severity.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 30 to 50% for crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Moderate – The onion fly has the capacity to survive in infested bulb and disperse during international trade. This may concern to export market.

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THREAT DATA

Taro beetle

(*Papuana huebneri*)

Source: http://www.spc.int/PPS/pest_of_the_month_for_december_2003.htm

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Taro beetle

(*Papuana huebneri*)

Taro beetle known as *Papuana spp*. is a major pest of taro in Papua New Guinea and other islands. It is a very notorious pest that causes significant damage in taro production in many Pacific Islands. The countries suffer from a negative impact on the export market. No effective control measure is available to manage this pest.

Distribution: Taro beetle is native to the Indo-Pacific region. The pest reported in Fiji, Kiribati, Papua New Guinea, the Solomon Islands, New Caledonia and Vanuata (APPPC 1987). Not currently recorded in Australia and New Zealand.

Host range/Alternate host: Taro is the main host for *P. huebneri.* Other plants such as sweet potato, yam, banana, Johnson grass *(Sorghum verticilliflorum*), Elephant grass (*Pennisetum purpureum*), Kunai (Imperata cylinrica) and pitpit (Phragmites karka) have also been reported as breeding host for taro beetle (Sar et al. 1997).

Biology of the Pest: The adult taro beetles are brown to black (15-25 mm long), and fly at night from the breeding sites to the taro field and tunnel into the soil just at the base of the taro corm. Generally, the male beetle is less mobile compared to the female. The male makes provisions (tunnels inside the corm) and waits for the female to come, feed, get mated and fly back to the breeding site. **The adult lives for 4-8 months.** The breeding sites are usually areas associated with high organic matter such as heaps of saw dust, manure, mulch, rubbish dumps, rotten logs/stumps etc. After mating the female will look for a breeding site to lay eggs. Each female can lay up to **100 eggs**. Eggs hatch in 11 to 16 days. The larvae feed on plant roots and dead organic matter at the base of the host plants. The **larva** moults about three times in its **3-4 months of life**, and then pupates. After about **two weeks**, the adults develop from the pupa and fly to neighbouring taro plots to cause another cycle of damage. The life cycle of *Papuana spp* is about **22 to 25 weeks** in Fiji (Autar & Singh 1988).

Symptom and Damage: Both the adults and larvae of taro beetle eat roots of plants. Larvae are usually found amongst the roots of grasses while adults feed on taro corms (underground stem resembling a bulb) and other plants root such as, Chinese taro, Giant taro, bananas, sweet potato, pitpit, coconut, sago, sugarcane and potato. Adults of taro beetles burrowing deep into the corms and make tunnels up to 2 cm in diameter (fig. below). This tunnel may continue up to the growing point and this cause young plant to wilt and die but the older plants usually recover. They can also badly damage young betel nut palms. With bananas in dry areas the taro beetle can kill the growing point of young plants.

Fig. 1. Taro corms – left one is undamaged and rest with holes caused by taro beetle (ref. http://www.spc.int/PPS/pest_of_the_month_for_december_2003.htm).

Affected plant parts: Mainly corms of taro plant but sometimes the growing points of other plants also affected.

Affected Industries: Mainly taro

Resistant plant variety: No resistant varieties are available yet but there are some varieties that are less susceptible to taro pest.

Pest movement and Dispersal: The infested taro planting materials carried out by people is the most common pathway to disperse the taro beetle in new areas. Traditional ceremonies where people get together from different locations and bring taro along with other things to meet their social obligations increases the further risk of spreading the beetle to new areas.

Impact: The taro beetle causes about 30% yield loss in taro-producing countries such as PNG and Fiji. In addition to yield loss, it also drastically reduces the market value of taro due to poor quality of crop with several holes on the surface (fig. 1). In 2000, PNG alone reported 96,600 tonnes of taro was damages by this pest that values A$45.9 million. Like taro other crop crops such as sweet potato, yams and banana also experience similar damage by this pest. The spread of taro pest also has adverse environmental and social impact in the taro growing regions. Because the farmers abandons infested taro fields and move on to pest free established forests for new fields. Since there is no effective control measure for this pest, therefore many farmers have lost their faith in continuing taro cultivation.

(LLLL) **Management:** Taro beetle management is difficult task and numerous efforts have been made to develop effective control measures for the taro beetle. Mulching with polythene, coconut husk or grass has only been partially effective. The application of metarhizium fungus with the chemical insecticide Imidacloprid recommended by PNG scientist has produced good results but costly, not affordable for the farmers. Similarly, the earlier recommendation of lindane for taro beetle control in Papua New Guinea has proved to be environmentally unsustainable. Other insecticides have proved not to be effective; nor has the use of physical barriers such as fly wire or shade cloth spread over the soil. The most recent research efforts are now concentrating on finding an effective biological control. Certain pathogens of the beetle have been identified. These include a fungus (*Metarhizium anisopliae*), a bacterium (*Bacillus popilliae*) and the protozoa

V*avraia*. The following basic cultural practices carried out by the grower are helpful in taro pest management at certain level.

(MMMM) 1. Garden location influences damage, keep new gardens separate from old and far from grassy areas.

(NNNN) 2. Barrier crops around the edges of taro gardens.

(OOOO) 3. Cultivate taro for one or possibly two years in the same area.

4. Cultivate the varieties of taro that get less affected.

Quarantine Risk: High. Taro beetle is an underground pest and attack plant part under soil. There is no effective control measure that makes it very difficult to manage once it establish in Australia.

Probabilities of Entry: Low -. Taro beetle has very limited host (mainly taro) and it also easy to spot on the infested plant part (corms). Therefore, the beetle has low possibility of entry via international trade and tourist under normal quarantine procedure.

Possibility of Establishment: Moderate – Following successful entry taro pest may find a suitable host with favourable climatic conditions to establish in many parts of Australia.

Probabilities of Entry and Establishment: Low – In spite of suitable climatic conditions, taro beetle with restricted host capacity is unlikely to find a suitable host upon its entry quickly.

Economic Impact: High - Taro beetle is a major and a serious pest for taro and no effective chemical control measure is available for this pest yet. Therefore, like in PNG the taro industry in Australia would also suffer significantly upon its establishment here in Australia,

Environmental Impact: Low – Under current situation where cultural practices are the only way to keep taro beetle population low in the field conditions, therefore the environmental pollution from chemical application would be very negligible.

Social Impact: Low/high – Like PNG, Fiji and other pacific Islands where local people are heavily depends on taro cultivation the beetle would have high social impact compared to the country (Australia) with multi industries along with taro would suffer less as restricted host capacity of the pest keep the other industry safe.

Pest management cost: Low/moderate – depending on pest severity the management cost may vary from $400 - $800/ha. This cost excludes involvement of any biological control and or resistant plant varieties. Effective and established control practices (both cultural and chemical) are available for taro beetle. However, the management with cultural practice could be more expensive in case pest severity.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 20– 30% for individual crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Medium – although taro beetle possess low risk of dispersion via international trade however, difficult and ineffective pest management in field are the main concerns in export market.

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THREAT DATA

Nettle caterpillar

(*Parasa lepida*)

Source: http://xespok.net/gallery/Limacodinae/Parasa_lepida_1000011422

Source: http://images.google.com/images

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Nettle caterpillar

(*Parasa lepida*)

Parasa lepida has number of other scientific and English names including nettle caterpillar (ref CPC). This insect is common in all south-western Asia, especially in Indonesia where it attack many different plants but preference for coconut palm. *P. lepida* attacks a wide range of crops in India and the Far East and become a serious pest of coconut in Kerala.

Distribution: *P. lepida* is widely distributed in Asian countries specially in Indonesia (Chenon 1982), and other countries like Bangladesh, Burma, China, Hongkong, India, Jammu & Kashmir, Japan, Kampuchea, Laos, Malaysia, Nepal, Pakistan, Sri Lanka, Thailand, Vietnam. Not currently recorded in Australia and New Zealand.

Host range/Alternate host: Including tea (*Camellia sinensis*) *P. lepida* attacks coconut, oil palm, castor, coffee, cacao, mulberry, mango, pineapple, pomegranate but it's preferred host is coconut (ref. CPC).

Habitat: Tea, coffee and other fruit growing areas.

Biology and Ecology of the Pest: Life span of *P. lepida* is 75-99 days. From egg to adults there are number of developmental stages like, egg, larva, pupa, and then adult. Female moth lays eggs (over **300 eggs/adult**) for 3-5 days usually undersides of older leaves. There are 5 generations a year (Kapoor et al. 1985). Following the incubation period (~5-7 days) the larvae (caterpillars) are produced. The caterpillars are 4-5 mm log and vary white to light gray colour, with a dark longitudinal strip down the back. The caterpillars are gregarious and they always stay closely grouped together on leaflets. Onset of pupation depends on food availability and environmental conditions. The pupal period ranges from 17-21 days. Pupation takes place on the leaf bases and it last for 21-24 days depending on the weather. Pupation can last longer in a dry condition and adults appearing only when the rains start. The adult moth is about 12 -13 mm long and they are active in twilight. During the day they are inactive remain clinging to the tips of the more or less dried-up leaf on the lower fronds, with their wings folded up in a ridge. These nocturnal adult moths have not been observed feeding and they begin mating in about two days after the emergence.

Disease Symptoms: The young caterpillars of *P. lepida* feed on the underneath of the leaf. The edges of the leaflet are eaten by this insect and usually they eat from tip to the base of the leaf. The midrib of infested leaf remained intact with jagged indentations (fig. A). Abnormal leaf fall and premature fruit drop is other sign of *P. lepida* attack.

Figure A. Damage done by *P. lepida* while feeding on coconut

Affected plant stages: Seedling to fruiting stages.

Affected plant parts: Mainly leaf.

Affected Industries: Tea, Coffee, Coconut and other major hosts mainly.

Susceptible plant variety: No information is available in the literature on susceptible/resistant plant variety for *P. lepida.*

Pest identification: *P. lepida* is gregarious in nature and large number of are laid undersides of older leaves. Fecal pellets on the leaves indicate the presence of caterpillar. The adult moths are brown, covered with spines and have a dark longitudinal stripe in the back (fig. in the cover page).

Pest movement and Dispersal: *P. lepida* eggs which are difficult to detect and these can be carried out into new areas by the infested host plant during trade/transportation. Therefore, it's better to avoid moving host plants from infested areas.

Impact: *P. lepida* is concern because of its spiny hairs that can cause physical damage to human health. The stinging hairs which cause intense irritation and distress to the labour staff that is greater than the damage to crops. The insect has voracious appetite, lengthy larval feeding stages (~ 2 months), high fecundity (over 300 eggs per female), and a wide host range (APPPC, 1987). A heavy infestation can defoliate plants that result yield loss and it takes long time (40 month for the coconut trees) to achieve normal yield. If no control measures are taken, the infestation spread rapidly by the next pest generation.

Natural Enemies: *P. lepida* has number of different types of natural enemies (Pathogen, Parasitoids and Predators) that attack different developmental stage of the pest (e.g. eggs, larvae, pupae). Pathogens, especially *Bacillus thuringiensis* is successfully used in biological control of *P. lepida.* The natural enemies of *Parasa lepida* in South-East Asia are critically reviewed by Cock *et al.* (1987). Among many parasites, the most common are the hymenopteran *Apanteles parasae* at most larval stages, and the dipteran *Chaetexorista javana* The entomopathogenic fungus *Cordyceps sp*. also attacks *P. lepida* cocoons. *Beauveria bassiana* parasitises the caterpillars of *P. lepida*. The populations of *P. lepida* that start to build up at the beginning of the rains are often drastically reduced during the rainy season by a viral disease. The efficacy of the virus and its dispersal is ensured by the dipteran Forcipomyia which sucks the haemolymph of sick and healthy caterpillars, thus disseminating the viral disease (ref. CPC).

Management: *P. lepida* is managed by different ways depending on it's severity, field conditions, and availability of the techniques. Among the different techniques the following are very few used by olive growers

- **Regulatory control –** avoid transporting the hosts from infested area where the insect eggs (difficult to detect) are present in the plant.
- **Mechanical control -** the adult moth is instinctively attractive to light. Therefore, the number of insects can be minimised by setting bug-zapper with ultraviolate bulbs and placing a soap water bucket directly under the bulb to catch the moths.
- **Physical and Cultural control -** at the beginning the attack is confined to a few trees and the insect is closely grouped, they can be collected by hand and destroyed. Weeds control and plantings landscape modification can limit caterpillar food availability, by which the spread of infection can be controlled.
- **Chemical control:** Number of effective insecticides available against *P. lepida*. Previously, dust spray with DDT or HCH and lead arsenate are used successfully. The insecticides traizophos and azinphos-methyl are effective against *P. lepida* but they are not very selective. Rotenone (derris solution is known to be effective against the *P. lepida* caterpillars. Synthetic pyrethrinoids and carbaryl are also effecgtive.
- **Biological Control -** *P. lepida* is attacked by a number of pathogens, parasitoids and predators. Among these, *Bacillus thuringiensis* has been used successfully against *P. lepida* that attack larval stage of the insect.

Quarantine Risk: Moderate. Tiny eggs of *P. lepida* in the infested plant parts are difficult to detect. This enhances spreading the pest in new areas through host plant transportation. The larva has long feeding time that causes more damage. The adult pest is also concern because of its spiny hairs that can cause physical damage to human health.

Probabilities of Entry: Low/moderate -. Although *P. lepida* has multiple host range but the pest is mainly associated with vegetative plant part (mainly leaf) and the international trade usually involve with fruits of the host plants. Therefore, *P. lepida* has low possibility of entry via international trade and tourist under normal quarantine procedure.

Possibility of Establishment: High – Multiple host rang and favourable climatic conditions in many parts of Australia provide high possibility of establishment for *P. lepida* after entry.

Probabilities of Entry and Establishment: Low/moderate – suitable climatic conditions, a multiple host range, and low possibility of entry of *P. lepida* are the main deciding factors in this issue.

Economic Impact: High - Large appetite, lengthy larval feeding stages (~ 2 months), high fecundity (over 300 eggs/female), and a wide host range of *P. lepida* play important roles in the damage cause by the pest.

Environmental Impact: Low – Available of effective chemicals and biological enemies for *P. lepida* reduce environmental pollution through limited chemical application in field by growers.

Social Impact: Low/moderate – depending on host and infestation severity, *P. lepida* could bring negative impact on local industries. For example, larvae of *P. lepida* mainly eat leaf therefore tea industry will suffer more than any other crops from this pest. Available biological enemies of the pest in nature might keep the population low in field conditions. But spiny hair of the adult pest cause both physical and psychological damage to human.

Pest management cost: Low/moderate – depending on pest severity, types of crops and other factors the management cost may vary from $150 - $300/ha. This cost excludes involvement of any biological control and or resistant plant varieties. Effective and established control practices (both cultural and chemical) are available for *P. lepida*. However, the management with cultural practice could be more expensive in case pest severity.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 – 20% for individual crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – *P. lepida* possess low possibility dispersion via international trade because the pest is mainly associated with vegetative plant parts (leaf) that are usually not involve in export.

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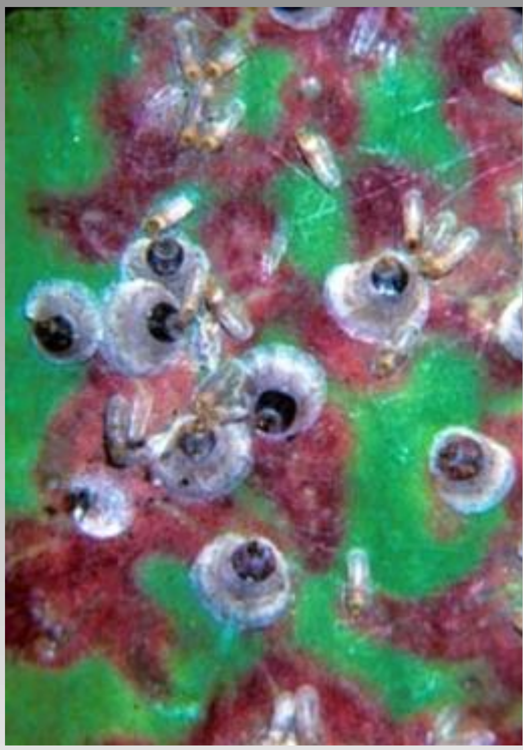
http://images.google.com/images

THREAT DATA

Olive scale

(*Parlatoria oleae*)



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Olive scale

(*Parlatoria oleae*)

Parlatoria oleae is a common insect pest of olives. It was originally described as Diaspis oleae by Colvee (1880) from specimens collected on olive at Valencia, Spain. Olive scale and olive parlatoria scale (Europe) are two common English name of *P. oleae.* In addition to olive, this pest also been reported in other fruits, nut, and ornamental plant species. Eastern Mediterranean and Indian regions are the two possible native places for this pest. Depending on geographic location, it can breed 2-3 times a year.

Distribution: This widespread species is found throughout southern Europe, North Africa, the Middle East, the Orient and North and South America. *P. oleae* is reported to be common on a variety of hosts in the Republic of Georgia (Aleksidze, 1995) and Italy (Longo et al., 1995). Although relatively restricted in its range within countries throughout Europe and the Middle East. In USA, olive scale was initially discovered in California (1934) and subsequently became a serious pest (Huffaker et al., 1962). Australia and New Zealand are still considered free of this pest.

Host range/Alternate host: Olive (*Olea europaea*) is the primary host but other numerous fruit, nut and ornamental plant species are also being infested by this pest. In USA (California) over 200 and in Central Europe over 80 species of host plant are associated with *P. oleae*. However, many of these host plants do not support the development of olive scale. The pest has been reported as major pest of apple, pear and plums in Afghanistan and Iran (Fowihan and Kozar, 1994; Kozar et al., 1996).

Habitat: Areas of both cultivated and wild olives

Biology and Ecology: Depending upon the geographical location, *P. oleae* produce **2 to 3** generations annually (El Hakim et al., 1985; Gill, 1997). In California, adults emerge in April-May and in July-August (Huffaker et al., 1962), with the highest density on the limbs and spurs of the host. In Egypt, lower parts of pear trees are preferred to infest by this pest (Hafez et al. (1967)

The insect overwinters as fertilised females on the bark. Each produces an average of about **90 eggs** (Garcia, 1973). The development and number of eggs produced depends on temperature, humidity and host plant (Habib et al., 1969). Summer populations migrate from the leaves to the fruit. In general, the highest numbers of females are found on the stems, although substantial numbers migrate to, and settle on, the leaves and fruits. In the autumn population, Huffaker *et al.* (1962) found that males represented about 80% of the population on the leaves, with the reverse true for those scales on the limbs.

P. oleae occurs on the bark, leaves and fruit of its host. Initially, the scale aggregates on the mid-ribs of the leaves, on the stems, and at the blossom end of the fruits. As the population increases, individuals settle at sites of opportunity. Heavy infestations often result in an encrustation of the twigs and limbs. The upper branches are usually more heavily infested than the lower branches (Selim *et al.*, 1981).

Symptoms: *P. oleae* occurs on the bark, leaves (fig. a & b) and fruit of its host. Infested olive fruit shows abnormal shape with purple discoloration that results premature drop. Other fruits (e.g. apples and peaches) may exhibit a dark red spot around the feeding site of the scale. External feeding, wilting and dieback signs are also visible in heavily infested leaves and stems.

Fig. a) Olive scale on bark   Fig. b) Olive scale on leaf

Source: http://www.forestryimages.org/browse/subimages.cfm?SUB=8348

Affected plant stages: Flowering, fruiting, post-harvest, and vegetative growing stages.

Affected Plant Parts: Fruits/pods, leaves, stems and whole plant.

Affected Industries: Mainly Olive, apple, pear and stone fruits.

Resistant plant variety: In literatures there is no report on resistant and susceptible varieties of olive plant species for *P. oleae*.

Affected time of the year: Adults emerge between April and August in California, USA with highest density on the limbs and spurs of the host (Huffaker *et al.,* 1962).

Pest identification: Identification of the species is based on the morphology of the adult female. The protective cover of the female is grey to white, subcircular, 1-2 mm long, with dark, centrally positioned exuviae. The male cover is white, elongate, about 1 mm long with a brownish-yellow exuviae positioned at the anterior end. The eggs and immature stages are pink to violet. Comprehensive descriptions and illustrations are provided by Ferris (1937), Gomez-Menor Ortega (1956) and Kosztarab (1996).

Detection and Inspection Methods: In areas where the olive fruit fly is not well established, the adult fly population are being monitored with yellow sticky traps containing a sex pheromone (spiroketa) and /or ammonium carbonate, ammonium bicarbonate, or diammonium phosphate bait. Male fly get attracted by sex hormone and the female one get attracted by ammonium volatile. Both sexes are attracted to yellow color of the trap and are captured on the sticky trap surface (CPC).

Impact: *P. oleae* is a common pest of olives and olive scale causes serious damage to olives, primarily the table variety in Greece (Argyriou and Kourmadas, 1981). It is considered a major agricultural pest by Westcott (1973). In addition, it has been reported to be an occasional economic pest of nut trees (Barnes et al., 1979), potentially the most injurious scale insect pest of Rosaceae and Oleaceae in Argentina, and a serious pest of fruits in Bulgaria (Gomma, 1978) and eastern Georgia (Yasnosh and Mindiashvili, 1972). Fowjhan and Kozar (1994) reported that *P. oleae* was one of the most important pests of apples and peaches in Afghanistan. Kozar et al. (1996) reported that it is also an important pest of apples, pears and plums in Iran.

P. oleae infests the branches and twigs of the host. Heavy populations result in the defoliation of leaves, and dieback of the limbs (Mallea et al., 1972). It may cause slight deformations and dark spots on olives, apples and other fruit. Infestation of olives often results in a reduction in oil content. Direct financial loss is incurred from this pest due to the marking and discoloration of smooth-skinned fruits such as plums, apricots and olives (Huffaker et al., 1962). Losses in quantity and quality of marketable produce may be attributed to infestations by the olive scale.

Natural Enemies: *P. oleae* has number of parasitoids and predators that attack different developmental stages of this pest and has been used in various countries for the biological control of olive scale. Following are few examples of their application in the biological control.

The use of the parasitoid *Coccophagoides utilis*, especially in combination with other ectoparasitoids, has been found to be effective in controlling the olive scale (Rosen, 1986).

Aphytis paramaculicornis was found to be widespread in Pakistan and effective against *P. oleae* regardless of pest density (Ahmad and Muzaffar, 1974). They found that this parasitoid had a parasitism rate of 8-12% at low densities. However, when combined with *C. utilis*, the parasitism rate increased to 24% in the pest population.

The principal pest of this species is *Aphytis paramaculicornis*. The most recent account of the successful campaign in California is by Huffaker et al. (1994). This indicates that since the establishment of *Coccophagoides utilis* which complements *A. paramaculicornis*, there have not in the past 20 years been reports of problems with *P. oleae* on any of its hosts, many of which were formerly encrusted and suffering dieback. Attempts to repeat this result in the USSR failed as the two parasitoids imported from the USA failed to become established (Izhevskii, 1988).

Five species of mites (*Amblyseius cucumeris, Bdella iconica, Cheletogenes ornatus, Cheyletia flabelluifera* and *Thyreophagus entomophagus*) were found under the covers of *P. oleae* in Bulgaria (Nachev and Grenchev, 1987). Kosztarab and Kozar (1988) listed 11 parasitoids and one predator associated with this pest in Central Europe.

Management: The grower uses biological, chemical and cultural techniques in olive scale management. The effectiveness and the application of these techniques depend on geographic location, field conditions, crop variety, insect severity, and availability of the techniques.

- **Biological Control:** Since the implementation of a biological control programme against olive scale in California, USA, in 1948, densities of this pest were eventually reduced below economic threshold levels and maintained so by the conservation and augmentation of natural enemies (Huffaker *et al.*, 1962). The parasitoids *Aphytis maculicornis* and *A. paramaculicornis* successfully reduced olive scale populations by up to 50% for the spring generation, but had less of an impact on the summer populations (Rosen, 1978). Because olive scale is maintained below economic threshold levels in California by parasitoids such as *A. maculicornis* and *Coccophagoides utilis*, Gill (1997) has classified this pest as maintaining a 'B' status. A variety of parasitoids, including *A. maculicornis*, have been recorded attacking the olive scale in countries throughout the world where olives are grown. Zaher and Soliman (1971) reported that the predaceous mite, *Cheletogenes ornatus*, was widespread in Egypt, and played an important role in suppressing populations of *P. oleae* by attacking the eggs and adult females.

- **Chemical Control:** Chemical control attempts are more effective when applied against overwintering females or emerging crawlers. However, successive applications were found to enhance populations of the pest on olive (Ehler and Endicott, 1984), possibly because of the negative impact on the natural enemies of the pest. Implementation of chemical control in summer is often crucial for control of the fruit-infesting generation.

- **Cultural Control:** Sanitation is also important for reducing the pest population by disposing of fallen fruit, which may serve as hosts for the overwintering females. The development of models based on the phenology of the pest has effectively been used to predict the onset of egg hatch and the implementation of control procedures in Israel (*Pinhassi et al.*, 1996).

Quarantine Risk: Very low. Both eggs and larvae in the infested plant parts are visible with naked eyes that help in detection easily.

Probabilities of Entry: Low - moderate. Although eggs and larvae of *P. oleae* are quite visible in infested plant part but its diverse host capacity may attribute in escaping of normal quarantine during trade.

Possibility of Establishment: Moderate – due to multiple host rang apart from olive growing regions, *P. oleae* has potential to establish in other suitable crop growing areas under favourable climates of Australia

Probabilities of Entry and Establishment: Low/moderate – suitable climatic conditions and a multiple host capacity of *P. oleae* are in favour of establishment of this pest in Australia.

Economic Impact: Moderate - based on pest biology and the damage severity reported in the literatures by *P. oleae.* Availability of resistant plant variety and other control measure are also important issues in economic impact.

Environmental Impact: Low – in spite of multiple host range, available biological enemies and effective control measures (both chemical and mechanical) of *P. oleae* (reported in literatures) contribute in less chemical applications that ultimately reduce environmental pollution.

Social Impact: Low – established, efficient and available management protocols of *P. oleae* would help in keeping the pest under control in field conditions. Therefore, social impact arise from the pest severity is consider to be low following its establishment in Australia.

Pest management cost: Low/moderate – depending on pest severity and the control techniques uses management cost may vary from **$500 – $900/ha** including chemical and application cost. This cost excludes involvement of any biological control and or resistant plant varieties. Effective and established control practices (both cultural and chemical) are available for *P. oleae*. However, the management with cultural practice could be more expensive in case pest severity.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 – 15% for individual crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low/moderate (5 – 10%). Multiple capacity and moderate dispersion rate of *P. oleae* during international trade are the main causes in export revenue loss.

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THREAT DATA

Taro root aphid

(*Patchiella reaumuri*)

Source: http://www2.ctahr.hawaii.edu/oc/freepubs/pdf/IP-1.pdf.

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Taro root aphid

(***Patchiella reaumuri***)

Taro root aphis, *Patchiella reaumuri*, is one of the destructive taro pests in dryland areas. It is a very notorious pest that causes significant damage in taro yield in many Pacific Islands. The aphids attack only taro and its closely related plants. The countries suffer from a negative impact on the export market. No effective control measure is available to manage this pest.

Distribution: Taro root aphid has been recorded in islands of Hawaii, USA since 1971. The aphid is also recorded in Europe on *Arum spp* and *Tilia spp.* In current literature no information is available whether the aphid is present in Australia.

Host range/Alternate host: Taro root aphid is very host specific and the aphid only known to attack taro plant in Hawaii. However, in Europe it also found in *Tilia spp*., a tree pant where is causes gall of the shoot tip.

Ecology and Biology of the Pest: The taro root aphids are very common in dryland and taros in wetland areas do not get attacked by this aphid. The aphid is yellow and covered with cottony mass and waxy threads. They feed on root sap and the infestation appears in that region as white mould. In case of high populations, aphid colonies are found in both root and basal parts of leaf sheaths. In Hawaii, the aphid does not produce winged sexual forms and reproduction occurs without fertilisation by male. Many ants have been found associated with taro root aphid. The association might help the aphid move around and also contribute in plant damage by increasing the aphid population.

Symptom and Damage: Taro root aphid feeds on taro root mainly that cause root rot. The infested plants become stunted with small yellowish leaves. Infestations appear as a white mould on the fibrous roots below the ground (fig.1 right). Therefore the initial symptom remains undetected until the infested plant shows stunted growth with yellow leaves at late stage of infection. The presence of ants surrounding the infested plants and sometimes on leaves can be an indication of taro root aphid attack. During the early stage of plant growth aphid could cause more damage along with drought condition. Young plants are more susceptible to the aphid then older plants.

Fig. 1. Dug-up taro roots with taro root aphids (left) Taro root aphid infestation on taro leaf petiole and sheath (right) (ref. Sato at al. 1989).

Affected plant parts: Mainly roots but sometimes leaf sheath also gets affected.

Affected Industries: Mainly taro

Resistant plant variety: No information on resistant varieties in the literatures.

Pest movement and Dispersal: The infested taro planting materials carried out by people is the most common pathway to disperse the taro root aphid in new areas. Traditional ceremonies where people get together from different locations and bring taro along with other things to meet their social obligations increases the further risk of spreading the beetle to new areas.

Impact: The taro root aphid is one of the serious pests for taro industry. The crop losses by this pest reached up to 75 – 100% with 'Lehua', 'Chinese', and dasheen taro on the island of Hawaii, USA. Damage is more severe at the early developmental stage of taro plant.

The spread of taro pest also has adverse environmental and social impact in the taro growing regions. Because the farmers abandons infested taro fields and move on to pest free established forests for new fields. Since there is no effective insecticide for this pest, therefore many farmers have lost their faith in continuing taro cultivation.

(TTTT) **Management:** Taro root aphid management is difficult task as there are no chemicals that can control the pest in the field. Insecticidal soap (1% active ingredient) has been in the field and also for the treatment of planting materials before planting. Hot water treatment (at 49^{0}C for 6 minutes, followed by immersion in cold water) of planting material also helps in disinfestations and pest free planting materials are very important in pest management. Since taro root aphis is specific to taro plant, therefore the crop rotation of heavily infested taro field by non-taro crop also help in pest management.

Quarantine Risk: High. Taro root aphid attacks plant parts below the ground mainly roots. No effective chemicals are available to control the aphid population in the field. This makes it very difficult to manage once it establish in Australia.

Probabilities of Entry: Low -. Taro root aphid is very host specific (mainly taro) but early stage of infestation on host plant can easily be missed during transport. Therefore, the aphid has possibility of escaping through normal quarantine during import.

Possibility of Establishment: Low – In spite of favourable climatic conditions in some part of Australia, the selective host capacity of taro root aphid reduces the chance of establishments in Australia. Successful entry may not ensure finding of a suitable host to initiate the establishment process.

Probabilities of Entry and Establishment: Low – In spite of suitable climatic conditions in some parts of Australia, taro root aphid with selective host capacity is unlikely to find a suitable host soon after its entry.

Economic Impact: High - Taro root aphid is a serious pest for taro industry without any known effective chemicals to control the pest in field. Therefore, like in other Pacific Islands the taro industry in Australia would also suffer significantly upon its establishment in Australia.

Environmental Impact: High – Under current situation where no effective control measures are available for this pest, the taro growers very frequently will move to new land for taro cultivations as reported in some taro growing countries. Excessive land use reduces the native forest that ultimately causes environmental damage.

Social Impact: Low/high – Like PNG, Fiji and other pacific Islands where local people are heavily depends on taro cultivation the aphid would have high social impact compared to the country (like Australia) with multi industries along with taro would suffer less as restricted host capacity of the pest keep the other industry safe.

Pest management cost: High/moderate – depending on pest severity and other factors the management cost may vary from $300 - $700/ha. Since no effective chemicals are available, therefore the aphid can be managed only through mechanical and cultural practices which are costly. For example, most commonly used hot water treatment.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 50 – 70% for individual crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Moderate – although taro root aphids possess low risk of dispersion via international trade however, unavailability of effective chemicals/methods to manage this pest at field level is the main concerns in export market.

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THREAT DATA

Cutworm

(*Peridroma saucia*)

Sources: http://bugguide.net/node/view/155522

http://www.leps.it/indexjs.htm?SpeciesPages/PeridSauc.htm

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Cutworm

(*Peridroma saucia*)

Peridroma saucia is an insect pest that is also known by several English and local names such as cutworm, underwing moth, pearly underwing moth etc. Cutworm has been recorded on a wide range of host including both in monocotyledonous and dicotyledonous plants. The pest can not survive cold winter therefore it's unable to survive in Canada (Ayre, 1985).

Distribution: Cutworm is distributed in many Asian, North American, European and Mediterranean regions (Nowacki and Fibiger, 1996). It's widely found in USA but not recorded in Australia and New Zealand yet.

Host range/Alternate host: Cutworm feeds on a variety of garden crops, trees, vines grasses, field crops, ornamentals, and greenhouse plant. Among these some are major, minor, wild and alternate hosts. Of the field crops, **potato**, tomato, cabbage, lettuce, *capsicum* are most affected by this pest. Beside this, cutworm has a long list of minor and wild host.

Habitat: The natural habitat of *cutworm* is open, disturbed areas where a wide range of host plants available in tropical and subtropical areas.

Biology and Ecology: Cutworms is highly polyphagous species. The adult appears in early spring and moth emerges at night. The moth overwinters as pupae in the soil with a high percent mortality occurring during this life stage. Female moths emerging from surviving pupae compensate by laying over **2000 eggs** during their short life span. Clusters of 60 or more eggs are deposited on stems or leaves of growing plants as well as on fences and buildings. During the summer, eggs usually hatch in 5 days. The active larvae feed at night and on cloudy days for about 3.5 weeks before burrowing into the soil to pupate. The non- overwintering pupal stage lasts 2 weeks to a month before second generation moths emerge. Require 48 days to complete a life cycle, cutworms produce **2 to 4 generations** each year depending on weather conditions and latitude.

Damage/Symptoms: Beginning in early spring and continuing throughout the summer, cutworms climb host plants and devour foliage, buds, and fruit. Felled young plants cut off at the base or near the ground level and much damage is done to young row crops. Damaging infestations, however, are sporadic. Because the cutworm is one of the few cutworm species that climbs the plant to feed, its presence is usually more striking than that of subterranean cutworms.

Affected plant stages: All stages like pre-emergence, seedling, growing, flowering, fruiting and post-harvest stages.

Affected plant parts: Leaves, stems, growing points, inflorescence, whole plant, seeds and fruit/pods.

Affected Industries: Field crop and fruit industries

Resistant plant variety: No report is available on resistant potato varieties against cutworm.

Affected time of the year: The largest populations of cutworm are most likely to early spring to summer.

Pest movement and Dispersal: Infested areal plant parts where both larvae and adult can hide and disperse locally via transportation but low dispersal possibility through international trade.

Natural Enemies: A list of pathogens, parasitoids, and predators are available in crop protection compendium (CPC) for *P. saucia*.

(UUUU) **Impact (ref. CPC)**: *P. saucia* is a major pest in USA, especially on potato, tomato, tobacco and lucerne, but estimates of financial loss are rarely reported. An exception was a major outbreak of the cutworm on potato in the early 1900s where losses were estimated at 2.5 million dollars (Crumb, 1929). Damage to lucerne crops is most severe in terms of time delay between harvesting a crop and growth of the next crop. Infestations of *P. saucia* in lucerne stubble after harvesting can delay the regrowth of the next crop by several weeks or more (Buntin and Pedigo, 1985a, b, c 1986a). *P. saucia* is considered to be a minor agricultural pest in most of Europe (Carter, 1984) and eastern Asia, but is a more significant pest in southern Europe (e.g. Italy).

(VVVV) MANAGEMENT

(WWWW) **Cultural Control:** The presence of weeds in crop increase crop damage, and intensive weed control can reduce the need for and amount of other control measures taken against *P. saucia* (Machuca et al., 1990). Damage to the fruit on the lower branches of fruit trees is also largely due to the presence of tall weeds that provide easily access to the fruit for climbing cutworms (Molinari et al., 1995).

(XXXX) **Biological Control:** A wide variety of parasitoids have been reared from *P. saucia* (see Natural Enemies), but only the hymenopterous parasitoid *Trichogramma* and bacterial and viral agents have been applied to crops for control.

(YYYY) **Chemical Control:** Chemical sprays used effectively against *P. saucia* include: carbaryl (Dibble et al., 1979; Brandenburg, 1985); chlorpyrifos (Balevski et al. 1974; Brandenburg, 1985); endosulfan (Millot and Bralavorio, 1973); methomyl (Brandenburg, 1985; Machuca et al., 1990); monocrotophos (Dibble et al., 1979); and trichlorfon (Balevski et al., 1974). Brandenburg (1985) reported that the use of chlorpyrifos, methomyl and carbaryl was detrimental to beneficial arthropods in the crop area. *P. saucia* is easily controlled with soil applications of granular insecticides or with applications of pyrethroid insecticides.

Quarantine Risk: Very low - because the pest is easily detectable with naked eyes and there is a low possibility of it's dispersion via international trade and tourism. The pest is also sensitive to cold temperature i.e. quarantine treatment will element them.

Probabilities of Entry: Very low - cutworm has low dispersal possibility through international trade as the insect mainly found near the base of seedling close to the soil. Trading components usually remain free from this insect.

Possibility of Establishment: Moderate – cutworm has a long list of both minor and wild host that makes a possible chance of finding a proper host after entering into Australia. This also support by a suitable climatic condition for the pest in many parts of the country.

Economic Impact: Moderate - based on pest biology, multiple host rang, the nature of damage reported by cutworm and the availability of it's management practices.

Environmental Impact: Low - applied chemicals in the management may cause environmental pollution that imbalance the ecosystem. In addition, cutworm might find some native plants as host.

Social Impact: Moderate – since cutworm is capable of attacking various agricultural crops that are valuable to the local farmers; therefore, yield loss by this pest will bring a negative economic impact in the infested region. Higher cost involves in disease management may also discourage the small growers to continue in future.

Pest Management cost: Low/moderate – The total production cost increases are to be expected from the chemical applications in order to control cutworm in the field. Although, a few biological agents are used to control cutworm but the grower still mainly depend on chemical treatment. Numbers of available chemical that are susceptible to this pest are used by the growers. Based on '*Farm Budget Guide 2001*' the minimum cost of using one of the insecticides assumed to be around $50-60/ha for a single application. In addition, vehicle, equipment and labour costs would be another $50/ha (labour = $20/hr, tractor and other spray costs include fuel, oil, maintenance = $30/ha, time requires for spray = 1hr/ha). The total cost assumed to be $100-110/ha. However, the total cost would increase by the number of applications in case of pest severity.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 – 15% for individual crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low - export markets may suffer from cutworm entering and becoming established in Australia. Cutworm has short life cycle, sensitive to cold, and mainly live in plant leaves. The biology of the pest indicates that there is a low possibility of it's spreading through agricultural commodities during the trade. Therefore, the presence of this insect may not have significant impact on export markets.

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THREAT DATA

Olive kernel borer

(*Prays oleae*)

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Olive kernel borer

(*Prays oleae*)

Olive kernel borer (*Prays oleae*), also know as olive moth is one of the important insect pests of olive. In addition to olive as major host, it also has some other minor hosts. *P. oleae* is found in the Mediterranean basin near the coast. The pest has 3 generations per year and attack different organs of the plant. Depending on the climatic conditions, the damage caused by this pest is up to 40% of olive fruit drop that lead to heavy economic losses.

Distribution: Mediterranean basin and very common near the Mediterranean coast. Present of *P. oleae* has been reported from several countries of Asia, Europe, and Africa. But it has not been recorded yet in Australia and New Zealand.

Host range/Alternate host: *P. oleae* has narrow host range with olives (*Olea europaea subsp. europaea*) as a major host. *Anemone* (windflower), *Jasminum* (jasmine), *Ligustrum* (privet), *Phillyrea* and *Ranunculaceae* are minor hosts of this insect.

Habitat: Olive orchards.

Pest Biology and Ecology: For details biology of *P. oleae* is referred to the article by Apostolov (1990). There are normally three generations per year, although El-Saadany et al. (1978) detected nine overlapping generations in Egypt. The egg stage lasts 3-5 days. Each female can lay more than **250 eggs but 100** is more usual with **3 generation** normally. The first generation eggs are laid in April on the calyx of flowers, the larvae feed on flower buds and flowers inhibiting their development. A single larva consumes many buds and spins a small web in which particles of frass can be caught. The larval stage lasts 79-134 days. The second generation eggs are laid in June on fruits. On hatching the larva tunnels into the fruit where it feeds, often causing premature fruit drop. The third generation eggs are laid in September on leaves. The larva feeds from October to March. At first, mining causes an irregular blotch, which becomes yellower than the rest of the leaf; frass is expelled from the underside and can become caught in silk making the mine more conspicuous; later the larva feeds externally. The pupae of each generation are contained in a dirty-white, loose silken cocoon, tapering at each end, which is spun in the soil, under bark or amongst dead flowers. The pupal stage lasts 8-14 days. Adults are on the wing in April, June and September. The whole life cycle from egg to adult takes 90-153 days (Ref. CPC).

Disease Symptoms: Presence of *P. oleae* is quite visible on leaf, flower and fruit. The symptoms on leaf show mines by leaf-feeding generation (fig. a), the symptoms on fruit are visible by twisted/rolled florets with silk containing grains of frass caused by flower-feeding generation. Similarly, the fruiting feeding-generation causes premature fruit drop, internal feeding and visible frass symptoms by this pest.


Fig. (a) Mines produced by larvae on leaves of olive

Affected plant stages: Vegetative, flowering and fruiting stages

Affected plant parts: Olive fruits, Inflorescence, flowers, and leaves.

Affected Industries: Olive

Resistant plant variety: Cultivar Aglandau is resistant to *P. oleae* (Anon 2000). Other cultivars such as Palma, Corsicanada Olio, Sivigliana da Olio, Olieddu and Bosana are reported less then 10% of fruits with larvae. Likewise, the cultivar with small fruits (e.g. Semidana, Palma and Bosana) found to be highly resistant to this pest (Ref. CPC)

Affected time of the year: Plants are affected almost through out the year because 3 generations of this pest attack all developmental stages (vegetative, flowering and fruiting stages) of plant.

Pest identification: The adults with approximately 12 mm wingspan, silvery grey colour, antennae simple and filiform. Forewings are shinny greyish white with variable blackish-brown marks (figure in the cover page of this data sheet). Insect pupas are brown in colour with dark abdomen and cremaster with eight short, thick, and hooked spines. Larval head is dark brown to black, body pale greenish brown or brownish green, and anal plate marked with brown. Eggs are elliptical, finely reticulated, and whitish.

Pest movement and Dispersal: The pest can fly to near host. But for distance it usually carried out by infested plant organs such as leaves, flowers and fruits. During trade/transport the eggs and larvae (visible to naked eye) carried out by the infected plant parts.

Disease Impact: *P. oleae* is one of the major pests throughout the Mediterranean area where olives are grown. The pest has 3 generations per year and attack different organs of plants (leaf, lower, inflorescence, flower and fruit). The damage caused to olive orchards by this pest fluctuates every year depending on the climatic conditions. In Calabria and Italy 5.5-10% losses are reported by Iannotta *et al.* (1998). Kaya et al. (1987) noted 37-41.1% fruit loss In Turkey and this level was taken as to economic threshold. Similarly, Ramos *et al*. (1998) reported more than 40% fruit fall, provoking heavy economic losses, even in presence of biological control by oophagous predators. Pesticides application to control *P. oleae* is not efficient because of their detrimental effect to natural enemies of this pest.

Natural Enemies: *P. oleae* has number of different types of natural enemies (Pathogen, Parasitoids and Predators) that attack different developmental stage of the pest (e.g. eggs, larvae, pupae). Predators, especially *chrysopids*, are the most important natural enemies of *P. oleae*, although others do account for some pest mortality. Chemical control is likely to kill the natural enemies and can pave the way for other pests such as mites. Liber and Niccoli (1988) found that predation could be increased by applying a spray containing L-tryptophan, autolysed brewers' yeast, sucrose and water in mid-June in Italy (Ref. CPC).

Detection and Inspection Methods: During winter, mined leaves indicate the presence of larvae. Spinning with suspended particles of frass among flowers and buds during flowering is another sign of infestation. Premature fruit drop with larvae boring within the fruit is another way to detect the pest.

Management: Olive moth is managed by different ways in by various growers in depending countries. Number of review articles on control methods of *P. oleae* by different authors is available in the literatures. These are Sobreiro (1993) in Portugal, Katsoyannos (1992) in the Near East, Lopez Villata and Dominguez de la Concha (1989) in Spain, and Loussert and Brousse (1978) in France. Among the different techniques the following are few used by olive growers

- **Host-Plant Resistance:** There are number of host resistant cultivars used in different countries that reduced the crop damage up to 40%. The list of resistant olive cultivars is mentioned under the title of resistant plant variety in the above of this data sheet.

- **Biological Control:** *Chrysopid* predators are the most commonly used agents for biological control. In Portugal, Bento et al. (1999) reported that the rate of predation by *chrysopids* on *P. oleae* eggs varied among different generations of the pest and in different years, reaching 34% for the carpophagous generation in 1996. Releasing 360 larvae of *Chrysoperla carnea* per tree halved the potential damage by *P. oleae*. Morris *et al.* (1999) surveyed a large number of predators in Spain. Afellah et al. (1998) in Morocco found that the rate of parasitism was low (0.12-0.36%). Often *P. oleae* has to be controlled with other pests of olive. In Turkey, Yalya (1983) recorded 25 species of pest and 24 species of predators and parasites and concluded that a natural balance had been established due to the lack of chemical treatment (ref. CPC).

- **Pheromonal Control:** Mazomenos *et al.* (1999) described the use of a pheromone. Pheromone trap catches were reduced by up to 96-100% in the mating-disruption plots. During the first year of mating disruption, a treatment with Bacillus thuringiensis kurstaki (Bt) was applied to reduce the first generation of larvae. Fruit damage in the mating disruption plots was lower than that in Bt, insecticide and untreated plots. In high-fruiting years, the proportion of fruit damage was lower than in low-fruiting years. Mating disruption applied in the same olive grove over several years progressively reduced the *P. oleae* population from year to year (ref. CPC).

- **Chemical Control:** In Spian, methidathion and dimethoate in field trials achieved 92 % and 89% control respectively 5 days after application (Cortes and Borrero (1998). A higher level of control was obtained after 18 days: 98% with methidathion, 94% with Bacillus thuringiensis kurstaki and 92% with dimethoate. Aerial treatment of 150-ha tracts of rough terrain with another formulation of B. thuringiensis kurstaki achieved up to 98% control. These are probably effective at reducing the larval population compared with the untreated. Nearly 50% mortality of larvae was achieved using bacterial insecticide (Bacillus thuringiensis) by Jardak and Ksantini (1986) in Tunisia against the third generation of *P. oleae.* Deltamethrin caused nearly complete mortality of the larvae. Diflubenzuron is ineffective against the larvae but it show 40% effective against pupa. Both products affected the following generation. However, most of the chemical cause detrimental effect on natural enemies of *P. oleae*. Therefore, the chemical control is not encouraged.

- **IPM Programmes*:*** Delrio (1995) carried out research on the integrated control in olive groves in various Italian regions during 1988-94. Population monitoring and the application of relevant economic thresholds were essential for integrated control. Rational control of olive pests relied on the integration of cultural, biological, biotechnical and chemical methods. Cultural control methods included pruning against *P. oleae*. The mass-trapping technique against *P. oleae* gave partial control. Supervised control with larvicidal treatments of non-lipophilic organophosphates applied at the economic threshold of 10-15% attacked olives enabled applications to be limited and allowed very low residues in the oil. Insecticidal bait sprays applied to specific parts of the olive canopy have proved less damaging to beneficial insects and enabled the further reduction of toxic residues (ref. CPC).

Quarantine Risk: Very low. Both eggs and larvae in the infested plant parts are visible with naked eyes that help in detection easily.

Probabilities of Entry: Low. Although eggs and larvae of *P. oleae* can be carried out by infested fruits and other plant parts but both larvae and eggs are quite visible by naked eyes and this makes low possibility of pest spread during trade.

Possibility of Establishment: Low – apart from olive growing regions, *P. oleae* has low potential to establish in Australia due to its selective host range.

Probabilities of Entry and Establishment: Low – with restricted host and low entry possibility, *P. oleae* is likely to find a good chance to establish in Australia, although Australian climatic conditions are in favour of the pest.

Economic Impact: Moderate - based on pest biology and the damage severity reported in the literatures by *P. oleae.* Availability of resistant plant variety and other control measure are also important issues in economic impact.

Environmental Impact: Low – effective chemical control measures, reports on available biological enemies of *P. oleae* plus a few pest resistant plant varieties would contribute in low chemical applications for the pest management compared to the pest with multi-host and chemically controlled. Less chemical application will limit the environmental pollution.

Social Impact: Very low – since olive is a major known fruit plant affected by *P. oleae* and proper control measures are also available. Therefore, very low social impact is considered due to the presence of this pest.

Pest management cost: Low/moderate – depending on pest severity and nature of the crops the management cost may vary from $150 to $300/ha. This cost excludes involvement of any biological control and or resistant plant varieties. Effective and established control practices (both cultural and chemical) are available for *P. oleae*. However, the management with cultural practice could be more expensive in case pest severity.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 – 20% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – due to very selective in host and low dispersion possibility of *P. oleae* during international trade.

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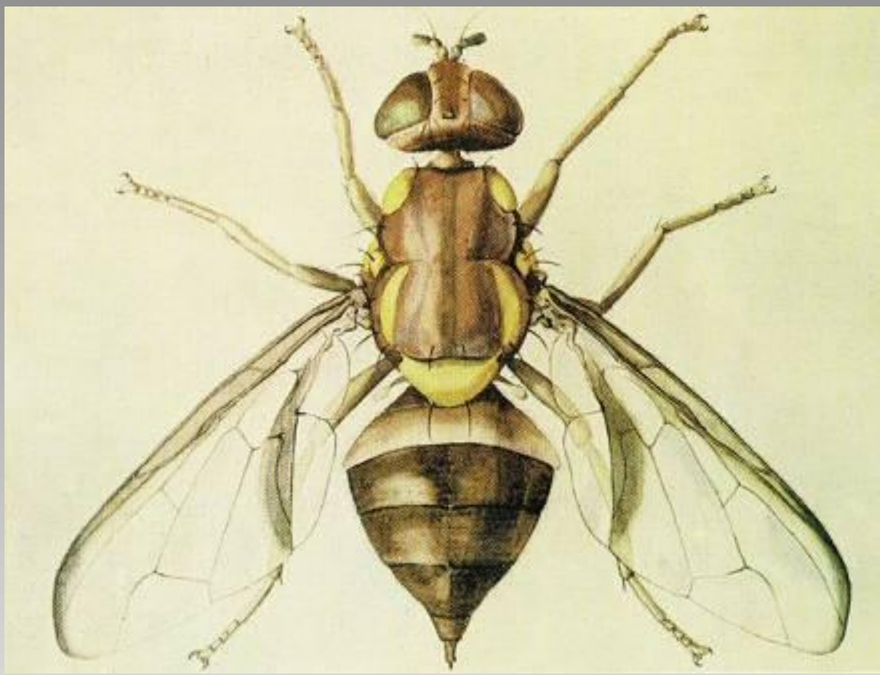
THREAT DATA

Queensland fruit fly

(*Bactrocera tryoni*)



www.pir.sa.gov.au/.../fruit_fly_identification

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Queensland fruit fly

(*Bactrocera tryoni*)

Queensland fruit fly (QFF) is one of the destructive pests for pome and stone fruits especially for citrus. The pest likes temperate to tropical climatic range. QFF attack a wide host range including cultivated and wild plant species belongs to 25 families. The pest well establishes in Australia and one of the serious pets for Qeensland horticultural industries.

Distribution: QFF is established in some parts of Queensland, New South Wales and Victoria of Australia. The pests were eradicated from other states of Australia. QFF eradication method was also successful in USA and South America. Therefore, these regions are free of QFF. No record of QFF in New Zealand, Papua New Guinea and Vanuatu Islands.

Host range: QFF is the most serious pest for Australian horticultural industries that attack all most all commercial fruit and vegetable crops. There are about 234 host species in 49 families that are porn to attack by this pest (Hancock et al. 2000). QFF also has a few wild host e.g. *Syzygium forte, Terminalia arenicola etc.*

Habitat: Areas of both cultivated fruits and vegetable crops.

Biology and Ecology: Unlike other fruit fly QFF does not breed continuously and the fly overwinter as adults. Under optimum conditions, a female can lay more than 1400 eggs during her lifetime. The total life cycle requires 2-3 weeks in summer and up to 2 months in fall. Adults occur throughout the year (Christenson & Foote 1960) and female have **4-5** overlapping generations in life time. Adult females lay eggs below the skin of host fruits and egg hatch within 1-3 days. The larvae feed on fruit juice for 10-21 days. Fruit damage cause by larvae and the infected fruits drop off the tree. The larvae come out from infected fruits under the tree and turn into pupa. The whole pupariation takes place into the soil under the infested host. The adult emerge after 1- 2 weeks (longer in cool climate) and it sits on healthy fruit and repeats the whole process again. Apparently, ripe fruit are preferred for oviposition, but immature ones may be attacked also and as many as 70 adults are found in a single infested fruits. QFF is a tropical species which would be unable to survive the winter in the EPPO region, except possibly in the south. Potential for population growth of QFF in Australia has been studied using CLIMEX model (Sutherst & Maywald 1991).

Symptoms: The flies attack fruit at different stages of maturity and the infested fruits drop off prematurely. Fruit attacked by QFF usually shows signs of oviposition punctures. Following oviposition there may be some necrosis around the puncture mark ('sting'). This is followed by decomposition of the fruit due to microbial infection. Fruit with high sugar content, such as peaches, will exude a sugary liquid, which usually solidifies adjacent to the oviposition site. Larvae bore through matured fruit and cause fruit to rot. Ripe fruit are more susceptible to attack then unripened and immature one.

Fig. QFF infested citrus fruits under the host plant

Ref.: www.bugsforbugs.com.au/library/fruit-fly-info

Affected plant stages: Fruiting stage and post-harvest

Affected plant parts: Mainly fruits

Affected Industries: Mainly horticultural industries

Resistant plant variety: No reports on QFF resistant plant varieties.

Affected time of the year: The largest populations of QFF occur in summer when there are more fruits on most trees.

Pest movement and Dispersal: *Bactrocera* spp (QFF) are good fliers and the adult can fly up to 50-100 km (Fletcher 1989). Adult flight and the transport of infested fruits are the main means of movement and dispersal to the uninfested areas. The eggs/larvae, borne internally in the infested fruits (visible to naked eye), can be dispersed in distanced area during the trade and by traveller. The insect pupae can also be dispatched through infested soil, gravel, water etc.

Disease Impact: QFF is considered one of the most devastating pests of fruit in areas where it occurs. QFF is a very serious pest of a wide variety of fruits and vegetables throughout its range and damage levels can be anything up to 100% of unprotected fruit. Under uncontrolled situation, in Australia every year A$100 million losses have been estimated by fruit fly and most this losses would cause by QFF.

Natural Enemies: Both parasitoids and vertebrates can reduce the QFF population by attacking larval stage. But the mortality trough fruit consumption by vertebrate can be very high as in the soil, either due to predation or environmental mortality (White and Elson-Harris 1994). Until now no biological agents are reported that can reduce the QFF population significantly (Wharton 1998).

Management: In conjunction with the post-harvest quarantine treatments, it is helpful to apply pre-harvest management practices to reduce QFF populations. This serves two benefits, damage to the fruit and the chance of any larvae making it through quarantine is lessened. Like oriental fruit fly in Hawaii, a number of methods may employ in attempts to reduce or prevent damage by this pest. They include: 1) mechanical control, 2) cultural control, 3) biological control, 4) post-harvest quarantine treatments and 5) chemical control.

- **Mechanical control:** Mechanical methods of controlling the oriental fruit fly include the use of protective coverings on the fruit and the destruction of adults by use of traps. Shrubs within 100 yards of larval hosts may be used advantageously in placing traps. The use of protective coverings is more effective and costly than the use of traps.

- **Biological control:** Several biological agents have tried to control QFF population in field conditions. Of these, only *Fopius arisanus* is capable of reducing the number of flies per fruit but had a little impact on the percentage of fruit damage (Waterhouse 1993).

- **Regulatory Control:** By placing high restriction on the import of susceptible fruit without strict post-harvest treatment by the exporter would be most effective way to control the entry of this pest in a new area. This may involve fumigation, heat treatment (hot vapour or hot water), cold treatments, insecticidal dipping, or irradiation (Armstrong and Couey, 1989). Recent work on hot water dipping was reported by Waddell et al. (2000). Heat treatment tends to reduce the shelf life of most fruits and so the most effective method of regulatory control is to preferentially restrict imports of a given fruit to areas free of fruit fly attack.

- **Cultural Control and Sanitary Methods:** One of the most effective control techniques against fruit flies in general is to wrap fruit, either in newspaper, a paper bag, or in the case of long/thin fruits, a polythene sleeve. This is a simple physical barrier to oviposition but it has to be applied well before the fruit is attacked. Little information is available on the attack time for most fruits but few *Bactrocera spp*. attack prior to ripening.

- **Chemical Control:** Although cover sprays of entire crops are sometimes used, the use of bait sprays is both more economical and more environmentally acceptable. A bait spray consists of a suitable insecticide (e.g. malathion) mixed with a protein bait. Both males and females of fruit flies are attracted to protein sources emanating ammonia, so insecticides can be applied to just a few spots in an orchard and the flies will be attracted to these spots. The protein most widely used is hydrolysed protein, but some supplies of this are acid hydrolysed and so highly phytotoxic. Smith and Nannan (1988) have developed a system using autolysed protein. In Malaysia this has been developed into a very effective commercial product derived from brewery waste.

Quarantine Risk: Very high - because it's very difficult to manage and have high potential to establish enormous population in other tropical areas (e.g. WA, Darwin) of Australia.

Probabilities of Entry: Very high - through a wide range of infested fruits carried by tourist, regular passengers and also via trade unless strict quarantine and phytosanitary restriction are applied on export fruits from the countries where this pest is established.

Possibility of Establishment: Very high - specially in Western Australia because of favorable climatic conditions along with a wide range of suitable host of this pest.

Environmental Impact: No environmental impact is to be expected since fruit trees are the main host of QFF and most unlikely the native plants of Australia would be affected by this insect.

Social Impact: High impact on backyard fruit trees to be expected and this will results negative impact on socio-economic condition of the society.

Pest Management cost: Since the fly can persist through out the season therefore, at least 3-4 times chemical treatments (bait spray) are required in a season. Assume this must be applied a minimum of three times per season. The tentative amount of bait spray (yeast autolysate) needed 1.2 L/ha and the cost is $10.00/L . In addition, vehicle, equipment and labour costs of $30/ha are assumed (labour = $15/hr, tractor and spray rig costs (ie. fuel, oil, maintenance) = $15/ha, time per hectare sprayed = 1hr/ha). It should be noted that the calculation of these costs is based on the bait spray cost published in the literature for other fruits. Depending on the other factors (e.g. rain) the total cost might be different.

Yield loss despite control efforts: Despite incorporating various control measures including bait spray into normal management practice, it is expected that a certain amount of loss will still occur through the effects of QFF. In literatures, there are no concrete figures on the yield loss despite of control efforts. However, based on biological nature of the pest and damage intensity on host, 5 to 20 per cent yield loss is expected under all control measures. Due to most favourable climatic conditions in WA, it is assumed that yield loss would be in the upper range compared to the other states in Australia.

Export revenue loss due to loss of Pest Freedom Status: Export losses result from QFF entering and becoming established in Australia would be at significant level. Australia's big fruit industries export various kinds of fruits that are susceptible to this pest. Therefore, the risk associated with the market loss is considered high. QFF causes damage to wide range of fruits that's price range is variable. This makes it difficult to predicting market losses that's highly subjective. It is conceivable that it may be in the order of 25%, but this is a highly subjective estimate. Hence, a variable estimate was assumed using a pert distribution with a minimum value of 0 per cent, a maximum value of 50 per cent, and a most-likely value of 25 per cent.

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THREAT DATA

Apple maggot

(*Rhagoletis pomonella*)

Enhanced Risk Analysis Tools

(Ref. http://www.agf.gov.bc.ca/cropprot/applemaggot.htm)

CRC10010

Enhanced Risk Analysis Tools

CRC PLANT biosecurity

Apple maggot

(*Rhagoletis pomonella*)

The apple maggot (*Rhagoletis pomonella*), also known as railroad worm, is a pest of several fruits, mainly apples. Apples affected by apple maggots are completely unsaleable. The apple maggot (*R. pomenella)*, is a native insect of North America and has historically been a pest of apples in the north eastern United States and eastern Canada. The adult form of this insect is about 3/16 of an inch long, slightly smaller than a house fly, with a white dot on its thorax and a characteristic black banding shaped like and "F" on its wings. The principal hosts of apple maggot are apple, crabapple and hawthorn trees, however it also occasionally attacks plum, cherry, peach and pear trees. It poses no threat to human health.

Distribution: Apple maggot is widely distributed in many states of USA and Canada. It is indigenous to North America and has been a serious pest of apples in Canada for over 100 years. It is now widespread throughout eastern Canada, with the exception of Newfoundland. It has restricted distribution Mexico. This pest is absent in both Central and South America. Apple maggot is not currently recorded in Australia and New Zealand.

Host range/Alternate host: Apple (*Malus domestica*), is the major commercial host of apple maggot. The pest also infests pears, plums, apricots, hawthorns and crabapples. The major natural hosts from which the pest populations have evolved are hawthorns (*Crataegus spp*.); *R. pomonella* is also recorded from some *Amelanchier, Aronia* and *Cotoneaster spp*. (all Rosaceae) (Bush, 1966).

Biology and Ecology: *R. pomonella* has only one generation a year. Females lay their eggs singly beneath the skin of the fruit. The larvae hatch 3-7 days later and tunnel into the fruit pulp. They complete their development within the fruit, taking anywhere from 2 weeks to several months to mature. Very rarely will larvae exit from hanging fruit. The infested fruit usually drops to the ground but the larvae remains in the dropped fruit until reaching maturity when they make an exit hole in the skin of the fruit and wriggle to the ground. Larvae then enter the soil where pupation occurs. They enter the soil to a depth of 2-5 cm, usually beneath the host plant. Pupae stay dormant over winter, and they may persist in the soil for several years. Adult emergence and may feed on insect honeydew and bird dung, reaching sexual maturity 7-10 days after emergence. As the flies mature and mate they respond more to oviposition-site stimuli, i.e., fruit shape and fruit odour. After mating, a single female fly is capable of laying more than 200 eggs in her lifetime. Adults usually die after 3-4 weeks but may live up to 40 days under field conditions (ref CPC).

Symptoms: *R. pomonella* burrow in all directions through the flesh of apples and small brown, decayed areas indicate sites where apple maggot eggs have been laid (fig. 1). When a single fruit is infested with several larvae, the pulp will be honeycombed with their burrows until it finally breaks down (fig. 2). Infested fruit are usually misshapen. Attacked fruit are pitted by oviposition punctures, around which some discoloration usually occurs.

Fig. 1 External evidence of infested fruit. Fig. 2 Larva and internal feeding damage with brown channels. (Photo sources: Agriculture & Agri-Food Canada, Research Branch, Ottawa and http://www.ipm.ucdavis.edu/PMG/R/I-DP-RPOM-CD.002.html).

Affected Plant Stages: Fruiting stage.

Affected Plant Parts: Fruits/pods.

Resistant plant variety: No report is available in the literatures on resistant plant variety against this pest.

Pest movement and Dispersal: Adult flight and the transport of infected fruits are the major means of movement and dispersal to previously uninfected areas. In general, *Rhagoletis* spp. are not known to fly more than a short distance; however, *R. pomonella* has been recorded moving up to 100 m in the presence of hosts and up to 1.5 km when released away from an orchard (Fletcher, 1989). In international trade, the major means of dispersal to previously uninfested areas is the transport of fruits containing live larvae. There is also a risk from the transport of puparia in soil or packaging with plants which have already fruited.

Natural Enemies: Up to 90% of larvae may be parasitised in *Crataegus* fruits (Gut and Brunner, 1994) in Washington State, USA. However, in a comparative study of parasitism levels in *Crataegus* and apple in Michigan, USA, Feder (1995) found only 46% and 13% parasitism, respectively. Allen and Hagley (1989) reviewed predators found in an orchard in Ontario, Canada, but indicated that the impact was probably very low.

Impact: *R. pomonella*, which primarily attacks apples, is the most serious fruit fly pest in North America, except for introductions of *Ceratitis capitata* (EPPO/CABI, 1996).

Detection and Inspection Methods: Traps that capture both sexes are based on visual attraction, or visual plus odour attraction. They are coated in sticky material and are usually either flat-surfaced and coloured fluorescent yellow to elicit a supernormal foliage response, or spherical and dark-coloured to represent a fruit; traps which combine both foliage and fruit attraction can also be used. The odour comes from protein hydrolysate or other substances emitting ammonia, such as ammonium acetate; for *R. pomonella* synthetic apple volatiles are also very effective attractants (Reissig et al., 1985). See Boller and Prokopy (1976) and Economopoulos (1989) for a discussion of these traps.

Management (ref. http://www.ipm.ucdavis.edu/PMG/r4300511.html):

In areas where apple maggot is established, the pest is managed with sprays of organophosphate insecticides targeted to the first emerging adult flies. Not all orchards require treatment. Use sticky traps for detection and treatment timing. If apple maggots are found in counties where it is not yet established, notify the county agricultural commissioner.

Biological Control: Because the apple maggot feeds within fruit, biological control agents have not been very effective.

(MMMMM) Organically Acceptable Methods: Baited sprays such as GF-120 are organically acceptable. Mass trapping with dark-colored, plastic sticky spheres (placed 1-2 per tree) has been used by organic growers on in the eastern U.S. to greatly reduce damage. Replace traps when sticky material is no longer effective.

Monitoring and Treatment Decisions: Emergence and dispersal of adult flies must be carefully monitored to effectively time treatments. Sticky traps, including yellow rectangles and red spheres, are both used in other areas to monitor adults and time treatments. Unfortunately, only provisional economic thresholds are available for apple maggots, even in areas where it has long been a pest. You can detect the first emergence of adults by hanging yellow sticky traps in abandoned orchards or unsprayed apple trees in infested areas. To detect the beginning of egg laying, hang red sticky spheres in apple trees, then treat as soon as the first fly is found. In Oregon, where some orchards are now being treated regularly for apple maggots, the first maggot spray is applied 7 to 10 days after the first fly has emerged. Later sprays follow at 10- to 14-day intervals as long as adults are active and are being caught in traps.

Phytosanitary Risk: *R. pomonella* has already shown its capacity to spread from its original range in eastern North America, to western states of the USA since 1979 (Foote et al., 1993) and it represents the most serious potential new tephritid pest for many apple producing temperate areas. Canada considers it as an internal quarantine pest (absent from the fruit-producing areas of British Columbia). *R. pomonella* is of quarantine significance for COSAVE, EPPO and OIRSA. Consignments of apples from countries where *R. pomonella* occurs should be inspected for symptoms of infestation and those suspected should be cut open in order to look for larvae. For example, EPPO recommends that such fruits should come from an area where *R. pomonella* does not occur, or from a place of production found free from the pest by regular inspection for 3 months before harvest. Fruits may also be treated, but specific treatment schedules have mostly not been developed for *Rhagoletis* spp. Schedules developed for other fruit flies on apples will probably be adequate, for example treatment in transit by cold treatment (13, 15 or 17 days at 0.5, 1 or 1.5°C, respectively) (USDA, 1994). Ethylene dibromide was previously widely used as a fumigant but is now generally withdrawn because of its carcinogenicity; methyl bromide is less satisfactory, damaging many fruits and reducing their shelf life, but treatment schedules are available for apple (for example, 32 g/m³ for 2 h at 21-29.5°C; USDA, 1994). Plants of host species transported with roots from countries where *R. pomonella* occurs should be free from soil, or the soil should be treated against puparia, and should not carry fruits. Such plants may be prohibited importation.

Quarantine Risk: Very high - because it's an indigenous to North America, major apple growing areas. The pest has high potential to establish enormous population in various apple growing regions in Australia.

Probabilities of Entry: High - through a wide range of infested fruits carried by tourist, regular passengers and also via trade unless strict quarantine and phytosanitary restriction are applied on export fruits from the countries where this pest is established.

Possibility of Establishment: High - because of favorable climatic conditions and a suitable host of this pest.

Environmental Impact: Low - environmental impact is to be expected low since fruit trees are the main host of apple maggot and most unlikely the native plants of Australia would be affected by this insect. However, indirect environmental impact may come from the insecticides use to control the pest.

Social Impact: High - impact on backyard fruit trees to be expected high and this will results negative impact on socio-economic condition of the society.

Pest Management cost: High **-**since the fly can persist in soil through out the season therefore, at least 7-10 times chemical treatments (depending on chemicals) are required in a season both in soil and trees. Assume this must be applied a minimum of seven times per season (ref. http://extension.oregonstate.edu/catalog/html/fs/fs271). The effective chemicals are Calypso 480 SC, Diazinon, Imidan WP, Sevin ZLR, Surround WP and Zolone Flo for apple maggot (http://www.agf.gov.bc.ca/cropprot/tfipm/applemaggot.htm). Depending on the chemicals used, the tentative cost is $70-80/ha (http://www.oktreefruit.com/Newsletters/costcomparison06.pdf). In addition, another $100/ha is the application for a single spray. The total cost would be $170 -180/ha for a single spray and it needs at least **7 spray** i.e. **$1190-1260** for each year. Depending on the other factors (e.g. rain) the total cost might be higher.

Yield loss despite control efforts: Based on biological nature of the pest and damage intensity on host, 5 to 20 per cent yield loss is expected under all control measures. Due to warm climatic conditions in Australia, it is assumed that yield loss would be in the upper range compared to the other cold-climate countries.

Export revenue loss due to loss of Pest Freedom Status: Export losses result from apple maggot entering and becoming established in Australia would be at significant level. Australia's big fruit industries export various kinds of fruits (specially apple) that are susceptible to this pest. Therefore, the risk associated with the market loss is considered high. Including apple, other fruits (pear, cherry, plum etc.) are also vulnerable to this pest. This makes it difficult to predicting market losses that's highly subjective. It is conceivable that it may be in the order of 25%, but this is a highly subjective estimate. Hence, a variable estimate was assumed using a pert distribution with a minimum value of 0 per cent, a maximum value of 50 per cent, and a most-likely value of 25 per cent.

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THREAT DATA

Cotton leafworm

(*Spodoptera littoralis*)

Source: http://www.inra.fr/internet/Produits/HYPPZ/RAVAGEUR/6spolit.htm

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Cotton leaf worm

(*Spodoptera littoralis*)

Spodoptera littoralis is an insect pest. It's also known by several English and local names and among these cotton leafworm or leafworm are very common. *S. littoralis is easily confused with S. litura* by many researchers. Both these species are polyphagous (Brown and Dewhurst, 1975; Holloway, 1989) and very close to each other. This insect is originally from Egypt and therefore it's also known as Egyptian cotton leafworm. It's a serious pest of many vegetables, ornamentals and other economic important plant species.

Distribution: *S. littoralis* is widely distributed in many African countries. It also has restricted distribution in some Asian and European countries. In North America, the pest has been reported in Hawaii only. Australia and New Zealand are free from *S. littoralis* (ref. CPC, 2008).

Host range/Alternate host: *S. littoralis is a* polyphagous species with wide host range that includes over 40 families. Among them some are major, minor and wild hosts. Of the major host attack by this pest are cotton, potato, tomato, pea, bean, cowpea, alfalfa, soybean, clover, avocado, cabbage, tea, pomegranate and so on. According to Salama *et al*. (1970) at least 87 species of economic importance are affected by this pest.

Biology and Ecology: The adult moths (*S. littoralis*) appear in early spring and merge at night time. After 2 -5 days of emergence, the female moth lays **1000 – 2000 eggs** in egg masses of 100-300 on the lower surface of younger leaves or upper parts of the host (Khalifa et al. 1982). The eggs hatch in about 3 to 4 days at 25 to 28^{0}C depending on host. At lower temperatures, it takes longer time. The young larvae feed in groups at night or early in the morning and shelter in the soil during the day, like butterflies. After about 2 weeks, pupation takes place in soil below 2 to 5 cm in depth. The adult moth occurs in less than a week and it lives about 4 to 10 days. The completion of whole cycle takes about 5 weeks depending on host and other environmental factors. The number of generations in it's life cycle also vary depending on geographic regions and host types. Total of **4 generations** (with possibility of 7) is reported by Nakasuji (1976) in Japan but studies in Egypt indicate that there are **7** overlapping generations of *S. littoralis* in a year when feeding on cotton (El-Shafei et al., 1981; Khalifa et al., 1982). The moth overwinter as a pupa in the soil.

Symptoms: In most crops, extensive feeding by larvae cause severe damage that lead to complete stripping of the plants. Caterpillars are nocturnal, i.e. they feed at night time and during the day it can be found at the base of plants or under pots. They mainly feed on leaves that cause "windows" in the leaves. In severe stage with a larger numbers, it can completely detfoliate the plants (fig. 1). In case of cotton, the larvae feed on the leaves creating large holes with an irregular shape in between the bigger veins. The larvae may also bore into the bud or young boll and consume the whole contents, causing them to be shed or dry up (Bishari, 1934). Stems, buds, flowers and fruits may also be damaged. The red-brown pupae form in a loose cocoon just under the surface of the soil, and are up to 2 cm long.

Fig. 1. *S. littoralis* feeding on a leaf (left) and it's egg mass on leaf (right, ref. CPC).

Ref. http://www.ice.mpg.de/bol/home/homefoto_en.htm

Affected plant stages: Mostly all stages like seedling, flowering, fruiting and vegetative stages.

Affected plant parts: Fruits/pods and leaves.

Resistant plant variety: In literature, no report is available regarding resistant plant varieties against this pest.

Affected time of the year: The largest populations of *S. littoralis* are most likely to occur between early spring and summer.

Pest movement and Dispersal: Adult moth of S. *littoralis,* is able to fly long distance (1.5 km) during night that enhance dispersion on different hosts (Salama and Shoukry, 1972). During international trade, the eggs or larvae can be transmitted with planting material, cut flowers or vegetables. For example, both *S. litura and S. littoralis* were introduced in the UK probably through imported commodities (Aitkenhead *et al*., 1974; Hachler, 1986).

Disease Impact: *S. littoralis* is one of the most destructive agricultural pests within its subtropical and tropical range. It can attack numerous economically important crops throughout the year (EPPO, 1997). Since it has a wide host range therefore the economic damage cause by this pest is very significant. The severity of damage depends on host species and regional climatic factors. In the literature, lack of mathematical figure on damage caused by this pest makes it difficult to estimate the exact economic loss in different host. However, the data are available in the literatures on damage caused by *S. litura* in different crops. For example, 42% of tomato (Srivastava *et al*., 1972), 23 to 50% of tobacco (Patel *et al*., 1971) and 10% of *Colocasia* and *Capsicum* yield loss (Nakasuji & Matsuzaki, 1977) were reported and based on these figures the economic loss by *S. littoralis* can be estimated roughly.

Natural Enemies: A list of pathogens, parasitoids, and predators are available in crop protection compendium (CPC) for *S. littoralis*. Most of these natural enemies attack larval stage of the pest. Most of this kind of work carried out in Egypt and Spain.

Management

Biological Control: Numerous studies have been carried out on possible biological control of *S. littoralis* but none of them were found that effective in field level. For example, Parasitic nematodes such as *Neoaplectana carpocapsae* have also been evaluate but direct use of these biocontrol agents has not been commercailised. Similarly, treatment with *Bacillus thuringiensis* has been used (Navon et al., 1983), but only some strains are effective as *S. littoralis* is resistant to many strains (Salama et al., 1989).

Chemical Control: Most of chemical control work on *S. littoralis* has been extensively reported in Egypt, especially in relation to cotton. The chemical methyl-parathion was found to be effective against *S. littoralis* until 1968 but then resistance to this compound developed. Since then, numerous other organophosphorus, synthetic pyrethroid and other insecticides have been used, with appearance of resistance and cross resistance in many cases (Issa et al., 1984a; 1984b; Abo-El-Ghar et al., 1986). However, compulsory limitation of the application of synthetic pyrethroids to one per year on cotton in Egypt has stopped the appearance of new resistance (Sawicki, 1986). Chemicals used against species of Spodoptera also include insect growth regulators. There is interest, especially in India, in various antifeedant compounds or extracts, and in natural products, such as azadirachtin and neem extracts.

Integrated pest management (IPM): IPM techniques are applied against *S. littoralis* on cotton in Egypt that causes mating disruption of the insect. Number of studies have been carried out by different researchers (Campion and Nesbitt, 1982; Hosny et al., 1983; Campion and Hosny, 1987; McVeigh and Bettany, 1987; Souka, 1980) and evaluated their findings but none of their techniques has been widely applied in the field.

Quarantine Risk: Low - the possible path ways of entry through trade and tourism could easily be missed out due to small size of its eggs that can be attached to the commodities. *S. littoralis* is listed as A2 quarantine pest by EPPO (OEPP/EPPO, 1981).

Probabilities of Entry: Low/moderate - the possible path ways of entry through trade and tourism is low as leaf is main infested plant parts that usually not involve in trade and also not carried by tourist.

Possibility of Establishment: Moderate – wide host range host capacity (both cultivated and wild plant species) of *S. littoralis* makes possibility of finding a proper host after entry into Australia. This also support by a suitable climatic condition for the pest in many parts of the country.

Economic Impact: High - based on pest biology, multiple host rang, the nature of damage reported by *S. littoralis* in other countries and the effectiveness of management practices.

Environmental Impact: Low to moderate - the applied chemicals will cause environmental pollution that imbalance the ecosystem. In addition, some native plants might be a new host for *S. littoralis.*

Social Impact: Moderate – since *S. littoralis* is capable of infecting various agricultural crops that are valuable to the local farmers; therefore, crop damage by this pest will bring a negative economic impact in the infested region.

Pest Management cost: Low/moderate – The total production cost increases are to be expected from the chemical application in order to control *S. littoralis* in the field. Based on some commonly use insecticides available in literature and their effective doses (~1.5L/ha) and cost (~$50.00/L) It's assumed that total cost would be $75.00 (chemical)

+ ~$100.00 (application cost) i.e. the total cost would be $175.00/ha for a single spray. Depending on climatic conditions it may requires at least 2 spay in one season for the effective control, therefore, the total cost would be 2 times of single spray i.e. $**350/ha**. The calculation is based on Farm Budget Guide 2001. For this pest control cost/ha may vary from crop to crop depending on number of spay. For examples, in case of pomegranate and tea plants the costs were calculated $800 and $500/ha respectively.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 5 – 15% for individual crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low/moderate - export losses will result from *S. littoralis* entering and becoming established in Australia. EPPO has listed *S. littoralis* as an quarantine pest and it can easily be carried by agricultural commodities during the trade. Therefore, the presence of this insect will hamper our export markets for a number of agricultural crops that involves multiple industries. It is difficult to form an estimate of the increment to the long-run export price of various products attributable to *S. littoralis* freedom. It is possible that it may be in a range of 10 to 20% for each industry including potato, but this is a highly subjective estimate.

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THREAT DATA

Taro planthopper

(*Tarophagus proserpina*)

Source:http://taropest.sci.qut.edu.au/LucidKey/TaroPest/Media/Html/Arthropods/Tproserpina/Tproserpina6.htm

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Taro planthopper

(*Tarophagus proserpina*)

Taro planthopper also known as taro leafhopper has at least three different species *T. colocasiae, T. persephone and T. proserpina* and taro is the main host of all three species. They are usually fond in most of taro growing regions.

Distribution: Three species of taro planthopper is widely distributed from East Asia (including Taiwan and the Ryukyu Islands of southern Japan), through Southeast Asia to Australia (Northern Territory and Queensland), Papua New Guinea, New Caledonia, and many Pacific island countries (Gagne 1982, Zettler et al. 1989, Asche and Wilson 1989). *T. proserpina* has a relatively narrow distribution extending from eastern New Guinea to Polynesia (Remote Oceania) but not reported in Australia yet. However, the species *T. colocasiae* is reported for the first time in Australia in 1989 (Asche and Wilson 1989). .

Host range/Alternate host: Taro planthoppers (*Tarophagus spp*.) is restricted to the monocotyledonous family Araceae and cultivated taro (*Colocasia esculenta*) is one of the members of this family. All three species exclusively or primarily associated with cultivated taro. In the Pacific Islands occasionally *T. proserpina* can be found in far fewer numbers on Alocasia and Cyrtospermum. Hosts other than Araceae are not likely to be attacked by these planthoppers.

Ecology and biology: Taro planthoppers feed only on taro and the biology of all three species is rather similar. The entire life history of a taro planthopper occurs on taro leaves, above ground. The female lay eggs serially in rows of a longitudinal slit cut into the plant tissue by the saw-like ovipositor of the females, often two eggs at a time (Waterhouse and Norris, 1987) and **10-20 eggs per slit**. The eggs are preferably laid in the midrib, petioles, or petiole bases of taro plants. The eggs hatch after 14 days into creamy white nymphs. The nymphs then become adults, which are black with a big white patch. The adults are short-winged and usually unable to fly in most of the time. Long-winged forms are often present in cooler periods or if the plants are beginning to mature and die. Nymphs and adults tend to congregate on the underside of leaves and on the unfurled central leaf. The insects normally move sideways, and both adults and nymphs hop easily if disturbed. The life duration of adults in field condition is not known but in the laboratory condition it may exceed 3 weeks. In most species, there is **one generation per year**, even in the tropics (O'Brien and Wilson, 1985).

Symptoms/Damage: Taro planthoppers feed mostly on taro leaf (fig. 1), Heavy infestations of taro planthopper cause plants to wilt and, in exceptional cases, to die. Sap sucking and the laying of eggs cause sap exudation, which forms small red encrustations on the petioles, particularly at the base. Older leaves are affected by severe infestations during dry weather: the petioles bend down giving the plants a splayed appearance, and the leaves die prematurely. Taro planthoppers may involve in some viral disease transmission. For example, alomae and bobone virus diseases reported from Solomon Islands and Papua New Guinea.

 

Figure 1. Taro leaves with taro planthoppers on them (Source:TaroPest: an illustrated guide to pests and diseases of taro in the South Pacific).

Affected plant stages: Vegetative growing stage.

Affected plant parts: Leaves, stems and whole plant.

Affected Industries: Mainly taro industry

Resistant plant variety: No resistant varieties for taro are available yet.

Pest movement and Dispersal: The dispersion of taro planthopper is facilitated by the movement of infested taro plants. Every effort must be made to avoid the transport of infested plant material across national and international boundaries. Longitudinal brownish or yellowish egg streaks can be visible in the midrib of the taro leaves. Similarly, third to 5th larval instars and adults can readily be detected undersides of the leaves and the stems. The taro root is usually not affected.

Disease Impact: Taro planthoopers associations with taro plant are important for many reasons, most notably because insects are often major pests and can also transmit various diseases. However, the economic impacts of pest on crops in the literate are lacking.

Management

Biological control: The egg predator *Cyrtorhinus fulvus* has successfully controlled *Tarophagus spp*. in many parts of the Pacific (Waterhouse and Norris1987), but the introduction of this predator was not successful in a few cases; e.g., Hawaii to Tahiti, Samoa to the Solomon Islands, and Fiji to Tuvalu (Asche and Wilson, 1989). *C. fulvus* is unlikely to reduce populations sufficiently to prevent the spread of alomae and bobone virus diseases.

Cultural Control: By planting clean stocks a considerable reduction of taro planthopper infestation is achieved. As the pest is unable to fly and thus limited in their dispersal ability. Thus infestation in new plantings is avoided if the clean stocks are planted away from old infested plantings. Locally, only healthy or disinfected taro stems should be used for crop establishment. Burning of infested fields is not recommended as natural enemies will also be destroyed along with the pests.

Chemical Control: Chemical control of taro planthopper has been attempted in Fiji and Samoa by spraying the undersides of leaves and the stems of the taro plants with malathion, carbaryl, acephate and diazinon (Swaine, 1971). However, the use of pesticides should be limited or avoided due to the risk of environmental pollution and interference with natural enemies of the taro planthopper. Pesticides should only be used when there are no natural enemies present in the field. For serious outbreaks, however, the following are registered for use in American Samoa and recommended by the Land Grant Extension Service.

Malathion: 2 ml/L (1-2 tsp/gal) of 55% a.i.; spray 1-2 L (1/4-½ gal) per 100 ft^2 (6).

Diazinon: 0.5-1 ml/L (½-1 tsp/gal) of 48% concentrate or 4.5 g/gal of 50% WP (6).

Quarantine Risk: Moderate. Although taro planthopper has restricted host capacity and causes less damage to the crop but the chance of viral spreading through this pest makes it more quarantine concern compared to others once it establish in Australia.

Probabilities of Entry: Low -. Taro planthopper has selective host (mainly taro) and it's mainly found in leaf areas (not in corm) where the pest is easy to spot. Moreover, export market is mainly includes taro corm not plant leaf. Therefore, the pest has low possibility of entry via international trade and tourist under normal quarantine procedure.

Possibility of Establishment: Moderate – Following successful entry taro planthopper may find a suitable host with favourable climatic conditions to establish in some parts of Australia.

Probabilities of Entry and Establishment: Low – In spite of suitable climatic conditions and host for taro planthopper, the selective host capacity of the pest is going reduce the chance of finding a host quickly after its successful entry in Australia.

Economic Impact: Low - Planthopper is not a serious pest unless the insect is responsible for spreading some viral diseases which is not confirm yet. The insect itself cause less crop damage because of its low fecundity, unable to fly and selective host range. The effective management practices are available to keep the insect population low in field conditions.

Environmental Impact: Low – Both biological and cultural methods are successfully used by growers to manage the crop damage cause by planthopper in the field. Only in case of pest severity, they use some chemicals; therefore the environmental pollution from chemical application would be negligible.

Social Impact: Negligible – Selective host range, low fecundity, less spreading capacity of planthopper and it's available control measures will allow the local growers to mange the pest successfully.

Pest management cost: Low – depending on pest severity the management cost may vary from $100 - $200/ha. This cost excludes involvement of any biological control and or resistant plant varieties. Effective and established control practices (both cultural and chemical) are available for taro beetle. However, the management with cultural practice could be more expensive in case pest severity.

Yield loss despite control efforts: Based on pest biology, available control measures and the damage severity, the total yield loss assumed to be between 3 – 10% for individual crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low/Unknown – although taro planthopper possess low risk of dispersion via international trade however, doubt of spreading some viral diseases by this insect are the main concerns in export market.

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THREAT DATA

False codling moth

(*Thaumatotibia leucotreta*)

http://www.padil.gov.au/viewPestDiagnosticImages.aspx?id=314

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False codling moth

(*Thaumatotibia leucotreta*)

Thaumatotibia leucotreta is a significant pest of both fruit trees and field crops in Africa (CIE 1976, Zhang 1994). Recently, this pest is also known as *Cryptophlebia leucotreta* (Komai 1999). The most common English name is false codling moth (FCL). It is endemic to sub-Saharan Africa and is classified as a quarantine/phytosanitary pest by many of the export markets of South African fruit. The chemical control of FCL is difficult because of its wide host range and biology of infection. Therefore, FCL is considered one of important pest in agriculture.

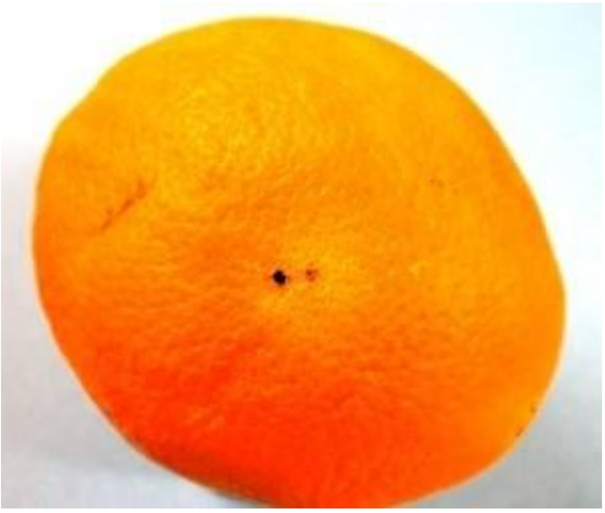
Distribution: FCL is native to the Ethiopian zoogeographic province and occurs throughout sub-Saharan Africa and the neighbouring islands of the Indian and Atlantic Oceans (CIE 1976, CAB 2000). The pest feeds on a broad spetrum of wild and cultivated host plants in these areas. Climates in the area occupied by this pest can be characterised as tropical, dry or temperate (CAB 2000). FCL is an important pest in all major citrus and avocado areas in the Republic of South Africa (Newton, 1998). So far FCL has not yet recorded in Europe, North America, Asia and Australasia (EPPO, 2006; CPC 2007.)

Host range/Alternate host: FCL has a wide host range that includes both tree and field crops. More than 70 plant species has been recorded as a host of this pest and some of them are *Olea europaea subsp. europaea* (olive), *Punica granatum* (pomegranate), *Camellia sinensis* (tea), *Abutilon hybridum* (Indian mallow), *Ananas comosus* (pineapple), *Annona muricata* (soursop), *Averrhoa carambola* (carambola), *Capsicum* (peppers), *Ceiba pentandra* (kapok), *Citrus*, *Coffea arabica* (arabica coffee), *Gossypium* (cotton), *Litchi chinensis* (lichi), *Mangifera indica* (mango), *Persea americana* (avocado), *Prunus persica* (peach), *Psidium guajava* (guava), *Ricinus communis* (castor bean), *Sorghum bicolor* (sorghum), *Zea mays* (maize).

Habitat: Areas of both cultivated and wild host plants

Biology of the Pest: The biology of this insect on pomegranate, tea and olive has not been reported. FCM is an internal fruit feeding moth that does not undergo diapause and may be found throughout the year in warm climates on suitable host crops. The female moth lays **100-400 eggs** by night, usually singly on fruit surface. Newly hatched larvae move around on the fruit surface searching for a suitable place to penetrate the fruit. The young larvae are creamy-white with a dark brown to black head. As they age, larvae darken through off-white and finally a pink body colour. The larvae develop inside the fruit until maturity. Mature larvae leave the fruit and pupate just under the soil surface. Pupae are dark brown and about 10mm long and enclosed in a cocoon which incorporates soil and leaf litter particles when being spun. The development time for each stage varies considerably with temperature and **5 generations** per year is recorded in South Africa (Daiber 1980). Populations increase towards late summer and then gradually decline with the onset of low winter temperatures.

Symptoms: The ovipositor scar where egg is laid is often the first evidence of infestation. With careful inspection number of tiny fresh holes can be visible on fruit surface through which larvae penetrate inside the fruit. Sometimes a few granules of excreta can be found around a fresh penetration hole or a mass of excreta can be found around older penetration holes as it continuously exudes form the hole as the larva feeds inside the fruit. The area around the penetration hole can become sunken and brown as the damaged tissue decays. Infestation can be identified by the brown spots (fig. left) and dark brown frass on the surface of infested fruits (Blomefield 1978). Larvae are quite visible following the cut of severely infested fruits (fig. right). The damaged fruit is susceptible to rot and drop prematurely.



FCM infested fruit with larval escape hole (black dot).

Ref. http://www.insectimages.org/browse/detail.cfm?imgnum=5137006

Fig. (right) FCM larva in infested fruit

Ref. http://oldwww.ru.ac.za/academic/departments/zooento/STUDENTS/Sishuba/nomahlubi.html

Affected plant stages: Fruiting stage

Affected plant parts: Mainly fruits and other reproduction parts like maize ears (Whitney, 1970), cotton bolls (Nyiira, 1974) etc.

Affected Industries: Both susceptible fruit and field crop industries.

Resistant plant variety: No reports are available on resistant/susceptible plant varieties against CFM in literature.

Affected time of the year: Mostly throughout the year.

Pest movement and Dispersal: Eggs and larva (visible to naked eye) can be carried out by the fruit/flowers/inflorescences/cone during trade/transportation.

Impact: The FCM fly is considered the most devastating insect pest of citrus in African region. The broad ranges of host plants, together with the mild tropical and subtropical winters, ensure that the pest is an all-year-round threat to crop hosts in most areas (Newton, 1998). The insect is capable to breed throughout the year in orchard with a continuous supply of fruit. Up to 50 eggs were counted on a single fruit and the in general the damage was estimated at approximately 80% (Joubert & Du Toit, 1993). FCM infestations lead to premature fruit drop and also left whole on the fruit surface that reduce the market price. The degree of damage is highly variable from orchard to orchard, host to host, location to location and from season to season. For example, 42 and 90% cotton losses reported in Uganda Reed (1974), up to 28% losses of late peach crop reported in South Africa Blomefield (1989) and citrus crop loss can be as high as 90% reported by Begemann *et al*. (1999).

Natural Enemies: Many natural enemies of FCM have been recorded and a review is given by Newton (1998). *Trichogrammatoidea* egg parasitoids appear to have the most significant impact. How many of these parasitoids are present or effective against FCM in fruit orchards has not been determined.

Management: FCM management is difficult because of its wide host range and potential for reinfestation (CABI, 2000). Internal feeding natures of CFM also protect the larvae from chemical application in the field. Parasitoids have been identified but are unlikely to be a cost effective control strategy.

Cultural control: Vineyard sanitation is important and contributes greatly to suppression of the FCM population, as well as other pests such as fruit flies. Remove old fruit remaining on trees following harvest and destroy all fruit that are on the ground by either burying at least 500 cm deep, or taking to the landfill. Extremely high FCM populations can occur in unmaintained ornamental situations. These can be a significant source for invasion of commercial groves. An area-wide approach is needed to reduce FCM densities where commercial plantings are near ornamental or unmaintained trees.

Chemical control: Chemical control of the FCM has proved to be of little practical value because it is expensive, liable and to lead to development of both pesticide resistance in the moth and unacceptable chemical residues on export fruit. Even repeated insecticide applications can be ineffective because eggs are laid continually during the fruiting season and also because other life stages, including the larvae that bore into fruit, are difficult to reach as targets (Catling *et al*., 1974). Apart from chemical control, contemporary methods of suppression, such as mating disruption and sanitation, have met with little practical success (Newton, 1989).

Post harvest control: Fumigation with ethylene dibromide (2 hrs @ 16 mg/L) combined with a cold treatment (21 days at 51°F [11C]) can control *T. leucotreta* in infested citrus (Schwartz and Kok 1976). Cold treatments of 31°F (-0.5C) for 24 days are effective at eliminating pupae (Myburgh and Bass 1969).

Quarantine Risk: .Moderate – internal inhabitant nature and diverse host of CFM make it easy to spread and establish in new areas. Moreover, CFM is also very destructive pest for a number of commercial fruit plants.

Probabilities of Entry: Moderate – internal feeding nature and diverse host capacity of FCM attribute in escaping of normal quarantine during transport and make moderate chance of entry even under proper quarantine measure

Possibility of Establishment: High – multiple host rang (both commercial and wild species) enhance scope of finding proper host following entry and then favourable climates encourage even further to establish FCM in Australia.

Probabilities of Entry and Establishment: Moderate – because of both suitable host and environment in Australia for FCM.

Economic Impact: High - based on pest biology and the damage severity in a number of commercial as well as native species reported in the literatures by CFM. Unavailable of resistant plant species and effective control measures are also important issues in the economic impact by CFM.

Environmental Impact: High – divers host range and ineffective chemical control measures encourage both commercial and residential growers to apply more chemicals that cause environmental pollution. Populations of wild and endangered plant species could be severely threatened or extirpated if CFM adapt to feeding on them.

Social Impact: Moderate – depending on infestation, CFM could cause negative impact on local industries by attacking number of commercial farms together. Absence of effective chemical control for CFM is more concern specially in areas where no biological enemies of CFM are present. Therefore, social impact of this pest may vary from low to moderate following its establishment in Australia.

Pest management cost: High – depending on crops, the pest severity and control measures uses the management cost may vary from **$2000 – $4000/ha** This includes some commonly used chemicals ($70-80/ha) (http://www.oktreefruit.com/Newsletters/costcomparison06.pdf) plus application cost ($100/ha). Since FCM can persist throughout the year therefore, the chemical spray should be carried out at every **6-7 days interval** from the early season till harvesting time. Assume it's a minimum of **12-15 times** per season. This cost excludes involvement of any biological control and or resistant plant varieties. No effective and established control practices are available for CFM. Management with cultural practice could even be more expensive in case of pest severity. However, the cost/ha also vary from crop to crop depending on number of spray. For example, in case of tea the costs was calculated about $700/ha.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 15 – 30% for individual crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: High (30 - 80%) – dispersion possibility of CFM during international trade and its diverse host range and biology of the pest are the main concerns in export revenue loss.

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THREAT DATA

Black twig borer

(*Xylosandrus compactus*)

http://www.forestryimages.org/browse/detail.cfm?imgnum=5007015

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Black twig borer

(*Xylosandrus compactus*)

The black twig borer, *Xylosandrus compactus*, is native to Asia but it has spread in many coffee growing areas of the world where it has caused significant damage to the crops. The beetle infests healthy plants and spends most of their lives inside the host plant. The black twig borer is very small, dark and more or less oval in top view (figure in the cover page). They feed on ambrosia fungus and are called ambrosia beetles. *The beetle* is familiar more than one with other scientific and English names (ref. CPC).

Distribution: Asia originated *X. compactus* reported to many Asian, African, North American, Central American, South American countries. In Oceania, it has been reported in Fiji, unconfirmed report in New Zealand but no report from Australia yet. There are unpublished records from Brunei Darussalam, Christmas Island and Malaysia (Sarawak) (RA Beaver, Chiangmai, Thailand, personal communication, 2004) (ref. CPC).

Host range: The main economic host of *X. compactus* is coffee. In Japan, *X. compactus* is a pest of tea (Kaneko et al., 1965). It is also a pest of avocado and cocoa in South-East Asia and elsewhere (Kalshoven, 1958; Browne, 1961; Beaver, 1976; Waterhouse, 1997; Nair, 2000; Matsumoto, 2002). Over 225 species of plants, belonging to 62 families, are susceptible (minor host) to X. compactus (Ngoan et al., 1976). Browne (1961) remarked that X. compactus does not appear to be highly host specific in its natural mixed-forest habitat, and it is only when it finds special conditions of concentrated cultivation that it tends to be a pest.

Wild hosts: *Caesalpinia kavaiensis*, *Colubrina oppositifolia*, *Dalbergia* (rosewoods), *Eusideroxylon zwageri* (billian), *Shorea*.

Habitat: Agriculture areas, natural forests, planted forests.

Biology of the Pest: The black twig borer, *Xylosandrus compactus*, is one of the few ambrosia beetles that attack healthy plants. Only adult females initiate infestation of the host plant. The male beetles are flightless and remain solely in brood galleries. This beetle is very small, dark and more or less oval in top view. The largest specimens are just over one-sixteenth inches long. The life cycle of the black twig borer is completed in about a month. Female beetles attack twigs or branches and bore in to the pith. Black twig borers are capable of laying eggs without mating (parthenogenesis). After the females bore into a twig, they form a small chamber in which the mostly female eggs are laid. The tiny eggs (less than 1 mm long) are smooth, white ovals laid over a period of several weeks. They hatch three to five days after being laid. Larvae are grubs, white and legless. The tiny grubs feed on the fungi that grow on the walls of the brood chamber. The grubs pupate and then (if males happen to have developed) the new beetles mate before leaving the twig to infest new twigs. The pupae are initially white, changing to light brown with black wings (female) near maturity.

This process takes at least 6 days. Female adults, initially light brown, turn shiny black in 3 to 4 days; females are 1.6-1.8 mm long (about 1/16 in). Males are about half as long and incapable of flight. After emerging from the pupal stage they turn from light brown to reddish brown in 3 to 4 days. If the twig is small, only one female will attack it. If the twig is more robust, up to 20 females will attack it. In the summer it takes about a **month from egg to adult beetles (about 10 generation/year with overwintering period)**. In the winter, development is much slower. The adults overwinter inside the damaged twigs.

Disease Symptoms: Leaves, stems and whole plants exhibit different symptoms following infected by *X. compactus*. The typical host symptoms that characterise *X. compactus* infestation are necrosis of the leaves and stem extending from the entrance hole (fig. A) distally to the end of the branch. Flagging of branches occurs about 5-7 days after initial tunnelling and gallery formation (fig. B). Wilting of twigs and branches usually becomes evident within weeks of infestation. The entrance holes are small (0.8 mm diameter) and are located on the underside of branches. Cankers, 10-210 mm long, are commonly seen around the attacked areas of larger twigs and branches (Dixon and Woodruff, 1983). A whitish pile of dust from boring may be seen at each hole.

Fig. A). Small attack-emergence holes   Fig. B). Infested twig with tunnel

Affected Plant Stages: Flowering stage, fruiting stage, seedling stage and vegetative growing stage.

Affected Plant Parts: Leaves, stems and whole plant.

Affected Industries: Tea, coffee, citrus, avocado, agricultural and natural forests etc.

Resistant plant variety: No information is available in the literature on resistant plant variety for *X. compactus.*

Pest identification: "Black twig borer is a very small (1/16 inch), shiny, black, cylindrical beetle. Twig entrance holes are about 1/32 inch in diameter and usually found on the lower surface of the twig. Eggs are extremely small, oval, white and translucent. Black twig borer grubs are white and legless. The body of young grubs is pointed at the rear. Older grubs have a brownish heads and round tails. The pupa is about the size of the adult and clearly shows the legs, wings and head." (Baker 1994).

Pest movement and Dispersal: Flight is one the main means of movement and dispersal to uninfected areas. The adult female flies can travel several kilometres, especially if wind-aided. However, long distance movement is mainly through transport of infested seedlings, small tree or cut branches.

Natural Enemies: Black twig borer has number of different types of natural enemies that attack different developmental stage of the pest (e.g. eggs, larvae, pupae). The female normally remains in the gallery entrance whilst the immature stages are developing, preventing the entry of potential predators and parasitoids. One species of entomopathogenic fungus, *Beauveria bassiana*, was found infecting X. compactus in India (Balakrishnan et al., 1994) and has also been recorded in West Africa (Brader, 1964).The adult black twig are frequently attacked by ants during gallery establishment (Brader, 1964). Lizards and clerid beetles prey on the adults of ambrosia beetles, such as *Xylosandrus* as the latter attempt to bore into the host tree (ref CPC).

Disease Impact: *X. compactus* is a serious pest of shrubs and trees. Therefore, including tea it has wide range of negative impact on crop production, forestry production as well as on rare/protected plant species. It causes extensive damage to tea, coffee and cocoa throughout tropical region. In India, the losses due to *X. compactus* were 21% on 45-year-old coffee plants and 23.5% on young plants (Ramesh (1987). Similarly in India, 60-70% infection in African mahogany reported by Meshram et al. (1993). In Cameroon, about 20% losses of the coffee crop reported by Lavabre 1959). In Japan, *X. compactus* is a major pest of tea causing extensive dieback (Kaneko et al., 1965). In China, Yan et al. (2001) recorded an attack rate of 78% on the main stems of young chesnut trees. In addition to these economic impacts, *X. compactus* has impact on biodiversity. For example, in Hawaii, it attacks several rare and threatened native trees, including *Colubrina oppositifolia* (Ziegler, 2001) and *Caesalpinia kavaiensis* (Ziegler, 2002), providing an additional threat to their survival. Similar threats to rare native trees may occur elsewhere in the range of the beetle as a result of its very wide host range (ref. CPC).

Management: The problem associated with *X. compactus* can be managed by cultural, chemical and biological control measures.

- **Cultural control:** Weak host is porn to attack by *X. compactus.* Therefore, maintaining healthy plants through proper nutrients, soil pH and soil moisture is the best line of defence against this beetle. Plants already infested with *X. compactus* should be pruned and destroyed in regular basis, although this practice is not economical for commercial purpose specially in severely infected field. Simultaneously, apply good tree care practices to promote tree vigor and health will assist in resisting infestation or recovering from infection.

- **Chemical control:** From environmental point of view chemical control is the not best option. However, the application of chlorpyrifos provided 83% mortality of all stages of the black twig borer infesting flowering dogwood in Florida (Mangold *et al.*, 1977). Hata & Hara (1989) reported 100% mortality of adult females with chlorpyrifos. In subsequent field studies, hydraulic sprays of chlorpyrifos killed 83-92% of all beetle stages per infested twig.

- **Biological control:** *X. compactus* is "singularly free from attack by parasites and predators" (Entwistle, 1972). The entomopathogenic fungus, *Beauveria bassiana*, causes some mortality in *X. compactus* and its potential usefulness is being investigated (Balakrishnan et al., 1994). However, biological control methods seem unlikely to be effective for *X. compactus* (ref. CPC).

Quarantine Risk: The risk of introduction for *X. compactus* must be considered high, most probably in the twigs and small branches of imported plants. Once established, such species are difficult to eradicate and are likely to spread with the movement of infested plants, as well as by normal dispersal of the adults. Transportation of habitat material like food products (e.g. seeds and nuts) and solid wood packing materials allow this pest in spreading (ref. CPC).

Probabilities of Entry: Moderate – based on biology of *X. compactus* (i.e. very small size of eggs and larvae in infested plant part that easily be missed by normal quarantine during the trade) and range of host plants that can carry the pest during trade and travel.

Possibility of Establishment: High – in addition to tea growing regions, *X. compactus* has high potential to establish in other areas in Australia due to its moderate host range (including wild host) with favourable climatic conditions.

Probabilities of Entry and Establishment: Moderate – multiple host with moderate entry and high establishment possibilities, *X. compactus* is likely to have a good chance of establishment in Australia under favourable climatic conditions.

Economic Impact: High - based on pest biology and the damage severity reported in the literatures by *X. compactus.* Availability of resistant plant variety and other control measure are also important issues in economic impact.

Environmental Impact: Moderate – although effective chemical control measures are available for *X. compactus* but multiple host range including wild plant species may cause environmental damage by pollution as well as by killing local native plants.

Social Impact: Low – including tea and a few known commercial plant species are affected by *X. compactus* and the proper control measures are also available. Therefore, low social impact is expected after the establishment of this pest.

Pest management cost: Low/moderate – depending on pest severity and types of crops the management cost may vary from $200 – $400/ha. This cost excludes involvement of any biological control and or resistant plant varieties. Effective and established control practices (both cultural and chemical) are available for *X. compactus*. However, the management with cultural practice could be more expensive in case pest severity.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 15– 25% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Moderate – due to multiple host range (both commercial and wild plant species) and high spreading possibility of *X. compactus* during international trade.

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THREAT DATA

Wood leopard moth

(*Zeuzera pyrina*)

Source: http://www.inra.fr/hyppz/IMAGES/7030260.jpg

CRC10010

Enhanced Risk Analysis Tools

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Wood leopard moth

(*Zeuzera pyrina*)

Wood leopard moth (*Zeuzera pyrina*) is also known by some other scientific, English and local names. *Z. pyrina* is a serious pest of apple, pear and olive orchards in Mediterranean regions. The damage cause by this pest depending on plant age and for a young tree one caterpillar is enough to kill the plant. Adult insect is harmless but the larvae (caterpillar) cause most of the damage.

Distribution: *Z. pyrina* is probably native to Europe and it distributed in many parts of Middle East and North America.

Host range/Alternate host: Including apple, pear, plum, olive, pomegranate, maple and oak a large number of shrub and tree plants are affected by *Z. pyrina* (Gatwick, 1992).

Habitat: Woodland, garden and orchards.

Biology and Ecology: *Z. pyrina* adults do not feed and its lifespan is extremely brief, from 8-10 days. In the UK, they are on the wing from mid-June to early August. Females mate soon after emergence and under optimum conditions can lay about **1000 eggs**, usually deposited in clusters on trees, in cracks or crevices. Usually one egg is laid per tree to minimise the competition between caterpillars Gatwick (1992). Embryonic development lasts for 7-23 days. Young caterpillars at first remain clustered in a silken cocoon from which they eventually disperse at dawn or at dusk. They then bore into the tips of branches and shoots, or into young shoots near an axillary bud, and then move downwards to attack younger parts of the tree. Feeding and tunnelling in older wood continue for 2-3 years. When fully grown, usually in late spring, caterpillars are about 50 mm long. After several migrations, the larvae attack the larger branches and the trunk, in which they form ascending galleries under the bark, then in the wood. Larval entry holes are marked by sap outflows, sawdust and frass (in the shape of small cylinders). The insect usually has **one generation** per year.

In France, the life cycle lasts 2 years, adults appearing from the beginning of June to August and pupation occurring from April to July. In spring, larvae continue boring galleries only in the wood, often in the centre of the branch. Infested branches break upon bending, due to the galleries made by caterpillars.

Symptoms: The caterpillars (larva) of *Z. pyrina* attack the larger branch and then trunk. The infested shoot shows wilting symptom with dead shoot tips and prematurely discolour leaves in the apical portion of the branches (Fig A). Infested branches break upon bending, due to the galleries made by caterpillars. Young caterpillars first enter shoots near the tip, and move onto older wood further down the branch when the shoot dies. Entry holes can be recognised by the frass, which resembles pellets of sawdust, and accumulates outside the entry hole for 6-9 months (Fig. B). Sufficient frass may fall on the ground to be a conspicuous symptom of infestation (Gatwick, 1992).

Fig. *Pear tree damage by Zeuzera pyrina* Fig. Apple tree damage by *Zeuzera pyrina*

Source: *http://www.inra.fr/hyppz/RAVAGEUR/6zeupyr.htm*

Affected plant stages: Vegetative growing stage.

Affected plant parts: Mainly stems

Affected Industries: Apple, pear, pomegranate, olive etc.

Pest movement and Dispersal: The natural movement of *Zeuzera pyrina* is restricted by wind. The young caterpillars that ate still attached to a silk thread can be carried by the wind. This kind infestation is common in young orchards. Eggs and larva (visible to naked eye) can be carried out by the fruit during trade/transportation.

Host-Plant Resistance: In literatures there are no reports on the susceptible or resistant plant varieties against *Zeuzera pyrina*

Affected time of the year: The adult *Zeuzera pyrina* do not feed, therefore, it's not dangerous. But most of the damage caused by the young caterpillar during the spring.

Pest detection: Thorax of adult *Zeuzera pyrina* is white or grey, hairy with six blueish-black spots; abdomen is relatively long. The wings are white, and are sprinkled with small metallic-blue spots; female wingspan 50-60 mm, male wingspan 35-40 mm. The larvae are 50 to 60 mm long, bright yellow with numerous small black points on each segment. The head and the thoracic plates are shiny black. The caterpillar first remains clustered in a silken cocoon from which they eventually disperse at dawn or at dusk and attack plants.

The insect can easily be detected in the orchards by looking at the symptoms following their infestation and also by their physical presence in the host plant.

Natural Enemies: *Zeuzera pyrina* has many different types of natural enemies (Pathogen, Parasitoids and Predators) that attack mainly eggs and larval stages of the pest. Most of these natural enemies are reported from Italy, Syria and Israel. Few of these natural enemies are successfully being used for the pest management (Deseo and Docci 1984, 1985).

Impact: *Z. pyrina* is one of the most important pests of apple and pear orchards in Mediterranean regions. It can also be a serious pest of olive. Since 1992 in Italy, *Zeuzera pyrina* is a notable pest of olives, especially on young trees. On young trees, one caterpillar is enough to kill a tree, whereas 3-year-old trees can become extremely vulnerable to wind damage due to damage of the central axis. Older trees can be severely damaged, particularly in dry years and on dry ground. In the UK, damage caused by *Z. pyrina* tends to be more severe following hot, dry summers (Gatwick, 1992). Trees weakened by leopard moth attacks are more susceptible to damage from other xylophagous pests, such as the goat moth (Cossus cossus), hornet clearwing moth (Synanthedon myopaeformis) and bark beetles.

Management: *Z. pyrina* management can be achieved by various means such mechanical, chemical and biological methods depending on various factors like field condition, fruit harvesting season, infestation rate, etc. For example, just before fruit harvesting, biological control is better than chemical application. Similarly in case of high rate of infestation chemical control is more economical then mechanical methods.

Mechanical control: In case of less infestation, *Z. pyrina* can be controlled by pruning and/or removing the infested branches.

Chemical control: Because long oviposition period (lasting until harvest) of *Z. pyrina* and the tunnelling habits of its larvae, the chemical control this pest is not very effective. However, the application of **diazinon** in apple orchards before and after harvesting (**3 successive sprays**) gave better results in Giza and Egypt (Othman *et al.* 1993). The chemical triflumuron, teflubenzuron, hexaflumuron and azinphos-methyl are also effective against this pest (Guario et al. 2001). Sex pheromones that disrupt mating of the insect has also been reported very effective against this pest in walnut orchards, Portugal (Patanita and Osuna, 2006).

Biological Control: The biological control by means of the nematodes *Steinernema bibionis* [*Neoaplectana bibionis*], *S. feltiae* [*N. feltiae*] and *Heterorhabditis sp*. was investigated in several apple orchards. Suspensions containing the nematodes were either applied by means of a motor sprayer at the rate of 1 x 10^6 nematodes/tree or used to soak cotton buds that were inserted into the entrance holes of larval galleries in the trees. The 1st method resulted in 70-100 mortality of the cossid and the 2nd in 90-95%. The infection rate was lower (60-70%) in trees heavily infested with *Z. pyrina* than in trees with less than 5 larvae each (84-100%). Cotton buds were also soaked in suspensions of the fungi *Beauveria bassiana* and *Metarhizium anisopliae* (at the rate of 1 g/litre water) or of the bacterium *Bacillus thuringiensis* (as liquid Bactospeine diluted to 50%) and gave 95-99% larval mortality of *Z. pyrina* in the galleries (Deseo and Docci, 1985).

Quarantine Risk: Low. Both eggs and larvae in the infested plant parts are visible with naked eyes that help in detection easily. Adult is harmless and unable to fly long distance.

Probabilities of Entry: Low/moderate - moderate. Although eggs and larvae of *Z. pyrina* are quite visible in infested plant part but its diverse host capacity may attribute in escaping of normal quarantine during transport.

Possibility of Establishment: Low/Moderate – due to multiple host rang apart from olive growing regions, *Z. pyrina* has potential to establish in other suitable crop growing areas under favourable climates of Australia.

Probabilities of Entry and Establishment: Low/moderate – suitable climatic conditions and a multiple host range of *Z. pyrina* are in favour of establishment of this pest in Australia.

Economic Impact: Moderate - based on pest biology and the damage severity reported in the literatures by *Z. pyrina.* Availability of resistant plant variety and other control measure are also important issues in economic impact.

Environmental Impact: Low – *Z. pyrina* with multiple host range and ineffective chemical control measure make bit environment concern but its available biological enemies (reported in literatures) reduces the chemical applications in pest management that may limit environmental pollution.

Social Impact: Low/moderate – depending on infestation, *Z. pyrina* could cause negative impact on local industries by infecting a number of crops together. Ineffective chemical control of *Z. pyrina* is more concern specially in absence of its biological enemies in the areas. Therefore, social impact of this pest may vary from low to moderate following its establishment in Australia.

Pest management cost: Low/moderate – depending on pest severity and the control measures uses the management cost may vary from **$600 - $800/ha** with minimum of 3 successive spray (http://www.oktreefruit.com/Newsletters/costcomparison06.pdf). It includes chemical price about ($120/ha) and application cost ($100/ha). This cost excludes involvement of any biological control and or resistant plant varieties. Effective and established control practices (both cultural and chemical) are available for *Z. pyrina*. However, the management with cultural practice could be more expensive in case pest severity.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 – 20% for individual crop under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low (5 – 10%). Low possibility of dispersion of *Z. pyrina* during international trade but multiple host range and biology of the pest are the main concerns in export revenue loss.

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THREAT DATA SHEET

Anthracnose

(*Colletotrichum higginsianum*)

Ref. http://osufact.okstate.edu

CRC10010

Enhanced Risk Analysis Tools

Anthracnose

(*Colletotrichum higginsianum*)

C. higginsianum causes anthracnose leaf spot disease in Crucifers vegetable plants and the disease is very destructive on turnip, Chinese cabbage, radish and mustard. But the pathogen also attacked some other Crucifers vegetables including broccoli. The disease is more severe in the southern United States, but it also causes some losses in some other places. The fungus overwinters in infected leaves and disseminate with seeds. *C. higginsianum* is not reported from Australia yet.

Distribution: *C. higginsianum* is reported in the USA, Jamaica, Puerto Rico and recently in Japan and China. No reports from Oceania.

Host range/Alternate host: Restricted mainly to Crusifers like turnip, Chinese cabbage, radish, mustard, broccoli, Brussels sprouts, collards, kale, rutabaga etc.

Biology and Ecology: The fungus *C. higginsianum* overwinters in infested crop residue and crucifer weeds. Warm and wet weather favors the infection and disease development. The fungus can be disseminated via seeds.

Symptoms: The fungus mainly attacks the leaves. The first symptoms appear as small, dry, circular lesions. Gradually the lesions turn pale-gray to straw colour and it may become perforated with splits through dried necrotic area. Under favourable conditions, the numerous lesions often coalesce that results large irregular spots. In severe case, the infected leaf turns yellowish and it may die. Spots also develop on the petioles that are elongated, sunken, grey to brown, and have a dark black border.

Fig 1. Symptoms of Anthracnose disease caused by *C. higginsianum*.

Affected plant stages: Vegetative growing stage

Affected plant parts: Mainly leaves.

Affected Industries: Vegetable industry belongs to Crucifer family.

Resistant plant variety: No resistant plant varieties/cultivars of broccoli against this Anthracnose disease has been reported yet.

Disease movement and Dispersal: Under field conditions, the fungal spores splash-dispersed mainly by wind, rain-splash and contaminated agricultural tools. The dispersal of spore is more strongly depending on the wind. In case of international trade, the fungus could spread via seed where the fungal spore can survive.

Disease Impact: Anthracnose cause by *C. higginsianum* is more severe on turnip and a few other Crusifers compared to broccoli and others vegetables. The disease has been reported as most destructive in the southern United State but no data on yield reduction found in the literature.

Disease Management: Both cultural practice and chemical spray can be used to manage the anthracnose disease. For examples, crop rotation with non-host, eradications of crucifers weeds and infected crop residues, avoidance of windbreaks, hot-water seed treatment etc. Under field conditions, Dithane Z-78, Captafol, Fermate, Maneb, Zerlate and Spergon gave significant control. Apply as spray (2 lb/100 gal) beginning at plant emergence and then every 7 days.

Quarantine Risk: Moderate – The anthracnose disease spore mainly disperse through wind locally. Although it's a foliage disease but the fungal spore has the potential to spread by vegetable seeds unless the seeds are treated with hot water before sowing.

Probabilities of Entry: Low to moderate – the fungal spore can be carried through the host seeds into the country unless prevented by quarantine at the entry.

Possibility of Establishment: Low to moderate – *C. higginsianum* has many host plants within the cruciferous family and most of these hosts are common vegetable crop in Australia. This makes it moderately easy to establish upon it's arrival via seeds. However, simple hot water treatment of seeds before sowing kill the spores and reduce the chance of it's establishment in Australia or any other new places.

Probabilities of Entry and Establishment: Low to moderate – seed-borne nature of *C. higginsianum,* suitable climatic conditions and available host in Australia provide moderate chance to it's establishment. However, strict quarantine at entry point and a simple hot water treatment of seeds before sowing can reduce the chance of entry and establishment in Australia.

Economic Impact: Low to Moderate – leaf anthracnose by *C. higginsianum* can cause significant damage in few hosts like turnip, cabbage and radish) only in sever case. Although, most the hosts are important vegetable crops in Australia but the damage can be reduced by cultural practice as well as by using some common fungicides. Simple hot-water treatment of seeds before sowing also play important role in preventing the disease spread in new locations.

Environmental Impact: Negligible – anthracnose disease by *C. higginsianum* is not expected to impact on environment as the disease effects a particular host group only and no reports on wild or native hosts. In addition, minimum fungicide application is required in managing the disease in field that will have negligible impact on human and animal health.

Social Impact: Low – The OLB disease symptoms are quite visible, control measures are available including cultural practices. Therefore, the grower should be able to handle the disease quickly and effectively to escape the damage intensity.

Pest management cost: Moderate – The biology of the disease and its available control measures will reduce the cost in disease management. The cost may vary from place to place depends to labour wages, pest severity, host variety and other factors. Based on 8 spary/season the cost calculated about $750/ha (ref. Peter Dawson, Project Manager, Potato, DAFWA).

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on major host like onion the total yield loss assumed to be between 10 - 15% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – *C. higginsianum* is seed-born pathogen i.e. there is risk of fungal spore dispersion via seeds in trading. However, simple hot water treatment of the seeds before sowing kills the spore and eliminates the risk. Therefore, having the pest in Australia would not be a major concerned in export market.

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THREAT DATA

Apple blotch

(*Phyllosticta solitaria*)

Source: http://www.forestryimages.org/images/192x128/5368943.jpg

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Enhanced Risk Analysis Tools

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Apple blotch

(*Phyllosticta solitaria*)

Phyllosticta solitaria is a fungus that causes apple blotch disease (AP) to both cultivated and some wild apple cultivars. The fungus is native to USA with history of limited distribution capacity. The disease symptoms can be found in fruits, twigs, leaves and newly growing points. The disease incidence and severity are directly correlated with rain. The disease can cause up to 90% fruit damage in unsprayed orchard but the damage can easily be managed by available and effective fungicide treatment. EPPO listed *P. solitaria* as an A1 quarantine pest. The economic impact of AP is considered to be highly depended on climatic conditions and host varieties.

Host Range: Cultivated apples are principal host of *P. solitaria* and the fungus also reported on some wild apples and other species of *Crataegus* (hawthorns). The apple varieties commonly affected are Rome Beauty, Northwestern Greening, Rhode Island Greening, Yellow Newtown, Yellow Transparent, and Dutchess. The disease is seen on the market occasionally.

Distribution: *P. solitaria* fungus is native to USA with restricted distributions. The fungus also reported in Canada with restricted distribution. In Denmark there is an isolated occurrence of this pest in Denmark (Johansen1948) and recent record in Colombia as a minor pathogen of apple orchards (Salazar 1998). No record of *P. solitaria* from Australia yet.

Biology and Ecology: *P. solitaria* fungus attack leaves, stems and fruits with obvious symptoms throughout apple growing season. Primary infections occurs in early spring and frequency and severity of this pest directly correlated with rainfall. The fungus overwinters by forming sclerotia (a mycelial mat) on infected twigs that can serve as inoculum source in the following year by producing spore (conidia) in early spring. The spore dispersion mainly occurs through wind, rain-splash and insect feeding. The radius of infection estimated to be 80 m with 100% infection within in 12 m from a 10 m apple tree by wind –blown rain. Unlike twig, fungus overwinters in leaves and stems are believed to be unable to serve as source of primary inoculum in spring. But infested fruits and leaves are good secondary sources of new infections during the growing season. *P. solitaria* has the capacity to survive long periods (at least 9 month) of clod storage at 1-2^{o}C (McClintock 1930).

Symptoms: Apple blotch disease attacks leaves, twigs, and the fruits of apple. Fruits are infected early in the growing season and by midsummer exhibit dark, blotch-like lesions with fringed margins (fig. below). The diameter of the blotch spots varies from 1/4 to 1/2 inch or more. Small, black fruiting structures (pycnidia) containing fungal spores, develop in the central portion of the hard, markedly sunken, and nearly black lesions. The fringed margins usually disappear as the spots merge to produce larger lesions.

Blotch lesions involve only the outer cell layers, and there is no rotting of the fruit tissues. However, badly blotched fruits are unmarketable, and any blotched fruits that arrive on the market are heavily discounted or rejected. Occasionally, blotch spots provide sites for secondary infections, of which blue mold rot and black rot are most common.

Fig. Apple blotch disease symptoms on apple (left) & leaf (right)

Affected plant stages: Fruiting stage and vegetative growing stage

Affected plant parts: Fruits, leaves, and stems.

Affected Industries: Apple industry.

Resistant plant variety: Currently, no information is available on resistant plant varieties/cultivars against AB disease of any host plant.

Disease movement and Dispersal: Under field conditions, AB fungal spores (conidia) dispersed mainly by wind, rain-splash and some by insect feeding and contaminated pruning tools. Fruit-to-fruit contact is one of the main mechanisms for spread of disease within a tree, and for which injuries are not necessary. Splash dispersal of conidia is one of the other mechanisms for spread of disease within a tree. The radius of infection estimated to be 80 m with 100% infection within in 12 m from a 10 m apple tree by wind-blown rain. In case of international movement, the planting materials with canker carry the risk of dispersion. The faunal ability to survive log period in clod storage is also a positive factor in terms of its dispersal capacity.

Disease Impact: *P. solitaria* causes a serious blotching of apples which reduces fruit quality and 5 to 10% losses were reported in the past in USA. In Illinois, in 1924, annual losses of approximately 6000 tone were recorded and up to 90% of the fruit were affected. However, currently the economic importance of this disease has declined, probably in connection with regular fungicide treatment of orchards. A recent description of the disease characterised its occurrence as rare (Yoder, 1990).

Disease Management: Since the AB disease characteristically occurs annually and therefore, control measures should be applied each year. The disease is controlled by orchard sprays and by regular cultural practices. Careful pruning will remove a large portion of the diseased twigs, which are the source of trouble. Their removal is a valuable operation supplemental to the application of a protective spray. Spraying must be done before inoculation takes place; this, as has been seen, occurs within a month after the petals fall. The number of applications depends on the nature of the weather. In the

Middle West and Southwest the schedule is as follows: First application, use bordeaux mixture, 3-4-50, three weeks after the blossoms drop. Lime sulfur should be substituted for bordeaux mixture in wet weather, since the latter produces injury to the fruit and foliage under such conditions. Second application should be made two to four weeks after the first. A third application is recommended ten weeks after the petals fall. The second and third applications correspond to those made for Bitter Rot, so that one course of spraying will suffice for both diseases.

Phytosanitary risk: *P. solitaria* has been listed as an A1 quarantine organism by EPPO (OEPP/EPPO, 1980) and is also of quarantine significance for COSAVE. It evidently presents a certain risk for European apple orchards. However, it is also importance to note that in North America the disease has considerably declined and its it now rare in USA. Currently the disease is readily controlled fungicide treatments.

Quarantine Risk: Low – *P. solitaria* spore mainly disperse through wind locally. Restricted host range and limited distribution through apple infested apple fruit during the trade reduce the quarantine risk.

Probabilities of Entry: Very low – because of very restricted host range (apple mainly) and limited geographic distribution. Therefore, import restriction on apple from the countries where the fungus has been reported will reduce the possibility of entry in Australia.

Possibility of Establishment: Low – although Australia has many apple growing regions and a suitable climatic condition but the chance of finding a suitable host following its entry is little because of its limited host capacity. The history of this disease also indicates poor chance of its establishment in any new countries. Therefore, chance of establishment is low in Australia.

Probabilities of Entry and Establishment: Very low – In spite of both suitable climatic conditions and hosts of AB still the chance of entry and establishment of this pest is very low because very low possibility of its entry in Australia.

Economic Impact: Moderate – Although up to 90% fruit damage is being reported by AB in unsprayed orchards in the past. But current effective chemical controls reduce this damage at very significant level.

Environmental Impact: Negligible – AB disease is not expected to impact on environment as the disease is restricted to apple hosts mainly and no reports on wild or native host except hawthorns. Insecticides application in AB management might will have negligible impact on human and animal health.

Social Impact: Negligible – impact on backyard apple trees to be expected and this will results very negligible impact on socio-economic condition of the society. However, the disease symptoms are quite visible and can easily be managed by cultural practices for small areas. Therefore, the grower should be able to handle the disease quickly and effectively to escape the damage intensity.

Pest management cost: Moderate – The biology of AB disease and its available control measures will reduce the cost of disease management. The cost may vary from place to place depends to labour wages, pest severity, host variety and other factors. Calculation based on 3 chemical spray in one season that include $36.0 chemical cost and $50.0 application cost/ha for a single spray i.e. (36 + 50)x3 = $258/ha. Sources - Martine Combret/Development officer/DAFWA/Bunbury.

Yield loss despite control efforts: Based on pest biology, available control measure, and its impact on the host plant the total yield loss assumed to be between 5 - 10% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – although the AB fungus is able to survive long period (9 months) of cold storage at 1-2°C in cold storage, however, dispersion of disease through infested apple is not reported. Moreover the fungal has very poor history of establishment capacity in any new countries. Therefore, having the pest in Australia would not be a major concerned in export market.

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THREAT DATA

Black blight of potato

(*Phoma andina*)

Source:http://www.eppo.org/QUARANTINE/fungi/Phoma_andigena/PHOMAN_images.htm

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Black blight of potato

(*Phoma andina*)

Phoma andina is a fungal disease of potato that causes leaf spot on leaf and the disease known by black blight of potato or *Phoma* leaf spot. The diseases symptoms are visible on leaf only, not in tuber and other underground parts. The fungus regarded as quarantine pest A1 by OEPP/EPPO and it presents risk to commercial potato-growing places around the world. The disease is confined in some parts of South America and not present in USA, Canada, New Zealand and Australia yet.

Distribution: Black blight of potato disease is very much confined to Bolivia and Peru in potato growing regions. The USA, Canada, Europe, Australia, New Zealand are free from this fungus.

Host range/Alternate host: Restricted host range. Mainly potato but other members of Solanaceae may also get infected by the causal agent of black blight of potato.

Biology and Ecology: *Phoma andina*, usually attack above ground plant parts mainly leaf not underground part like potato tubers and roots. The fungal spores (pycnidia) survive on plant debris in the field soil. Infections initiated on leaf by pycnidiospores splashes from the field soil. Cool weather (15^0C) along with high humidity and rain favour the disease severity by spreading disease inoculums (conidia). The disease on tomato found in a warmer climate than that of potato (Anon 1984). The persistent capacity of fungal spore in field condition is not know yet. Further information on biology of this fungus is available in literatures published by Torres et al. (1970) and Turkensteen (1978, 1981).

Symptoms: *Phoma andina* causes leaf spot (fig. 1) disease on the host plant and the symptoms resemble to early blight leaf spot disease cause by another fungus (*Alternaria solani*) except the spots are not depressed in case of black blight of potato as common in early blight leaf spot. Leaf spots first appear on lower leaves that gradually spread in whole plants. In late stage of infection numerous small spots/lesions may combine and results large lesions delimited by leaf veins. Leaves turn blackish and appear scorched (fig. 1). Initially the infected leaves remain attached but later it drop. In severs cases, elongated lesions also fund on leaf petioles and stems of the infected plants.

Figure 1. Symptoms of *Phoma andigena* on a potato leaf
Source:http://www.eppo.org/QUARANTINE/fungi/Phoma_andigena/PHOMAN_images.htm

Affected plant stages: Vegetative growing stage

Affected plant parts: Mainly leaves but also notice in stems.

Affected Industries: Potato industries

Resistant plant variety: Resistant potato varieties again *Phoma andina* may be available but there is no enough information in literatures.

Disease movement and Dispersal: Under field conditions, the fungal spores splash-dispersed (by rainwater and wind) only over short distances. In case of international trade, the fungus could spread via leaves (e.g. import germplasm materials for research), or on dead plant material (for research purpose) or on crop residues or soil attached with tubers.

Disease Impact: Black blight of potato is an important disease in potato growing regions in Bolivia and Peru and up to 80% production losses are reported in literature by this fungus. Therefore, the *P. andina* has considerable economic importance and the fungus also consider A1 quarantine pest by OEPP/EPPO (1984). The damages also vary from variety to variety depending on disease resistance of the crop.

Control: Black blight of potato can be managed by fungicides specially at early stage of infection (turkensteen, 1981). The disease resistant cultivar can also be used. General control measures such use of resistant cultivars, disease free planting materials, crop rotation, elimination of the weed *Datura stramonium* (may act as a host). Varietal resistance would seem to offer the best possibility of control.

Phytosanitary risk: EPPO listed *P. andina* as a quarantine pest (A1) (OEPP/EPPO, 1984) e.i. fungus certainly presents a significant risk to potato production in the EPPO region. But restricted host capacity and limited trade opportunity between it's current location (e.g. Bolivia and Peru) and other parts of the world provide less possibility of it's spread.

Quarantine Risk: Low - *P. andina* is host specific, currently confined in areas that are less important in terms of international trade and the fungus also has very limited dispersion capacity. Never the less *P. andina* designated as a quarantine pest (A1) by EPPO.

Probabilities of Entry: Low - *P. andina* can only disperse through infested leaf and field soil that are less likely to be trade components. Unless, the materials bring for research purpose are infected.

Possibility of Establishment: Low – Because of restricted host-range *P. andina* has limited chance to find a suitable host at the entry points upon its arrival, although suitable climatic conditions are available in some parts of Australia.

Probabilities of Entry and Establishment: Low – In spite of suitable climatic conditions, specific host capacity of *P. andina* reduce the chance of entry and establishment in Australia.

Economic Impact: High – significant potato damage (20 to 80%) reported by *P. andina* in Peru. Therefore, it would have high impact on commercial potato industries in Australia.

Environmental Impact: Low – The severity of black blight of potato disease depends on local climates and effective chemicals are available to control the disease in field conditions. This means comparatively less chemical will be applied by the grower for the disease management that will have less environmental impact.

Social Impact: Low – The disease symptoms are quite visible, control measures are available and the severity is climate dependent (cool temperature). Therefore, the grower should be able to handle the disease quickly and effectively to escape the damage intensity.

Pest management cost: Moderate – The biology of black blight of potato disease and its available control measures will reduce the cost in disease management. Compared to rust, this fungus produces less innoculums (spore) in short time. Therefore, number of fungicide spary needs less compared to rust. Hence, 5 sprays are considered in one season and the total cost includes both chemicals and application cost. The application cost at least $400/ha based on guess by Peter Dawson/Project Manager, Potatoes/DAFWA. The cost may vary from place to place depends to labor wages, pest severity and other factors.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 - 15% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – although *P. andina* possess very low risk of dispersion via international trade as there is no record of transmission of *P. andina* on contaminated seed. However, listed as quarantine pest (A1) by EPPO would be main concerned in export market.

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THREAT DATA

Black spot of Japanese pear

(*Alternaria gaisen*)

Source: http://www.forestryimages.org/browse/detail.cfm?imgnum=1263074

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Black spot of Japanese pear

(*Alternaria gaisen*)

Alternaria gaisen is a fungus that causes black spot of Japanese pear (BSJP) that includes young fruit, leaves and branches. BSJP is a serious disease in Japan and Korea. Unlike *A. alternata*, *A. gaisen* has very specific host (Japanese pear only) and restricted distributions. The fungus survives adverse condition as resting spores on leaf debris in soil and the spore (conidia) spread locally by winds. The possibility of spreading internationally during trade is very limited as the infection occurs only in young fruits (not mature fruits) that are not used in trading. However, *A. gaisen* has been listed as a quarantine pest by EPPO.

Host Range: *A. gaisen* has very specific host and mainly recoded in Japanese pear (Pyrus pyrifolia) but no record in European pear (*Pyrus communis*). However, *A. alternate* has been recorded from wide range of *Pyrus* spp. including *P. communis* and *P. pyrifolia*

Distribution: *A. gaisen* has limited distribution and only recorded in China, Japan, Korea and Taiwan (Simmons and Roberts 1993). The pest has been intercepted in imports to the USA and Australia and has been recorded from France (Baudry et al., 1993).

Biology and Ecology: *A. gaisen* overwinters on fallen leaves on the ground and under favourable conditions (warm and moist) conidia are produced and dispersed by wind and rain. Conidia landing on young leaves and fruits cause new infections through stomata and lenticels and show numerous black spots. High humidity (90%) with around 23^0C is in favour of infection and fungal growth. The fungus is unable to produce conidia above 40^0C. BSJP disease incidence has been observed to increase where trees are grown under polythene covers to promote early flowering. The covers increase air temperature by 8-10°C, and average soil temperature by 3-5°C (Hong *et al.*, 1988). Fruit rot cause by *A. alternate* is also very common in pears.

Symptoms: BSJP disease occurs on the fruit, young leaves and young shoots of *Pyrus pyrifolia*, but never on old leaves and branches. On fruits, infection first appears as small black dot in early summer when fruits are still very small. The dots gradually expand and turn into a characteristic black spots with clear black concentric rings (fig. below), typical symptoms cause by most of *Alternaria spp*. Under rainy conditions, the spots rapidly enlarge and coalesce to become a large irregular dark brown lesion. Enlargement of the spots causes uneven growth and often cracking of the affected fruit. In advanced stages, fruit may crack and white mycelium with black spore masses can be seen in the spots. Disease progress appears to be relatively retarded in ripe fruit on the tree. On leaves, small dark-brown or black/brown specks appear in early summer and slowly enlarge. Concentric rings appear on the lesions, which coalesce into large irregular patches under favourable conditions. Severely affected leaves can turn brown and fall. On young shoots, small black specks develop into oblong streaks and finally cause shoot death. Lesions are slightly shrunken with slight concentric rings.

Fig. Black spot of Japanese pear disease symptoms caused by *Alternaria gaisen*

Affected plant stages: Flowering stage and vegetative growing stage

Affected plant parts: Leaves and fruits.

Affected Industries: European pear industry mainly.

Resistant plant variety: Currently, two varieties (Chuwhang Bae and Shugyku pear) are reported to be resistant to BSJP disease (Kim et al. 1986, Kozaki 1987).

Disease movement and Dispersal: Under field conditions, BSJP fungal spores splash-dispersed mainly by wind and rainfall and some by insect feeding and contaminated pruning tools. Fruit-to-fruit contact is one of the main mechanisms for spread of disease within a tree. Internationally, possibilities for spread are fairly limited. The fungus is not liable to be carried on dormant planting material (except leaves). It could be carried in fruits but, since infection occurs on the young fruit, it is unlikely that infected fruits would be harvested and traded.

Disease Impact: *A. gaisen* is a widespread and serious disease of *Pyrus pyrifolia* in Japan and Korea Republic. According to Sakuma (1990), it has been important since the very susceptible cv. Nijisseiki was widely planted in the early part of this century. Its importance arises from the fact that it is both a leaf and a fruit disease. However, available control measures including planting resistant varieties have reduced damage cause by this fungus.

Disease Management: Common cultural practices, available fungicides and resistant cultivars are used to manage BSJP disease. Modern cultivars of *Pyrus pyrifolia* reported to show resistance include Shinsei (Machida *et al*., 1984), Whangkeum Bae (Kim *et al*., 1985), Chuwhang Bae (Kim *et al.*, 1986) and Shugyoko (Kozaki, 1987). Many cultivars have some degree of resistance, which is believed to be determined largely by one pair of genes, resistance being homozygous recessive (Kozaki, 1974). Chemical control of *A. gaisen* has been reported with captafol (Adachi & Fujita, 1984) and guazatine (Yagura *et al*., 1984). The importance of good sanitation in the orchard is vital part of cultural practices and removal of fallen leaves (source of inocula) on the ground reduce the inocula level for next year.

Phytosanitary risk: The risk of introduction of *A. gaisen* into new countries is connected with usually trading of fruits. But in this case the fungus mainly attacks young fruits that are usually not traded.

Quarantine Risk: Low – *A. gaisen* spore mainly disperse through wind locally. Specific host fruit (Japanese pear) import from the countries where the fungus has been reported and firm quarantine will reduce the risk of entry of this fungus in Australia.

Probabilities of Entry: Very low – because of very selective host (Japanese pear only) and limited geographic distributions. Therefore, import restriction on pears from the countries where the fungus has been reported will reduce the possibility of entry in Australia.

Possibility of Establishment: Low – although Australia has many pear growing regions and suitable climatic conditions but the chance of finding a suitable host following its entry is very little because of its specific host capacity. The history of this disease also indicates poor chance of its establishment in any new countries. Therefore, chance of establishment is low in Australia.

Probabilities of Entry and Establishment: Very low – In spite of both suitable climatic conditions and presence of host, still the chances of entry and establishment of *A. gaisen* is very low due to very low possibility of its entry in Australia.

Economic Impact: Low – Australia grows a number of pear species. Therefore, even *A. gaisen* can cause considerable damage in pear productions but the overall damage would be insignificant due to its very host specificity and also for readily available control measures against this fungus including resistant varieties.

Environmental Impact: Negligible – BSJP disease is not expected to impact on environment as the disease is very restricted to a particular pear cultivar and no reports on wild or native hosts. Therefore, fungicide applications in BSJP management will have negligible impact on human and animal health.

Social Impact: Nil – No impact on backyard pear tree and small growers to be expected therefore, there will be zero impact on socio-economic condition of the society.

Pest management cost: Moderate – The biology of BSJP disease and its available control measures will reduce the cost of disease management. The cost may vary from place to place depends to labour wages, pest severity, host variety and other factors. Calculation based on at least 6 chemical spray in one season that include $20.0 chemical cost and $50.0 application cost/ha for a single spray i.e. (20 + 50)x6 = $420/ha. Sources - Pest data sheet/ERAT and Martine Combret/Development officer/DAFWA/Bunbury.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 1 - 5% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Nil – BSJP found in a very particular pear species. Therefore, export of that species easily can be avoided without losing any export market.

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THREAT DATA

Blister canker

(*Botryosphaeria berengeriana f.sp.pyricola*)

Source: http://kentcoopextension.blogspot.com/2008_02_01_archive.html

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Blister canker

(*Botryosphaeria berengeriana f.sp.pyricola*)

Blister canker (also known by pear or apple canker) is a fungal disease and the pathogen known as *Physalospora pyricola* in Japan. Many countries the name of this fungus (*B. berengeriana***)** confused with other similar fungus *B. dothidea* that cause white rot disease in apple and pear and widely distributed unlike blister canker. The canker pathogen mainly attack apple and pears and it has restricted distribution mainly in Japan where it's economically important disease.

Distribution: Unlike *B. dothidea,* the causal agent of blister canker fungus has very restricted distributions mainly in Japan but recently also reported in China. The fungus is not reported in Australia and New Zealand.

Host range/Alternate host: The main host is Japanese pear (*Pyrus pyrifolia,* but it also cause disease in European pear (*Pyrus communis*) and apple. Besides these, *Chaenomeles japonica* and *Malus micromalus* has also been reported as hosts of this fungus by Kato (1973).

Biology and Ecology: The biology of *B. berengeriana f.sp.pyricola* is very similar to *B. dothidea*. The fungus infects the branches, shoots, leaves and fruits of its hosts. Pycnidia produce on diseased branches and shoots. The pycnidiospores are rain-dispersed, usually up to about 10 m, but exceptionally up to 20m by strong wind-driven rain. Sporulation is most abundant on infected shoots of 2-3 years old and less on older wood. They mostly germinate within the first 24 h, and infection is favoured by warm humid conditions (optimum temperature 28°C). Infection of young fruits requires 5 h of surface wetness, while older fruits need longer. Natural infection of shoots probably occurs through the shoot tip. Similarly, young fruits can be infected early in the season through stomata or lenticels (Kishi & Abiko, 1971). Thereafter, wounds are needed for infection of fruits (EPPO/CABI, 1996). The occurrence of the disease on fruits can be predicted from the number of rainy days in early season by a quadratic regression equation (Kato, 1973).

Symptoms: The fungus forms wart-like protuberances (wart bark) on the surface of trunks and branches of Japanese pear (Kato, 1973) rather than typical *Botryosphaeria* cankers. These are subsequently surrounded by dark-brown spots. Infected twigs eventually wither and die back. Large contoured dark-brown spots are formed on the leaves and also on the fruits. The warts on trunks and branches damage the tree, reducing its growth and productivity. The leaf spots are of minor importance and do not affect yield. The fruit spots progress after harvest, and thus cause a loss of fruit quality. On apples, the fungus causes similar symptoms of rough bark (Koganezawa & Sakuma, 1980) and apple ring rot (Koganezawa & Sakuma, 1984).

Fig. Infected stem of pear plant by canker fungus (*B. berengeriana f.sp.pyricola)*

Affected plant stages: Post-harvest and Vegetative growing stage

Affected plant parts: Fruits, leaves and stems.

Affected Industries: Pear and apple industries.

Resistant plant variety: No reports on resistant host variety against this canker diseases.

Disease movement and Dispersal: Under field conditions, the fungal spores splash-dispersed mainly by wind, rain-splash and some by insect feeding and contaminated pruning tools. The dispersal of ascospores is more strongly depending on the wind. In case of international trade, the fungus could spread via trading of host plants where the fungus can live as an asymptomatic endophyte of undefined periods. Although fruits are infected, infection occurs on the young fruit, and would be detectable on harvested fruits, rather than only appearing later in storage (post-harvest rot). Accordingly, infected fruits are relatively unlikely to be traded.

Disease Impact: Blister canker fungus causes dieback and fruit rot listed as one of the economically important pests of apples and pears in Japan (Anon., 1984). The disease has become more important since Bordeaux mixture has been less frequently used in orchards and the practice of bagging fruits has declined (Koganezawa & Sakuma 1984). In Japan, high quality pome fruits are often individually bagged on the tree to protect them from all kinds of damage. Presumably, the disease was previously well controlled by copper fungicides.

Disease Management: Both cultural practice and chemical control are used to manage this disease. Copper fungicides have proved effective in Japan, and the reduction in their use has led to a resurgence of apple fruit rot. Captafol, benomyl, captan, difolatan, polyoxin and 8-hydroxyquinoline are other fungicides which have been shown to be effective (Kishi & Abiko, 1971; Kato, 1973). Organic arsenic emulsion has been recommended in Japan for treatment of the warts on the shoots, though it is doubtful whether such products would now be authorised for this use. Sato *et al.* (1987) have recently investigated eradicant fungicides for trunk lesions. In general, it is recommended to take measures to reduce the pycnidiospore inoculum. Branches showing symptoms of infection should be pruned. The warts on shoots can be shaved away. Affected fruits should be removed and destroyed. Some cultivars are reported to have resistance (Cho *et al.*, 1986).

In the USA and Korea similar fungicides are recommended against *B. dothidea* (McGlohon 1982, Kim & Kim, 1989)

Phytosanitary risk: The risk of introduction of blister canker disease into new countries is connected with the incautious trading of host plants where the fungus is able to live as an asymptomatic endophyte for undefined periods. Neither EPPO nor any other regional plant protection organisation has considered *B. berengeriana* f.sp. *pyricola* to be a quarantine pest. However, the fungus is certainly claimed to be more important than *B. dothidea* and to cause different symptoms in Japan. Though mainly occurring on Japanese pears, the fungus has been recorded damaging European pears and apples in Japan. It is not clear, however, whether the fungus can really be distinguished from *B. dothidea*, and how feasible it is to take measures against f.sp. *pyricola* alone. In addition, it may be noted that the Japanese fungus, like *B. dothidea* in south-eastern USA, is favoured by rather warmer, more humid conditions than prevail in Europe or the Mediterranean region.

Quarantine Risk: Low – *B. berengeriana* f.sp. *pyricola* spore mainly disperse through wind locally. The most common trading component like fruits is unlikely to carry or escape quarantine to spread the fungus in a new area/country.

Probabilities of Entry: Low – because of low possibility of trading host plants of blister canker in Australia that carry the fungal spores. Unless, the materials bring for research purpose are infected.

Possibility of Establishment: Low – Because of limited host-range *B. berengeriana* f.sp. *pyricola* has less chance to find a suitable host at the entry points upon its arrival, although suitable climatic conditions are available in some parts of Australia.

Probabilities of Entry and Establishment: Low – In spite of suitable climatic conditions, limited host capacity of *B. berengeriana* f.sp. *pyricola* reduce the chance of entry and establishment in Australia.

Economic Impact: High – significant fruit (e.g. pear and apple) reported by *B. berengeriana* f.sp. *pyricola* in Japan. Therefore, it would have high to moderate impact on commercial apple and fruit host industries in Australia.

Environmental Impact: Low – *B. berengeriana* f.sp. *pyricola* has restricted hosts mainly pear and apple. Therefore, the disease is expected to have very low impact on environment from the fungicides used in control measures.

Social Impact: Low – The blister canker disease symptoms are quite visible, control measures are available including cultural practices. Therefore, the grower should be able to handle the disease quickly and effectively to escape the damage intensity.

Pest management cost: Moderate – The biology of blister canker disease and its available control measures will reduce the cost in disease management. The cost may vary from place to place depends to labour wages, pest severity, host variety and other factors. Calculation based on at least 6 chemical spray in one season that include $20.0 chemical cost and $50.0 application cost/ha for a single spray i.e. (20 + 50)x6 = $420/ha. Sources - Pest data sheet/ERAT and Martine Combret/Development officer/DAFWA/Bunbury.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 - 15% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – *B. berengeriana* f.sp. *pyricola* possess low risk of dispersion via international trade and there is no record of transmission of this fungus on contaminated trading component like fruit. Therefore, having the pest in Australia would not be a major concerned in export market.

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THREAT DATA

Brown rot

(*Monilinia fructigena*)

Source: www.padil.gov.au/pbt/index.php?q=node/13&pbtID=79

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Brown rot of Apple

(*Monilinia fructigena*)

Monilinia fructigena is a fungus that causes brown rot disease (BR) to a number of stone and pome fruits including apple. BR also occurs by other three species of this fungus and cause considerable economic damage to fruit industry throughout the world as it found in many parts of fruit growing areas except Australia. Although, the fungus associated with illegally imported fruit has been detected number of times by AQIS. The economic impact of BR is considered to be high depending on climatic conditions and host varieties.

Host Range: BR is most serious on apples and pears but also affects fruits like plum, sweet cherry, peach, quince, nectarine, apricot loquat, fig, guava, hazelnut, capsicum, tomato and berry fruits such strawberry, blackberry, raspberry and blueberry. Sagasta (1977) stated that *M. fructigena* had been found on more than 40 species in a number of families. Plum reported as most susceptible to this fungus by Anon. (1991) and Byrde and Willetts (1977).

Distribution: *M. fructigena* is found in most temperate regions of Europe, Asia (Middle and Far East, India), North Africa and in some South American countries where apples and pears are grown (Batra, 1991). Only in Central and Eastern Asia where *Pyrus*, *Malus* and *Prunus* spp. originate are all three brown rot fungi established (CABI/EPPO, 1991, 1999, 2000). *M. polystroma* is restricted to Japan (Leeuwen *et al*. 2002). *M. fructigena* not present in Australia yet.

Biology and Ecology: *M. fructigena* is very similar to other three species of this fungus and like other species it also produces similar symptoms on blossoms, stems and fruits. BR fungi can be grown in common potato dextrose agar medium where colourless mycelial growth with small discoid sclerotia found. On the host, both conidia and sclerotia are usually found on all infected organs. BR fungi overwinter in dried infected fruit called mummies or in cankered twigs. In winter BR mummies may remain hanging in the trees or be scattered on the orchard ground. The fungus resumes growth in the spring and start blossom infections. Two types of spores are produced known as the sexual ascospores and the asexual conidia. Ascospores produced on mummies only which are fallen to ground. Conidia are in abundance on both mummies and infected twigs. Both the twig and mummies serve as a source of inoculum for new infection and the spores is usually spread by wind, rain and insect.

Symptoms: BR fungi cause similar symptoms on all hosts, which are blossom blight, fruit rot and stem canker. The primary and most common symptoms are fruit rot (Jones and Aldwinckle 1990) found in apple and pear. Circular and superficial brown lesions are found on the surface of the fruit. Gradually the lesions expand over the fruit surface with visible mould, turn brown and eventually decay the entire fruit (fig. below at left). Often concentric rings formed by mycelium are visible on the surface of the lesion. Rotted fruits may either fall to the ground or dry out on the tree. BR disease also results in characteristic blighting of spurs and blossom in spring. Infected floral parts wilt, turn brown and collapse. Stem blights and cankers may also develop from blossom infection (Xu el al 1998). The outer bark of the infected twigs and shoots is discoloured with underlying necrotic tissue (fig. below at right). Gum exudates and tufts of mycelium may also occur on the surface of the active lesion, specially under humid conditions (Jones 1997).

Fig. Infected fruit (left) and stem (right) of apple plant by Brown rot fungus, *Monilinia fructigena* (source: www.padil.gov.au/pbt/index.php?q=node/13&pbtID=79)

Affected plant stages: Fruiting stage, pos-harvest and vegetative growing stage

Affected plant parts: Fruits/pods, growing points, leaves and stems.

Affected Industries: Apple and other host plant industries.

Resistant plant variety: Currently, no information is available on resistant plant varieties/cultivars against BR disease of any host plant.

Disease movement and Dispersal: Under field conditions, BR fungal spores splash-dispersed mainly by wind, rain-splash and some by insect feeding and contaminated pruning tools. Fruit-to-fruit contact is one of the main mechanisms for spread of disease within a tree, and for which injuries are not necessary. Splash dispersal of conidia is one of the other mechanisms for spread of disease within a tree. *BR disease* easily splash dispersed over short distances; this process facilitates spread of propagules within a tree, though final infection depends on the presence of injuries in this case. The disease can be transmitted on fruits, flowers, calyx, leaves, stems, shoots, trunks and branches. In the field spores are disseminated by wind and rain. In case of international trade, the fungus could spread via trading of both fruits and host plants.

Disease Impact: BR disease is a serious disease of apple and pear and it considered to have high economic impact on many other fruit industries in Australia. Although, the disease severity may varies from year to year depending on environmental conditions. Fruit losses due to BR have been reported from 5% up to 35% (Berrie, 1989, Rosenberger 1997, Burchill & Edney 1972, Xu & Robinson 2000). Serious economic problems on stone fruit caused by other two species (*M. fructicola* & *M. laxa*) of this fungus already been reported in Australia (AQIS 1991). This problem might be more aggravated in presence of *M. fructigena* in Australia.

Disease Management: Both cultural practice and chemical control are used to manage Brown rot disease. For effective chemical control fungicide spray from bloom through harvesting period is required. The proper use of fungicides with some systemic activity protects fruit, reduces the amount of sporulation formed on the infected tissue, and reduces sources of overwintering inoculum. There is an extensive range of fungicides available for rot control, including the dicarboximides (iprodione and vinzoclozolin), benzimidazoles (benomyl and thiophanate methyl), triforine, chlorothalonil, ergosterol biosynthesis inhibitors (myclobutanil, fenbuconazole, and propiconazole), and anilinopyrimidines (Zhang et al., 1991; Vucinic, 1994; Reynaud, 1997; Rueegg et al., 1997; Cotrones et al., 1998). Other fungicides used are copper compounds, sulfur, and captan (Byrde and Willetts, 1977). The selection of a fungicide or mixture of compounds is often influenced by the need to control other conditions that may occur more or less simultaneously with *M. fructigena*, such as scab, powdery mildew, rust, russet scab, or grey mould. Insect control may be an important consideration because *M. fructigena* can infect via wounds. Particular care is needed in packing and storage of fruit because the fungus can pass by growing from one fruit to others in contact with it. Damaged fruit should not be stored (Wormald, 1954).

The importance of good sanitation in the orchard is vital part of cultural practices. Cultural practices such as the removal of mummified fruit and pruning of infected twigs, and subsequent burning or deep-burying reduce the inocula level, but these procedures alone are not sufficient to control the disease. Wormald (1954) emphasised that hygiene is equally necessary during and after seasons of light infection. Good hygiene can also reduce the population of spore vectors. *M. fructigena* cause postharvest decay/damage of fruit that usually results from the infection in field condition. Therefore, care must be taken during harvesting and handling to avoid postharvest damage. Fruit chilled below about 5°C in transit and storage, reduce the fungal growth and damage. Hydrocooling, or hydraircooling, is now extensively used on peaches after harvest in the south-eastern USA.

Phytosanitary risk: The risk of introduction of brown rot disease into new countries is connected with the incautious trading of fruits and host plants where the fungus is able to survive. However, the occurrence of entry is unpredictable because sometimes fruits carried by international passengers illegally or unknowingly during the travel.

Quarantine Risk: Low – *M. fructigena* spore mainly disperse through wind locally. Restricted host fruit (e.g. apple, pear etc.) import from the countries where the fungus has been reported and firm quarantine will reduce the risk of entry of this fungus in Australia.

Probabilities of Entry: Medium – because of a number of interceptions of apples infested by the *M. fructigena at* the Sydney and Perth International Airports. A high volume of travellers from Europe usually carries pome fruit and have confiscated a number of times at Australia's international airports (AIMS database).

Possibility of Establishment: High – because Australia has many regions with a number of host of *M. fructigena* and a suitable climatic conditions for BR to establish. Moreover, two other species of this fungus already been established in Australia.

Probabilities of Entry and Establishment: Moderate – with moderate possibility of entry along with suitable climatic conditions and presence of multiple hosts for BR indicates moderate chance of entry and establishment in Australia.

Economic Impact: High – significant fruit losses (up to 35%) by BR reported in the literature (Rosenberger 1997, Xu & Robinson 2000) and the damage can cause in both field and storage conditions to a number of different fruits such as apple, pears, cherry, etc. Therefore, it would have high impact on commercial apple and fruit host industries in Australia.

Environmental Impact: Negligible – BR disease is not expected to impact on environment as the disease is restricted to horticultural crops and no reports on wild or native host. Fungicides applications in BR management might have negligible impact on human and animal health.

Social Impact: Moderate – impact on backyard fruit trees to be expected and this will results negative impact on socio-economic condition of the society. However, BR disease symptoms are quite visible; control measures are available including cultural practices. Therefore, the grower should be able to handle the disease quickly and effectively to escape the damage intensity.

Pest management cost: Moderate – The biology of brown rot disease and its available control measures will reduce the cost in disease management. The cost may vary from place to place depends to labour wages, pest severity, host variety and other factors. Calculation based on at least 6 chemical spray in one season that include $20.0 chemical cost and $50.0 application cost/ha for a single spray i.e. (20 + 50)x6 = $420/ha. Sources - Pest data sheet/ERAT and Martine Combret/Development officer/DAFWA/Bunbury.

Yield loss despite control efforts: Based on pest biology, available control measure, and its impact on the host plant the total yield loss assumed to be between 10 - 15% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: High – the import of pomes and stone fruit is prohibited from countries where BR, caused by *M. fructigena,* is recorded (AQIS 1991) because high risk of spore dispersions by infested fruits during international trade. Therefore, having the pest in Australia would be a major concerned in export market.

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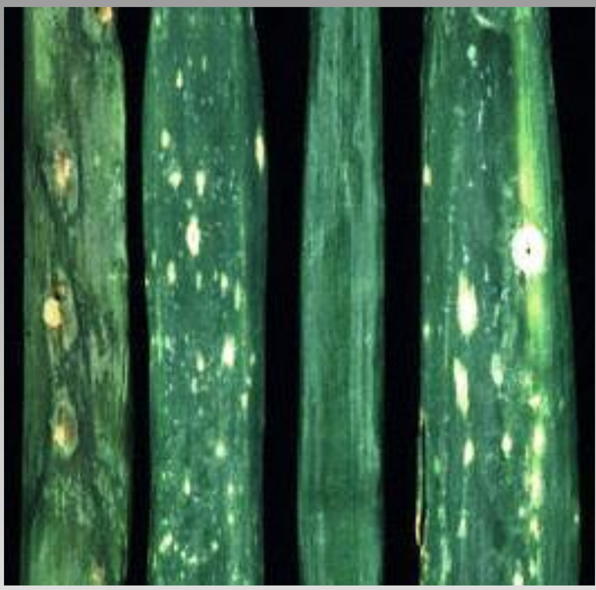
THREAT DATA

Cladosporium leaf blotch

(*Cladosporium alli-cepae*)



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Cladosporium leaf blotch

(*Cladosporium allii-cepae*)

Cladosporium leaf blotch is another important fungal disease of onion and other Allium species. It is foliar disease and occurred only infrequently in temperate growing areas in the past. Severe outbreaks were reported in Ireland and the UK with significant yield loss. The disease symptom appears as large brownish spots or blotches at any stage of plant growth but mostly occurs after bulb setting. The symptoms easily confused with herbicidal burn. The pathogen of Cladosporium leaf blotch is not reported in Australia yet.

Distribution: Pathogen of Cladosporium leaf blotch (*Cladosporium allii-cepae*) has been reported in Ireland, UK, Canada and USA. But Australia seems to be free of this pathogen.

Host range/Alternate host: Restricted to *Allium* spp. like onion, garlic, shallot, Welsh onion, chives, and a number of wild species e.g. *Sisyrinchium* spp., *Triteleia* spp. (Farr et al. 1989, Maude 1990).etc.

Biology and Ecology: Cladosporium leaf blotch disease may occurs at any developmental stages of the host but most common at late stage during leaf senesce. The inoculum is mostly found on infested crop residues and optimum temperatures for spore germination and infection are 15 to 20^{O}C at 100% relative humidity. Spore germination might be inhibited by free water. The disease symptoms may be visible after 2-days of infection under optimum conditions and infection occurs more readily on damaged and senescing leaves. The production of conidia is very light sensitive and even moonlight can inhibit this production. The conidia are released in the day, mostly during late morning to early afternoon. The fungus can persist for 3 months on host debris and it's not seed borne (Maude 1990).

Symptoms: The fungus Cladosporium attacks host leaves only and the symptoms can be found at any stage developmental stage of the host. However, the disease mostly occurs after bulb setting and particularly at senescing stages of the host leaf. The symptoms on onion leaves are conspicuous, large white spots or blotches parallel to leaf veins. With time the blotches turns into brown or dark brown as the fungus sporulates on the affected tissue. In sever cases, blotches merge together that may lead to collapse of the infected leaf. The disease symptoms are easily be confused with burns results from herbicides or nitrogen fertilisers.

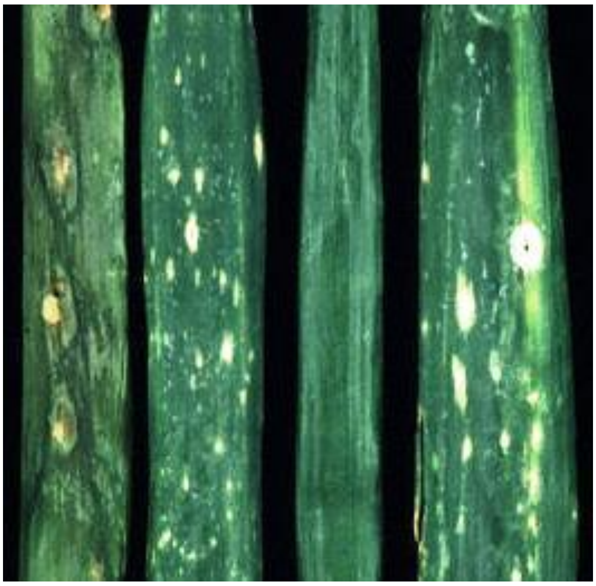

Fig 1. Symptoms of Cladosporium leaf blotch disease in Onion

Affected plant stages: Vegetative growing stage

Affected plant parts: Mainly leaves.

Affected Industries: Onion and garlic.

Resistant plant variety: No resistant plant varieties/cultivars of onion against the Cladosporium leaf blotch disease has been reported yet.

Disease movement and Dispersal: Under field conditions, the fungal spores splash-dispersed mainly by wind, rain-splash and some by insect feeding and contaminated pruning tools. The dispersal of spores is more strongly depending on the wind. In case of international trade, there is very little chance of fungal spore spread via onion bulb as there is no record of it's association with onion bulb. Moreover, the spore can survive only up to 3 month on onion debris.

Disease Impact: Generally, cladosporium leaf blotch is a minor foliage disease of onion and leek. However, the disease emerged as a serious problem in onion in Ireland in late 1970s and southern England in the early 1980s that caused significant yield loss. Onion and leek are also susceptible to other species of *Cladosporium* fungus.

Disease Management: Both cultural practice and chemical spray are important to manage cladosporium leaf blotch disease. Removal of infected crop debris promptly after harvest, crop rotation with non-hosts, and apply proper fungicides when necessary.

Quarantine Risk: Low – Cladosporium leaf blotch disease spore mainly disperse through wind locally. It's a foliage disease and therefore, the most common trading component like onion bulb has no chance to carry the fungal spore that spread the disease in a new area/country.

Probabilities of Entry: Low – pathogen of cladosporium leaf blotch disease has very restricted host and it's a foliage disease i.e. not associated with onion bulb that are main pathway of entry in Australia through international trade. Unless, the materials (whole plant) bring for research purpose are infected. Moreover, the spore can survive only up to 3 month on crop residues.

Possibility of Establishment: Low – Restricted host-range of cladosporium leaf blotch pathogen reduce the chance to find a suitable host at the entry points upon its arrival, although suitable climatic conditions are available in some parts of Australia. However, Plant Health Australia (PHA) reported high entry possibility in Australia

Probabilities of Entry and Establishment: Low – In spite of suitable climatic conditions, limited host capacity of the pathogen reduces the chance of entry and establishment in Australia. PHA considers high establishment possibility in Australia.

Economic Impact: Low – Generally cladosporium leaf blotch is considered as a minor foliage disease of *Allium* spp. including onion, garlic, leek and the *Allium* spp. There are important vegetable crops in Australia and therefore the disease will have some negative economic impact specially on commercially grown onion regions.

Environmental Impact: Negligible – Cladosporium leaf blotch disease is not expected to have any impact on environment as the disease is very restricted to a particular host group and no reports on wild or native hosts. The disease management is also very effective by cultural practice and hardly requires any fungicides. Therefore, the chance of environmental pollution due to fungicides and its impact on human and animal health is very negligible. PHA believed that the disease would have high impact on the economy.

Social Impact: Low – The disease symptoms are quite visible, control measures are available including cultural practices. Therefore, the grower should be able to handle the disease quickly and effectively to escape the damage intensity.

Pest management cost: Moderate – The biology of OLB disease and its available control measures will reduce the cost in disease management. The cost may vary from place to place depends to labour wages, pest severity, host variety and other factors. Based on 3 spary/season the cost is calculated about $300/ha (ref. Peter Dawson, Project Manager, Potato, DAFWA).

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on major host like onion the total yield loss assumed to be between 10 - 15% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Negligible – cladosporium leaf blotch pathogen posses very low risk of dispersion via international trade and there is no record of transmission of this pathogen on contaminated trading component like onion bulb. Therefore, having the pest in Australia would not be a major concerned in export market.

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THREAT DATA

Crater rot

(*Rhizoctonia carotae*)

http://www.bspp.org.uk/publications/new-disease-reports/ndr.php?id=010022

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Crater rot

(*Rhizoctonia carotae*)

Crater rot is one of the fungal diseases of Carrot and the disease frequently causes serious damage to carrot in storage conditions. But the disease can also occur in field conditions. The pathogen persist as sclerotia for long period in both conditions and 50 to 70% crop damage has been reported by this pest in a number of carrot growing counties. Australia is free of the pathogen associated with crater rot of carrot.

Although the disease may initiate in field conditions but the symptoms are visible usually following 2-3 months of storage. The disease development is favoured by relatively high humidity along with cool temperature.

Distribution: The causal agent of crater rot (*R. carotae*) has been reported from USA, Denmark, Norway, Sweden, Russia, UK and very recently from Turkey (Kurt at al. 2005). Oceania countries are still free of this fungus.

Host range/Alternate host: In addition to carrot, crater rot fungus also attacks celery, swedes, cabbage and beet.

Biology and Ecology: Limited information is available on crater rot disease, but it is probably a soil-borne disease. Although, a rapid disease development occurs with visible symptoms under storage conditions but initial host infection usually happen in the field. Cool temperate with relatively high humidity of storage condition are in favour of crater rot development. The pathogen can survive for long time both in field soil and packing wooden materials in post-harvest condition. Primary infection from field may not play a major role in disease spreading in storage conditions as infected wooden crates are reported as most important infection sources. The fungus persists in wood of storage bins from which new infections are initiated. It may also be present in the soil (as sclerotia) and initiate infection before harvest. The fungus rarely produce any sclerotia in normal conditions but infected carrot under prolong period in dry condition develop sclerotia in the craters. The fungal development is favoured by high humidity with low temperature in storage conditions.

Symptoms: The fungus mainly attacks primary carrot root and white cottony mycellial growth on the surface of carrot are quite visible in storage condition but such symptoms usually not notice in field as well as in freshly harvested carrots. The symptom initiate as a small band of dark brown necrosis around the carrot crown and horizontal brown canker-like lesions mostly on the crown and upper roots. Subsequently small pits developed beneath the lesions, that gradually enlarged into sunken brown crater lined with a white flocculent mycelium. The disease was named "crater rot" because of the crater development. In storage condition under high humidity white mycelia growth cover the crates and spread the disease rapidly. The symptoms may easily be confused with Fusarium dry rot of carrot disease.

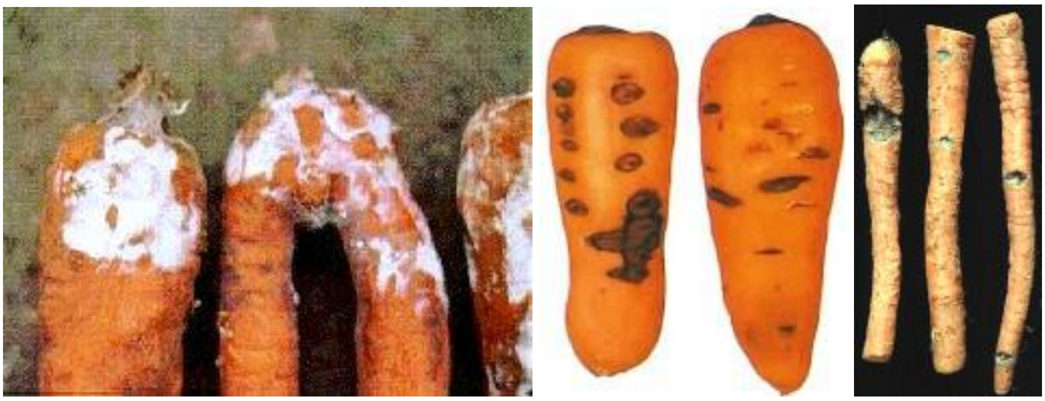

Fig. Symptoms of Crater rot on stored carrots (ref. http://www.omafra.gov.on.ca/english/crops/facts/98-001.htm)

Affected plant stages: Vegetative growing stage

Affected plant parts: Primary carrot root

Affected Industries: Mainly carrot and related host industries

Resistant plant variety: No resistant plant varieties/cultivars against the disease has been reported yet.

Disease movement and Dispersal: Crater rot of carrot mainly develop in storage conditions and the disease spread from there through infested carrots and packing materials. Under field conditions, the disease usually spread through fungal scterotia in infested soil. The soil attached with famer feets, agricultural machinery and others help in spreading the disease in new locations. In case of international trade, the fungal sclerotia can easily be carried by infested carrots and packing materials. .

Disease Impact: *R. carotae* generally consider as a minor pathogen but it can cause severe disease outbreaks. Losses of 50-70% have been reported in storage from Denmark and some areas in the USA (Punja, 1987). Recently, in Turkey 55-70% yield reductions has been recorded in field (Kurt et al. 2005).

Disease Management: Both cultural practice and chemical spray are equally important to manage crater rot disease. There is no evidence of varietal resistance. On farms with a previous history of the disease, control with fungicide is advisable. Fungicides should be sprayed in the field once or twice before lifting, with sufficient pressure to ensure the fungicide reaches the crown. Damage during harvesting should be avoided, and soil and leaf debris should not be left adhering to the roots. Good hygiene is required, with thorough cleaning of storage bins and stores. Chlorothalonil and fenpropimorph are the commonly used fungicides Sprays for this disease.

Quarantine Risk: Moderate – Crater rot disease pathogen can survive in both field and storage conditions as sclerotia for many years. The sclerotia can easily be transfer both long and short distance with infested and carrots packing materials during the trades and also in field conditions via agricultural tools.

Probabilities of Entry: Moderate to High – pathogen of crater rot disease able to survive as sclerotia both in carrots and it's packing materials. Therefore, the pathogen can easily be entered into the country during carrot trading from infested county unless strong quarantine measure is applied.

Possibility of Establishment: Low to Moderate – Limited host-range of the pathogen reduces the chance to find a suitable host at the entry points upon its arrival. However, long survival capacity of fungal sclerotia without host allows plenty of time to find a suitable host to establish. Dry climatic conditions in Australia not in favour of this disease but the main damage caused by crater rot disease in storage conditions.

Probabilities of Entry and Establishment: Moderate – In spite of limited host range and restricted climatic conditions, long period survival capacity of fungal sclerotia out side the host plants enhances the scope of the pest to establish in carrot growing regions of Australia.

Economic Impact: Low - Moderate – Crater rot is one of the damageing storage diseases of carrot and other related hosts that are important vegetable crops in Australia and therefore the disease will have some negative economic impact specially on commercially grown carrot regions.

Environmental Impact: Negligible – Crater disease is not expected to impact on environment as the disease causes most of the damage in storage conditions that needs more of cultural practice with limited chemical application to manage. Therefore, there would be a negligible environmental impact due to the chemicals.

Social Impact: Low – The crater rot disease symptoms are quite visible and the damage restricted in storage condition following harvesting. Effective control measure are available, therefore the grower should be able to handle the disease quickly and effectively to escape the damage intensity.

Pest management cost: Low – The biology of crater rot disease and its available control measures will reduce the cost in disease management. The cost may vary from place to place depends to labour wages, pest severity, host variety and other factors. Crater rot is a soil-borne fungus that's difficult to manage by chemical. Using soil disinfestant chemicals keep the infestation low and sanitation measures play important role in the management. The total cost includes both chemicals and application cost. The application cost $400/ha based on guess by Peter Dawson/Project Manager, Potatoes/DAFWA.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on major host like carrot the total crop loss assumed to be between 10 - 15% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Moderate – Although, crater rot disease pathogen posses risk of dispersion during trade but there is no record of transmission of this pathogen via infested carrots under quarantine. Therefore, having the pest in Australia would not be a major concerned in export market.

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THREAT DATA

European canker

(*Neonectria galligena*)

Source: http://www.agf.gov.bc.ca/cropprot/tfipm/european.htm

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European canker

(*Neonectria galligena*)

Neonectria galligena is a fungus that causes canker disease in apple, pear and more than other 60 plant species. The disease is also known by other names such as European canker, apple canker, pear canker, Nectria canker etc. This is one of the most economically serious apple diseases in Europe, North America and South America. The fungus is more aggressive in wait areas compared to dry regions and it can infect both fruits and woody plant parts. European canker is present in all commercial apple and pear growing regions except Australia where it was completely eradicated in 1991.

Host range: In addition to its primary hosts (apple, pear, sugar maple and yellow birch) European canker has wide and diverse host range that includes more than 60 tree and shrubs species.

Distribution: The fungus of European canker perhaps native to Europe and it has been known there for many years. Now the disease wide spreads in many countries in Asia, North America, South America and Africa, specially in apple and pear growing regions. In Australia the disease was reported in Tasmania in 1954 but it was successfully eradicated and Australia is free from European canker since 1974.

Biology and Ecology: European canker is perennial and the fungal mycelium lives over from year to year in the diseased bark. In the spring and early summer red perithecia develop in the wound and under favourable conditions discharge their ascospores. Conidial tufts are developed at this time of year also, so that there are two kinds of spores for initiating primary infections. It has been shown that insects are highly important as agents of inoculation; the woolly aphis, for example, is very active in carrying the spores of the fungus. In Europe an outbreak of canker is said to follow closely an unusual prevalence of this insect. It has been estimated that in a single canker 300,000 ascospores are available for dissemination. The spores germinate in a few hours and the germtubes enter the bark through wounds or lenticels. Within a week the effects of the fungus are visible. The mycelium, developing from the germtube, permeates the bark, the wood and the pith. The attacks are confined chiefly, however, to the bark, where the cortical cells are killed by the fungus. As a result of death, the affected portion of the bark turns brown, the cells collapse, and the canker shows a sunken surface. If the atmosphere is continuously humid, conidial tufts arise from the mycelium. From these tufts, conidia are liberated; they are then carried to other points where new cankers are formed. The mycelium grows more rapidly parallel to the long axis of the limb and hence the canker is the longer in this direction. Where the wood is entered, the mycelium invades the sap - tubes in which it passes up and down. It is believed that at points above and below the canker the fungus again attacks the cortex, this time from within, thus forming a new canker without direct external inoculation. About a year after the canker starts to develop the mycelium forms the red perithecia. These may act as a means of carrying the fungus through the winter.

Symptoms: European canker disease mainly affects branches and trunks of tree but is also damage fruits. The symptoms on stem initiate as discolouration of the bark (reddening) and gradually blister development occurs when the infected bark lifts away from the wood. The canker develops quickly with ring shaped cracks forming in the bark, which may appear swollen. If the canker girdles the trunk or branch, shoots above the canker die. The canker usually stops growing after one year. A ridge or collar of healthy tissue walls off the canker. Young cankers produce small, whitish fruiting bodies. Older cankers may produce orange-red fruiting bodies. Large canker lesions on main stems or branches usually develop at the junction with side shoots. European canker can sometimes be confused with anthracnose canker.

Figs. European canker symptoms on apple tree

Ref: http://www.agf.gov.bc.ca/cropprot/tfipm/european.htm

http://www.padil.gov.au/pbt/index.php?q=node/70&pbtID=143.

Affected plant stages: Fruiting stage and vegetative growing stage

Affected plant parts: Stem and fruits

Affected Industries: Apple and pear industries mainly.

Resistant plant variety: Currently, no information is available on resistant plant varieties/cultivars against European canker disease of apple and pear.

Disease movement and Dispersal: Under field conditions, European canker fungal spores (ascospores) dispersed mainly by wind, rain-splash and some by insect feeding and contaminated pruning tools. Fruit-to-fruit contact is one of the main mechanisms for spread of disease within a tree as well as in storage condition. In case of international movement, the planting materials with canker carry the risk of dispersion. The faunal ability to survive in canker is a positive factor in terms of its dispersal capacity.

Disease Impact: Including apple and pear European canker is one of the destructive diseases for other fruits and 10 - 60% fruit losses have been recorded in various parts of the world (Plant Health Australia). Compared to apple the rust causes less damage to pear. Thousands of trees are killed in their prime. In many localities certain varieties can no longer be grown, and there are even districts in which apple-culture has become a real problem as a result of the ravages of this disease. Nor are the losses confined to the apple, nor to fruit trees. It will be less difficult to give an impression of the economic importance of this disease if brief reference to the plants affected is made. Among these are, in addition to the apple, the pear, quince, cherry, gooseberry, lime, beech, maple, ash, alder, hazel-nut, linden, plane-tree, oak, hornbeam, ironwood, dogwood and magnolia. In Germany, for example, beech- - stands are often ruined by it. And while the greatest damage done to forest trees is in foreign countries, its importance on the apple makes it a serious pest. In case of forest trees, the damages leading to significant reduction in log quality, value and inevitable loss of saleable timber.

Disease Management: Epidemics of Nectria canker in apple usaully localised and therefore the control measures are not essential in every orchard. A number of chemical and cultural measures have been developed that are generally applied only in case of outbreak. Once the disease has become established in young orchards it can be very difficult to control. Fungicides based on copper or mercury were found to be effective when applied at the commencement of leaf fall, at 50% leaf fall and again at bud burst (Brook and Bailey, 1965; Mulder, 1966; Wilson, 1968). Phenyl mercury nitrate is now banned, so protectant sprays now use copper, especially copper oxychloride (Cooke et al., 1993; Lolas and Latorre, 1997). In areas with significant summer rainfall some fungicides used to control apple scab (Venturia inaequalis) were also found to provide excellent control of Nectria canker (Swinburne et al., 1975). Protectant fungicides such as dodine and dithianon can give good control of both diseases (Cooke et al., 1993) and are recommended in integrated programmes. Some fungicides, notably carbendazim markedly reduce sporulation of *N. galligena* from existing canker lesions (Swinburne et al., 1975), and although ineffective as a protectant at leaf fall, gave excellent overall control of both diseases when combined with dithianon (Cooke et al., 1993). Demethylation-inhibiting fungicides including myclobutanil and penconazole, effective against scab, also reduce Nectria canker but were less effective than programmes which included benzimidazoles in spring and summer (Cooke and Waters, 1994). Berrie (1992) considered the implication of including carbendazim in orchard sprays. Guidelines for testing fungicides for the control of canker have been produced by OEPP/EPPO (1991). Paints containing formulations of fungicidal agents are widely used to protect pruning scars from new infections (Schaefer and Ficke, 1986; Cooke and McCracken, 1988) and to treat lesions on main stems and major branches (Corke et al., 1972; McCracken and Cooke, 1985; McCracken et al., 1986; Clifford et al., 1987).

Cultural Control: Infected branches removed during pruning continued to produce spores for up to 2 years when left on the orchard floor. This led to a general recommendation for the removal and destruction of prunings. However, this is a costly operation, and it is now usual to chip pruned shoots within the orchard, where the fragments are left. Test have shown that this practice does not result in increased canker incidence (van der Sheer, 1981; Swinburne and Souter, 1984).

Host-Plant Resistance: All cultivars of apple are susceptible to Nectria canker, but the prevalence and severity of the disease is much greater on some, such as McIntosh, Cox and Spartan, than on others

Prevention of Fruit Rotting: Application of fungicides to apple trees in the period immediately before harvest can reduce rotting of fruit in storage, but there are practical difficulties in providing adequate cover under commercial conditions (Swinburne and Cartwright, 1974). The materials used (captan, carbendazim, thiophanate-methyl and dithianon) tend to be those used for the control of apple scab and, as a consequence, increase the number of fungicide applications within a season.

In storage, fruit can be subject to rotting by many species of fungi (Berrie, 1997) of which *N. galligena* can, under some circumstances, be the dominant cause (Swinburne, 1975a; Palm, 1986). After harvest, in many countries, fruit are dipped in a 'cocktail' of compounds designed to control physiological disorders such as scald and bitter pit (Cartwright, 1976) and rots due to fungi from diverse orders, including Phytophthora and Nectria. The inclusion of compounds that can generate carbendazim in solution has long been known to control N. galligena (McDonnel, 1970, 1971; Phillips, 1972). What is less certain is how these rots will be controlled when postharvest dips are prohibited (Colgan, 1997).

Quarantine Risk: Moderate – *N. galligena* spore mainly disperse through wind locally but the pest can be spread internationally in latent conditions on fruits and timbers. Moreover, the fungus also possesses diverse host range and wide distribution throughout the world. All together the disease has moderate quarantine risk.

Probabilities of Entry: High – because of diverse host range and wide geographic distribution. Moreover, the infection can be latent on fruits like apple.

Possibility of Establishment: High – because Australia has many regions with both primary and secondary hosts of *N. galligena* and suitable climatic conditions for this canker disease to establish.

Probabilities of Entry and Establishment: High – with high possibility of entry along with suitable climatic conditions and presence of both primary and secondary hosts for the disease indicates high chance of entry and establishment in Australia.

Economic Impact: Moderate to high – European canker one of the distractive diseases in Europe and including apple lot of other fruits also get affected by this disease in both field and storage conditions. Bedside, fruits the canker also cause damage to forest trees and timber quality.

Environmental Impact: Moderate – European canker is not restricted to fruits plants it also damage forest tress that might include many native species. Therefore, the pest will have negative impact on our landscape and finally on the environment**.**

Social Impact: Moderate – impact on backyard fruit trees to be expected and this will results negative impact on socio-economic condition of the society. However, European canker symptoms are quite visible; control measures are available including cultural practices. Therefore, the grower should be able to handle the disease quickly and effectively to escape the damage intensity.

Pest management cost: Moderate – The biology of brown rot disease and its available control measures will reduce the cost in disease management. The cost may vary from place to place depends to labour wages, pest severity, host variety and other factors.

Calculation based on at least 6 chemical spray in one season that include $20.0 chemical cost and $50.0 application cost/ha for a single spray i.e. (20 + 50)x6 = $420/ha. Sources - Pest data sheet/ERAT and Martine Combret/Development officer/DAFWA/Bunbury.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 - 20% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Moderate – although the European canker is able to survive as latent condition, however, dispersion of disease through infested fruits is not reported yet. The canker has good history of establishment capacity in any new countries. Therefore, having the pest in Australia might be concerned in export market.

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THREAT DATA

European pear rust

(*Gymnosporangium fuscum*)

Source:http://images.google.com.au/images?hl=en&q=Gymnosporangium%20fuscum&um=1&ie=UTF-8&sa=N&tab=wi

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European pear rust

(Gymnosporangium fuscum)

Gymnosporangium fuscum is a rust fungus commonly known as European pear rust (EPR) or pear rust. Like other rust, EPR requires two different hosts (e.g. summer and winter hosts) to complete its life cycle. EPR is an important pest of pear tree in northern Europe and it cause severe leaf defoliation and stem canker. EPR has restricted distribution in China, USA, Canada, but no report from Australia and New Zealand. The fungus has listed as quarantine pest by COSAVE.

Host Range: EPR fungus has very specific host e.g. Pyrus (pears) both cultivated and wild). The secondary hosts are member of plant species belong to both *Juniperus* and *Cupressus* spp.

Distribution: *G. fuscum* originates in central and southern Europe and now occurs in northern Europe (e.g. Belgium, Denmark, Netherland, Norway, Sweden and UK). The fungus has been introduced in other parts of the world like USA, Canada, China, etc.

Biology and Ecology: *G. fuscum* is heteroecious i.e. it requires two different host plants to complete its life cycle. In spring a fruiting body (called telia) produce on stems in host plant *Juniperus chinesis*. The telia release windborne basidiospores capable of infecting susceptible apple leaves. These windborne basidiospores can be dispersed up to 6 km. Once the basidiospore reaches a susceptible pear leaf, infection takes place, causing yellow orange spots on pear leaf. The spots eventually enlarge and become crimson red along the margins, making them very noticeable in early summer. In the centre of the yellow spots are tiny raised pimples called pycnia that exude a sticky sugary substance. These pimple-like structures contain sex spores and following fertilisation it results a tiny lantern-shaped growths called aecia protrude from the blister on the underside of the pear leaves in late summer. The aecia contain many spores called aeciospores that can infect only susceptible juniper hosts. The aeciospores are windborne and eventually land on a susceptible juniper host twig where infection occurs. As the fungus grows within the juniper twig or branch, a swelling or gall is produced in which the fungus overwinters. Reports indicate that the host plant (*Juniperus* spp) infection occurs once in a year and teliospores being produced one year only. The perennial cankers give rise to infested shoots with pycnia and most often die out after 2 years (Hunt and O'Reilly, 1978). Hilber et al. (1990a) have more recently studied the epidemiology of pear rust.

Disease symptoms: Yellow to reddish-orange spots visible on the upper surface of apple leaf. Gradually the spots become large and develop tiny raised pimples called pycnia in the centre of the spots. In later, brown colour blister with fibrous creamy-white bundles appear as outgrowth (known as aecia) underside of the orange spots in pear leaf (fig. as below). Premature defoliation and canker formation on pear branches occurs due to this disease. The symptoms in *Juniperus* spp plant appear as swellings or gall formations on stem in which the fungus overwinters.

 

Fig. Infected pear leaf by rust

(Source: http://images.google.com.au/images?hl=en&q=Gymnosporangium%20fuscum&um=1&ie=UTF-8&sa=N&tab=wi)

Affected plant stages: Vegetative growing stage

Affected plant parts: Leaves mainly but also found in fruits and stems.

Affected Industries: Pear industry only.

Resistant plant variety: Currently, no information is available on resistant plant varieties/cultivars against EPR disease.

Disease movement and Dispersal: Under field conditions, EPR fungal spores dispersed mainly by wind and rain. In case of international trade, the fungus could spread via trading of secondary host (*Juniperus* and Cupressus spp.) in which the fungus remain latent and may escape the quarantine at the entry point. But introduction of EPR fungus on commercial importation of pear plants is very unlikely as infection is not persistent in the dormant stage on fruits. Because *G. fuscum* can be perennial on pear shoots, there is also a danger of movement with plants for planting of pear; this was probably the pathway by which *G. fuscum* entered North America. While fruits can be infected, it is very unlikely that infected fruits would be harvested or meet quality standards for export.

Disease Impact: *G. fuscum* causes a moderately important disease of pear in southern Europe (OEPP/EPPO, 1999). Pear trees suffer some defoliation, and stem cankers may distort young trees. The incidence of European pear rust depends simply on the frequency of the alternate host, and the distance between sources of infection and pear orchards. In Turkey (Dinc and Karaca, 1975), incidence on pear was related to the distance from juniper plants, obstacles, direction of the wind and susceptibility of cultivars. Hilber et al. (1990b) attribute a recent increase in severity of pear rust in Switzerland. The disease is rare and unimportant in northern Europe. In western North America, *G. fuscum* has apparently been more damaging than it is in Europe. This is presumably connected with a greater frequency and diversity of *Juniperus* species Although *G. fuscum* has recently been recorded in China, there is no indication that it is of any importance there. There is no indication that *G. fuscum* causes any significant damage to junipers but, in countries like Canada where the disease is very localised, it is important that nursery stock of junipers should not be infected so that the disease should not be further spread on this material (Ormrod et al., 1984).

Disease Management: EPR can be controlled adequately by routine fungicide applications (e.g. example, sterol-inhibiting fungicides). A new triazole (HF-6305) fungicide successfully uses in Japan against this disease (Ohyama et al. 1988). The best way to minimise this disease is to keep the alternate hosts at least 1 km apart from each other. Inspect *Juniperus* plants periodically and prune out any suspicious swellings or galls. Pear growers should also insure that susceptible *Juniperus* hosts are removed within at least one or two km of the orchard.

Phytosanitary risk: *G. fuscum* is listed as a quarantine pest by COSAVE. It has shown its ability to spread between continents. The fungus was regarded as a dangerous introduced pest when it first appeared in North America, subject to regulatory measures. It is regulated in Canada, where pear trees must be dormant and defoliated at the time of importation or movement from infested area, juniper is prohibited from infested areas of the USA and the world where *G. fuscum* occurs. *G. fuscum* has been deregulated in the USA, essentially since it was found that the commonly used fungicides were cheaper than regulation.

Quarantine Risk: Low – EPR disease spores mainly disperses through wind locally and has very restricted host range. The fungus is also not persistent in dormant conditions on pear fruits.

Probabilities of Entry: Very low – because of very selective primary host (i.e. pears only. Also the fungus can only survive in dormant condition on its secondary host like *Juniperus* sp. Therefore, import restriction on this host from the countries where the fungus has been reported will reduce the possibility of entry in Australia.

Possibility of Establishment: Low – although Australia has many pear growing regions, a possible presence of secondary host (*Juniperus* spp.) of EPR and a suitable climatic conditions but the rust fungus can survive for a limited period only in its winter host e.g. *Juniperus* spp.

Probabilities of Entry and Establishment: Very low – with very low possibility of entry along with suitable climatic conditions and presence of hosts for EPR indicates low chance of entry and establishment in Australia.

Economic Impact: Low/moderate – EPR causes both premature defoliation of and spots of pears that can reduce both production and market values of pears. There is no data on pear production loss by this rust but depending on climatic condition the damage may very from low to moderate.

Environmental Impact: Negligible – EPR disease is not expected to impact on environment as the disease is restricted to very selective hosts only and no reports on wild or native host. Insecticides application in EPR management might have negligible impact on human and animal health.

Social Impact: Negligible – impact on backyard pear trees to be expected and this will results very negligible impact on socio-economic condition of the society. However, the disease symptoms are quite visible and it can be controlled by cultural practices. Therefore, the grower should be able to handle the disease quickly and effectively to escape the damage intensity.

Pest management cost: Moderate – The biology of EPR disease and its available control measures will reduce the cost of disease management. Calculation based on 3 chemical spray in one season that include $36.0 chemical cost and $50.0 application cost/ha for a single spray i.e. (36 + 50)x3 = $258/ha (Sources - Pest data sheet/ERAT and Martine Combret/Development officer/DAFWA/Bunbury). Note that this fungus needs an alternate host to complete its life cycle, therefore removal of alternate host will reduce the management cost for apple growers (ref. Pest data sheet/ERAT). The cost may vary from place to place depends to labour wages, pest severity, host variety and other factors.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 5 - 10% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – the rust fungus (EPR) infect pear leaves and fruit. But, the fungal spore unlike to persist in dormant condition on the fruit. Therefore, trading of pear fruits does not involve any risk of carrying this rust fungus. Therefore, having the pest in Australia would not be a major concerned in export market.

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THREAT DATA

Japanese apple rust

(*Gymnosporangium yamadae*)

Source: http://nu-distance.unl.edu/Homer/disease/Hort/Trees/ApCdRust.html

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Japanese apple rust

(*Gymnosporangium yamadae*)

Gymnosporangium yamadae is a rust fungus commonly known as Japanese apple rust (JAR). Like other rust, JAR requires two different hosts (e.g. summer and winter hosts) to complete its life cycle. JAR is an important pest of apple tree in northern Japan and it cause severe leaf defoliation but fruit infections are rare. JAR reported in a number of Asian countries including Japan only. No reports from USA, Africa, EPPO region and EU. The fungus has listed as A1 quarantine pest by EPPO (OEPP/EPPO 1983). JAR is not present in Australia.

Host Range: JAR has restricted host range mainly apple tree (*Malus domestica*), and other plant species of *Malus.* The secondary host is *Juniperus chinesis*, widely grown as ornamental tree or bonsai plant.

Distribution: *G. yamadae* has limited distribution in Asia especially in China and Japan. The pest is absent in Europe, USA, Africa and Australia.

Biology and Ecology: *G. yamadae* is heteroecious i.e. it requires two different host plants to complete its life cycle. In spring a fruiting body (called telia) produce on stems in host plant *Juniperus chinesis.* The telia release windborne basidiospores capable of infecting susceptible apple leaves. These windborne basidiospores can be dispersed up to 6 km. Once the basidiospore reaches a susceptible apple leaf, infection takes place, causing yellow orange spots on the apple leaf. The spots eventually enlarge and become crimson red along the margins, making them very noticeable in early summer. In the centre of the yellow spots are tiny raised pimples called pycnia that exude a sticky sugary substance. These pimple-like structures contain sex spores and following fertilisation it results a tiny lantern-shaped growths called aecia protrude from the blister on the underside of the apple leaves in late summer. The aecia contain many spores called aeciospores that can infect only susceptible juniper hosts. The aeciospores are windborne and eventually land on a susceptible juniper host twig where infection occurs. As the fungus grows within the juniper twig or branch, a swelling or gall is produced in which the fungus overwinters. Reports indicate that the host plant (*Juniperus chinesis)* infection occurs once in a year and teliospores being produced one year only.

Disease symptoms: Yellow to orange spots visible on the upper surface of apple leaf. Gradually the spots become large and develop tiny raised pimples called pycnia in the entre of the spots. In later, brown colour blister with tiny lantern-shaped growths known as aecia develop underside of the orange spots in apple leaf (fig. as below). Premature defoliation occurs due to this disease. The symptoms in *Juniperus chinesis* plant appear as swellings or gall formations on stem in which the fungus overwinters.

Fig. Infected apple leaf by Japanese apple rust

(Source: http://nu-distance.unl.edu/Homer/disease/Hort/Trees/ApCdRust.html)

Affected plant stages: Fruiting stage and vegetative growing stage

Affected plant parts: Leaves mainly

Affected Industries: Apple industry mainly

Resistant plant variety: Currently, no information is available on resistant plant varieties/cultivars against JAR disease.

Disease movement and Dispersal: Under field conditions, JAR fungal spores dispersed mainly by wind and rain.

In case of international trade, the fungus could spread via trading of secondary host (*Juniperus chinesis)* in which the fungus remain latent and may escape the quarantine at the entry point. But introduction of JAR fungus on commercial importation of apple plants is very unlikely as infection is not persistent in the dormant stage. Fruits are rarely gets infected.

Disease Impact: JAR is an important disease for apple in northern Japan. The disease causes premature defoliation that results negative impact on apple production.

Disease Management: JAR can be controlled adequately by routine fungicide applications (e.g. example, sterol-inhibiting fungicides). A new triazole (HF-6305) fungicide successfully uses in Japan against this disease (Ohyama et al. 1988). The best way to minimise this disease is to keep the alternate hosts at least 1 km apart from each other. Inspect *Juniperus* plants periodically and prune out any suspicious swellings or galls. Apple growers should also insure that susceptible *Juniperus* hosts are removed within at least one or two km of the orchard.

Phytosanitary risk: The risk of introduction of JAR disease into Australia is connected with the incautious trading of winter host (i.e. *Juniperus chinesis*) where the fungus is able to survive. Trading of apple plants and fruit is very unlikely to introduce this disease as the pest is unable to persist on this host plant in dormant condition.

Quarantine Risk: Low – JAR disease spores mainly disperses through wind locally and has very restricted host range. The fungus is also not persistent in dormant conditions on apple tree.

Probabilities of Entry: Very low – because of very restricted host range. For example, the fungus only can survive in dormant condition on its secondary host like *Juniperus chinesis.* Therefore, import restriction on this host from the countries where the fungus has been reported will reduce the possibility of entry in Australia.

Possibility of Establishment: Low – although Australia has many apple growing regions, a possible presence of secondary host (*Juniperus chinesis)* of JAR and a suitable climatic conditions but the rust fungus can survive for a limited period only in its winter host e.g. *Juniperus chinesis.*

Probabilities of Entry and Establishment: Very low – with very low possibility of entry along with suitable climatic conditions and presence of multiple hosts for BR indicates low chance of entry and establishment in Australia.

Economic Impact: Low/moderate – JAR causes premature defoliation of apple tree that can reduce the apple production as reported in Japan. There is no data on apple production loss by this rust but depending on climatic condition the damage may very from low to moderate.

Environmental Impact: Negligible – JAR disease is not expected to impact on environment as the disease is restricted to two hosts only and no reports on wild or native host. Insecticides application in JAR management might have negligible impact on human and animal health.

Social Impact: Negligible – impact on backyard apple trees to be expected and this will results very negligible impact on socio-economic condition of the society. However, the disease symptoms are quite visible and it can be controlled by cultural practices. Therefore, the grower should be able to handle the disease quickly and effectively to escape the damage intensity.

Pest management cost: Moderate – The biology of JAR disease and its available control measures will reduce the cost of disease management. The cost may vary from place to place depends to labour wages, pest severity, host variety and other factors. Calculation based on 3 chemical spray in one season that include $36.0 chemical cost and $50.0 application cost/ha for a single spray i.e. (36 + 50)x3 = $258/ha (Sources - Pest data sheet/ERAT and Martine Combret/Development officer/DAFWA/Bunbury). Note that this fungus needs an alternate host to complete its life cycle, therefore removal of alternate host will reduce the management cost for apple growers (ref. Pest data sheet/ERAT).

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 5 - 10% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: None – the rust fungus (JAR) infect apple leaves and rarely apple fruit. Moreover, the fungal spore unlike to persist in dormant condition on apple fruit. Therefore, trading of apple fruits does not involve any risk of carrying this rust fungus. Therefore, having the pest in Australia would not be a major concerned in export market.

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THREAT DATA

Olive canker/dieback

(*Cytospora oleina*)

Source: http://www.oliveoilsource.com/peacock_spot.htm.

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Olive canker/dieback

(*Cytospora oleina*)

C. oleina is a fungal pathogen that causes both canker and dieback (OCD) in olive. The disease symptoms are very similar to *Phomosis* canker of Russian-olive. Over 40 pathogenic species of Cytospora have been described but very limited information on *C. oleina* in literature. The disease symptoms causes by this fungus found in leaves twigs and main trunk of infected plant that gradually lead to death of the whole plant. No effective chemicals measures are available to control except cultural practices. So far *C. oleina* reported in olive pants in Greece and not present in Australia

Distribution: The distribution of *C. oleina* is not well known because of limited information in the literature. Rumbos (1988) describes the fungus as causal agent of canker and dieback of olive in Mount Pelion region of central Greece. Biosecurity Australia listed *C. oleina* as one of the important exotic pests of olive.

Host range/Alternate host: *Olea europaea subsp. europaea* (olive) is main host. But apple, plum, cherry, peach and apricot also showed positive sign of canker symptoms (xylem discoloration) in laboratory conditions Rumbos (1988).

Biology and Ecology: Typically Cytospora fungal infection take place in above ground woody tissue that has been damaged by frost, fire or sunburn, or through wounds caused by pruning injuries and broken twigs and branches.The cankers are perennial and continue to enlarge each year. The fungus slowly invades and girdles limbs or trunks. The result is a dead limb above the infection site. Black pycnidia of Cytospora can easily be seen emerging from infected bark with use of a hand lens. The pycnidia are roundish and pinhead in size. They are scattered in the cankered area. During wet weather, sticky masses of orange-yellow conidia are extended in long tendrils. These conidia are wind disseminated to injured tissue where they germinate and infect host tissue. Cytospora is active during spring and summer. The extruded conidial stage is most commonly seen during our summer monsoon season. Inoculum can be found on cankered trunks and branches throughout the year.

Symptoms: OCD symptoms are confined to above ground. The symptoms initiate by wilting of leaves on young twigs. The leaves turn yellow but remain attached. The twigs of heavily-infested tree show longitudinal stripes of variable shape and length with a brown discoloration of the xylem. The disease could also be distinguished by the presences of a canker along the older branches. These canker show dark necrosis after removing the bark

Fig. Olive canker/dieback symptoms (Ref. *http://www.oznet.k-state.edu/path-ext/factSheets/Trees/Phomopsis%20Canker%20of%20Russian%20Olive.asp*)

Affected plant stages: Vegetative growing stage

Affected plant parts: Leaves, twigs and stems.

Affected Industries: Olive and may be other fruit industries

Resistant plant variety: No resistant plant variety is available for commercial cultivation yet.

Disease movement and Dispersal: Under field conditions, the fungal spores splash-dispersed mainly by wind, rain-splash and some by insect feeding and contaminated pruning tools. The spores dispersal also influence by strong wind. In case of international trade, the fungus could spread via trading of host plants where the fungus can live as an asymptomatic endophyte of undefined periods.

Disease Impact: In published literature there is no information on the impact of olive canker and dieback disease. However, its consider one of the important disease for commercial olive that has negative impact on olive productions. Death of twigs, branches and canker on stems have serious consequences on the plant's vegetative activity and yield. The disease progress is slow but gradually it kills the plants. Moreover, the disease does not have any effective chemical control measures that may attribute in production loss as well as high management cost.

Disease Management: There are no effective chemicals to control OCD disease except application of a white interior latex paint to woody tissue following pruning that prevent infection. Trees that are properly fertilised and watered are not normally susceptible to infection. Avoid severe pruning. Disinfect pruning cuts with a 1/10 dilution of a household bleach. Cut out infected branches as they are a continual source of infection. Remove and burn where feasible. Removing of all dead wood, including spurs, twigs and branches where the fungus is able to survive and colonise for new infection.

Quarantine Risk: Low – OCD spore mainly disperse through wind locally. The most common trading component like fruit has less chance to carry or escape quarantine to spread the fungus in a new area/country. However, trading young plants with latent OCD disease may spread the disease in a new location.

Probabilities of Entry: Low – because of low possibility of trading host plants of OCD in Australia that carry the fungal spores. Unless, the materials bring for research purpose are infected.

Possibility of Establishment: Moderate – Because of specific host (olive only) OCD pest has less chance to find a suitable host at the entry points upon its arrival. However Australia provides a suitable environmental condition for this fungus to establish in olive growing areas in Australia.

Probabilities of Entry and Establishment: Low – In spite of suitable climatic conditions, specific host capacity of OCD fungus reduces the chance of entry and establishment in any new location.

Economic Impact: Low/moderate – OCD is slow growing disease but gradually it's capable of killing the whole tress and that reduces olive production. Moreover, not chemical control measure is available for OCD i.e. more chance of production loss. In literature no figure of production damage is being reported other then indirect loss on production. However, based on pest biology and the disease severity the damage may be vary from 15 to 40% without control measure depending on climatic conditions. Under proper cultural control measure the damage level may be 10-20%.

Environmental Impact: Nil – OCD disease is not expected to impact on environment as the disease is restricted to olive and few other crop and no reports on wild or native host. In addition, no fungicide is being used in the disease management have impact on human and animal health.

Social Impact: Low – OCD symptoms are quite visible, slow progress disease and can easily be handled through proper cultural practice by small farmers. Therefore, the grower should be able to handle the disease timely and effectively to escape the damage intensity.

Pest management cost: Moderate – The biology of OCD disease i.e. it's slow progress on host plant makes it easy to manage. But lack of effective chemical control measure increases the management cost due to cultural methods such pruning, painting, sanitary etc. Its expected at least **$400 to $600/ha** is required to keep the disease under control in the field by pruning off diseased plant part, painting and burning. The calculation is based on total of 15 hour labour/ha with $30 to $40/hour (15 – 20 min/tree of total 60 trees out of 250 trees/ha).

Yield loss despite control efforts: Based on OCD pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 5 - 20% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Nil – OCD fungus possesses low risk of dispersion via international trade and there is no record of transmission of this fungus on contaminated trading component like fruit. Therefore, having the pest in Australia would not be a major concerned in export market.

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THREAT DATA

Onion leaf blight

(*Botryotis squamosa*)

http://images.google.com.au/images?hl=en&um=1&q=Botrytis+squamosa&sa=N&start=0&ndsp=20

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Onion leaf blight

(*Botrytris squamosa*)

Onion leaf blight (OLB) is one of the important fungal diseases of onion that occurs in many onion growing areas of the world. OLB can reduce both onion bulb growth and yield. The fungus primarily attack host leaf and the disease turns severe under prolong wet condition. The pathogen overwinters in soil as sclerotic form. The disease symptoms cause by the fungus *B. squamosa* can easily be confused by other species of the same fungus that also are causal agents of number of diseases of onion. The pathogen of OLB is not reported in Australia yet.

Distribution: Pathogen of OLB (*B. squamosa*) widespread in UK but has restricted distributions in France, China and Canada. The fungus is endemic in commercial onion fields in Florida and Texas (USA) and it also reported from some other states of USA, Japan and a few European countries. *B. squamosa* is not reported in Australia yet but the other *Botrytris* species that causes onion neck rot (*B. allii*) has been reported in Tasmania with considerable negative impact on onion industry (Dennis 1996, Chilvers et al 2004).

Host range/Alternate host: Restricted to *Allium* spp. like onion, garlic, leek etc.

Biology and Ecology: OLB pathogen primarily attack onion leaf and results reduction of both onion growth and yield. The fungus overwinters on infected plant parts in the field as sclerotia. The sclerotia are produced on infected onion leaves, bulbs and the necks and upper portions of bulbs before or after harvest. Infected leaves may be raked or washed together and persist as leaf tissue debris in which many sclerotia can be found. Sclerotia in the soil result from the disintegration and decay of infected leaves. Sclerotia in the infected onion fields produce both conidia and ascospores (sexual spores) that infect the leaves of nearby onion plants. Because ascospores are the result of sexual reproduction, they may serve as the source of new strains of the pathogen that are tolerant to fungicides used to control OLB. The ability of sclerotia to germinate and produce conidia repeatedly (up to four times) results in the production of conidia over an extended period of time. It is assumed that sclerotic in the soil and plants debris provides the primary source of inoculum for outbreaks of OLB in commercial onion fields. During moist periods with moderate temperatures, fungal spores that arise from sclerotia or infected leaves and debris are dispersed. The spores land on susceptible tissues, and infection occurs. This disease can spread rapidly when environmental conditions are favorable for development. Prolong wet condition with high relative humidity and little air movement enhances the spore production and disease spread.

Symptoms: The fungus mainly attacks the leaves. The first symptoms appear as small white spots surrounded by a greenish halo (Fig 1. left). The centre of spots often are tan, making it difficult to distinguish between leaf blight and damage from insect feeding, mechanical damage, or herbicide injury (Fig 1. centre). Lesions expand with age and, when numerous, may cause leaf tips to die back ((Fig 1. right). Eventually, leaf death results, and severely affected onion fields develop a blighted appearance. Bulbs from infected plants may be small because growth is reduced by leaf loss.

Fig 1. Symptoms of Onion leaf blight (OLB) diseases.
Ref.http://images.google.com.au/images?hl=en&um=1&q=Botrytis+squamosa&sa=N&start=0&ndsp=20

Affected plant stages: Vegetative growing stage

Affected plant parts: Mainly leaves.

Affected Industries: Onion and garlic.

Resistant plant variety: No resistant plant varieties/cultivars against the OLB disease has been reported yet.

Disease movement and Dispersal: Under field conditions, the fungal spores splash-dispersed mainly by wind, rain-splash and some by insect feeding and contaminated pruning tools. The dispersal of ascospores is more strongly depending on the wind. In case of international trade, the fungus could spread via onion bulb where the fungus can live as sclerotia for a long period.

Disease Impact: OLB is a serious foliage disease of onion and it causes reduction of both onion bulb growth and yield. It's a major disease of onion in cool climate areas. Light infections do not affect yields but heavy infections causing major yield reductions can occur (up to 50%) if not protected. In USA where the disease is endemic (Florida and Texas) reported 19 - 23% yield loss from untreated commercial onion field (Sonoda et al. 1981).

Disease Management: Both cultural practice and chemical spray are important to manage OLB. A Number of effective fungicides (e.g. Rovral, Bravo, or Mancozeb) along with developed disease-forecasting systems that determine the optimum timing for sprays are very useful in managing OLB in commercial onion field. In USA, spraying mancozeb (2 lb/100 gal at weekly intervals) reported to be effective in controlling OLB disease in commercial field (Sonoda et al. 1981). Destroying onion- or debris-cull piles will help reduce sources of inoculum. Orienting plant rows and spacing to maximise air movement helps reduce the time that leaves are wet, and results in less disease incidence and severity. Cultural practices, such as deep plowing and crop rotation, will help reduce numbers of sclerotia in the soil.

Quarantine Risk: Low – OLB disease spore mainly disperse through wind locally. It's a foliage disease and therefore, the most common trading component like onion bulb has less chance to carry the fungal sclerotia that spread the disease in a new area/country.

Probabilities of Entry: Low – pathogen of OLB disease has very restricted host and it's a foliage disease and usually not associated with onion bulb that are main pathway of entry in Australia through international trade. Unless, the materials (whole plant) bring for research purpose are infected. However, Plant Health Australia (PHA) reported high entry possibility in the country.

Possibility of Establishment: Moderate – Restricted host-range of OLB pathogen reduce the chance to find a suitable host at the entry points upon its arrival, although suitable climatic conditions are available in some parts of Australia.

Economic Impact: Low - Moderate – OLB is one of the serious foliage diseases of *Allium* spp. including onion and garlic. Both of these are important vegetable crops in Australia and therefore OLB disease will have some negative economic impact specially on commercially grown onion regions.

Environmental Impact: Negligible – OLB disease is not expected to impact on environment as the disease is very restricted to a particular host group and no reports on wild or native hosts. Therefore, fungicide applications in OLB management will have negligible impact on human and animal health.

Social Impact: Low – The OLB disease symptoms are quite visible, control measures are available including cultural practices. Therefore, the grower should be able to handle the disease quickly and effectively to escape the damage intensity.

Pest management cost: Moderate – The biology of OLB disease and its available control measures will reduce the cost in disease management. The cost may vary from place to place depends to labor wages, pest severity, host variety and other factors. The total cost would be at least $900/ha based on 10 spary/season.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on major host like onion the total yield loss assumed to be between 10 - 15% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – OLB disease pathogen posses low risk of dispersion via international trade and there is no record of transmission of this pathogen on contaminated trading component like onion bulb. Therefore, having the pest in Australia would not be a major concerned in export market.

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THREAT DATA

Pomegranate fruit/dry rot

Coniella granati

Source:http://www.bspp.org.uk/publications/new-disease-reports/ndr.php?id=016022

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Pomegranate fruit/dry rot

(*Coniella granati*)

C. granati is a fungal pathogen that causes fruit rot/dry rot of pomegranate both on the tree and in storage. Brown to black spots/dots on the fruit surface is the common symptoms of this disease. The fungus has several synonyms (e.g. *Phoma granati, Macrophoma granati, Pilidiella granati, Zythia versoniana and Anathasthoopa samba*) and wide spread in many countries. The disease can cause 10 to 60% fruit damage depending on disease severity. General cleaning of infected fruits and spraying Bordeaux mixture are the best ways to manage the disease.

Distribution: *C. granati* wide spread in India, Iran, Korea, Greece, Cyprus, North Carolina (Farr et al 2007) and Turkey (Yildiz and Karaca 1973). The disease has not been reported in Australia yet.

Host range/Alternate host: So far in the literature, pomegranate *(Punica granatum)* has been reported the only host of *C. granati.*

Disease Symptoms and Biology: Coniella rot of pomegranate causes fruit rot both on the tree and in storage. The symptoms first appear as small spots/dots on the fruit surface which later increased in size, coalesce and develop into expanded brown lesions with back dots known as fugal fruit body (pycnidia) inside the lesions. Broken fruit peel in the lesion is common symptoms of the disease. The symptoms are very similar to apple scab disease. In severe cases, the lesions may deep into pulp and seeds of the infested fruit. The infected fruits may drop off or hang on the tree. The fruits infected at early stage usually drop off. The fungus also infects young twig and overwinter on this infected twigs as fruiting body (pycnidia). Conidia, formed at the apex of short conidiophores, are usually carried by rain droplets. Rain water and wind are the main means of disease spreading after winter. The infected twigs play important role in spreading the disease in a new location. Chemical control includes fungicide (especially copper, Bordeaux mixture) treatments during the main infection seasons (spring and autumn) are effective.

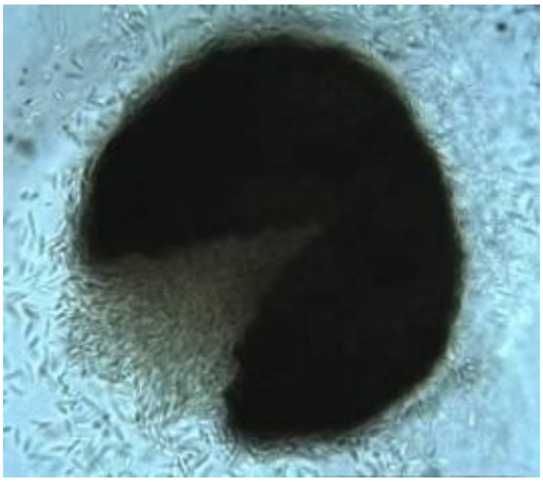

Fig. Rotted pomegranate fruit covered by pycnidia of *Coniella granati (left)* Pycnidium and conidia of *Coniella granati* (right).

Ref. http://www.bspp.org.uk/publications/new-disease-reports/ndr.php?id=016022

Affected plant stages: Vegetative growing stage

Affected plant parts: Mainly fruits but also infect young twigs

Affected Industries: Pomegranate industry only

Resistant plant variety: In literatures no reports on resistant plant variety against *C. granati.*

Disease movement and Dispersal: Under field conditions, the fungal spores splash-dispersed mainly by wind, rain-splash and some by insect feeding and contaminated pruning tools. The spore dispersal also strongly depends on wind speed. In case of international trade, the fungus could spread via trading of host plants specially with infected twigs where the fungus can survive for long period.

Disease Impact: Only a very few short publications available on fruit rot/dry of pomegranate in the web sites. This limits the knowledge of the biology, impact, management and other aspect of this disease. Due to this disease in Greece, 40-50% yield loss has been reported in 2005 and 2006 (Tziros et al. 2007). Likewise in another website the loss was mentioned about 10 to 60% depending on disease severity.

Disease Management: Both cultural practice and chemical control are used to manage fruit rot/dry rot of pomegranate. In case of cultural practice, intensive pruning is important during the dormant period and removing of all dead wood, including spurs, twigs and branches where the fungus is able to survive and colonise for new infection. Bordeaux mixture applications before and after the flowering stage is known to be effective chemical measure for this disease.

Quarantine Risk: Moderate – *C. granati* spore mainly disperse through wind and rain water locally. However, the most common trading component like fruit has good chance to carry or escape quarantine to spread the fungus in a new area/country. Trading plants (e.g. nursery, research purposes) with infested twigs also enhance the chance of disease spreading in a new location.

Probabilities of Entry: Moderate – because of good possibility of carrying the fungal spores with both fruits and host plants during trade as well as by tourist. However, our strict quarantine at the entry points will reduce the chance of entry of infested materials in Australia.

Possibility of Establishment: Moderate – Because of specific host (pomegranate only) the fungus *C. granati* has less chance to find a suitable host at the entry points upon its arrival. However, rapidly growing pomegranate orchards in Australia and its suitable environmental conditions are in favour of this fungus to establish in many areas of the country.

Probabilities of Entry and Establishment: Moderate – In spite host specificity, suitable climatic conditions and growing pomegranate cultivations enhance the chance of entry and establishment of *C. granati* in many regions of Australia.

Economic Impact: Moderate – Fruit rot disease of pomegranate can cause 10-60% yield loss depending on disease severity. Under proper control measure the loss may reduce with increased management cost. Based on the information in the literature, it assumes that the newly growing pomegranate industry in Australia may face moderate impact if the causal agent of fruit rot disease (*C. granati*) establish in the country.

Environmental Impact: Negligible – Pomegranate fruit rot disease is not expected to impact on environment as the disease is restricted to single fruit plant (pomegranate only) and no reports on wild or native host. Fungicides application in the disease management might have negligible impact on human and animal health.

Social Impact: Low – The fruit rot symptoms are quite visible and very common and readily available fungicides are used in the management. Cultural practice such timely pruning and removing infected plant parts also help in diseases management without using any fungicides. Therefore, the grower should be able to handle the disease quickly and effectively to escape the damage intensity.

Pest management cost: Moderate/Low – The biology of the fruit rot disease and it's readily available control measures will reduce the cost in disease management. The cost may vary from place to place depends to labor wages, pest severity, host variety, climatic conditions and other factors. The minimum of two spray of Bordaux mixture would cost **$160 to $200/ha** including chemical and spray cost.

Yield loss despite control efforts: Based on the pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 - 20% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Moderate – the pomegranate fruit rot fungus possesses moderate risk of dispersion via international trade but there is no record of transmission of this fungus on contaminated trading component like fruit. Still, having the pest in Australia would be some kind of concern in export market.

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THREAT DATA

Wilt of Pomegranate

(*Ceratocystis fimbriata*)

Source: http://www.thewisegardener.com/pictures/article_126_1217476172.jpg

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Wilt of Pomegranate

(Ceratocystis fimbriata)

C. fimbriata is one of the fungal pathogens that causes wilt of pomegranate plants and it also causes canker, blight, black rot etc. to many other plant species including vegetable, fruits and trees. *C. fimbriata* is distributed in many countries with great economic importance in terms of plant pest that cause significant damage in agriculture industry of the country. The fungus considered being a serious threat to many EPPO countries and also the recent reports from India and China stated the threatening pathogen of pomegranate in some parts of the countries. *C. fimbriata* listed as A2 quarantine pest by EPPO (OEPP/EPPO 1986).

Distribution: *C. fimbriata* most likely indigenous to North and South America or Asia. But now have been introduced in many other countries of Europe, Africa and Oceania. In Australia the fungus has been reported in NSW, VIC, Qld and SA with restricted distributions (Walker et al 1988).

Host range/Alternate host: Including pomegranate *C. fimbriata* cause number of diseases (canker, blight, wilt etc.) to many annual and perennial (forest horticultural, and agronomic plants) species such Acacia, eucalyptus, citrus, taro, coffee, carrot, stone fruit, sweet potato etc.

Biology and Ecology: In China, *Ceratocystis* wilt of pomegranate found more severe in older plantings than in younger plantings. Disease incidence was 1% in 1 to 5-year-old bushes, 3.6% in 6 to 10-year-old bushes, and 6% in bushes more than 10 years old. Favourable temperature for this disease is 18 to 30°C with occasional rain and usually occurs during late spring and summer in China. The infection occurs through fresh wounds but root infections are also common (Moller et al., 1969). The fungus disperse as fragments of mycelium, conidia, aleurioconidia or ascospores but aleurioconidia are probably the most common survival units because of its thick-walled that facilitate survival in soil (Accordi, 1989) and in insect frass (Iton, 1960). The fungus is able to survive in wood fragments in river water (Grosclaude et al., 1991). *C. fimbriata* f.sp. *platani* can survive for several years at -17°C but unable to grow below 10°C or above 45°C. During winter the fungus can survive at least 3 months in the soil but 35-40°C soil temperature are lethal to the pathogen in soil (Accordi, 1989).

Symptoms: *C. fimbriata* is primarily a xylem pathogen that causes wilting of whole plant. In pomegranate, initial symptoms are yellowing and wilting of leaves on one to several branches, follows by sudden death of the bush within 3 to 4 weeks. Roots of diseased bushes appear brown to black, and irregularly shaped lesions observe under the bark. The leaves remain attached to the tree for several weeks. The fungus causes dark reddish-brown to purple to deep-brown or black staining in the xylem. In severe cases, the staining may extend from the roots to the trunk or even to branches of the tree. Cross section of the infected branches or trunks shows distinctive wedge-shaped or starburst-like pattern of vascular ray with staining (Sinclair et al., 1987). Canker development with gum exudation may observe on the surface of the trunk or branches over xylem discoloration areas. This type of cankers development are particularly common on *Populus*

, *Prunus* , *Platanus* (Sinclair et al., 1987) and *Eucalyptus* (Laia et al., 2000) but wilting may also occur in absence of canker development. On *Platanus* , individual leaves of affected branches often show interveinal chlorosis and necrosis, perhaps associated with fungal-produced phytotoxins (Ake et al., 1992; Alami et al., 1998; Pazzagli et al., 1999).

Fig. Xylem discoloration in the base of a *Coffea* tree infected with *C. fimbriata (right*) & Declining *Coffea* tree infected by *C. fimbriata,* showing thin crown (left). Note: No picture of symptoms for pomegranate available in the literature.

Ref.
http://www.discoverlife.org/mp/20q?go=http://www.public.iastate.edu/~tcharrin/pictures.html

Affected plant stages: Vegetative growing stage.

Affected plant parts: Roots, leaves, stems and whole plant.

Affected Industries: Pomegranate and other host industries.

Resistant plant variety: No information on resistant plant varieties against *C. fimbriata.*

Disease movement and Dispersal: *C. fimbriata* is a soil-born fungus i.e. fungal spore spreading confined with ground water movement and through infested field soil. Pruning tools and some fungal-feeding insects also reported to involve in spreading the spores. No reports on air-borne and seed-borne dispersal of the spores. In case of international trade, the fungus could spread via trading of host plants where the fungus can live as an asymptomatic endophyte for long periods.

Disease Impact: Disease caused by *C. fimbriata* can be of high local importance of its wide host range and history of sporadic epidemics. Ceratocystis wilt of pomegranate in India estimated 7.5% crop loss in 1995-1998 (Somasekhara 1999). In USA, many almonds orchards (especially old) seriously been affected by this fungus (DeVay et al. 1968). Eucalyptus plantations are also severally affected by *C. fimbriata* in Brazil, Congo and Uganda (Roux et al. 2000). Besides these, significant damage in other hosts (e.g. coffee, mango, ipomea, theoboma, citrus, platanus etc.) also been reported from different countries in the literatures (Borja et al 1995, Matasci and Gessler 1997, Ribeiro et al. 1995, Reyes 1988).

Disease Management: Apart from phytosanitary measures i.e. disinfecting pruning tools between plants, control methods are not immediately available. Breeding for resistance and related research are being carried out (Vigouroux, 1986; Vigouroux & Rouhani, 1987). Although, some fungicides are being used to control the disease for some hosts but the success is poor in terms of the associated cost (Minervini et al 2001, Causin et al. 1995).

Phytosanitary risk: The risk of introduction of *C. fimbriata* into new countries is connected with the incautious trading of host plants where the fungus is able to live as an asymptomatic endophyte for long periods. In view of the speed of spread of the disease and the extent of damage, it must be considered a serious threat to Australia like many EPPO countries. The disastrous European experience with *Ceratocystis ulmi* (Dutch elm disease) should serve as an example. *C. fimbriata* f.sp. *platani* is listed as A2 quarantine organism by EPPO (OEPP/EPPO, 1986).

Quarantine Risk: Moderate – *C. fimbriata* spore mainly disperse through soil water, infested soil and pruning tools locally. The most common trading component like fruit has no report to carry the spore in a new area/country. However, container and packing materials (wood) are capable of transporting and spreading the disease long distance (Panconesi 1981, Grosclaude et al. 1995).

Probabilities of Entry: High – because of packing materials (wood) commonly used in trading are capable of carrying fungal spores. It also to be noted that *C. fimbriata* already been reported in a number of States in Australia with restricted distributions.

Possibility of Establishment: High – Because of diverse host range including native plants *C. fimbriata* has reasonably good chance to find a suitable host at the entry points upon its arrival. Moreover, Australia provides a suitable environmental condition for this fungus to establish and in fact restricted distribution of *C. fimbriata* has been reported in a number of States in Australia.

Probabilities of Entry and Establishment: High – both host availability and suitable climatic conditions provide good chance of entry and establishment of *C. fimbriata* in many regions of Australia.

Economic Impact: High/moderate – *C. fimbriata* causes wilting of whole mature plants by infecting roots and xylem of number of plant species including native plants. In China and India this fungus has been reported as a threat to pomegranate cultivation. Significant damage also been reported for eucalyptus, citrus, mango, coffee etc. plantations from many other countries. Moreover, till now no effective chemical treatment is available for the diseases cause by *C. fimbriata.*

Environmental Impact: Moderate – *C. fimbriata* has an impact on a diverse host i.e. annual, perennial, forest, fruit and cultivated species. The fungus also consider as a natural component of many forest ecosystems in various regions of Americas and Asia. Declining of forest trees and other native species due to this fungus has been reported in the literature from many countries like USA, Europe, Africa etc.

Social Impact: Moderate – Platanus species, especially *P. acerifolia*, is a very common street tree in many regions of the world, especially in the eastern USA and southern Europe. The loss of plane trees in southern France and Italy due to *C. fimbriata* has been dramatic, thus seriously reducing the aesthetics of urban areas. Earlier epidemics in urban areas of the eastern USA also had severe impact, though sanitation practices greatly reduced the impact of the disease since the 1940s (Walter et al., 1952). Australia might have similar impact by having wide distribution of *C. fimbriata.*

Pest management cost: High – The biology of *C. fimbriata* and its unavailable effective control measures increase the cost in disease management through cultural practices. The cost may vary from place to place depends to labor wages, pest severity, host variety, climatic conditions and other factors. Regular pruning off the diseased plant parts or whole plants cost at least **$1000.00/ha** at the rate of $25/hour labour that requires minimum 5 min to check and prune each plant i.e. about 40 hours for 500 plants in one hectare.

Yield loss despite control efforts: Except cultural practices, no effective fungicides are available to control the disease caused by *C. fimbriata*. Therefore, its impact on total yield loss assumed to be more or less same under proper control measures (15-20%).

Export revenue loss due to loss of Pest Freedom Status: Medium – *C. fimbriata* fungus possesses low risk of dispersion via international trade and there is no record of transmission of this fungus on contaminated trading component like fruit. However, fungal dispersions through packing wood materials make a big concern in the export markets for Australia.

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THREAT DATA

Potato rust

(*Puccinia pittieriana*)

Source:http://www.cabicompendium.org/cpc/report.asp?Criteria=P/4906;P/4905&CCODE=PUCCPT

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Potato rust

(*Puccinia pittieriana*)

Puccinia pittieriana is a fungal disease of potato and it also known by potato rust disease. The disease symptoms are visible on leaf. The disease can cause severe defoliation and impact on crop production. The fungus mainly attack cultivated potato and tomato plants. The spore spread by wind. Potato rust is native to Central and South America. The fungus presents moderate risk to commercial potato-growing places around the world. Fungicide carbamate is effective against this disease. *P. pittieriana* is an EPPO A1 quarantine pest and not present in Australia.

Distribution: Potato rust is indigenous to Central and South America. For example *P. pittieriana* reported in Costa Rica, Brazil, Colombia, Peru, Venezuela Paraguay and Mexico. The pest is not reported in Europe, USA, Canada, Australia and New Zealand yet.

Host range/Alternate host: Restricted host range. Mainly cultivated potato and tomato but other wild members of Solanaceae may also get infected by this rust disease.

Biology and Ecology: *P. pittieriana*, the rust fungus mainly potato leaf not underground tubers and roots. The fungus has short life cycles i.e. produce only teliospores and this spore germinate to produce basidia and basidiospore (French 1981). The basidiospore spread by wind to a new host leaf and begin infection process, cool temperatures (~10^{o}C) are in favour of effective spread. The longevity of teliospores is not known yet but it can persist in host debris under field conditions and also in accompanying exported potato tubers.

Symptoms: The rust disease symptoms are quite visible at the underside of leaves as rusty colour lesions that correspond with depressions on the upper side of the leaf (fig.1). The lesion at beginning looks as minute rounded spot (3-4 mm) with greenish-white colour but gradually it changes to creamy with reddish centres and finally turns into rusty-red to coffee-brown. Some lesions may become elongated with longer axes reaching 8 mm. The upper surface of the leaf shows necrotic spots that correspond with lesions underside of the leaf. The defoliation may results in case of heavy infection with numerous lesions on leaves, petioles and stems (French 1981). No symptoms are observed in tubers and roots of the infected plants.

 

Figure 1. Potato leaves showing rust symptoms (protruding pustules) caused by *P. pittieriana.*

Source:
Source:http://www.cabicompendium.org/cpc/report.asp?Criteria=P/4906;P/4905&CCODE=PUCCPT

Affected plant stages: Vegetative, flowering and fruiting stages

Affected plant parts: Mainly leaves but stems and other areal parts may also be affected in sever cases.

Affected Industries: Potato and tomato industries

Resistant plant variety: Resistant potato varieties again *P. pittieriana* may be available but there is no enough information in literatures.

Disease movement and Dispersal: *P. pittieriana* spores mainly dispersed by wind. Fungal spore survive in host debris in field conditions and soil attached with tubers are sources of diseases dispersion in new areas. There is no record of transmission of *P. pittieriana* on contaminated seed

Disease Impact: Potato rust disease could be serious specially in cool climatic conditions. Significant losses have been reported in Colombia and Ecuador (Frence 1981). Severe defoliation by fungus reduce significant crop yield. No reports on significant tomato yield loss by *P. pittieriana.*

Control: *P. pittieriana* is air-borne fungus and possible to control through proper chemical treatments. The fungicide carbonate has been reported as effective chemical against this fungus that can be applied at 14-day intervals (Diaz and Echeverria 1963). General control measures such as sanitary methods including destruction or removal of crop debris and control of associated weeds in the field are also recommended. No biological control measures are available for this fungus yet.

Quarantine Risk: Low to Moderate. Dissemination of *P. pittieriana* has not been confirmed on tubers during the trade. Therefore, the risk of spread of this disease is low unless live specimens are carried to disease fee regions for research purpose. There is no record of *P. pittieriana* transmission through seeds. However, *P. pittieriana* is an EPPO A1 quarantine organism (OEPP/EPPO 1998).

Probabilities of Entry: Low -. *P. pittieriana* can disperse in limited distance through wind. The possible entry through tubers during the trade is very unlikely and even there is a chance then it can be eliminated by quarantine

Possibility of Establishment: Low/moderate – Because of restricted host-range *P. pittieriana* has limited chance to find a suitable host at the entry points upon its arrival, although suitable climatic conditions are available in some parts of Australia.

Probabilities of Entry and Establishment: Low – In spite of suitable climatic conditions, specific host capacity of *P. pittieriana* reduce the chance of entry and establishment in Australia.

Economic Impact: Moderate – significant potato damage reported by *P. pittieriana* in Colombia and Ecuador. Only under favorable climatic conditions (cool temperature) the disease causes significant damage to yield. Therefore, it would have moderate impact on commercial potato industries in Australia.

Environmental Impact: Low – The severity of potato rust disease is local climate dependent and effective chemicals are available to control the disease in field conditions. This means comparatively less chemical will be applied by the grower for the disease management that will have less environmental impact.

Social Impact: Low – The disease symptoms are quite visible, control measures are available and the severity is climate dependable (cool temperature). Therefore, the grower should be able to handle the disease quickly and comfortably before the damage.

Pest management cost: Moderate – The biology of potato rust disease and its available control measures will reduce the cost in disease management. The cost may vary from place to place depends to labor wages, pest severity and other factors. Rust has very short life cycle i.e. produce innoculums (spore) in short time. Therefore, number of fungicide spray needs more compared to other fungi. For rust at least 7 sprays are required in one season and the total cost includes both chemicals and application cost. The application cost $600/ha based on guess by Peter Dawson/Project Manager, Potatoes/DAFWA.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 - 15% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – although *P. pittieriana* possess very low risk of dispersion via international trade as there is no record of transmission of *P. pittieriana* on contaminated seed. However, listed as quarantine pest (A1) by EPPO would be main concerned in export market.

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THREAT DATA

Potato smut

(*Thecaphora solani*)

Source: http://www.ipmimages.org/browse/detail.cfm?imgnum=5356848

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Potato smut

(*Thecaphora solani*)

Thecaphora solani is a fungal disease of potato and it also known by potato smut disease. The diseases symptoms are visible on tubers only, not in the aerial plant parts. The fungus presents high risk to commercial potato-growing places around the world. Once established it may be impossible to eradicate the fungus due to its soil-borne nature.

Distribution: Potato smut is indigenous to the Andean region, South America. Although the fungus still very much confined to this region, it has limited distribution in other parts of the world. The USA, Canada, Europe, Australia, New Zealand are seems be free from this fungus.

Host range/Alternate host: Restricted host range. Mainly potato but other member of Solanaceae may also get infected by this smut disease.

Biology and Ecology: *T. solani*, the smut fungus attack potato tubers not roots of the plant and the spore can survive long time in the infested tubers debris or in the soil (O'Brien and Thirumalachar 1974). High humidity and soil salinity enhance the disease severity. The fungus has a very low natural dispersal potential and infested tubers (used as seed) are main source of disease transmission into a new areas (Abbott 1932. The process of fungal infection is not known yet.

Symptoms: Areal parts of infected pant by *T. solani* do not show any symptoms except the underground tubers that shows warty swellings on the surface. The infected tubers become hard and deformed structure (fig. 1). Many brown to black specks are visible inside the tubers. The whole or part of the tubers may get infected. Infected tubers later become a dry brown powdery mass that contains numerous fungal spores. Galls resembling deformed tubers may arise on the stems or stolons underground.

Figure 1. Potato tuber showing symptoms of infection with potato smut.

Source: http://www.ipmimages.org/browse/detail.cfm?imgnum=5356848

Affected plant stages: Vegetative growing stage

Affected plant parts: Tubers only.

Affected Industries: Potato industries

Resistant plant variety: Resistant potato varieties again *T. solani* may be available but there is no enough information in literatures.

Detection and inspection methods: No reliable inspection method to detect the fungal spores on the potato surface is available. Therefore a quarantine period is necessary to ensure freedom from the disease.

Disease movement and Dispersal: Infected tubers are main source of diseases dispersion during trade. The soil from infected field is also responsible in disease spreading via spore lives in the soil.

Disease Impact: Potato smut is a serious disease for potato (Bazan de Segura 1960) and up to 80% production losses reported by Abbott in 1932. The fungus directly infects the tuber that reduces both quantity and quality of the crop. Primitive cultivars are more prone to this in Peru reported by Gregory (1979).

Control: *T. solani* is a soil-borne fungus that's difficult to manage using chemicals. Methyl-bromide and dazomet used in field trials in Peru (Torres & Henfling, 1984), as soil disinfestants against *T. solani*. This reduce the total weight of tuber but unable to eliminate the fungal spore from soil. Screening for resistance is actively carried out at CIP (International Potato Center) in Peru (Torres & Martin, 1986). General control measures recommended in Hooker (1981) are: use of resistant cultivars, planting of smut-free seed potatoes, long rotation, elimination of the weed *Datura stramonium* (also reported as a host), removal of smutted galls. Varietal resistance would seem to offer the possibility of control.

Phytosanitary risk: *T. solani* is a soil-borne disease that's difficult to eradicate once it established. Both EPPO and CPPC listed *T. solani* as a quarantine pest (A1) (OEPP/EPPO, 1979). The fungus certainly presents a significant risk to both seed and ware potato production in the EPPO region. However, which part of the EPPO is at high risk remain uncertain due to very limited information on the biology and life cycle of this fungus.

Quarantine Risk: Moderate. *T. solani* is host specific but difficult to manage in field conditions of it's soil-borne nature. *T. solani* designated as a quarantine pest (A1) by EPPO and CPPC.

Probabilities of Entry: Low -. *T. solani* can only disperse through infested tuber and field soil. Possible entry through tubers during the trade may be eliminated by quarantine. According to Plant Health Australia (PHA) report the pest has high possibility of entry in the country.

Possibility of Establishment: Low – Because of restricted host-range *T. solani* has limited chance to find a suitable host at the entry points upon its arrival, although suitable climatic conditions are available in many parts of Australia. PHA reported as high establishment possibility in Australia.

Economic Impact: High – significant potato damage (~80%) reported by *T. solani* s in Peru. It's one of serous fungi for potato and difficult to control in the field. Therefore, it would have high impact on commercial potato industries in Australia.

Environmental Impact: Moderate – Under current situation where no effective chemicals are known to control this fungus in potato field, i.e. additional chemical applications will lead to environmental pollution.

Social Impact: Moderate – Since no effective chemicals are available to control *T. solani* in the field. Therefore, many small growers would suffer by the damage severity of this pest. This will have negative impacts on local community.

Pest management cost: Moderate – In absence of effective chemical controls, the cultural practices (crop rotation and others) are going to be very cost effective to manage *T. solani*. Smut is a soil-borne fungus that's difficult to manage by chemical. Using soil disinfestant chemicals keep the infestation low. The total cost includes both chemicals and application cost. The application cost at least $300/ha based on guess by Peter Dawson/Project Manager, Potatoes/DAFWA. The cost may vary from place to place depends to labor wages, pest severity and other factors.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 30 - 50% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Medium – although *T. solani* possess low risk of dispersion via international trade however, listed as quarantine pest (A1) by EPPO is the main concerns in export market.

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THREAT DATA

Potato wart disease

(*Synchytrium endobioticum*)

Source: httphttp://www.nepdn.org/DesktopDefault.aspx?tabindex=2&tabid=22

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Potato wart disease

(*Synchytrium endobioticum*)

S. edobioticum is a fungal disease of potato, also known by several English names e.g. potato wart disease, wart disease of potato, black wart of potato and potato back scab. This soil-borne fungus is difficult to control in field condition that leads to significant crop damage. *S. edobioticum* is a quarantine pest and the disease is common in many European countries but not been reported in Australia yet.

Distribution: Potato wart disease (PWD) is native to potato-growing regions of Chile or Peru (South America). From there it spreads in many parts of Europe, part of Asia, Africa, North America, Oceania (New Zealand) and N. America (Newfoundland). The disease has not been reported in Australia yet.

Host range/Alternate host: Restricted host range. Mainly cultivated potato but other member of Solanaceae may also get infected by *S. edobioticum*.

Biology and Ecology: PWD pathogen (*S. edobioticum*) is an obligate parasite but can survive in the field soil for more than 30 years in absence of host. So the disease outbreak is possible in the field where potato is not even cultivated for long time. A thick wall of resting spore (also know as winter sporangia) of the fungus attribute to the long persistent in soil. The spore longevity contributes to the wart disease problem where no effective control measures are available. In presences of potato, winter sporangia germinate in spring and release zoospores in soil water. Therefore, presence of abundant soil water following heavy rain is a sign of disease initiation in the field. In susceptible potato the infection occurs through most eyes of tubers and the infected cell get enlarged and produce many summer sporangia. These are short-lived and produce many zoospores that infect new host cells. The surrounding tissue proliferate to produce out-growth on infested potato that known as wart. The cycle of re-infection and proliferation continue under cool and wet conditions. The PWD is therefore less damaging in warm, light, well drained soils. The fungal sporangia are resistant to digestion by animals, and can thus be spread in faces. There are many pathotypes of the fungus and pathotype 1 is the most common in EPPO region.

Symptoms: Areal parts of infected plant by *S. edobioticum* usually do not show any obvious symptoms except the underground tubers and stolons that show soft and swollen warty structure outgrowth like a cauliflower on the surface. Both young and mature tubers get infested and in case of young the whole tuber may be replaced by a warty proliferation (fig. 1). The warts are initially white (turn green if exposed to light) but gradually get darker with age that decay and disintegrate at end. Similar symptom may found in stolons. The disease symptoms are also noticed in storage conditions (i.e. in dark) where colour of wart becomes as skin colour of potato. In case of sever infection, the areal plant part may show stunted growth with greenish warty outgrowth at the ground level of areal stem.

Figure 1. Infested potato tuber showing symptoms of wart disease.

Source: www.bspp.org.uk/.../ndr.php?id=011012

Affected plant stages: Both vegetative growing and post-harvest stages

Affected plant parts: Mainly tubers but also affect other plant parts except root.

Affected Industries: Potato industries

Resistant plant variety: Resistant potato varieties again *S. edobioticum* may be available but there is no enough information in literatures.

Disease movement and Dispersal: *S. edobioticum* has limited capacity to spread by natural means. Infested tuners, contaminated soil attached with foot wares, vehicles, animals, heavy wind etc. are the main means of spore dispersion from infested areas. In infested field zoospore can spread a limited distance (50mm or less) through soil water. Long distance dispersal by infected tubers during the trade is the major dispersal method.

Disease Impact: Potato wart disease is a serious disease for potato and listed as A2 quarantine pest by EPPO (OEPP/EPPO 1982). Once the fungus established in the field, the whole crop may be devastated and unmarketable for many years because the fungal spore remain active more than 30-years in field soil. This discourage the potato growers to use the field further for potato cultivation or even any other crop that are intended for export. European countries where the fungus is present face indirect losses arising from the restrictions on export.

Control: *S. edobioticum* is a soil-borne fungus that's difficult to manage using chemicals and the chemical treatment may also harm beneficial soil organisms. Therefore resistant plant variety, stringent quarantine and sanitation measures are to be considered to control this fungus. New screen methods towards the resistant varieties have described (Stachewicz 1984, Potocek & Broz 1988).

Phytosanitary risk: Potato wart disease is soil-borne and difficult to eradicate once it established. The fungal spore can survive in soil for more than 30 years. Both EPPO listed *S. edobioticum* as a quarantine pest (A2) (OEPP/EPPO, 1982). The fungus certainly presents a significant risk to both seed and ware potato production in the EPPO region. Although warm climate, well drained and dry soils in Australia may not be in favour of this fungus and unlikely to cause serious crop losses. But its introduction and persistence could still be a problem in both domestic and export markets.

Quarantine Risk: Moderate to High - *S. edobioticum is* very host specific but it as very high persistent capacity to remain active in field soils for more than 30 years even in absence of host. That makes it very difficult to manage in field conditions. EPPO designated it as a quarantine pest (A2).

Probabilities of Entry: Low -. *S. edobioticum* can only disperse through infested tuber and field soil. Possible entry through tubers during the trade may be eliminated by strict quarantine.

Possibility of Establishment: Low – Because of restricted host-range *S. edobioticum* has limited chance to find a suitable host at the entry points upon its arrival. Also dry climate and well-drained soils of Australia are not in favour of this fungal growth. However, Plant Health Australia (PHA) believe reported as high potential of establishment of this pest in the country.

Economic Impact: High – Significant potato damage (~80%) and losses of export market would have high impact on commercial potato industries in Australia as no effective control measures are currently available to manage this disease.

Environmental Impact: Low – Under current situation where resistant plant variety, strict quarantine and sanitation measures are only ways to control this fungus. Therefore, the chance of environmental damage due to chemicals application will be very low

Social Impact: Moderate – High economic impact, difficult management and long persistent capacity in field conditions of *S. edobioticum* will have a negative impact on the society but restricted host and limited distributions capacities of the fungus may keep this impact at moderate level.

Pest management cost: High – In absence of effective chemical controls, resistant plant variety, strict quarantine and sanitation measures are going to be very cost effective to manage potato wart disease. Like smut, PWD is a soil-borne fungus that's difficult to manage by chemical. Using soil disinfestant chemicals keep the infestation low and sanitation measures play important role in the management. The total cost includes both chemicals and application cost. The application cost is at least $300/ha based on guess by Peter Dawson/Project Manager, Potatoes/DAFWA. The cost may vary from place to place depends to labour wages, pest severity and other factors.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 30 - 50% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: High – although *S. edobioticum* possess low risk of dispersion via international trade however, listed as quarantine pest (A2) by EPPO is the main concerns in export market.

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THREAT DATA

Skin spot of potato

(*Polyscytalum pustulans*)

Source:http://www.potato.org.uk/department/sbeu/potato_diseases/index.html?did=43&pg=1

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Skin spot of potato

(*Polyscytalum pustulans*)

Skin spot of potato is a fungal disease caused by *P. pustulans*. The symptoms are visible on tubers mainly both in storage and field conditions. This is an important potato disease in UK and parts of Russia but not preset in Australia. The disease spread by infected potato tubers main. The fungus presents risk to commercial potato-growing places around the world.

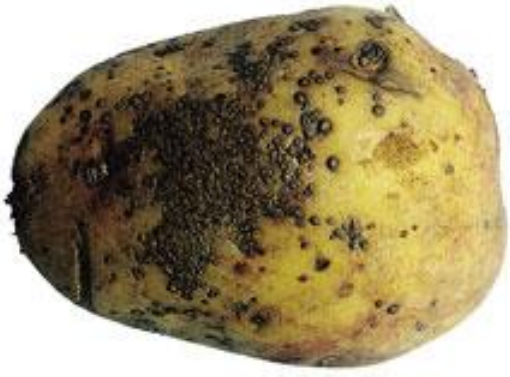
Distribution: Skin spot of potato disease is widespread in UK and Central Russia. The disease also has restricted distribution in USA and Canada. But not reported in Australia yet (ref. CPC 2008).

Host range/Alternate host: Restricted host range. Mainly potato but other member of Solanaceae may also get infected by the causal agent of skin spot of potato disease.

Biology and Ecology: *P. pustulans*, a causal agent of skin spot of potato disease mainly found on potato tubers in storage conditions. Skin spot may not be visible until after approximately 2 months of storage. Contaminated seed tubers are the main source of inoculum in most seed and ware crops. The fungus spreads and sporulates first at the base of stems, stolons and roots nearest the mother tuber and then spreads outwards (Hirst and Salt, 1959). The disease easily develops on tissue where the periderm has been removed (Hide et al., 1994). Infection increases throughout the growing season and heavy soils is favourable to the spread of the pathogen than light soils (McGee et al., 1972). The disease spread and development also enhanced by wet, cool soils during the harvest period. Skin damaged at this stage can be readily infected by fungal spores dispersed into the soil during harvesting (Hide et al., 1994). New tuner Infection can occur from airborne inoculum (Carnegie and Cameron, 1987). Contaminated and infected tubers are usually symptomless at harvest. The disease commonly develops after 1-2 months storage although it can occasionally be present at harvest on late harvested crops. The fungus can be detected in field soil up to 4 years after a potato crop and can cause the infection of healthy tubers (Carnegie and Cameron, 1990). Microsclerotia can be observed in ageing cultures and also in lesions on stem bases and decayed seed tubers (Hide and Ibrahim, 1994). The sclerotia could be disease source for new potato crop when healthy tubers are used for plantings.

Symptoms: *P. pustulans* causes black spots on the surface to potato tubers. The symptoms are small, discrete, black or purplish pimples, slightly raised occurring singly or in groups on the tuber surface. The mature spots are frequently sunken with a raised centre. The spots may be distributed at random or aggregated around eyes stolons and damaged skin and generally only penetrate the tuber skin to a depth of 1-2 mm. Skin spot can also lead to necrotic buds in eyes and dense white mould on infected sprouts. The disease commonly develops after 1-2 months in storage although it can occasionally be present at harvest on late-harvested crops.

Infection of stem bases, stolons and roots produces initially small, light-brown spots and patches which later coalesce to form large brown superficial patches with occasional deep longitudinal cracks.



Dark skin spots on potato tubers   Closer view of the dark skin spots

Figure 1. Potato tuber with symptoms of skin spot of potato by *P. pustulans*

Source:http://www.potato.org.uk/department/knowledge_transfer/pests_and_diseases/ref.html?item=25

Affected plant stages: Pos-harvest

Affected plant parts: Roots, stems and vegetative organs

Affected Industries: Potato industries

Resistant plant variety: Resistant potato varieties again *P. pustulans* may be available but there is no enough information in literatures.

Disease movement and Dispersal: Infected tubers are main source of diseases dispersion during trade. The soil from infected field is also responsible in disease spreading via spore lives in the soil.

Disease Impact: *P. pustulans* is severe in the UK, the Irish Republic, Norway and parts of Russia where temperature is cool. The disease affects the quality, reduces sale value of potato and the return on the crop. The applications of sprout suppressants in potato cold storage enhance a change of the disease (French, 1976) that causes significant economic damage for the potato processors. Skin spot of potato also delay or prevent and reduce the number of main stems (Hide et al., 1973). Therefore, the total yield of infected seed stocks becomes usually significantly lower than that of healthy stocks.

Detection and Inspection Methods: *P. pustulans* can be detected in field soil up to 4 years after a potato crop and can cause the infection of healthy tubers (Carnegie and Cameron, 1990). The disease can be seen in the store (see Symptoms). Latent contamination of the tubers can be estimated by two methods from a sample of the stock (see Diagnostic Methods).

Seed production programmes aim to control the disease by applying minimum tolerances for skin spot based on the percentage tubers affected above a specified surface area coverage.

Control: The skip spot of potato disease can be managed by both cultural and chemical controls

Cultural Control: The disease is greatly influenced by storage conditions and temperatures (Boyd and Lennard, 1962). Therefore, good hygiene in the store is essential to minimise the transfer of inoculum between stocks during storage on the seed farm and in the chitting store of ware producers. This will involve extracting dust generated during grading, cleaning stores and machinery regularly to minimise infested soil available for dispersal and cleaning the stores and machinery between storage seasons. In seed production, separate storage facilities for each field generation would also be advantageous.

Chemical Control: Until the 1990s the main fungicides used to control skin spot were 2-aminobutane [butylamine], applied as a gas, and thiabendazole applied as a spray or dust. Subsequently other compounds including imazalil, prochloraz and fenpiclonil have been approved for use in controlling skin spot on seed tubers. All give good reductions in skin spot (Carnegie et al., 1994) although the most consistently effective fungicide is butylamine (Graham et al., 1981; Carnegie et al., 1990). The gaseous nature of butylamine means that it penetrates the tuber skin to a limited extent and so acts against any penetrating mycelia.

Phytosanitary risk: *P. pustulans* is not seedborne on true seed potato, but is present on seed tubers. Therefore, the primary source of infection within a crop is largely the seed tuber (Boyd and Lennard, 1961). Seasonal factors and soil conditions have a greater influence on the frequency of infection than the level of seedborne inoculum. The proportion of severely affected tubers in a stock, however, usually increases with the number of tubers affected by skin spot. In the absence of seedborne infection other sources of inoculum such as soil or store-dispersed inoculum play an important role in contaminating stock and allowing spread to occur between plants and tubers in a stock (Carnegie, 1992).

Quarantine Risk: Moderate. *P. pustulans* is host specific and confined in cool temperate countries. The disease common in storage conditions than in the field and seed tuber is the main source of dispersion. .

Probabilities of Entry: Moderate -. *P. pustulans* has possibility of entry through infested tubers that do not show any disease symptoms at initial stage.

Possibility of Establishment: Low/Moderate – Because of restricted host-range *P. pustulans i*has limited chance to find a suitable host at the entry points upon its arrival, although suitable climatic conditions are available in many parts of Australia.

Economic Impact: Moderate – reported as serious pest in cool temperate regions of potato growing countries only. The damage mainly occurs in storage conditions and that's manageable through maintaining good sanitation. In additions, effective fungicides are also available to control the damage. .

Environmental Impact: Low – Under current situation where proper sanitations are commonly used to manage the disease compared to chemical applications. This will leads to less environmental pollution.

Social Impact: Low – The disease occurs mainly in storage condition that influence by cool temperate and easily manageable through proper sanitations or available chemicals in market. Therefore, the grower should be able to handle the disease quickly and effectively to escape the damage intensity.

Pest management cost: Low – The skin spot of potato disease severity greatly influence by climates (cool temperature) and the damage mainly occurs in storage that can be control through proper sanitation. Therefore, the management cost would be low. Like smut fungus, skin spot fungus is a soil-borne fungus that's difficult to manage by chemical. Using soil disinfestant chemicals keep the infestation low. The total cost includes both chemicals and application cost. The application cost at least $300/ha based on guess by Peter Dawson/Project Manager, Potatoes/DAFWA. The cost may vary from place to place depends to labor wages, pest severity and other factors.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 - 30% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – *P. pustulans* possess low risk of dispersion via international trade as the disease symptoms are quick visible on potatoes in storage conditions.

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THREAT DATA

White rot of Apple

(*Botryosphaeria dothidea*)

Source: http://www.caf.wvu.edu/kearneysville/pdfFiles/whiterot.PDF .

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White rot of Apple

(*Botryosphaeria dothidea*)

B. dothidea is a fungal disease of apple, peach, chestnut, blueberry and other woody plants. The disease causes by this fungus also known by white rot of apple, bot rot of apple and others. It's serious disease of apple in USA where up to 50% fruit losses have been reported. The fungus can also cause damage to tree plants like eucalyptus, pine, elm, chestnut etc. *B. dothidea* has a world-wide distribution except Australia and capable of infect more then 80 plant spp.

Distribution: *B. dothidea* has been reported in many parts of China, Japan, Europe, Africa, USA and South America. The fungus is not reported in Australia and New Zealand.

Host range/Alternate host: Including apple, peach, chestnut, blueberry, kiwifruit and other trees and shrubs host belongs to more than 80 genera (Hepting 1971, Slippers et al. 2004).

Biology and Ecology: *B. dothidea*, usually attack above ground plant parts mainly fruit, leaf and stem not underground part roots. The fungus overwinters in cankered wood and ascospores and conidia are produced there throughout the growing season at optimum temperature 28 to 32^0C. During wet periods, spores ooze out of fruiting bodies and are dispersed by wind, rain-splash, insect feeding, and contaminated pruning tools. Spores infect through wound site of the bark (insect feeding, growth crack, natural opening etc.) and once the fungus colonise the site, it produces enzymes that help fungus to get nourishment. The fungus survives dormant periods in infected branches. The exact mechanism of fruit infection is not known yet but it's assumed that fruit infection occurs during the last 6-8 weeks of the growing season and degree of infection depend on sugar content of the fruit of individual cultivars. Fruit is most commonly infected at an injury but it can also happen without the fruit being injured.

Symptoms: *B. dothidea,* white rot fungus infects only fruit and woody plant parts (figure as below). Infection on twigs and limbs appear as small, circular spots or blisters in early summer. With time the lesions expand and the area becomes depressed with watery exudates in blisters. In 4-8 weeks black fruiting bodies appear within the cankers zone. As the cankers progress the outer bark often sloughs off and under favourable conditions the cankers fuse together and make a big girdling on limbs. White rot infected plants show bright yellow foliage in early summer. The symptoms on fruit usually found in 4-6 weeks before the harvest and it start with a small, slightly sunken brown spots that may be surrounded by a red halo. The decayed area in fruit expands and the central part becomes rotten and eventually the entire fruit rots. In advanced stage of disease black fruiting bodies may found on the fruit surface. Apple colour bleaches and become light brown during the infection process and that's why the disease is sometimes refer as "white rot." The decayed part turns white, soft and watery under warm condition.

Fig. Infected fruit (left) and stem of apple plant by white rot fungus, *B. dothidea*

Ref. http://www.caf.wvu.edu/kearneysville/pdfFiles/whiterot.PDF.

Affected plant stages: Vegetative growing stage

Affected plant parts: Fruits and stems.

Affected Industries: Apple and other host plant industries.

Resistant plant variety: The plant varieties/cultivars do not vary greatly in their susceptibility to white rot apple disease. However, Golden Delicious, Empire, Jersey Mac appear to get more severely affected then others.

Disease movement and Dispersal: Under field conditions, the fungal spores splash-dispersed mainly by wind, rain-splash and some by insect feeding and contaminated pruning tools. The dispersal of ascospores is more strongly depending on the wind. In case of international trade, the fungus could spread via trading of host plants where the fungus can live as an asymptomatic endophyte ofr undefined periods.

Disease Impact: White rot disease is a serious disease of apple fruit and wood in USA where 50% losses has been reported. It is also a pest for number of wild and ornamental plant species including eucalyptus, pine, juniper in a number of countries etc.

Disease Management: Both cultural practice and chemical control are used to manage white rot disease. For effective chemical control fungicide spray from bloom through harvesting period is required. Follow a suggested fungicide spray program. Home fruit growers should follow the spray schedule for apples outlined in *Midwest Tree Fruit Pest Management Handbook*. Where white rot has been serious in the past, spray every 10 to 14 days, starting when the fruit are half an inch in diameter. The cover sprays are critical, especially starting at the fifth cover and continuing close to harvest. No fungicide, however, is effective enough by itself to control *Botryosphaeria* rot. The importance of good sanitation in the orchard and of the sound cultural practices that insure tree vigor cannot be overstressed. Therefore, intensive pruning is important during the dormant period and removing of all dead wood, including spurs, twigs and branches where the fungus is able to survive and colonise for new infection. To minimise drought stress that encourage twig and branch infection the tree should be irrigated during hot period.

Phytosanitary risk: The risk of introduction of white rot disease into new countries is connected with the incautious trading of host plants where the fungus is able to live as an asymptomatic endophyte for undefined periods. However, the occurrence of new epidemics is unpredictable because it dependence on climatic variations as well as on presence of stressed hosts. For example, in Italy the fungal species appears not able to spread significantly in northern regions, in spite of their closeness to central sites with high incidence and the availability of suitable predisposed hosts.

Quarantine Risk: Low – *B. dothidea* spore mainly disperse through wind locally. The most common trading component like fruits is unlikely to carry or escape quarantine to spread the fungus in a new area/country.

Probabilities of Entry: Low – because of low possibility of trading host plants of *B. dothidea* in Australia that carry the fungal spores. Unless, the materials bring for research purpose are infected.

Possibility of Establishment: Low – Because of limited host-range *B. dothidea* has less chance to find a suitable host at the entry points upon its arrival, although suitable climatic conditions are available in some parts of Australia.

Probabilities of Entry and Establishment: Low – In spite of suitable climatic conditions, limited host capacity of *B. dothidea* reduce the chance of entry and establishment in Australia.

Economic Impact: High – significant fruit (e.g. apple) and wood damage (up to 50%) reported by *B. dothidea* in USA. Therefore, it would have high to moderate impact on commercial apple and fruit host industries in Australia.

Environmental Impact: Moderate – *B. dothidea* has an impact on certain types of vegetation, i.e. woody plants such as pine, eucalyptus, junipers and ashes. However, when the infected host is a characteristic component of the landscape (e.g. in the case of oaks), its decline caused by the fungus induces a perception of weakness and decline of the whole environment.

Social Impact: Low – The disease symptoms are quite visible, control measures are available including cultural practices. Therefore, the grower should be able to handle the disease quickly and effectively to escape the damage intensity.

Pest management cost: Moderate – The biology of white rot disease and its available control measures will reduce the cost in disease management. The cost may vary from place to place depends to labour wages, pest severity, host variety and other factors. Calculation based on at least 6 chemical spray in one season that include $20.0 chemical cost and $50.0 application cost/ha for a single spray i.e. (20 + 50)x6 = $420/ha. Sources - Pest data sheet/ERAT and Martine Combret/Development officer/DAFWA/Bunbury.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 - 15% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – *B. dothidea* possess low risk of dispersion via international trade and there is no record of transmission of *B. dothidea* on contaminated trading component like fruit. Therefore, having the pest in Australia would not be a major concerned in export market.

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http://www.cabicompendium.org/cpc/datasheet.asp?CCODE=BOTSDO&COUNTRY=0

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http://ipm.ncsu.edu/apple/chptr5.html

THREAT DATA

White fruit rot of olive

(*Botryosphaeria dothidea*)

Source: http://beautifulgrace2008.blogspot.com/2008/04/picture-of-olive-tree.html.

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White fruit rot of olive

(*Botryosphaeria dothidea*)

B. dothidea is a fungal disease of apple, peach, chestnut, blueberry, olive and other woody plants. The disease causes by this fungus also known by white rot of apple, bot rot of apple and others. It's serious disease of apple in USA where up to 50% fruit losses have been reported. The fungus can also cause damage to tree plants like eucalyptus, pine, elm, chestnut etc. *B. dothidea* has a world-wide distribution except Australia and capable of infect more then 80 plant spp.

Distribution: *B. dothidea* has been reported in many parts of China, Japan, Europe, Africa, USA and South America. The fungus is not reported in Australia and New Zealand.

Host range/Alternate host: Including apple, peach, chestnut, blueberry, kiwifruit and other trees and shrubs host belongs to more than 80 genera (Hepting 1971, Slippers et al. 2004).

Biology and Ecology: *B. dothidea*, usually attack above ground plant parts mainly fruit, leaf and stem not underground part roots. The fungus overwinters in cankered wood and ascospores and conidia are produced there throughout the growing season at optimum temperature 28 to 32^{0}C. During wet periods, spores ooze out of fruiting bodies and are dispersed by wind, rain-splash, insect feeding, and contaminated pruning tools. Spores infect through wound site of the bark (insect feeding, growth crack, natural opening etc.) and once the fungus colonise the site, it produces enzymes that help fungus to get nourishment. The fungus survives dormant periods in infected branches. The exact mechanism of fruit infection is not known yet but it's assumed that fruit infection occurs during the last 6-8 weeks of the growing season and degree of infection depend on sugar content of the fruit of individual cultivars. Fruit is most commonly infected at an injury but it can also happen without the fruit being injured.

Symptoms: *B. dothidea,* white rot fungus infects only fruit and woody plant parts (figure as below). Infection on twigs and limbs appear as small, circular spots or blisters in early summer. With time the lesions expand and the area becomes depressed with watery exudates in blisters. In 4-8 weeks black fruiting bodies appear within the cankers zone. As the cankers progress the outer bark often sloughs off and under favourable conditions the cankers fuse together and make a big girdling on limbs. White rot infected plants show bright yellow foliage in early summer. The symptoms on fruit usually found in 4-6 weeks before the harvest and it start with a small, slightly sunken brown spots that may be surrounded by a red halo. The decayed area in fruit expands and the central part becomes rotten and eventually the entire fruit rots. In advanced stage of disease black fruiting bodies may found on the fruit surface. Apple colour bleaches and become light brown during the infection process and that's why the disease is sometimes refer as "white rot." The decayed part turns white, soft and watery under warm condition.

Fig. Infected olive fruit (left), apple (middle) and apple stem (right) by white rot fungus, *B. dothidea*. (Ref. http://www.caf.wvu.edu/kearneysville/pdfFiles/whiterot.PDF)

Affected plant stages: Vegetative growing stage

Affected plant parts: Fruits and stems.

Affected Industries: Apple and other host plant industries.

Resistant plant variety: The plant varieties/cultivars do not vary greatly in their susceptibility to white rot apple disease. However, Golden Delicious, Empire, Jersey Mac appear to get more severely affected then others.

Disease movement and Dispersal: Under field conditions, the fungal spores splash-dispersed mainly by wind, rain-splash and some by insect feeding and contaminated pruning tools. The dispersal of ascospores is more strongly depending on the wind. In case of international trade, the fungus could spread via trading of host plants where the fungus can live as an asymptomatic endophyte ofr undefined periods.

Disease Impact: White rot disease is a serious disease of apple fruit and wood in USA where 50% losses has been reported. It is also a pest for number of wild and ornamental plant species including eucalyptus, pine, juniper in a number of countries etc.

Disease Management: Both cultural practice and chemical control are used to manage white rot disease. For effective chemical control fungicide spray from bloom through harvesting period is required. Follow a suggested fungicide spray program. Home fruit growers should follow the spray schedule for apples outlined in ***Midwest Tree Fruit Pest Management Handbook***. Where white rot has been serious in the past, spray every 10 to 14 days, starting when the fruit are half an inch in diameter. The cover sprays are critical, especially starting at the fifth cover and continuing close to harvest. No fungicide, however, is effective enough by itself to control *Botryosphaeria* rot. The importance of good sanitation in the orchard and of the sound cultural practices that insure tree vigor cannot be overstressed. Therefore, intensive pruning is important during the dormant period and removing of all dead wood, including spurs, twigs and branches where the fungus is able to survive and colonise for new infection. To minimise drought stress that encourage twig and branch infection the tree should be irrigated during hot period.

Phytosanitary risk: The risk of introduction of white rot disease into new countries is connected with the incautious trading of host plants where the fungus is able to live as an asymptomatic endophyte for undefined periods. However, the occurrence of new epidemics is unpredictable because it dependence on climatic variations as well as on presence of stressed hosts. For example, in Italy the fungal species appears not able to spread significantly in northern regions, in spite of their closeness to central sites with high incidence and the availability of suitable predisposed hosts.

Quarantine Risk: Low – *B. dothidea* spore mainly disperse through wind locally. The most common trading component like fruits is unlikely to carry or escape quarantine to spread the fungus in a new area/country.

Probabilities of Entry: Low – because of low possibility of trading host plants of *B. dothidea* in Australia that carry the fungal spores. Unless, the materials bring for research purpose are infected.

Possibility of Establishment: Low – Because of limited host-range *B. dothidea* has less chance to find a suitable host at the entry points upon its arrival, although suitable climatic conditions are available in some parts of Australia.

Probabilities of Entry and Establishment: Low – In spite of suitable climatic conditions, limited host capacity of *B. dothidea* reduce the chance of entry and establishment in Australia.

Economic Impact: High – significant fruit (e.g. apple) and wood damage (up to 50%) reported by *B. dothidea* in USA. Therefore, it would have high to moderate impact on commercial apple and fruit host industries in Australia.

Environmental Impact: Moderate – *B. dothidea* has an impact on certain types of vegetation, i.e. woody plants such as pine, eucalyptus, junipers and ashes. However, when the infected host is a characteristic component of the landscape (e.g. in the case of oaks), its decline caused by the fungus induces a perception of weakness and decline of the whole environment.

Social Impact: Low – The disease symptoms are quite visible, control measures are available including cultural practices. Therefore, the grower should be able to handle the disease quickly and effectively to escape the damage intensity.

Pest management cost: Moderate – The biology of white rot disease and it's available control measures will reduce the cost in disease management. The cost may vary from place to place depends to labor wages, pest severity, host variety and other factors. The total cost would be at least **$600.00** based on 8-10 spray/year that includes chemical price (Captan) and application cost The calculation based on 60 trees (¼ of total 500 trees/ha) that require at least 15 hours (15min/tree) at the $30 to $40/h rate (Ref. Pestgenie and Landmark chemical companies and Mrs. Martine Combret/Development officer/DAFWA/Bunbury). In case of apple and pear the cost expect to be half (i.e. **$300/ha**) because the same spray can be used for apple and pear scab diseases that need less number of spray (~4-5). Therefore, the cost would be half in case of theses hosts compare to olive, cherry and other that are not host for scab diseases.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 10 - 15% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – *B. dothidea* possess low risk of dispersion via international trade and there is no record of transmission of *B. dothidea* on contaminated trading component like fruit. Therefore, having the pest in Australia would not be a major concerned in export market.

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http://www.cabicompendium.org/cpc/datasheet.asp?CCODE=BOTSDO&COUNTRY=0

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THREAT DATA

Bacterial blight of Pomegranate

Xanthomonas axonopodis pv. punicae

Source: http://www.nhm.nic.in/Vasanta_Pome.ppt#294,22,Slide 22

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Bacterial blight of Pomegrante

(Xanthomonas axonopodis pv. punicae)

X. axonopodis pv. punicae is a bacterial pathogen that causes serious blight disease of pomegranate. The disease reported in a number of states of India where it's a great threat to pomegranate cultivation as there is no effective control measures are available yet. The blight can cause 50 to 100% production loss depending on disease severity. General cleaning of infected fruits, Bordeaux mixture, antibiotics and copper spray reduce partial damage only.

Distribution: Only reported in some states of India. The disease has not been reported in Australia yet.

Host range/Alternate host: So far in the literature, pomegranate *(Punica granatum)* has been reported the only host of *X. axonopodis pv. punicae.* The other strain of this bacteria like *X. axonopodis pv. citri* causes citrus canker, a disease that poses a serious economic threat to citrus industries worldwide.

Disease Symptoms and Biology:

The pathogen attacks all the above ground plant, but main damage is observed on fruits that develop black spots and splits leading to considerable reduction in yield loss, fruit quality and market value. The initial symptoms appear as water-soaked translucent irregular to circular minute black spots (2-5 mm diameter) on the leave. Gradually, the centre of the spot become necrotic and turns dark brown with prominent water-soaked margins. In severe cases, many spots coalesces that cover a large leaf area and finally the leaf drop off. Dark spot symptoms also developed around the nodes on the stem that causes carking of nodes and girdling. The infected nodes break off at the infection points that cause the loss of whole plant branches. In some orchard, up to 100% infection rate has been reported. Bacterial ooze is used for chemical diagnostic of the disease.

The increase in day temperature (38.6°C) and afternoon relative humidity of 30.4% along with cloudy weather and intermittent rainfall favoured the disease initiation and further spread of the disease. The disease spreads from infected plant to healthy plant mainly through rain-splashed and infection initiated through wounds. The pathogen overwinters in infected plant debris and leaves of other plant planted along the bund of pomegranate fields. The continuous growing of pomegranate over three seasons leads to increase susceptibility of crop in India.

Fig. Symptoms of bacterial blight disease on pomegranates.

Ref. http://www.nhm.nic.in/Vasanta_Pome.ppt#294,22,Slide 22

Affected plant stages: Vegetative growing stage

Affected plant parts: All above ground plant parts including fruit.

Affected Industries: Pomegranate industry only

Resistant plant variety: In literatures no reports on resistant plant variety against bacterial blight caused by *X. axonopodis pv. punicae*

Disease movement and Dispersal: Under field conditions, the bacterium mainly spread by rain-splash and some by insect feeding and contaminated pruning tools. The dispersal also influence by strong wind. In case of international trade, the disease could spread via trading of host plants specially with infected twigs, fruits and whole plants where the bacteria can survive for long period.

Disease Impact: Only a very few short publications available on bacterial blight of pomegranate in the web sites and the disease only reported in some states of India only. This limits the knowledge of the biology, impact, management and other aspect of this disease. In India 50% of the total area under pomegranate cultivation has been affected by this disease and farmers have reported yield reduction by 60-70% while in some cases up to 80%.

Disease Management: Satisfactory control measures are not available for this disease. Therefore, the farmers are suffering from tremendous yield loss and frustration. However, removal and burning of infected leaves, fruits, and twigs, use of clean disease free planting material, phytosanitary cultivation techniques, and bacteriocidal sprays containing antibiotics or copper may help in disease management in some extend. Spraying of Bordeaux mixture (1%) or copper oxychloride (0.3%) or 1:50 lime sulphur has been reported partial effective to control bacterial blight of pomegranate. Recently, Kumer et al. (2009) reported that Bacterinashak (500 ppm) along with Copper oxychloride (2,000 ppm) at 8-10 days intervals for 5 times as effective and economical in the management of Bacterial blight of pomegranate in northern Karnataka , India.

Quarantine Risk: High – *X. axonopodis pv. punicae* bacterium of pomegranate blight disease mainly disperse through wind-driven rain splash, birds and pruning tools. However, the most common trading component like fruit has very good chance to carry or escape quarantine to spread the fungus in a new area/country. Trading plants (e.g. nursery, research purposes) with infested twigs also enhance the chance of disease spreading in a new location.

Probabilities of Entry: High – like citrus canker bacterium (*X. axonopodis pv. citri) X. axonopodis pv. punicae* has high possibility of entry in Australia because of good possibility of carrying the bacterium with both fruits and host plants during trade as well as by tourist. Although, our strict quarantine at the entry points will reduce the chance of entry of infested materials in Australia but it may easily escape the quarantine due to difficulties by visual identification.

Possibility of Establishment: Moderate – Because of specific host (pomegranate only) the bacterium has less chance to find a suitable host at the entry points upon its arrival. However, rapidly growing pomegranate orchards in Australia and its suitable environmental conditions are in favour of this pathogen to establish in many areas of the country.

Probabilities of Entry and Establishment: High – In spite host specificity, suitable climatic conditions and growing pomegranate cultivations enhance the chance of entry and establishment of pomegranate blight bacterium in many regions of Australia.

Economic Impact: High – In India, pomegranate yield loss has been recorded from 60 to up to 90% due to blight disease depending on disease severity. No suitable control measure is available yet for the farmers. The existing control techniques mainly depend on phytosanitary measures may reduce the loss maximum of 10 - 20% but these are labour extensive and costly. Based on the information in the literature, it assumes that the newly growing pomegranate industry in Australia will face high impact if the causal agent of blight disease establish in the country.

Environmental Impact: Negligible – Pomegranate blight disease is not expected to impact on environment as the disease is restricted to single fruit plant (pomegranate only) and no reports on wild or native host. Chemical application in the disease management might have negligible impact on human and animal health.

Social Impact: Moderate – Bacterial blight symptoms are visible and cultural practice such timely pruning and removing infected plant parts may help in initial diseases management without using any chemicals. But if the grower fail to manage the disease at initial stage before it spread area of orchard then it's difficult to manage as there is no effective chemical spray. In severe cases the grower need to up rooted the whole tree and go for a crop holiday for 10 years. This would have significant impact on the society where people depend on this newly emerging pomegranate industry.

Disease management cost: Moderate/High – The biology of blight disease and it's existing control measures the disease management expected to be high. The cost may vary from place to place depends to labor wages, pest severity, host variety, climatic conditions and other factors. Based on research work in India it needs at least 5 spray/year and that would cost from $500 to $700/ha excluding regular pruning cost for removing disease plant parts

Yield loss despite control efforts: Based on the pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 20 - 50% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Moderate –pomegranate blight disease possesses moderate to high risk of dispersion via international trade but there is no record of transmission of this bacterium on contaminated trading component like fruit. Still, having this pest in Australia would be very concern in export market like citrus canker pest (*X. axonopodis pv. citri.*

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THREAT DATA

Fire blight

(*Erwinia amylovora*)

Source: http://extension.missouri.edu/publications/DisplayPub.aspx?P=G6020

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Fire blight

(*Erwinia amylovora*)

E. amylovora is a bacterial disease and occurs only in plant species belong to rose family (the Rosaceae). Among these, apple and pear are the most affected and economically important horticultural plants in many countries. The disease first recorded in USA in 1780 and since it has spread more than 20 countries. Number of disease outbreak occurred in different countries that caused significant economic damage due to lack of effective control measures in the management. Fire blight kills blossoms, shoots, limbs, and, sometimes, entire trees that lead to loss both fruit production as well as whole orchard. Australia is currently free from *E. amylovora.*

Distribution: After the first report since late 1700s in USA, the fire blight disease has managed to spread at least another 39 countries of North America, Africa, Europe, the Pacific rim and the East Mediterranean. There might be countries where this bacterium is present without being a major concern and not reported yet. In Australia, fire blight was first detected in 1997 in the Melbourne Royal Botanic Gardens but it was successfully eradicated and since the country is considered free of this disease.

Host range: *E. amylovora, a* bacterium causes fire blight disease is knows as a pathogen of Rosacease family. The pest is capable of causing the disease in many plant species within this family. About 200 plant species belong to 40 genera are reported susceptible to this disease (Van der Zwet and Keil 1979). Among these apple and pear are considered the most affected commercial plant species. Other susceptible species include crab apple, raspberry, loquat, hawthorn, firethorn, mountain ash, cotoneaster etc.

Biology and Ecology: Fire blight bacteria become active at the beginning of apple and pear growing season (spring) and remain active through to summer. The disease severity depends on weather factors specially, temperature and occasional rain with wind. The bacteria overwinter in cankers on twigs, branches, or trunks of host trees. In spring when host plants resume growth and temperature become warm (18 - 30^{o}C) the bacteria begin to multiply in infected tissues and produce bacterial ooze on the surfaces of branch or twig. From there the bacteria spread to nearby blossoms and other succulent growing shoots by splashing rain or insects, especially honey bees. The infection usually occurs through natural openings such stomata, entry point of leaves, shoots, fruits etc. However, the infections enhance in injured tissues that cause by wind, hail, or insect feeding. Wounds from hail and strong wind with rain often lead to a sever outbreak of fire blight. Any fresh wound can serve as an entry point. Ideal conditions for infection, disease development, and spread of the pathogen are rainy or humid weather with daytime temperatures in the range of 18 - 30^{o}C especially when night temperatures stay above 15°C.

The extensive of fire blight damage influences by vigorous growth of the host plant. The distance of pathogen movement from diseased plant relates directly to the rate of tree growth. Vigorously growing shoots are the most severely affected; therefore, conditions that favour rapid shoot growth, such as high soil fertility and abundant soil moisture, increase the severity of damage to trees. Rootstock blight can develop from internal spread of bacteria within trees from infections (Momol et al. 1998).

Symptoms: The basic symptoms of fire blight are very similar to all hosts that include blight of shoot, canker on limbs and bacterial ooze formation on the surface of the infected zone. Flowers are usually get infected first and then both infected flowers and flower stems wilt and turn black in case of pear trees but brown on apple tree. Blight infections often spread to twigs and branches and causes small shoots to wilt, forming a crook at the end of each infected shoot. Infected shoots, twigs, and suckers turn brown to black and often bend in a characteristic shepherd's-crook. The dark, shriveled leaves hang downward and usually cling to blighted twigs.

Fruit infected by fire blight bacteria turns dark, shrivels, mummifies, and rots. Mummified fruit may cling to the tree for several months. Bacterial ooze appears clear or milky turning red to brown and glassy when dry may be visible on the infected fruits. The fruits infected following injury by hail or insects often develop red, brown, or black lesions.

A canker is formed when an infection progresses into larger branches. Initially cankers are reddish and gradually they become brown and then black. A characteristic sign of fire blight disease is visible of watery exudates (known as bacterial ooze) in the infected sites, especially under humid conditions.

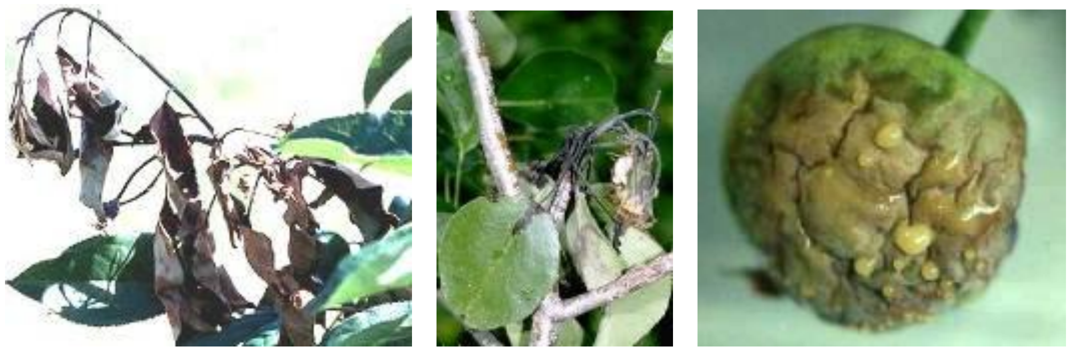

Fig. Fire blight symptoms on apple plant

Shoot blight on young Fuji apple. Note shepherd's crook and browning of leaves at end of shoot. Flower clusters infected with fire blight bacteria. Fire blight-infected apple fruit with bacterial ooze.

Ref. http://www.agf.gov.bc.ca/cropprot/tfipm/images/fb8.JPG

http://www.ipm.ucdavis.edu/PMG/E/D-PE-EAMY-BL.001.html

Affected plant stages: Flowering, Vegetative and pos-harvest stages

Affected plant parts: Fruits, leaves and stems.

Affected Industries: Apple and other host plant industries.

Resistant plant variety: The plant varieties/cultivars do not vary greatly in their susceptibility to fire blight apple disease. However, Fuji, Gala, Golden Delicious, Granny Smith, Gravenstein, Jonathan, Mutsu, Pink lady, and Yellow Newtown appear to get more severely affected then others.

Disease movement and Dispersal: Under field conditions, fire blight bacterium spread mainly by rain-splash and insects and some by wind and contaminated pruning tools. The dispersal is more strongly depending on bacterial ooze formation. In case of international trade, the bacterium could spread via trading of host plants where the fungus can live as an asymptomatic endophyte of long periods.

Disease Impact: Fire blight is one of the most destructive diseases for apple and pear fruits in most of commercially cultivated regions. The damages cause by the disease turn out to be very severe because the infected plant suffer from normal growth developmental, yield loss and finally die. Fire blight may cause up to 50% apple and pear production loss in a serious epidemic condition and 60% fall in canneries. According to Australian Bureau of Agriculture and Resource Economics (ABARE) fire blight has the potential to cause a significant loss of yield of fruit such as up to 20% for apples and 50% for pears in Australia. Moreover, if it occurs in 100% of production areas across the Australian pome Industry, the cost to the Industry would be approximately $126 million or 37.5% of the gross value of annual apple and pear production. In addition to the impacts on the Pome Industry, an outbreak of Fire blight would also impact on commercial honey production. Honeybees are considered to be an important insect vector for the diseases and outbreaks could result in quarantining of hives that are located in the vicinity of an outbreak (see BeeGuard plan).

Historically the disease has a number of outbreaks in many commercial apple and pear growing regions of different countries and that causes losses of millions of dollar. For example, in Michigan (USA) 35% of apple yields is reported in 2000 with 100% losses for some growers and the total economic loss in the regions is calculated $42 million (Longstroth 2000). In New York State, 10% tree loss has been reported by this disease (Momol et al. 1999). In Macedonia, the disease was very destructive to pear and quince and the eradication of this disease cost $7 million (Mitrev 1996).

Disease Management

There is no single method that can control the fire blight. Therefore, effective management of fire blight is multi-faceted and largely preventative. The grower must utilise a combination of sanitation, cultural practices, and sprays of chemical or biological agents to keep the disease in check. An effective chemical cure for fire blight is unknown. Those sprays which are presently used, function more as preventatives than curatives. Most of the registered chemicals are fungicides which use elemental sulphur or copper as the control agent. The antibiotic streptomycin is also registered for use on apple and pear trees. Once the disease is established it is very unlikely to have success in complete eradication.

Cultivars: Selection of a cultivar that are comparatively less susceptible or a resistant variety (if available) is the most effective way of controlling fire blight. In apple, for example, some cultivars exist that are moderately resistant to the disease (e.g., Red and Golden Delicious). In case of pear, cultivar choices are more limited because superior horticultural traits (e.g., taste, storage, and marketing qualities) have been difficult to combine with higher levels of disease resistance.

Pruning: Pruning of all visible infected (canker) plant parts during the winter time is another effective approach to manage this disease by reducing the source of infection where the bacteria multiply and spread to newly growing plants parts (flower bloom, bud, leaf, etc) during early spring.

Prevention of blossom blight: Most of fire bight damage causes by blossom infection that provide much of the inoculums for secondary infections such as infection of shoots, fruits, and rootstocks. Therefore, prevention of blossom infection is important in fire blight management. At bloom, antibiotic sprays are highly effective against the blossom blight phase of the disease. These sprays are critical because effective early season disease control often prevents the disease from becoming established in an orchard. The most effective chemical control of fire blight is achieved by the application of streptomycin (Agri-Strep) during bloom. Because blossoms open over a period of several days, **3 to 4** applications (in case of pear **5-12** applications) during bloom are necessary. However, excessive use of streptomycin may result in the development of resistant strains of the fire blight bacterium.

Cultural practices. Plants with vigorous growth are more vulnerable to fire blight infection of an excessive amount of new growth occurs. Rapidly growing, succulent twigs which have been stimulated by excessive fertility or heavy pruning are extremely susceptible to the fire blight bacteria. Therefore, it is best to use a balanced fertiliser with fairly low nitrogen content for moderate plant growth.

Phytosanitary risk: The risk of introduction of fire blight disease into new countries is mainly connected with human activities and the incautious trading of host plants where the bacteria is able to live as an asymptomatic endophyte for log periods. However, the occurrence of new epidemics is unpredictable because it dependence on climatic variations, presence of hosts and early detection in the field.

Quarantine Risk: High– Fire blight bacteria*, E. amylovora,* is of quarantine concern in most countries that commercially grow apple, pear and other host crops. The bacteria easily and effectively get spread locally by natural factors such as rain-splash, wind, insects, birds etc. The most common trading component like fruits is unlikely to carry the bacteria in a new area/country.

Probabilities of Entry: Low – the infected fruit is most unlikely to carry the bacteria during trade and also by travellers because of strict quarantine regulations especially on 'fire blight'. However, the history of spreading of this bacterium into a new country indicates risk of entry in Australia. Moreover, in Australia (Victoria) the bacterium previously detected but eradicated successfully in 1997. Plant Health Australia (PHA) reported as high potential of entry of this pest in the country.

Possibility of Establishment: High – because Australia has many regions with a number of hosts of *E. amylovora* along with a suitable climatic conditions for the disease to establish following its entry in the country.

Economic Impact: Very high – significant damage and losses in Australian pome industry and commercial honey production indicated by The Australian Bureau of Agriculture and Resource economics. Also history of the damages by this disease in published literatures easily reflects its impact on economy of the country.

Environmental Impact: Low – fire blight disease is not expected to have high impact on environment as the disease is restricted to a single family members of plant and no reports on wild or native host. Chemical applications in fire blight management might have low impact on human and animal health.

Social Impact: Moderate – impact on backyard fruit trees to be expected and this will results negative impact on socio-economic condition of the society. However, fire blight disease symptoms are quite visible and managble by small growers through cultural practices. Therefore, the small grower should be able to handle the disease quickly and effectively to escape the damage intensity.

Pest management cost: High – The biology of fire blight disease and its history of management in commercial orchards indicate laborious and time consuming (e.g. pruning, sanitation etc). Fire blight disease is a weather driven and the management depends heavily on ongoing cultural practices such as pruning rather then any chemical spray like other diseases. The cost may vary from place to place depends to labour wages, pest severity, host variety and other factors. Tentative cost of pruning would be about **$4000/ha** in each year. This calculation based on 2000 trees/ha and needs 20 minute/tree for manual pruning with labour wages $25.00/hour. In addition to pruning cost, the fire blight spray would cost **$1650.00/ha** that .include 3-spary with chemical cost ($1500/ha) and labour cost ($150/ha). The total cost would be **$5,650/ha**. Depending on the other factors (e.g. rain, disease severity etc.) the total cost might be higher. In case of pear this cost would be **25%** more because the disease is usually more severe in pear than apple.

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on the host plant the total yield loss assumed to be between 20 – 30% even under currently available control measures.

Export revenue loss due to loss of Pest Freedom Status: High – Australia currently prohibited import of pomes and stone fruit from the countries where fire blight is present. The disease is high concern of most of the countries involve in commercial pomes and stone fruit cultivations. Therefore, having the pest in Australia would be a major concerned in export market.

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THREAT DATA

Onion bacterial blight

Xanthomonas axonopodis pv. *allii*

Source: http://www.ipmimages.org/browse/subthumb.cfm?area=86&sub=14265

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Onion bacterial blight

(*Xanthomonas axonopodis* pv. *allii)*

Onion bacterial blight (OBB) caused by *X. axonopodis* pv*. allii* is also know by 'Xanthomonas leaf blight' or 'bacterial leaf blight' is common foliar bacterial disease of onion. The disease first reported in USA (1974) and becoming a challenging and yield-threatening disease in onion production regions worldwide. The bacteria of the disease could transmit through seed i.e. seed-borne but it does not infect onion bulb. The disease severity and production losses influence by many environmental factors including temperature and under disease favourable conditions yield losses could vary from 20 to 100%. Cultural, chemical and biological control or combination of all could reduce the disease damage.

Distribution: OBB first described in 1978 from Hawaii and since then the disease spared to some other onion production regions in the East Caribbean, continental United Sates, South America, South Africa, Asia and France (Reunion Island). In the1940s and 1950 a very similar disease was recorded on onion from Arkansan valley but it was not reported again or investigated until recently. The disease is not reported in Australia yet.

Host range/Alternate host: Including onion other members of *Allium* sp. (e.g. garlic, leek, chives, shallot etc.) are the major hosts of this strain of *X. axonopodis.* The same bacterial strain that causes OBB has also been reported on common bean (*Phaseolus vulgaris*) and other leguminous plants where the bacterium persists and multiplies but no or mild disease symptoms on the hosts. However, the strain *X. axonopodis* pv. *phaseoli* is causal agent for a common bacterial blight of bean.

Disease Biology: OBB disease occurs when bacteria are blown or splashed onto new leaves, where they multiply to form large populations under moist conditions (e.g. dew), and infect through natural openings (e.g. stomata) or wounds. Leaf injury by wind and other mechanisms favour the infection. Usually, OBB is associated with moderate to high temperatures and rainfall at bulb initiation and continue through bulb development. Severe disease outbreaks often occurs shortly (7-10 days) after a period of humid and rainy weather. Overhead irrigation or frequent rains after bulb initiations favour the disease and the symptoms usually confined on middle-aged to older leaves. Early season weather conditions do not appear to have significant influences on disease spreading and severity. The pathogen can be disseminated between fields by irrigation water and contaminated workers and equipment. The pathogen survives between onion crops epiphytically and pathogenically on weeds, volunteer onion, and leguminous hosts such as alfalfa, in crop debris, and on contaminated seed.

Disease Symptoms: OBB disease symptoms usually confined to host leaf and the symptoms may appear at any stage of crop development in case of short-day onion cultivars, but the long-day cultivars generally develop symptoms during or after bulb-initiation. No OBB symptoms are known to appear on onion bulb of the infected host. On leaves the blight symptoms begin as small, chlorotic spots or lens-shaped lesions with water-soaked margins. As the disease progresses, the lesions enlarge, coalesce and turn into a long chlorotic streaks (Fig 1. right). In some cultivars, the chlorotic streaks may extend the entire length of leaves and result premature plant death or stunted plant gowth. Under hot and dry conditions infected tissues or lesions dry out and become brittle, but retain their characteristic tan to brown color. Symptoms are similar on chive

(*A. schoenoprasum*), garlic (*A. sativum*), leek (*A. porrum*), shallot (*A. cepa* var. *ascalonicum*), and Welsh onion (*A. fistulosum*) but tend to be most severe on onion.

Fig. Symptoms of onion bacterial blight disease in the field.

Ref. http://www.ipmimages.org/browse/subthumb.cfm?area=86&sub=14265

Affected plant stages: Vegetative growing stage

Affected plant parts: Above ground plant parts mainly leaf.

Affected Industries: Onion and the members of *Allium* sp.

Resistant plant variety: In literatures no reports on resistant plant variety against bacterial blight caused by *X. axonopodis* pv. *allii*

Disease movement and Dispersal: Under field conditions, the OBB bacterium readily spreads by surface irrigation water, and presumably by contaminated debris and exudates adhering to workers and equipment. Rain-splash, strong wind, insect, and contaminated pruning tools also play role in the diseases dispersion. In case of international trade, the disease could spread via seeds where the bacteria can survive for long period because OBB is a seed-bone disease. .

Disease Impact: OBB disease reduces both quality and yield of the infected crops by attacking photosynthetic plant part (leaf). Depending on disease severity, the damage could vary from 20 to 100% under disease-favourable conditions (Schwartz and Gent 2007). Infection time, host susceptibility, weather conditions, and the type and time of applied control measures also influence the damage.

Disease Management: To minimise the impact of OBB diseases on onion crops, the producer must carefully integrate recommended strategies of crop rotation, sanitation, use of clean seed and transplants, varietal selection, stress and wound avoidance and proper pesticide selection and scheduling. The following management tips would reduce the crop damage.

- Planting of certified seeds - free of *X. axonopodis* pv. *allii*
- Practice a 2-year or longer rotation to a non-susceptible host such as winter wheat or corn.

- Tolerant and moderately resistant varieties include white and red market class varieties such as 'Cometa', 'Blanco Duro' and 'Redwing'. Yellow varieties such as 'X-202', 'Cannonball' and 'Vantage' are most susceptible.
- Eliminate volunteer onion and weeds in and around fields.
- Avoid overhead irrigation and reuse of irrigation water.
- Avoiding excessive nitrogen fertilisation can reduce OBB disease severity.
- Copper bactericides (e.g.Champ, Cuproxide, Kocide, NuCop), alone or mixt with ethylenebis dithiocarbamate fungicide such as maneb, provide effective disease control in semi-arid production regions. Spray intervals of 5 to 10 days are recommended.
- Biological control of Xanthomonas leaf blight with bacteriophage and commercially available antagonistic bacteria appear promising, and research is ongoing.

Successful disease management depends on the integration of as many of these management tools as possible.

Quarantine Risk: High – *X. axonopodis* pv*. allii,* bacterium of OBB mainly disperse through wind-driven rain splash, irrigation water, insects and pruning tools. Although, the most common trading component like onion bulb has no record of carrying the bacterium but it can easily be transmitted via onion seeds into a new area/country.

Probabilities of Entry: Moderate/high – although the pathogen of OBB disease has very limited host range and it's a foliage disease but OBB is a seed-born nature that's the main pathway of entry in Australia through international trade. Unless, strict quarantine restriction on importing onion seeds the pest has moderate to high chance of entry in Australia.

Possibility of Establishment: Low/moderate – Restricted host-range of OBB pathogen reduces the chance to find a suitable host at the entry points upon its arrival, although suitable climatic conditions and hosts are available in some parts of Australia.

Economic Impact: Low to Moderate – OBB is one of the serious foliage diseases of *Allium* spp. including onion and garlic. Both of these are important vegetable crops in Australia and therefore OBB disease will have some negative economic impact specially on commercially grown onion and garlic regions.

Environmental Impact: Negligible – OBB disease is not expected to impact on environment as the disease is very restricted to a particular host group and no reports on wild or native hosts. Therefore, applied chemicals in OBB management will have negligible impact on human and animal health.

Social Impact: Low – The OBB disease symptoms are quite visible, control measures are available including cultural practices, chemical and biological techniques. Therefore, the grower should be able to handle the disease quickly and effectively to escape the damage intensity.

Pest management cost: High – The biology of OBB disease and its available control measures will reduce the cost in disease management. The cost may vary from place to place depends to labour wages, pest severity, host variety and other factors. Based on 10/12 spray/season the cost is calculated about $900/ha (ref. Peter Dawson, Project Manager, Potato, DAFWA).

Yield loss despite control efforts: Based on pest biology, available control measures, and its impact on major host like onion the total yield loss assumed to be between 15-20% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Low – OBB disease is not associated with onion bulb but it's a seed-borne disease. Therefore, trading onion bulb should not be affected but seed export market would be very much concerned if the disease establish in Australia.

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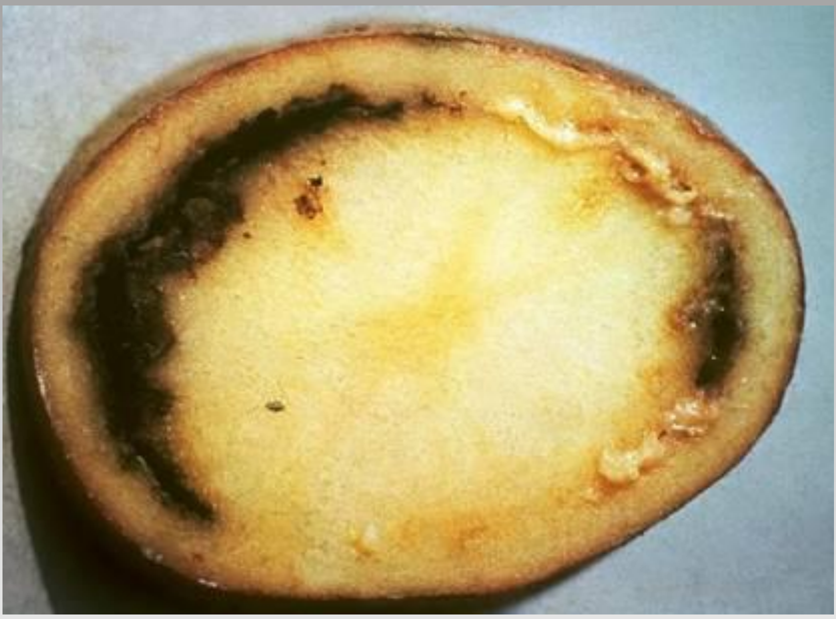
THREAT DATA

Potato ring rot

Clavibacter michiganensis subsp. sepedonicus



Source: http://photos.eppo.org/index.php/image/925-corbse-02

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Potato ring rot

(*Clavibacter michiganensis subsp. sepedonicus*)

Potato ring rot is a bacterial disease that causes by *C. michiganensis subsp. sepedonicus* (CMS*),* a gram positive bacterium. It's a one of the most feared diseases of the potato industry, specially for seed producers. The disease first reported in Germany in 1906. Potato is the only naturally infected host by this bacterium with a few unconfirmed hosts. The disease symptoms could be latent or visible in both host plants and tubers. The damage occurs in both field and storage conditions and up to 50% loss been reported in the literature by this disease. Infested potato tubers are the main source of new infections therefore seed certification has a vital role in the disease management.

Distribution: CMS first in Germany in 1906 and since then it has spread in other European countries like Denmark, Norway, Sweden, Finland, Poland, Ukraine, Russia, Greece and Spain, and across into Algeria (DEFRA, 1998). The disease was introduced into USA in the early 1930's and by the 1940's had spread to many potato growing areas (Rich, 1983). It is also reported in several South America and Asian countries. In recent times there have been reports of isolated incidents in the Netherlands, France and Estonia (EPPO Secretariat, 1999). The disease not recorded in Australia but the disease favours the cool climates of temperate in some reason of the country that could easily encourage the pest to establish in the places.

Host range/Alternate host: Potatoes (*Solanum tuberosum*) is only natural infecting host for CMS. Although, the inoculation tests with many other Solanaceae members like tomatoes and aubergines were reported to be susceptible to CMS.

Disease Biology: Infected seed potatoes are the main source of infection in the field. After planting diseased seeds, bacteria multiply and spread to the vascular tissue of stems, petioles, roots and developing tubers. Symptoms rarely develop quickly and infections usually remain latent for long periods. The bacterium infects tubers through wounds which predominantly occur during the cutting and handling of seed. A knife or machine blade that cuts infected tuber can spread the bacterium. The bacterium is viable for about 5 years in dried infected pulp and pathogenic mucilage on agricultural equipments, carrying baskets etc. These can serve as a source of inoculum to spread the disease both locally and distance. The bacterium overwinters primarily in infected tubers, either during storage or in tubers left in the ground (volunteer potatoes) but unable to survive in soil in the absence of potato debris. In the field bacterial spread from plant to plant is not common although some insects may be capable of transmitting the disease from plant to plant. For example, potato flea beetle, Epitrix cucumeris (Harris), the Colorado potato beetle, the green peach aphid, Myzus persicae and the fruit fly have all been suggested as possible vectors of CMS in the literature. CMS has a relatively low temperature optimum for growth (21°C) and is mainly confined to cooler areas of the world.

Disease Symptoms: Potato ring rot disease symptoms develop both in field and storage conditions. In field the symptoms usually appear late in the growing season. Severe ring rot can result in wilting of leaves and stems along with yellowing and death of leaves. Lower leaves usually wilt first, are slightly rolled at the margins, and are paler green than healthy leaves. As wilting progresses, leaf tissues between veins become yellow. In the later stages of disease, margins of lower leaves die and become brittle, and eventually entire stems yellow and die. Frequently, only one or two stems in a hill will develop symptoms and, in some cases, there are no above-ground symptoms at all. Ring rot derives its name from a characteristic breakdown of the vascular ring within the tuber. This often appears as a creamy-yellow to light-brown, cheesy rot. The symptom is most frequently observed when a diseased tuber is cut crosswise at the stem end. In severe cases, the vascular ring may be separated, and a creamy or cheesy exudate can be forced out from this tissue when the tuber is squeezed. On the outer surface, severely diseased tubers may show slightly sunken, dry, cracked areas. Infected tubers are often invaded by secondary decay organisms which may lead to complete breakdown. Symptoms of ring rot in the vascular tissue of infected tubers are often less obvious than described above, appearing as only a broken, sporadically appearing dark line, or as a continuous, yellowish discoloration.

The disease symptoms may vary from cultivar to cultivar and easily confused with other potato plant disease symptoms like potato blight, potato wilt, stem canker etc. Hot and dry weather conditions enhance the disease symptoms but sometimes the infected plant may not show any symptoms as the disease remain in latent until storage conditions.

Fig. Potato ring disease symptoms.

Ref. http://www.invasive.org/browse/subthumb.cfm?sub=11051

Affected plant stages: Both vegetative growing and post-harvest stages

Affected plant parts: Above ground plant parts (leaves, stems and whole plant) and potato tuber.

Affected Industries: Mainly potato industry.

Resistant plant variety: In literatures no reports on resistant plant variety against potato ring rot disease.

Disease movement and Dispersal: Under field conditions, spreading of CMS bacteria from plant to plant is usually very low. But involvement of some insects like colorado beetle, leafhoppers and aphids in the field has been reported. In case of international trade, in absence of seed certifications CMS could spread via seed potatoes where the bacteria can survive and initial the disease. In addition, contaminated containers, equipment and premises play important roles in local as well as distance dispersions of CMS.

Disease Impact: Potato ring rot disease causes damage both in field and storage conditions by wilting the plants and total rotting of harvested potato tubers respectively. Depending on disease severity, the damage could vary from 15 to 50% under disease-favourable conditions. In North America up to 50%, Russia 15 -47% and in France up to 30% crop loss had been reported in the literature. Infection time, host susceptibility, weather conditions, and the type and time of applied control measures also influence the damage.

Disease Management: Good hygiene is the best way to prevent infection, and the use of only certified seed for planting. In the U.S. and Canada, certified seed potatoes are produced under regulations mandating zero tolerance for ring rot. Although use of certified seed tubers will not guarantee total freedom from ring rot bacteria, it is the best assurance. Before handling seed tubers, all containers, tools, knives and mechanical cutters, planters, and other equipment should be thoroughly washed with a detergent solution, rinsed, and then sanitised with a disinfectant.). Disinfection can be obtained by treatment with compounds from the quaternary ammonia, bleach, chlorine dioxide, iodine and phenol groups for at least 10 min, preferably under low organic load (Secor *et al.*, 1987). For example, use of i) copper 8—Quinolinolate (PQ 80) - 10 % solution in a 1:200 dilution. ii) Quaternary ammonium compounds at 5 oz of a 10% solution/10 gal water. iii) Sodium hypochlorite in a 1,000 to 2,000 ppm chlorine solution. Successful disease management depends on the integration of as many of these management tools as possible.

Quarantine Risk: High – CMS is listed as an A2 quarantine pest by EPPO. It is considered of quarantine significance throughout the Old World because of its high spread potential, highly contagious nature and difficult to manage. Successful eradication of the CMS requires long-term strict quarantine procedures at considerable cost.

Probabilities of Entry: Moderate – although the CMS has very limited and specific known host (mainly potato). However, the pest can easily be transmitted by infected seed potatoes and potato carrying materials during the trade, specially in absence of strict seed certification procedure in importing seed potatoes to Australia.

Possibility of Establishment: Moderate – specific host capacity of CMS limit its chance to find a suitable host at the entry points upon its arrival but the history of its spreading capacity and a suitable climatic conditions in Australia are in favour of the pest.

Probabilities of Entry and Establishment: Moderate– In spite of suitable climatic conditions and available host, specific host capacity of CMS reduces the chance of entry its and establishment in Australia.

Economic Impact: High – presence of bacterial ring rot in Australia has the potential to reduce both tuber yields and export market of Australian seed potatoes to South-East Asian markets. The European Community, Canada and the United States have set zero tolerance levels for both import and export of seed potatoes in an effort to eradicate the disease.

Environmental Impact: Negligible – potato ring rot disease is not expected to impact on environment as the disease is very host specific and no reports on wild or native hosts. Therefore, applied chemicals in the disease management will have negligible impact on the ecosystems.

Social Impact: High - A large reduction in the sale of seed potatoes would be expected to cause major social impact with significant losses to seed producing areas. Yield losses and increased costs for cleaning equipment would be incurred in ware producing areas.

Pest management cost: Moderate – potato ring spot disease posses high potential to spread because the pathogen is highly contagious. The success of managing this disease heavily depend on good hygiene both in field and storage conditions along with adaptation of zero tolerance seed certification program during importation of seed potato. The total cost may vary from place to place depends to labour wages, pest severity, host variety and other factors.

Yield loss despite control efforts: Based on disease biology, available control measures, and its impact on host like potato the total loss assumed to be between 15 - 30% under proper control measures.

Export revenue loss due to loss of Pest Freedom Status: Moderate – potato ring spot disease is associated with potato tuber, specially the seed potato act as new source of infection. Therefore, export markets of seed potato would be affected as CMS designated as quarantine pest by many countries and they placed restriction on importing seed potato from CMS infested countries. Hence, the export revenue would be affected if the disease establish in Australia.

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