Future Surveillance Needs for Honeybee Biosecurity

RIRDC Publication No. 10/107
Future Surveillance Needs for Honeybee Biosecurity

by Simon Barry, David Cook, Rob Duthie, David Clifford, Denis Anderson

July 2010

RIRDC Publication No. 10/107
RIRDC Project No. PRJ-003317
Foreword

The Australian honeybee industry produces honey and other bee products for domestic consumption and export, through apiculture of *Apis mellifera*. The industry has an estimated GVP of A$80 million. In addition, the annual benefit of apiculture to general agriculture through plant pollination in Australia is estimated to range from A$4 to 6 billion.

Because of the significant value of this industry there is a need for effective biosecurity. A component of this is the use of surveillance. This report considers a risk-based framework for exploring the costs and benefits of surveillance for exotic honeybee pests and diseases.

The report has developed a risk-based framework for considering the cost benefit of surveillance for pests both now and in the future. This will be of use to both industry and decision makers. The study also developed a number of tools to assist in this process and has assessed the high-risk pests that currently pose a threat to the Australian industry.

This project is part of the Pollination Program – a jointly funded partnership with the Rural Industries Research and Development Corporation (RIRDC), Horticulture Australia Limited (HAL) and the Australian Government Department of Agriculture, Fisheries and Forestry. The Pollination Program is managed by RIRDC and aims to secure the pollination of Australia’s horticultural and agricultural crops into the future on a sustainable and profitable basis. Research and development in this program is conducted to raise awareness that will help protect pollination in Australia.

RIRDC funds for the program are provided by the Honeybee Research and Development Program, with industry levies matched by funds provided by the Australian Government. Funding from HAL for the program is from the apple and pear, almond, avocado, cherry, vegetable and summerfruit levies and voluntary contributions from the dried prune and melon industries, with matched funds from the Australian Government.

This report is an addition to RIRDC’s diverse range of over 2000 research publications which can be viewed and freely downloaded from our website [www.rirdc.gov.au](http://www.rirdc.gov.au). Information on the Pollination Program is available online at [www.rirdc.gov.au](http://www.rirdc.gov.au).

Most of RIRDC’s publications are available for viewing, free downloading or purchasing online at [www.rirdc.gov.au](http://www.rirdc.gov.au). Purchases can also be made by phoning 1300 634 313.

Craig Burns
Acting Managing Director
Rural Industries Research and Development Corporation
Acknowledgments

The authors acknowledge the participants in the project workshop who provided their time and considerable expertise and experience to greatly improve the outcomes of the study. These participants are listed in the Appendices. We thank Iain East of DAFF for provision of unpublished reports. The background information presented in the introduction to Chapter 1 is directly sourced from these. An unpublished study produced by Biosecurity Australia was used as a source document in preparing the risk analysis presented in Chapter 2.

We thank Dave Alden, Iain East and Kim James for detailed comments that have significantly improved this report.

We thank Catherine Leather and Karen Barndt for assistance in organising and running the workshop and Amy Nason for assistance in preparing the final report. We thank Dave Alden and David Dall of RIRDC for project management.
Contents

Foreword ............................................................................................................................................... iii
Acknowledgments ................................................................................................................................. iv
Executive Summary .............................................................................................................................. ix
1. Introduction ....................................................................................................................................... 1
2. Pathway Analysis for the Entry of Exotic Bees and Exotic Bee Pests into Australia .......... 5
   Summary ........................................................................................................................................... 5
   Introduction ....................................................................................................................................... 6
   Pathway analysis methodology ......................................................................................................... 6
   Pathways considered ......................................................................................................................... 6
   Existing surveillance, awareness and quarantine programs and policy ........................................... 7
   A stocktake of previous exotic bee detections and incursions .......................................................... 9
   Unassisted pathways for the introduction of Varroa spp. and Tropilaelaps spp. into Australia ........ 11
   Assisted pathways for the introduction of Varroa spp. and Tropilaelaps spp. into Australia ............ 12
   Pest information .............................................................................................................................. 13
   Risk assessments for the identified pathways ................................................................................. 14
   Pathway analysis conclusion ........................................................................................................... 23
3. Predictive Economic Modelling ...................................................................................................... 24
   Introduction ..................................................................................................................................... 24
   Background to the evaluation of pollination services ..................................................................... 24
   Impact simulation modelling ........................................................................................................... 26
4. Efficiency of Sentinel Hives for the Early Detection of Exotic Bee Mites ............................... 35
   Introduction ..................................................................................................................................... 35
   Physical set up of the simulation ...................................................................................................... 35
   ‘Dying off’ and detection ................................................................................................................ 36
   Swarming and Foraging .................................................................................................................. 36
   Swarming rates that increase with age ............................................................................................ 37
   Running a Simulation ....................................................................................................................... 37
   Results of Simulation ....................................................................................................................... 37
5. Development and Use of the Risk-Based Framework ................................................................. 39
   Introduction ..................................................................................................................................... 39
   Integrative framework ..................................................................................................................... 39
   Application to future pests ............................................................................................................. 40
Tables

Table 1  Exotic bees and associated exotic mites considered in the preliminary scoping phase of the pathway analysis .......................................................... 7
Table 2  A list of incursions and potential incursions involving honeybee pests ......................... 10
Table 3  Approximate dates of introduction and spread of Varroa destructor around the world......... 13
Table 4  Overall probability of entry of Varroa destructor, V. jacobsoni and Tropilaelaps spp for the pathways under consideration ...................................................... 21
Table 5  Overall probability of entry, establishment and spread of Varroa spp. and Tropilaelaps spp. for the pathways under consideration .................................................. 22
Table 6  Crop statistics, production cost increases and yield losses .......................................... 27
Table 7  Biological parameters ...................................................................................... 29
Table 8  Swarm probabilities for various values of the rate parameter lambda .................... 36
Table 9  Simulated average time to detect a pathogen under sixteen experimental model conditions ... 37
Table 10 Std. errors for average time to detection under sixteen experimental conditions via simulation .................................................................................. 38
Table 11 Expected costs of pests that impact on A. mellifera pollination services ............... 41
Table 12 Nomenclature for qualitative likelihoods ...................................................................... 51
Table 13 Matrix of rules for combining qualitative likelihoods ...................................................... 52
Figures

Figure 1  Average annual production damage that could result from honeybee mite incursions over 30 years ................................................................. 30
Figure 2  Estimated area affected by honeybee mites in Australia over time in the absence of surveillance ................................................................. 31
Figure 3  Estimated loss of Plant Industry production over time attributable to honeybee mite incursions ................................................................. 32
Figure 4  Estimated benefits to selected Australian plant industries of honeybee mite area freedom ..... 33
Figure 5  Hypothetical shift in the distribution of average production loss resulting from surveillance .................................................................................. 34
Figure 6  Estimated change in time to detection as the sentinel hives are moved from the coast ........ 45
Figure 7  Estimated change in time to detection as the number of sentinel hives is increased .......... 46
Figure 8  Change in time to detection as the probability of detection for each sentinel hive is varied .... 47
Figure 9  Distances travelled while swarming .................................................................................... 53
Figure 10 Distances travelled while foraging ....................................................................................... 54
Figure 11 Histograms of time to discovery under sixteen situations .................................................. 55
Figure 12 Histograms of distance travelled until time of discovery for sixteen situations ............... 56
Figure 13 Histograms of area of grid affected by pathogen by time of discovery for sixteen situations ......................................................................................... 57
Figure 14 Example Simulation – January .......................................................................................... 58
Figure 15 Example Simulation – March ............................................................................................ 59
Figure 16 Example Simulation – May ............................................................................................... 60
Figure 17 Example Simulation – July ............................................................................................... 61
Figure 18 Example Simulation – September ..................................................................................... 62
Figure 19 Example Simulation – November ...................................................................................... 63
Executive Summary

What the report is about?

This report describes the development and use of a risk-based framework to assess future surveillance needs for honeybee pests that are exotic to Australia.

A risk-based framework considers the likelihood of occurrence of pest and disease incursions as well as the costs and benefits of their early detection. It is designed to provide a more transparent assessment of the costs and benefits of an early detection system. This can feed into decision making for the sector, for example, when justifying a particular early detection system or for identifying ways by which an early detection system can be improved.

Who is the report targeted at?

The report is targeted at decision-makers in the State and Commonwealth Governments as well as the Australian beekeeping industry, apiarists and horticulture industries that depend on bees for pollination.

Background

The Australian honeybee industry produces honey and other bee products for domestic consumption and export, through apiculture using the European honeybee, *Apis mellifera*. The industry has an estimated GVP of A$80 million. In addition, the annual benefit of the apiculture industry to general agriculture through plant pollination is estimated to range from $4 to 6 billion. The 5-year average for the annual gross value of production of 25 horticulture industries dependent upon pollination by *A. mellifera* is $3.9 billion. Thus, even a 10% reduction in production as a result of a pest or disease incursion would result in losses exceeding $350 million per annum.

There are a number of significant threats to Australian honeybees that could impact on these industries. Surveillance systems are one component of a biosecurity system that can protect against these threats.

Aims/objectives

The aim of the research was to produce a risk-based framework for considering the costs and benefits of surveillance systems for honeybee pests and diseases.

Methods used

The project relied on the expertise of a core team and a reference group of individuals.

The core team brought together individuals with skills in economics, modelling, risk assessment and bee pathology and biology.

The reference group consisted of Commonwealth, State and Industry representatives with relevant experience with the honeybee or horticulture industries. The group provided feedback and endorsement on all aspects of the risk-based framework and assumptions that underpinned its development. The group also came together for a one-day workshop in Canberra to provide input into the project, and this report synthesises the group’s views with those of the core team.

To develop the risk-based framework it was first necessary to carry out some preliminary analyses and then to integrate the results of those analyses to form a risk-based framework. The first preliminary analysis was to identify exotic pests or diseases of importance to Australian
honeybees and then subject those pests and diseases to a standard ‘pathway analysis’. The pathway analysis, supported by expert opinion from the workshop, identified the same entry pathway (seaports) for each identified pest of importance. This significantly narrowed the potential surveillance possibilities for the pests and, as existing surveillance was already in place at seaports for detecting these pests (the National Port Surveillance Program - NPSP); all further analyses were focussed at determining the costs and benefits of that surveillance.

To determine the costs and benefits of the NPSP our analyses focussed on the use of sentinel hives at seaports to detect only exotic bee mites, as evidence indicated that the use of sentinel hives at seaports for the early detection of the only other identified exotic pest of importance (the Asian honeybee, *Apis cerana*) was inadequate.

An economic analysis of the impact of exotic bee mites and potential cost-savings from using surveillance at seaports for their early detection was carried out together with a simulated analysis of the potential spread and likelihood of detection of these mites in sentinel hives at seaports.

Values obtained from these three analyses (pathway, economic and spread) were then integrated to form a risk-based framework under which costs and benefits of the current use of sentinel hives in the NPSP could be assessed.

Exotic pests and diseases of most importance to Australian honeybees, the Australian beekeeping industry and other industries that depend on honeybees for pollination were identified by subjecting pests and diseases that have been prioritised by Plant Health Australia for national cost-sharing arrangements in the event of incursions to the following set of 4 criteria:

- Was the pest on an identified entry pathway?
- Was there a diagnostic test/trap available for early detection of the pest?
- Could the pest be eradicated/managed following its detection?
- Would the incursion/establishment of the pest cause a significant impact?

With the candidate pests identified, a pathway analysis estimated their likely arrival and most likely route of entry into Australia.

A bioeconomic model was used to simulate the potential damage of exotic bee mites and the likely return on investment by using surveillance to detect them. An analysis of a simulated spread of the mites provided information on their potential rates of spread away from the port environment before they were likely to be detected in sentinel hives.

Information from the three analyses (pathway, economic and spread) was integrated into a risk-based framework under which the costs and benefits of using sentinel hives in the current NPSP were assessed.

**Results/key findings**

The following exotic honeybee pests were identified as being most important to Australian honeybees:

1. *Varroa destructor* (parasitic mite);
2. *Varroa jacobsoni* (parasitic mite);
3. *Tropilaelaps clareae* and *T. mercedesae* (parasitic mites);

The pathway analysis showed that the likelihood of entry of *A. mellifera* or *A. cerana* as unassisted swarms was ‘**Extremely Low**’ and it was not considered further. The analysis showed that each pest was most likely to enter Australia on (in the case of mites) or as assisted swarms of bees on an international sea vessel. The overall probability of entry of:

- *V. destructor* associated with *A. cerana* by assisted entry was ‘**Low**’;
- *V. destructor* associated with *A. mellifera* by assisted entry was ‘**High**’;
- *V. jacobsoni* associated with *A. cerana* by assisted entry was ‘**High**’;
- *V. jacobsoni* associated with *A. mellifera* by assisted entry was ‘**Low**’;
- *Tropilaelaps* spp. associated with *A. mellifera* or *A. dorsata* (the Asian native bee host) by assisted entry was ‘**Very Low**’.

As the pathway analysis showed that each pest was most likely to enter Australia on an international sea vessel, workshop participants agreed unanimously that the use of sentinel hives at seaports was the method most likely to detect exotic mites quickly should they arrive in assisted bee swarms on international sea vessels. However, the use of sentinel hives at seaports was deemed unsuitable for the early detection of *A. cerana* and this is also borne out by the fact that sentinel hives failed to detect the current incursion of that bee at Cairns. There was also much scepticism among workshop participants as to the effectiveness of ‘log-hives’ or ‘bait-hives’ for the early detection of *A. cerana*, as they also failed to detect the Cairns incursion. The general consensus was that more studies were needed to determine the role that these hives may play in honeybee biosecurity. Hence, log and bait hives were not considered further in this project and the remainder of the risk-based analysis focussed solely at determining the costs, benefits and areas of improvement for port surveillance as currently exists under the NSHP.

A bioeconomic model predicted that, without surveillance, the average damage cost to Australian plant industries as a result of an exotic bee mite incursion would be about $72 million over the next 30 years. The spread simulation showed that sentinel hives located at seaports were effective in the early detection of exotic bee mites, with one simulation showing that mites could spread only about 6km away from a seaport before being detected in sentinel hives located at the seaport.

Values obtained from the pathway, economic and spread analyses were integrated to form a risk-based framework. This framework consisted of two models, one to determine a probability of entry establishment and spread of exotic mites, and a second, an economic model, which takes values from the former model to calculate expected returns on the surveillance effort. The probability model of entry, establishment and spread of exotic mites can be summarized as:

\[
h = p \times g \times (1 - e) + p \times (1 - g)
\]

Where:

- \(h\) = the expected probability of entry, establishment and spread after we apply surveillance
- \(p\) = the expected probability of entry, establishment and spread without surveillance
- \(g\) = the proportion of the threat (i.e. trade from risk regions) that is covered by the surveillance and;
- \(e\) = efficiency of surveillance system (see details in Chapter 5).
The values $p$ and $h$ from this model were then used in the following economic model to calculate the expected return on the surveillance effort as an annual cost:

$$ PV(ED_n) = \sum_{t=0}^{n} (1 + \alpha)^{-t} \sum_{j=1}^{q} p.d.A.N . $$

This model shows production loss per unit of area (d), spread area (A), population density (N) and the numbers of satellite sites in each time period (St) are with the probability of entry and establishment (p) in an expression of probability-weighted, or expected damage over time. Given a discount rate $\alpha$, the present value of expected damage after $n$ time periods can be calculated as $PV(EDn)$ (see Cook et al. 2007):

An example of this working framework can be seen when determining cost savings in the use of sentinel hives to detect and respond to incursions of $V. destructor$. The pathway analysis determined that the risk of this is high so $p=.85$ based on the typical definition of high used. If we assume that we cover 95% of the risk (i.e. trade) then $g=0.95$. If the probability that the surveillance system at a port detects an incursion early enough for a successful response is 50% (i.e. $e=.5$) we can calculate the expected probability of entry, establishment and spread:

$$ h = 0.85 \times (1 - 0.5) \times 0.95 + 0.85 \times (1 - 0.95) = 0.45 . $$

From the bioeconomic model the reduction of $p$ from .85 (high) to 0.45 is associated with a reduction in expected cost from $47.1$ million per annum to $43.2$ million per annum.

**Conclusions**

This study used a risk-based analysis to assess exotic threats to Australian honeybees. While this is the standard approach applied by Biosecurity Australia to other exotic threats to Australian agriculture, the reliance here on qualitative descriptors for the exotic bee pests means that there is potential ambiguity in the outcomes of the analysis. Thus it is important that users consider carefully the indicative probability ranges to ensure the interpretability of the results of any future analysis.

The economic analysis used here to develop the risk-based framework could also be further developed in a number of ways, particularly in terms of the way it could be communicated to the bee surveillance community and used in risk mitigation strategy formulation. Given the significant pollination (i.e. private) benefits, there may be a case for revising the model to improve its explanatory power. A spatially explicit modelling approach may be more appropriate given the large geographic spread of honeybee surveillance beneficiaries.

This analysis showed that the use of sentinel hives to detect exotic bee mites ($Varroa$ and $Tropilaelaps$) has potential to deliver positive cost-effective outcomes. However, their use as a surveillance method for those mites is underpinned by a lack of knowledge as to how sensitive they are at actually detecting the mites. The risk-based framework developed here can now be used in future studies to determine how the NSHP can be improved using different numbers of sentinel hives at different numbers of ports.

There was unanimous agreement at the project workshop that more thought and experimentation was needed to optimise the current NSHP. This could include training and research in countries with exotic mites to determine the sensitivity of using sentinel hives and for examining the rates of spread of bee mites. In addition, genetic techniques could be developed to streamline pest identification.
While there are clear benefits from using sentinel hives for the early detection of exotic bee mites, the current surveillance for the early detection of Asian honeybees (*A. cerana*) is ineffective and needs to be re-examined.

**Recommendations**

- That the risk-based framework developed here be adopted as the mechanism for determining future costs and benefits of improved surveillance for honeybee pests and diseases.
- That the current National Sentinel Hive Program be maintained and improved for the early detection of exotic bee mites using information provided in this report.
- That the active management of honeybees within port areas, as already occurs in some locations, be strongly encouraged.
- That targeted studies be funded to obtain clear empirical data of the efficiency of sentinel hives to detect exotic bee mites. Experiments should be performed outside Australia to determine the sensitivity of sentinel hives to detect low numbers of bee mites.
- That surveillance for the early detection of *A. cerana* be re-examined urgently with the aim of developing a new surveillance system that can detect low numbers of bees at remote locations.
- That AQIS continue to target bees as serious threats to the Australian honeybee industry and other industries that depend on honeybees for pollination and that port operations be strengthened to ensure a well educated and proactive work force to safeguard biosecurity for bee pests and diseases.
1. Introduction

General introduction

The Australian honeybee industry produces honey and other bee products for domestic consumption and export, through apiculture using the European honeybee, *Apis mellifera*. The industry has an estimated GVP of A$80 million (Standing Committee on Primary Industry and Resources, 2007). In addition, the annual benefit of the apiculture industry to general agriculture through plant pollination is estimated to range from $4 to 6 billion (Standing Committee on Primary Industry and Resources 2007). The 5-year average for the annual gross value of production of 25 horticulture industries dependent upon pollination by *A. mellifera* is $3.9 billion. Thus, even a 10% reduction in production as a result of a pest or disease incursion would result in losses exceeding $350 million per annum.

Australia is free of several important disease-causing honeybee mites and other pests of honeybees. Exotic mites include the varroa mite (*Varroa destructor* and *V. jacobsoni*), Tropilaelaps mite (*Tropilaelaps mercedesae* and *T. clareae*) and tracheal mite (*Acarapis woodi*). Other pests of honeybees (through natural competition) include several species of exotic bees including the Asian cavity-nesting honeybee (*Apis cerana*), giant Asian honeybee (*Apis dorsata*) and Africanised honeybees (*Apis mellifera scutellata* and *A. m. capensis*).

If varroa mite were to establish in Australia its impact has been predicted to be devastating to the Australian apiculture industry (CIE 2005). However, the impact would not be limited to the apiculture industry as many horticultural, seed grain and pastoral industries would also be adversely affected due to reduced pollination of their plants (Cook et al. 2007).

The economic impact of *V. destructor* in North America following its establishment in the 1980’s is estimated to range from US$0.6 to 14.6 billion (Robinson et al. 1989; Muth and Thurman 1995; Morse and Calderone 2000). In Australia, the pollination benefits that would be lost following Varroa mite introduction are estimated to be A$27.5 million for a group of 25 horticultural and seed grain industries (Cook et al. 2007).

The risk to Australia of exotic bee species entering via cargo movements has been highlighted by several detections of exotic bees in ships at Australian seaports in recent times (Boland 2005). In addition, exotic bee introductions may also introduce *Varroa* or other exotic disease-causing mites. *Varroa destructor* is now endemic in much of the world, including areas of New Zealand, increasing the possibility of its introduction to Australia.

Biosecurity is a continuum with elements operating pre-border, at the border level and beyond the quarantine border (post-border). A possible component of a biosecurity system is the use of surveillance techniques. These techniques are deployed post-border to attempt to detect incursions so that management actions can be implemented.

This project was commissioned to assess future surveillance needs for exotic pests and diseases of honeybees to protect the Australian honeybee and horticulture industries. There are several existing surveillance programs targeting honeybee pests and diseases. The National Sentinel Hive Program is the major program targeted at new pests.

---

1 Much of the information in this introduction is sourced from unpublished material supplied by Dr Iain East, Australian Government Department of Agriculture, Fisheries and Forestry.
The National Sentinel Hive Program (NSHP) was established in 2000 to enhance early detection of incursions of varroa mite, Tropilaelaps mite, tracheal mite and Asian honeybees. Early detection of these pests is expected to improve the chance that incursions will be eradicable, and possibly, that the eradication program will be smaller and less costly. This program operates by situating sentinel hives near seaports identified as a ‘high risk’ of an incursion. The program is the result of consultation between Biosecurity Australia (BA), State and Federal Government Departments and Australian Honey Bee Industry Council (AHBIC) and the beekeeping industry.

**Objectives**

The aim of the research was to produce a risk-based framework for considering the costs and benefits of surveillance systems for honeybee pests and diseases.

A risk-based framework considers the likelihood of occurrence of pest and disease incursions as well as the costs and benefits of their early detection. It is designed to provide a more transparent assessment of the costs and benefits of an early detection system. This can feed into decision making for the sector, for example, when justifying a particular early detection system or for identifying ways by which an early detection system can be improved.

**Methodology**

The project relied on the expertise of a core team and a reference group of individuals.

The core team brought together individuals with skills in economics, modelling, risk assessment and bee pathology and biology.

The reference group consisted of Commonwealth, State and Industry representatives with relevant experience with the honeybee or horticulture industries. The group provided feedback and endorsement on all aspects of the risk-based framework and assumptions that underpinned its development. The group also came together for a one-day workshop in Canberra to provide input into the project, and this report synthesises the group’s views with those of the core team.

For surveillance to be effective a number of issues need to be taken into account. First the pest or pathogen must exist on an importation pathway; otherwise the surveillance effort is wasted. Second, the pest must be detectable by the surveillance system in a timely manner so that management actions can be successfully applied; otherwise it provides no useful management information. Third, there must be a management action that can be applied. Fourth, the impact of the pest must be large enough that the expenditure on the surveillance scheme is justified.

The consideration of all possible pests and production systems within the honeybee and horticulture industries is a complex task. There are a large number of potential pests and surveillance covers a range of activities from individual inspection of a grower’s own hives to potential regional, state and national programs. To consider the effectiveness of all these scenarios in a detailed manner is clearly beyond the scope of this project. Instead, an initial expert-based assessment was performed to target further analysis. This assessment focussed on those pests and diseases that have been prioritised by Plant Health Australia for national cost-sharing arrangements in the event of incursions.

For these pests we considered a pathway assessment to determine that they were on a pathway and to determine a level of threat. This pathway analysis, supported by expert opinion from the workshop, identified the same entry pathway for each identified pest of importance. This significantly narrowed potential surveillance possibilities to the extent that all further work in the project was focussed on determining the costs and benefits of using sentinel hives at sea ports to detect exotic bee mites (see below).
Finally, we have provided a framework to bring this information together to inform decision-making.

**Scope of Project**

The aim of the project was to develop a risk-based framework for the assessment of honeybee pest and disease surveillance options. The framework was then to be applied to the future threats to the industry.

Bee surveillance within Australia involves a number of programs including vessel declarations and cargo inspections as well as the National Sentinel Hive Program and state based trap hive programs. These programs are described in more detail in Chapter 2 of this report. This project focuses on the development of an assessment method that is applicable to the National Sentinel Hive Program and other trapping programs. The use of vessel declarations and cargo inspection are generic technologies that are applicable to a wide range of insect and non-insect species and indeed even to undesirable non-biological imports. The value of these programs therefore extends well beyond their role in bee surveillance and they are not considered further when constructing the risk based framework.

The core reference teams discussed the potential coverage of any national surveillance program. It was agreed that the focus should be on pests prioritised for national cost-sharing arrangements. Each pest was assessed in relation to whether:

- It was on an identified pathway,
- There was a diagnostic test/trap available for its detection,
- Eradication/management be feasible if it was detected, and
- The expected impacts of its incursion/establishment would be significant.

These criteria were used as a primary filter to assess whether surveillance would represent a feasible management strategy.

Based on these criteria, the following pests were identified as being worthy of further analysis:

- *Varroa destructor*
- *Varroa jacobsoni*
- *Tropilaelaps sp (T. mercedesae and T. clareae)*
- *Apis cerana*

A number of other pests such as tracheal mites and Africanized bees were also discussed, but were not considered further because of practical difficulties in their detection.

To assess the identified pests we developed a pathway analysis using the standard protocols used by Biosecurity Australia to assess the likelihood and mechanism of their introduction to Australia. This is described in Chapter 2. That pathway analysis, supported by expert opinion from the workshop, identified the same entry pathway for each pest (entry at seaports on international vessels). This significantly narrowed the potential surveillance possibilities and, as existing surveillance was already in place for the early detection of these pests, all further analysis here was focused on determining the costs and benefits and possible areas of improvement of that surveillance. In particular, we focussed on the use of sentinel hives at seaports as they were at the
heart of that surveillance. There was unanimous agreement among the workshop participants that
the use of sentinel hives at seaports was the most likely method to detect exotic bee mites quickly
but that this method was not suitable for the early detection of Asian honeybees. This was also
supported by the fact that sentinel hives at Cairns had failed to detect the current incursion there
of *A. cerana*. Further, there was much scepticism among workshop participants as to the
effectiveness of ‘log-hives’ or ‘bait-hives’ for the early detection of *A. cerana*. Hence, all further
analyses were directed at determining the costs, benefits and areas of improvement of sentinel
hives at seaports for only the early detection of exotic bee mites.

The core of the approach was an economic analysis, which considers the cost/benefit of particular
options, as outlined in Chapter 3. A key determinant of the efficiency of a surveillance system
for exotic mites is whether an incursion might be detected sufficiently quickly to allow successful
management actions to occur. To assess this possibility we have developed a spatial modelling
system and synthesised knowledge of honeybee and mite behaviour to explore the potential
spread of exotic mites and the likelihood of their detection in sentinel hives. This is described in
Chapter 4. These efforts are brought together in Chapter 5, which considers the implications of
the analyses for honeybee surveillance in Australia. Chapter 6 presents analysis of the National
Sentinel Hive Program.
2. Pathway Analysis for the Entry of Exotic Bees and Exotic Bee Pests into Australia

Summary

A pathway analysis examining the likelihood of entry, establishment and spread of the Varroa mites (*Varroa destructor* and *Varroa jacobsoni*) and Tropilaelaps mites (*Tropilaelaps* spp.) under existing Australian quarantine, surveillance and awareness arrangements was conducted using a qualitative risk assessment methodology. As a by-product, this analysis also considered the probability of entry of *Apis cerana* and *Apis dorsata*. This analysis can be used as the basis for assessing threats any new pests of honeybees that may arise in the future. The technique was applied to the current pests determined to be detectable by surveillance and that represent a significant threat to the honeybee population in Australia.

It was determined that:

- The likelihood of entry of Varroa spp. or Tropilaelaps spp. with European honeybees (*A. mellifera*) or Asian honeybees (*A. cerana*) as unassisted swarms is extremely low; accordingly this possibility was not considered further and was not considered further;

- Seaports and associated vessels and cargo are the most likely assisted entry points for exotic bees and exotic honeybee pests;

- There is a low risk of assisted entry, establishment and spread of *Varroa destructor* associated with *Apis cerana*;

- There is a high risk of assisted entry, establishment and spread of *Varroa jacobsoni* associated with *Apis cerana*;

- There is a low risk of assisted entry, establishment and spread of *Varroa jacobsoni* associated with *Apis mellifera*;

- There is a high risk of entry, establishment and spread of *Varroa destructor* with *Apis mellifera*; and

- There is a very low risk of assisted entry, establishment and spread of *Tropilaelaps* spp. with *Apis mellifera* or *Apis dorsata*.

- There is a high probability of entry of *Apis cerana*, and

- There is a low probability of entry of *Apis dorsata*.

Importantly, the assessment reported here considered the likelihoods of entry, establishment and spread under current quarantine, surveillance and awareness requirements. If the relevant current quarantine, surveillance and awareness requirements were to change the risk associated with each pathway might also change.

---

2 There is currently a prohibition on the importation of all live bees into Australia. This measure reduces the risk of introduction but it may also increase the temptation to introduce new genetic stock illegally over time. This may increase the risk of introduction via this pathway over time.
Introduction

Australia enjoys freedom from a wide range of exotic bees and their associated pests and diseases. There is currently a range of awareness, surveillance and quarantine measures in place across the biosecurity continuum (pre-border, border and post-border) to maintain this freedom. Off-shore surveys for exotic pests and diseases, extensive screening of mail using x-ray and detector dogs, stringent air and seaport quarantine awareness, surveillance, inspection and reporting requirements, and bans on the importation of live honeybees and used bee keeping materials all contribute to the maintenance of the nations favourable quarantine status.

However, the introduction of Varroa mite (*Varroa destructor*) into Hawaii (in 2007) and New Zealand (in 2000), and the recent detection of a strain of *Varroa jacobsoni* that is pathogenic to *A. mellifera* in Papua New Guinea have heightened concerns of an incursion of these exotic mites and other bee pests and diseases into Australia.

To help address these concerns and to determine options for future honeybee biosecurity arrangements, pathway analysis for the introduction of exotic bees and their associated pests and diseases has been conducted.

Pathway analysis methodology

This pathway analysis was conducted using a qualitative risk assessment approach. This methodology is in accordance with the International Standards for Phytosanitary Measures (ISPMs), including ISPM 2: Framework for Pest Risk Analysis (FAO 2007) and ISPM 11: Pest Risk Analysis for Quarantine Pests, including analysis of environmental risks and living modified organisms (FAO 2004). The likelihood that an event will occur was evaluated and reported qualitatively, using descriptors for the likelihood of entry, establishment and spread of the honeybees as vectors for the exotic mite species of concern. Appendix 1 provides a brief outline of methodology used.

The methodology in this assessment can be used as the basis for the calculation of the probability of entry, establishment and spread of any new pests. It is a general methodology consistent with international standards.

Pathways considered

There are several exotic bee species and associated exotic mites that have been identified as risks to Australian industries. Table 1 provides a list of the exotic bees and their associated exotic pests that were considered in the preliminary scoping phase of this pathway analysis.

However, based on the initial assessment by the core team it was determined that this pathway analysis would focus on the two species of Varroa mites (*V. destructor* and *V. jacobsoni*) and *Tropilaelaps* spp. Tracheal mites where not considered because of the practical difficulties in detection. The probability of entry of *A. cerana* and *A. dorsata* was picked up as a by-product of the analysis. The two Varroa species were considered to pose the greatest potential economic impact to the Australian honeybee industry, and *Tropilaelaps* spp. was seen as a potentially serious emerging threat to the honeybee industry. It should be noted that whilst this pathway analysis focused on these three groups of mites, it is considered that the analysis could be extrapolated equally to other exotic bees, pests and diseases.
Table 1  Exotic bees and associated exotic mites considered in the preliminary scoping phase of the pathway analysis

<table>
<thead>
<tr>
<th>Bee species</th>
<th>Associated exotic mite</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Apis mellifera</em></td>
<td>Varroa destructor</td>
</tr>
<tr>
<td></td>
<td>Varroa jacobsoni</td>
</tr>
<tr>
<td></td>
<td><em>Tropilaelaps</em> spp.</td>
</tr>
<tr>
<td></td>
<td><em>Acarapis woodi</em> (honeybee tracheal mite)*</td>
</tr>
<tr>
<td><em>Apis cerana</em></td>
<td>Varroa destructor</td>
</tr>
<tr>
<td></td>
<td>Varroa jacobsoni</td>
</tr>
<tr>
<td><em>Apis dorsata</em> (Giant honeybee)</td>
<td><em>Tropilaelaps</em> spp.</td>
</tr>
<tr>
<td><em>Apis mellifera scutellata</em> and <em>Apis mellifera capensis</em> (African or Africanised)*</td>
<td></td>
</tr>
</tbody>
</table>

* Not considered further in this pathway analysis

**Scope**

This pathway analysis considered the likelihood of entry, establishment and spread of *V. destructor*, *V. jacobsoni* and *Tropilaelaps* spp. associated with *A. cerana* and *A. mellifera* under existing Australian quarantine, surveillance and awareness arrangements. It also considered the likelihood of entry, establishment and spread of *Apis cerana* and *A. dorsata*.

The entry of exotic bees and their associated mites into Australia was considered for both assisted and unassisted transport modes. Unassisted transport was considered to be by swarming, or by swarms or individual bees floating in hollow logs or other debris. The likelihood of this pathway was considered to be extremely low, but a brief analysis was presented for consistency. Assisted transport was considered to be the entry of hives, swarms or individual bees into Australian seaports, airports or mail centres by means other than swarming or floating. Assisted entry was considered to have a much greater likelihood and detailed analysis was provided.

**Existing surveillance, awareness and quarantine programs and policy**

This pathway analysis was conducted with consideration given to Australia’s current quarantine, surveillance and awareness arrangements. The current requirements of relevance are outlined below.

**The National Sentinel Hive Program (NSHP)**

The National Sentinel Hive Program (NSHP) was established in 2000 to assist in the early detection of honeybee parasites (most notably Varroa spp.) and exotic bees at or around seaports. The NSHP maintains between one and six beehives at 26 different ports throughout Australia. The program also maintains pheromone-baited log traps for Asian honeybees in Darwin, Gove, Cairns and Brisbane.

Throughout its eight years of operation, the NSHP has not detected any incursions. Importantly, as a result of the 2007 incursion of the Asian honeybee in Cairns at least seven colonies of *A. cerana* were established in the Cairns port area, and despite their proximity to sentinel hives the sentinel hives did not detect the incursion.

---

3 Information on Programs compiled by Iain East.
**Bait hives at ports in Tasmania, South Australia and Victoria**

The Australian Quarantine and Inspection Service (AQIS) assists the Department of Primary Industries, Victoria and the Department of Primary Industries and Water, Tasmania to monitor bait hives located within ports in those states. The South Australian Primary Industries and Resources agency independently operates a similar program in that state’s ports.

Tasmania maintains between one and three bait hives at each of seven ports in the state. One swarm was captured at the Port of Burnie in December 2006. Victoria maintains five bait hives at the port of Melbourne and further bait hives at Geelong and Portland. Two swarms have been trapped at Melbourne and at least one in Portland. None of the swarms had exotic pests or diseases. South Australia maintains approximately 40 bait hives at ports and other high-risk locations such as container storage areas. In the past 18 months, ten swarms have been detected but all were A. mellifera and carried no parasitic mites.

**Queensland apiary survey**

During 2007, 43 beekeepers in Queensland participated in a producer survey examining hives for external parasites. This survey used the standard Bayvarol strip and sticky mat technique. No exotic mites were found.

**NSW ‘sugar shake’ program**

Sugar shaking bees is a method used to detect external parasites, such as *Varroa* spp, and *Tropilaelaps* spp. The sugar-shake technique relies on the separation of *Varroa* spp. from the adult bee in the presence of fine sugar particles. The legs of *Varroa* spp. mites have sticky pads that help them hold onto the honeybees and it is believed that fine sugar particles break down that bond, causing dislodgment. The sugar covering the honeybees also stimulates grooming behaviour, assisting to dislodge mites. The sugar–parasite mix is then separated from the honeybees and inspected for any mites. In 2007-08, the NSW program surveyed hives at 43 locations in NSW, two in Victoria and one in Queensland, and found no parasitic mites.

**Victorian ‘sugar shake’ program**

Victoria has recently introduced a sugar-shake program for industry surveillance, and it is currently focussed on members of the amateur beekeeping clubs that operate in the greater Melbourne area.

**Health Certification for interstate movement**

Within Australia interstate movement of honeybees requires health certification of hives by a government inspector or some other authorised person prior to their movement. New South Wales currently has 17 regulatory officers authorised to inspect beehives. However, dependent upon the apiarist and their hives’ health history, certificates may be issued without physical inspection of hives.

**Vessel and cargo inspections conducted by AQIS**

As part of AQIS’ international vessel clearance process, vessel masters en route to Australia are required to report any detection of honeybees to AQIS before arriving at an Australian port. Before or upon arrival, AQIS responds to any reports and instructs that any bees on board be destroyed.
Border inspections by AQIS also include the process of cargo inspection after arrival of a vessel in Australia. AQIS staff also undertakes wharf surveillance as part of their ongoing duties, and work closely with port workers to ensure that sightings of honeybees are reported to AQIS and state authorities. AQIS responds as necessary to reports of insect sightings.

Offshore surveillance conducted by NAQS

The AQIS Northern Australia Quarantine Strategy (NAQS) Program focuses on pests and diseases with the potential to enter Australia from Timor Leste, Indonesia or Papua New Guinea. This includes natural or non-conventional pathways such as wind currents, migratory animals, traditional vessel movements and illegal fishing activity. *Apis dorsata* (Giant Asian Bee), *Apis florea* (Dwarf honeybee) and *A. cerana* and the parasites *Varroa* spp., *Tropilaelaps* spp. and *Acarapis woodi* (tracheal mite) are all targeted by the NAQS program in their surveillance activities.

A stocktake of previous exotic bee detections and incursions

Numerous detections of exotic bees have been documented over the past 30 years. Table 2 provides details of the majority of these detections. The most serious incursion would appear to be the discovery of numerous swarms of *A. cerana* in the Cairns port area and surrounds from 2007 to 2009. Fortunately no exotic mites have been found to be associated with this exotic bee incursion.

Whilst the historical data does not provide extensive detail in several cases, analysis clearly indicates that a majority of detections or incursions originated from vessels and or cargo in the vicinity of seaports. Occasionally exotic bees have been detected at airports and mail centres in airfreight and personal possessions. However, the likelihood of an incursion of exotic bees and possibly exotic mites via an airport or mail centre is considered to be extremely low under existing quarantine, surveillance and monitoring arrangements, and the data presented in table 2 supports this assumption.
<table>
<thead>
<tr>
<th>Date</th>
<th>Agent</th>
<th>Place</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early 1970s</td>
<td><em>Apis dorsata</em></td>
<td>Fremantle</td>
<td>From Java, Indonesia. No details available.</td>
</tr>
<tr>
<td>February 1994</td>
<td><em>Apis mellifera scutellata</em></td>
<td>Fremantle</td>
<td>A nest of live bees was found on a container and destroyed.</td>
</tr>
<tr>
<td>1992</td>
<td><em>Bombus terrestris ssp audax</em></td>
<td>Tasmania</td>
<td>Bumblebees accidently introduced into Tasmania possibly from NZ.</td>
</tr>
<tr>
<td>April 1995</td>
<td><em>Apis cerana</em></td>
<td>Near Brisbane</td>
<td>Machinery via sea cargo from PNG.</td>
</tr>
<tr>
<td>June 1996</td>
<td><em>Apis cerana</em></td>
<td>South Australia</td>
<td>No further details</td>
</tr>
<tr>
<td>February 1997</td>
<td><em>Apis mellifera scutellata</em></td>
<td>Fremantle</td>
<td>Abandoned nest only. Originated from Durban in South Africa.</td>
</tr>
<tr>
<td>December 1997</td>
<td>Bumble bee (Bombus Vosnesenski)</td>
<td>Buderim, Qld</td>
<td>Not diagnosed till May 1999. Mites were found – identified as Kunzenia sp. which are basically scavengers in bumble bee nests, not significant for <em>Apis</em> spp.</td>
</tr>
<tr>
<td>June 1998</td>
<td><em>Apis cerana</em></td>
<td>Darwin</td>
<td>Nest discovered by a local beekeeper. Eradication program instituted and intensive surveillance. DNA test showed the honeybees were Java type. No mites seen on inspection.</td>
</tr>
<tr>
<td>July 1999</td>
<td><em>Apis dorsata</em></td>
<td>Sydney</td>
<td>Airfreight from Penang Malaysia - computer motherboards. Examination showed no mites.</td>
</tr>
<tr>
<td>September 1999</td>
<td><em>Apis cerana</em></td>
<td>Brisbane</td>
<td>Asian honeybees were detected on a ship (ex Singapore, Lae and Port Moresby) berthed in Brisbane. A swarm of approximately 50-100 bees left the ship but follow up monitoring revealed nothing.</td>
</tr>
<tr>
<td>December 1999</td>
<td><em>Apis cerana</em></td>
<td>Brisbane</td>
<td>Introduced with heavy earth moving equipment from Lae, PNG. Hive of 5,000 bees destroyed. DNA test showed the honeybees were Java type. Varroa jacobsoni found.</td>
</tr>
<tr>
<td>January 2002</td>
<td><em>Apis cerana</em></td>
<td>Melbourne</td>
<td>Hive (well established with 4 healthy combs and approx. 1000 healthy individuals) on under surface of a shipping container from Lae, New Guinea. Destroyed. Inspection revealed Varroa jacobsoni.</td>
</tr>
<tr>
<td>December 2002</td>
<td><em>Apis cerana</em></td>
<td>Brisbane</td>
<td>One bee found on ship from PNG. Follow-up surveillance in Hamilton area revealed nothing.</td>
</tr>
<tr>
<td>February 2003</td>
<td><em>Apis dorsata</em></td>
<td>Vessel off north Australia</td>
<td>Oil tanker from Singapore. A &quot;quite large swarm&quot; found by crew and (inexpertly) destroyed before arrival. Only dead bees found. No mites seen on inspection.</td>
</tr>
<tr>
<td>February 2003</td>
<td><em>Apis dorsata</em></td>
<td>Vessel off north Australia</td>
<td>Vessel from Indonesia. Seven dead and one dying bee found. No evidence of swarm found despite repeated checks. No mites found on inspection.</td>
</tr>
<tr>
<td>May 2004</td>
<td><em>Apis cerana</em></td>
<td>Cairns</td>
<td>Vessel from PNG. Swarm of <em>Apis cerana</em> found in hold on arrival in port. Bees destroyed. Spread considered unlikely. No mites found on inspection.</td>
</tr>
</tbody>
</table>
Unassisted pathways for the introduction of *Varroa* spp. and *Tropilaelaps* spp. into Australia

*Probability of entry by swarming or with flotsam*

Factors considered to be of importance include the following:

- *Apis cerana* is present throughout Asia including the southern coast of the island of New Guinea adjacent to the Torres Strait. *Apis mellifera* is distributed throughout the world. The closest non-endemic populations of *A. mellifera* are in New Zealand, Port Moresby (PNG) and Timika (West Papua).

- *Apis cerana* has a high rate of reproductive swarming (6–12 times per year) as compared to *A. mellifera* (1-2 swarms per year). However, the distance of normal reproductive swarming of both species is less than 10 km.

- *Apis* spp. swarms normally travel only relatively short distances over open water. There has been no observed unassisted spread of *A. cerana* from the northern Torres Straits islands to the southern Torres Straits islands or to northern Australia, despite *A. cerana* being present in the northern Torres Straits islands since 1993. It is unlikely that *Apis* spp. could reach the Australian mainland due to swarming behaviour.

- *Apis cerana* inhabits the tropical coastal areas of PNG and favours hives in hollow logs. *Apis mellifera* may also favour hollow logs in some instances. It is theoretically possible that a viable hive could survive in a fallen log or other debris that is washed as flotsam from the coast of PNG or Western Papua to the northern Australian coast. However, survival is considered unlikely due to the distance to be travelled over open ocean and the extended travel time without food or water.

**Conclusion**

On the basis of these considerations it was concluded that the likelihood of entry of *A. mellifera* or *A. cerana* as unassisted swarms is considered to be Extremely Low; accordingly it was not considered further in this analysis.
Assisted pathways for the introduction of *Varroa* spp. and *Tropilaelaps* spp. into Australia

**Pathway 1 – *Apis cerana* with *Varroa destructor***

*Varroa destructor* is a relatively benign external parasite of brood and adults of *A. cerana*. There are several *V. destructor* genotypes that naturally infest different populations of *A. cerana* on mainland Asia, including the Japan, Korea, China, Vietnam, Nepal and Sri Lanka genotypes. Only the Korea and Japan genotypes of *V. destructor* are known to be pathogenic to *A. mellifera*.

**Pathway 2 – *Apis cerana* with *Varroa jacobsoni***

*Varroa jacobsoni* is a complex of several genotypes that naturally infest different populations of *A. cerana* in the southern mainland Asia–Malaysian–Indonesian region. Included are the Java, Sumatra, Malaysia, Borneo, Bali, Lombok, Sumbawa, Flores, and Ambon genotypes.

**Pathway 3 – *Apis mellifera* with *Varroa jacobsoni***

In 2008, surveys in PNG detected the widespread presence of a strain of *V. jacobsoni* that is pathogenic to *A. mellifera*. Further research is required to confirm whether this strain can reproduce on both *A. mellifera* and *A. cerana*, but this discovery potentially constitutes a new and significant risk pathway for the Australian honeybee industry. For the purposes of this pathway analysis it was assumed that the PNG strain of *V. jacobsoni* can reproduce on both *A. mellifera* and *A. cerana*.

**Pathway 4 – *Apis mellifera* with *Varroa destructor***

*Varroa destructor* infests *A. mellifera* causing severe damage to colonies; the pest is now distributed throughout most beekeeping areas of the world other than Australia. The mite feeds on internal body fluids of larvae, pupae and adult worker bees, and transmits or activates several viral diseases.

**Pathway 5 – *Apis mellifera* or *A. dorsata* with *Tropilaelaps* spp.***

Mites in the genus *Tropilaelaps* were originally described as external parasites of the brood of *Apis dorsata* (Giant honeybee). However, a host switch occurred onto the brood of *A. mellifera* where infestations can rapidly lead to colony death. *Tropilaelaps* is now considered to be a serious threat to *A. mellifera* wherever it is present.

**Pathway 6 – Additional vectors of *Varroa* spp.***

*Varroa* spp. can attach themselves to other flower-visiting insects such as bumble bees (*Bombus* spp.), hoverflies (*Syrphidae*), some species of honeybeetles (*Scarabaeidae*) and wasps (*Vespidae*). The association with *Bombus* spp. is an important consideration in any future introduction of the bumble bee as a pollinator. However, it is considered that current quarantine requirements for exotic species of these insect groups and associated commodities will adequately manage any risk associated with the introduction of *Varroa* spp. via these pathways. No further consideration of these additional vectors of *Varroa* spp. is therefore provided.
Pest information

*Varroa destructor*

There are more than 25 different genotypes of *Varroa* spp. on *A. cerana*. The various genotypes of *V. destructor* are found on *A. cerana* throughout mainland Asia, but only the Korea and Japan genotypes have become pests of *A. mellifera*. The Korea genotype is the most common on *A. mellifera* and is found in the United Kingdom, Europe, Russia, the Middle East, Africa, Asia, Canada, North and South America, and New Zealand. The Japan genotype is found on *A. mellifera* in Japan, Thailand, North and South America, and Canada.

The Korea and Japan *V. destructor* genotypes have spread rapidly through both managed and feral honeybee colonies worldwide. In many cases human distribution of infested bees has been a key factor in the spread of the mites. In 2000, *V. destructor* was detected on the North Island of New Zealand and it had spread to the South Island by 2006. The mite was also detected on the Hawaiian Islands in 2007, and is now present in all major beekeeping regions of the world except for Australia. Table 4 provides approximate dates of introduction and spread of *V. destructor* around the world.

If *V. destructor* were to become established in Australia, international experience would suggest that apiarists would experience loss of productive colonies and the need to adopt costly control measures. Feral bee populations would also be severely reduced. A reduction in the pollination capability would also affect the viability of many horticultural and agricultural industries and have an impact on the national economy.

Table 3  Approximate dates of introduction and spread of *Varroa destructor* around the world

<table>
<thead>
<tr>
<th>Date of introduction</th>
<th>Country</th>
<th>Date of introduction</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early 1960’s</td>
<td>Japan and the USSR</td>
<td>1987</td>
<td>Portugal</td>
</tr>
<tr>
<td>1960’s – 1970’s</td>
<td>Eastern Europe</td>
<td>1987</td>
<td>USA</td>
</tr>
<tr>
<td>1971</td>
<td>Brazil</td>
<td>1989</td>
<td>Canada</td>
</tr>
<tr>
<td>Late 1970’s</td>
<td>South America</td>
<td>1992</td>
<td>England</td>
</tr>
<tr>
<td>1982</td>
<td>France</td>
<td>2000</td>
<td>New Zealand (North Island)</td>
</tr>
<tr>
<td>1984</td>
<td>Switzerland, Spain and Italy</td>
<td>2006</td>
<td>New Zealand (South Island)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2007</td>
<td>Hawaii</td>
</tr>
</tbody>
</table>

*Varroa jacobsoni*

*Varroa jacobsoni* is defined as consisting of genotypes that naturally infest different populations of *A. cerana* in the southern mainland Asia–Malaysian–Indonesian region. Included are the Java, Sumatra, Malaysia, Borneo, Bali, Lombok, Sumbawa, Flores, and Ambon genotypes.

*Varroa jacobsoni* has until recently only been known as a relatively benign external parasite of *A. cerana*. However, surveys in PNG in 2008 detected the widespread presence of a strain of the mite pathogenic to *A. mellifera*. Further research is required to confirm whether this strain can reproduce on both *A. mellifera* and *A. cerana* but this discovery potentially establishes a new and significant risk pathway for the Australian honeybee industry. For the purposes of this pathway
analysis it was assumed that the PNG strain of *V. jacobsoni* will reproduce on both *A. mellifera* and *A. cerana*.

*Varroa jacobsoni* is considered to be widely dispersed throughout Asia but is not present in Australia. If *V. jacobsoni* were to become established in Australia, international experience would suggest that apiarists would experience loss of productive colonies and need to adopt costly control measures. Feral bee populations would also be severely affected. A reduction in the pollination capability would also affect the viability of many horticultural and agricultural industries and have an impact on the national economy.

**Tropilaelaps** spp.

Mites in the genus *Tropilaelaps* are external parasites of the brood of honeybees (*Apis* spp.). Different *Tropilaelaps* subspecies were originally described from *Apis dorsata* (Giant honeybee), but a host switch occurred to *A. mellifera*, where infestations can rapidly lead to colony death. There are four species documented in the literature and two (*Tropilaelaps clareae* and *Tropilaelaps mercedesae*) are considered harmful to *A. mellifera*.

*Tropilaelaps* spp. are thought to be distributed throughout Asia, including Indonesia and the western half of New Guinea (Papua). *Tropilaelaps* spp. are not present in Australia, Europe or New Zealand. If *Tropilaelaps* spp. were to become established in Australia, international experience would suggest that apiarists would experience loss of productive colonies and need to adopt costly control measures. Feral bee populations would also be severely affected. A reduction in the pollination capability would also affect the viability of many horticultural and agricultural industries and have an impact on the national economy.

**Risk assessments for the identified pathways**

*Varroa destructor*, *V. jacobsoni* and *Tropilaelaps* spp. are not present in Australia and have the potential for entry, establishment, spread and delivery of economic consequences in Australia, and thus meet the criteria for a quarantine pest.

The risk assessments in this section focus on assisted pathways identified for the mite species associated with *A. cerana*, *A. mellifera* and *A. dorsata*. The probability of entry has been considered individually for each identified pathway as these pathways each have a significant effect on the overall assessments. The probability of entry has been considered as the probability of importation (the likelihood that the honeybees and mites are transported to the quarantine barrier alive) combined with the probability of distribution (the likelihood that bees and mites will cross the quarantine barrier alive).

However, the combined probability of establishment (the likelihood that the mites will find suitable resources to survive and reproduce post-barrier) and spread (the likelihood that the mites will move from the original incursion site/s) have been assessed only once for the pathways considered here. This is because the probability of establishment and spread is influenced by many relatively constant factors such as the efficacy of current awareness, surveillance and quarantine requirements, the suitability of the environment, and the biology of the bees and the mites themselves. The majority of these variables are not considered to vary significantly between pathways.

**Pathway 1– *Apis cerana* with *Varroa destructor***

**Probability of importation**

- *Varroa destructor* is a relatively benign external parasite of *A. cerana*. 
• The Korea and Japan genotype only infests *A. mellifera* and is only found on *A. cerana* in mainland Asia.

• *A. cerana* is present throughout Asia including the southern coast of the island of New Guinea, the Solomon Islands and some of the northern Torres Straits islands. However, it is unlikely to be infested with the Korea and Japan strains of *V. destructor* within PNG or the northern Torres Strait Islands.

• Smuggling of *A. cerana* is unlikely to occur as it is considered an inferior species for honey production, and there is no demand for its genetics.

• Commercial aircraft travel at high altitudes greatly reducing the likelihood of bee survival in the cargo or luggage areas. There would also be a high probability of discovery of a viable hive or swarm during loading and unloading of cargo.

• AQIS interception records (Table 2) show that there has been one and possibly several other detections of individual exotic bees with air cargo. However, records do not indicate if the specimens were alive or dead.

• Large ocean-going vessels tend to have a large variety of cryptic habitats for bee swarms, which would decrease the likelihood of detection. Colonies may survive for a significant time, particularly if there is a comb associated with the honeybees.

• Incursion and interception records (Table 2) indicate that *A. cerana* has been detected on freighters and their cargo several times over the years. *Varroa* spp. mites have also been detected on *A. cerana* specimens that have been intercepted on several occasions.

**Conclusion**

The likelihood of importation of *V. destructor* with *A. cerana* by assisted entry is **Low**.

**Probability of distribution**

• It is likely that swarms of bees would be detected in or on small aircraft upon arrival and it is unlikely that swarms of sufficient size to establish would survive commercial flights. Therefore distribution from airports is considered unlikely.

• Incursion and interception records (Table 2) clearly indicate that sea ports for commercial vessels and cargo represent the highest risk of importation and distribution for exotic bees and mites.

• AQIS have clearly defined international vessel and cargo clearance procedures and requirements and have responded to several suspected exotic bee detections upon cargo ships and in seaport areas (Table 2).

• The majority of commercial ports have been monitored using the National Sentinel Hive Program since 2000. Some ports also have bait hives and the ports of Darwin, Gove, Cairns and Brisbane maintain pheromone-baited log traps for Asian honeybee. However, the National Sentinel Hive Program has not detected any incursions, including the 2007 incursion of *A. cerana* in Cairns.

• *A. cerana* has a high rate of reproductive swarming (6–12 times per year) and is likely to swarm from an original arrival point relatively rapidly (dependent upon the availability of food and shelter).
• An incursion of *A. cerana* will have contact with the hives of local bee populations (feral or managed *A. mellifera*, or native bees) where they exist. *Varroa destructor* may be transmitted to native populations if present on *A. cerana*.

**Conclusion**

The likelihood of distribution of *V. destructor* associated with *A. cerana* is **High**.

**Pathway 2 – Apis cerana with Varroa jacobsoni**

**Probability of importation**

• *Varroa jacobsoni* is a relatively benign external parasite of *A. cerana*.

• *A. cerana* is present throughout Asia including the southern coast of the island of New Guinea, the Solomon Islands and some of the northern Torres Straits islands.

• A pathogenic strain of *V. jacobsoni* has been found on *A. mellifera* in PNG. Whilst yet to be scientifically proven, it has been assumed that this strain can reproduce on both *A. mellifera* and *A. cerana*.

• Smuggling of *A. cerana* is unlikely to occur as it is considered an inferior species for honey production, and there is no demand for its genetics.

• Light planes travel regularly between the islands of New Guinea and northern Australia. Light planes travel at relatively low altitudes increasing the likelihood of survival of bees. However, it is a very likely that a hive would be quickly detected in the small spaces within the aircraft.

• Commercial aircraft travel at higher altitudes greatly reducing the likelihood of honeybee survival in the cargo or luggage areas. There would also be a high probability of discovery of a viable hive or swarm during loading and unloading of cargo.

• AQIS interception records (Table 2) show that there has been one and possibly several other detections of individual exotic bees with air cargo. However, records do not indicate if the specimens were alive or dead.

• The small boat inter-island traffic between the islands in Torres Strait and these islands and the mainlands of PNG and Australia provide a means for the transfer of live bees and *V. jacobsoni*. However, any hive or swarm on a small boat will almost certainly be detected.

• Large ocean-going vessels tend to have a large variety of cryptic habitats for bee swarms, which would decrease the likelihood of detection. Colonies may survive for a significant time, particularly if there is a comb associated with the bees.

• Incursion and interception records (Table 2) indicate that *A. cerana* has been detected on freighters and their cargo several times over the years. *Varroa* spp. mites have also been detected on *A. cerana* specimens that have been intercepted on several occasions.

**Conclusion**

The likelihood of importation of *V. jacobsoni* with *A. cerana* by assisted entry is **High**.
Probability of distribution

- It is likely that swarms of honeybees would be detected in or on small aircraft upon arrival and it is unlikely that swarms of sufficient size to establish would survive commercial flights. Therefore distribution from airports is considered unlikely.

- Incursion and interception records (Table 2) clearly indicate that sea ports for commercial vessels and cargo represent the highest risk of importation and distribution for exotic bees and mites.

- AQIS have clearly defined international vessel and cargo clearance procedures and requirements and have responded to several suspected exotic bee detections upon cargo ships and in seaport areas (Table 2).

- The majority of commercial ports have been monitored using the National Sentinel Hive Program since 2000. Some ports also have bait hives and the ports of Darwin, Gove, Cairns and Brisbane maintain pheromone-baited log traps for Asian honeybee. However, the National Sentinel Hive Program has not detected any incursions, including the 2007 incursion of *A. cerana* in Cairns.

- *A. cerana* has a high rate of reproductive swarming (6–12 times per year) and is likely to swarm from an original arrival point relatively rapidly (dependent upon the availability of food and shelter).

- An incursion of *A. cerana* will have contact with the hives of local bee populations (feral or managed *A. mellifera*, or native bees) where they exist. *V. jacobsoni* may be transmitted to native populations if present on *A. cerana*.

Conclusion

The likelihood of distribution of *Varroa jacobsoni* associated with *A. cerana* is **High**.

Pathway 3 – *Apis mellifera* with *Varroa jacobsoni*

Probability of importation

- Recent surveillance in PNG has revealed that a strain of *V. jacobsoni* pathogenic to *A. mellifera* is widespread on the mainland. Further research is required to confirm if this strain can reproduce on both *A. mellifera* and *A. cerana* but this discovery poses a new and significant risk pathway for the Australian honeybee industry. For the purposes of this pathway analysis it was assumed that the PNG strain of *V. jacobsoni* can reproduce on both *A. mellifera* and *A. cerana*.

- The closest *A. mellifera* hives within *V. jacobsoni* distribution are thought to be at Port Moresby in PNG and at Timika in Papua. However, there is not a significant apiary industry or sufficient numbers of feral *A. mellifera* in these areas to suggest that feral *A. mellifera* are likely to swarm onto seagoing vessels or cargo.

- Due to the undeveloped nature of the apiary industry in these areas and relatively few feral hives, assisted entry of *A. mellifera* with *V. jacobsoni* from these areas is considered unlikely.

- The legal and illegal movement of queen bees has assisted the dispersal of *Varroa* spp. internationally. However, due to the underdeveloped nature of the *A. mellifera* apiary industry in PNG and Papua it is unlikely that genetic material, potentially infested with *V. Jacobsoni*, would be smuggled from these areas.
Conclusion

The likelihood of importation of *V. jacobsoni* with *A. mellifera* by assisted entry is **Low**.

Probability of distribution

- It is likely that swarms of bees would be detected in or on small aircraft upon arrival and it is unlikely that swarms of sufficient size to establish would survive commercial flights. Therefore distribution from airports is considered unlikely.

- Incursion and interception records (Table 2) clearly indicate that ports for commercial vessels and cargo represent the highest risk of entry for exotic bees and mites.

- AQIS have clearly defined international vessel and cargo clearance procedures and requirements and have responded to several suspected exotic bee detections upon cargo ships and in seaport areas (Table 2).

- The majority of commercial ports have been monitored using the National Sentinel Hive Program since 2000. Some ports also have bait hives and the ports of Darwin, Gove, Cairns and Brisbane maintain pheromone-baited log traps for Asian honeybee. However, the National Sentinel Hive Program has not detected any incursions, including the 2007 incursion of *A. cerana* in Cairns.

- Bait hives at some ports have detected *A. mellifera* but it is difficult to determine if they are exotic or not, and the likelihood of distribution is considerable.

Conclusion

The likelihood of distribution of *Varroa jacobsoni* associated with *A. mellifera* is **High**.

Pathway 4 – *Apis mellifera* with *Varroa destructor*

Probability of importation

- *Varroa destructor* has spread rapidly throughout the world (table 4) and is now present in all areas of the world as an external parasite of *A. mellifera*, except for Australia.

- Recent incursions of *V. destructor* have occurred in New Zealand in 2000 and Hawaii in 2007.

- The mode of entry of *V. destructor* into New Zealand remains unclear but the cluster of detections around southern Auckland and the associated port area would suggest an undetected swarm infested with *V. destructor* associated with a container or large vessel.

- The mode of entry of *V. destructor* into Hawaii remains unclear but once again the cluster of detections would suggest an undetected swarm infested with *V. destructor* associated with a container or large vessel.

- The spread of *V. destructor* between countries and continents has also been assisted by the introduction of infested hives, infested queen bees and infested beekeeping material.

- The importation of live bees and used beekeeping material is not permitted into Australia.

- The ban on the importation of queen bees into Australia may increase the likelihood of smuggling. However, the risks associated with the introduction of *V. destructor* are well...
known to the beekeeping community and smuggling is considered to currently be a relatively low risk.

**Conclusion**

The likelihood of importation of *V. destructor* with *A. mellifera* by assisted entry is High.

**Probability of distribution**

- It is most likely that *A. mellifera* could enter either on imported cargo or as a swarm from a cargo vessel (Table 2).

- It is likely that swarms of bees would be detected in or on small aircraft upon arrival and it is unlikely that swarms of sufficient size to establish would survive commercial flights. Therefore distribution from airports is considered unlikely.

- Incursion and interception records (Table 2) clearly indicate that ports for commercial vessels and cargo represent the highest risk of entry for exotic bees and mites.

- AQIS have clearly defined international vessel and cargo clearance procedures and requirements and have responded to several suspected exotic bee detections upon cargo ships and in seaport areas (Table 2).

- The majority of commercial ports have been monitored using the National Sentinel Hive Program since 2000. Some ports also have bait hives and the ports of Darwin, Gove, Cairns and Brisbane maintain pheromone-baited log traps for Asian honeybee. However, the National Sentinel Hive Program has not detected any incursions, including the 2007 incursion of *A. cerana* in Cairns.

- Bait hives at some ports have detected *A. mellifera* but it is difficult to determine if they are exotic or not, and the likelihood of distribution is considerable.

**Conclusion**

The likelihood of distribution of *V. destructor* with *A. mellifera* is **High**.

**Pathway 5 – *Apis mellifera* or *A. dorsata* with *Tropilaelaps* spp.**

**Probability of importation**

- There are four *Tropilaelaps* species. Two of the species (*Tropilaelaps clareae* and *Tropilaelaps mercedesae*) have spread from their original host, the giant honeybee (*Apis dorsata*), to *A. mellifera*.

- *Tropilaelaps clareae* is found in the Philippines (except Palawan Island) and Sulawesi. *Tropilaelaps mercedesae* is found throughout mainland Asia, Indonesia and New Guinea.

- *Tropilaelaps* spp. are external parasites of bee brood only and cannot survive more than seven days away from bee brood.

- *Tropilaelaps* spp. do not parasitise adult bees but can attach and transfer between adult bees.

- *Tropilaelaps* spp. may be imported on adult *A. dorsata* and *A. dorsata* have been detected by AQIS at the barrier on several occasions (Table 2). However, it appears that no *Tropilaelaps* spp. mites have been detected on intercepted adult specimens.
The short survival time of *Tropilaelaps* spp. away from brood would suggest that establishment on exotic adult bees is unlikely.

The importation of any *Apis* spp. brood into Australia is currently prohibited.

**Conclusion**

The likelihood of importation of *Tropilaelaps* spp. with *A. mellifera* or *A. dorsata* by assisted entry is Low.

**Probability of distribution**

- It is most likely that *A. mellifera* or *A. dorsata* could enter either on imported cargo or as a swarm from a cargo vessel.

- It is likely that swarms of bees would be detected in or on small aircraft upon arrival and it is unlikely that swarms of sufficient size to establish would survive commercial flights. Therefore distribution from airports is considered unlikely.

- Incursion and interception records (Table 2) clearly indicate that ports for commercial vessels and cargo represent the highest risk of entry for exotic bees and mites.

- AQIS have clearly defined international vessel and cargo clearance procedures and requirements and have responded to several suspected exotic bee detections upon cargo ships and in seaport areas (Table 2).

- The majority of commercial ports have been monitored using the National Sentinel Hive Program since 2000. Some ports also have bait hives and the ports of Darwin, Gove, Cairns and Brisbane maintain pheromone-baited log traps for Asian honeybee. However, the National Sentinel Hive Program has not detected any incursions, including the 2007 incursion of *A. cerana* in Cairns.

- Bait hives at some ports have detected *A. mellifera* but it is difficult to determine if they are exotic or not and the likelihood of distribution is considerable.

- It would only be likely that exotic bees cross the quarantine barrier carrying *Tropilaelaps* spp. if there is a relatively short transit time of several days or an active hive with infested brood has been transported to an Australian sea or airport.

**Conclusion**

The likelihood of distribution of *Tropilaelaps* spp. with *A. mellifera* or *A. dorsata* is **Low**.

**Overall probability of entry**

The probability of entry is determined by combining the probability of importation with the probability of distribution using the matrix of rules for combining descriptive likelihoods (Appendix 1). The overall probabilities of entry for the five pathways being assessed in this PRA are set out in Table 4.
Table 4  Overall probability of entry of Varroa destructor, V. jacobsoni and Tropilaelaps spp for the pathways under consideration

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Probability of importation</th>
<th>Probability of distribution</th>
<th>Overall probability of entry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pathway 1– A. cerana with V. destructor</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Pathway 2– A. cerana with V. jacobsoni</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Pathway 3 – A. mellifera with V. jacobsoni</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Pathway 4 – A. mellifera with V. destructor</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Pathway 5 – A. mellifera or A. dorsata with Tropilaelaps spp.</td>
<td>Low</td>
<td>Low</td>
<td>Very low</td>
</tr>
</tbody>
</table>

Probability of establishment and spread of Varroa spp. and Tropilaelaps spp.

- Australian climatic conditions and resource availability would favour the establishment and spread of exotic bee species and exotic mites.

- The majority of commercial ports have been monitored using the National Sentinel Hive Program since 2000. Some ports also have bait hives and the ports of Darwin, Gove, Cairns and Brisbane maintain pheromone-baited log traps for Asian honeybee. However, the National Sentinel Hive Program has not detected any incursions, including the 2007 incursion of A. cerana in Cairns.

- Bait hives at ports have detected A. mellifera. However, once past the quarantine barrier it would be difficult to distinguish exotic from domestic or feral A. mellifera.

- Interaction between exotic and endemic A. mellifera would occur. The level and extent of interaction would be dependent upon the number of domestic hives and feral A. mellifera within flight distance of the exotic incursion.

- Apis cerana will also interact with endemic bee populations through swarming and robbing behaviour.

- It is likely that transfer of Varroa spp. or Tropilaelaps spp. could occur during these interactions.

- If domestic hives or feral populations become infested with Varroa spp. it may be twelve months or more before mite levels increase to detectable levels.

- Tropilaelaps spp. cannot survive without brood for more than seven days but the reproductive cycle is more rapid than Varroa spp. If susceptible brood are found populations could establish rapidly.

- Human-assisted transfer of domestic A. mellifera infested with undetectable levels of Varroa spp. or Tropilaelaps spp. may occur before infestations are detected.
Conclusion

The likelihood of establishment and spread of *Varroa* spp. and *Tropilaelaps* spp. is **High**.

**Overall likelihood of entry, establishment and spread**

The probability of entry, establishment and spread is determined by combining the probability of entry, of establishment and spread using the matrix of rules for combining descriptive likelihood (Appendix 1).

The overall assessment of likelihood that *Varroa* spp. and *Tropilaelaps* spp. will enter Australia by the pathways discussed in this pathway analysis, be distributed in a viable state to susceptible hosts, establish in that area, and subsequently spread within Australia are set out in Table 5.

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Probability of entry</th>
<th>Probability of establishment and spread</th>
<th>Overall probability of entry, establishment and spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pathway 1 - <em>A. cerana</em> with <em>Varroa destructor</em></td>
<td>Low</td>
<td>High</td>
<td>Low&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
<tr>
<td>Pathway 2 - <em>A. cerana</em> with <em>Varroa jacobsoni</em></td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Pathway 3 – <em>A. mellifera</em> with <em>V. jacobsoni</em></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Pathway 4 – <em>A. mellifera</em> with <em>V. destructor</em></td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Pathway 5 – <em>A. mellifera</em> or <em>A. dorsata</em> with <em>Tropilaelaps</em> spp.</td>
<td>Very low</td>
<td>High</td>
<td>Very low&lt;sup&gt;5&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>4</sup> The probability of entry of *A. cerana* without any associated exotic pests or diseases is considered to be high (this likelihood is supported by the recent Cairns incursion and subsequent eradication campaign).

<sup>5</sup> It should be noted that the probability of entry of *A. dorsata* without any associated exotic pests or diseases is considered to be low (this is supported by the infrequent border detections and no recorded post barrier incursions of this species).
Pathway analysis conclusion

The pathway analysis has indicated that:

- there is a low risk of entry, establishment and spread of *Varroa destructor* associated with *Apis cerana*;
- there is a high risk of entry, establishment and spread of *Varroa jacobsoni* associated with *Apis cerana*;
- there is a low risk of entry, establishment and spread of *Varroa jacobsoni* associated with *Apis mellifera*;
- there is a high risk of entry, establishment and spread of *Varroa destructor* with *Apis mellifera*; and
- there is a very low risk of entry, establishment and spread of *Tropilaelaps* spp. with *Apis mellifera* or *Apis dorsata*.

The pathway analysis for *Varroa destructor*, *Varroa jacobsoni* and *Tropilaelaps* spp. has considered scientific information and other relevant literature. The pathway analysis has also considered the relevant current quarantine\(^6\), surveillance and awareness requirements. It is important to note that if the relevant current quarantine, surveillance and awareness requirements should change the risk associated with each pathway may also change.

\(^6\) There is currently a prohibition on the importation of all live bees into Australia. This measure greatly reduces the risk of introduction but it may also increase the temptation to introduce new genetic stock illegally over time. This may increase the risk of introduction via this pathway over time.
3. Predictive Economic Modelling

Introduction

The analysis in this chapter formed a core component of the risk-based assessment framework. For reasons given earlier in this report, the analysis focussed on an incursion of the exotic bee mite *Varroa destructor*. However, the economic model and methodology presented here also provides a framework for the future analysis of other pest species of interest.

Background to the evaluation of pollination services

Australia is particularly vulnerable to the impact of invasive species that affect the European honeybee due to the absence of other native pollinators capable of delivering the same pollination benefits. There are several studies that place a value on pollination services for different regions of the world. Gill (1989a) provided an overview of the methodologies used in some of these valuations, with particular reference to the North American experience.

*Varroa destructor* is thought to have been introduced into the U.S. in the mid-1980s by way of illegal commercial bee movements from Europe and South America (Guzman et al. 1997) and has subsequently led to severe losses of both feral and commercial *Apis mellifera* colonies (Watanabe 1994). The extent of the resultant economic impact is not clear. Robinson et al. (1989) placed a value of U.S.$9.3 billion on pollination services to crops across the whole of North America. Morse and Calderone (2000) revised this value upwards to around U.S.$14.6 billion. These estimates are thought to be exaggerated, and were more conservatively estimated at around $600 million by Muth and Thurman (1995).

Given the significant proportion of the community potentially affected by a decrease in pollination services it is surprising there have not been more economic analyses undertaken of pollination markets, particularly in the U.S. where a government-provided price support scheme operated until 1996. Ostensibly, the reasoning for this support scheme was to correct a market failure caused by private providers of pollination services being unable to capture all the benefits attributable to their operations. The existence of positive externalities generally leads to a level of service provision below a socially desirable level. Analyses concerning the existence and internalisation (or lack thereof) of these externalities include Cheung (1973), Johnson (1973) and Burgett et al. (2004). Olmstead and Wooten (1987) might also be added to this list, but their research focused on a specific pollination market, that of the Californian alfalfa market of the 1940s and 1950s. Although government intervention in the U.S. pollination market acknowledged the existence of externalities, it is interesting to note that the decision was taken to support the price of honey rather than to subsidise the provision of pollination services.

Research into the pollination benefits enjoyed by Australia’s plant industries is also scarce. In conducting an investigation into the feasibility of employing biological control agents to reduce the abundance of the noxious weed Patterson’s Curse (*Echium plantagineum*), the Industries Assistance Commission (1985) put forward a value of just under $160 million for pollination benefits. This study was based on a pollination index ranking reliance on pollination of certain crops, but contained an upward bias due to excessive attribution rates to *A. mellifera* as opposed to other pollinators. Although not attempting a valuation exercise, Cunningham et al. (2002) contains a similar index which we have revised and used as the basis for assumptions later in the impact simulation modelling to follow. Cook et al. (2007) used this index combined with a
bioeconomic model to simulate the likely impact on 25 Australian plant industries if the *V. destructor* mite were to become established. They estimated losses of between $20 million and $50 million per year could result.

Perhaps the most cited Australian study is Gill (1989b), who used a closed-market partial equilibrium model to examine the loss of producer and consumer surplus brought about by a negative supply shock (induced by an incident like *V. destructor* establishment and spread). The results indicated that production benefits of between $0.6 billion and $1.2 billion were attributable to pollination services provided by both commercial and feral honeybee pollinators. These results were repeated in Gibbs and Muirhead (1998). Using a methodology derived from Gill (1989b), Gordon and Davis (2003) then put forward a value of pollination service in Australia of $1.7 billion.

Each of these estimates contains an upward bias due to the assumed closed economy in the absence of pollinators, but more importantly (with the exception of Cook et al. (2007)) through their lack of a transitional period between the ‘with’ and ‘without’ pollinator states. Nonetheless, they indicate a substantial private benefit is generated by maintaining pollination services, and hence by maintaining the country’s area freedom from pests and diseases capable of decreasing the level of crop pollination. This is reinforced by invasion response cost sharing arrangements between Federal and State governments and livestock industries set out in Animal Health Australia (2002), known as the Emergency Animal Disease Response Agreement (EADRA).

The model on which the EADRA is based is described in Centre for International Economics (1998). It involves ‘high-profile’ diseases being placed in one of four cost sharing categories relating to their significance in terms of potential damage to public resources and private industries. The categories relate to species with little or no impact on the community beyond agricultural industries (or low public cost) to those with high environmental/social costs. If a species categorised under the agreement is detected in Australia, the category chosen dictates an appropriate split of eradication funding between government and private industry. Eradication is conditional on a benefit cost analysis being completed, which indicates that a net social gain will result from a successful campaign.

Currently the EADRA lists the *V. destructor*, *Tropilaelaps* and Tracheal mites as category 2 species, meaning that funding arrangements for any future eradication campaigns mounted against them will be funded 80% by government and 20% by the honeybee keeping industry (i.e. 80/20). *V. jacobsoni* is listed as a category 4 species in the same agreement (i.e. 20/80), but this is likely to change given the recent detection of a new form of *V. jacobsoni* that is pathogenic to *A. mellifera* in Papua New Guinea. For each of these pests, the apiculture industry is obliged to pay all of the private costs of any future eradication campaign. A similar agreement applying to priority plant pests and diseases, the Emergency Plant Pest Response Deed (EPPRD) detailed in Plant Health Australia (2005) and Plant Health Australia (2001), does not currently include *V. destructor*. Pests of significance to the apiculture industry have typically been dealt with under the banner of livestock industries.

As past studies have shown, and as we will verify, these arrangements mean that other beneficiaries can receive a free ride on the eradication benefits provided by the apiculture industry when an incursion takes place. To some extent, apiculturists could recover a small proportion of these positive flow-ons through horizontal integration, but transaction costs are likely to be prohibitively high. Moreover, successful eradication would mean that pollination by wild *A. mellifera* would continue to make up a large proportion of market share.
In this analysis we are not concerned with the appropriateness of the 80 per cent government, 20 per cent private categorisation of honeybee pests under the EADRA. Our analysis is limited to the potential response benefits accruing to private agricultural industries.

**Impact simulation modelling**

We use the bioeconomic model developed in Cook et al. (2007) to estimate the likely benefits of surveillance measures over time. The model is adapted to simulate the possible effects of three bee mites, *V. destructor*, the recently discovered Varroa variant found in PNG and Tropilaelaps mites simultaneously. Three biological models were run concurrently and used to populate a common space to avoid double or triple counting. We note that there are actually two Tropilaelaps species of concern to Australia, (*T. clareae* and *T. koenigerum*), but we treat them as a single species for the purposes of this analysis. The objective of the model is to assess the significance of the threat posed by these three mite species to Australian agriculture by simulating total expected (or probability-weighted) damage over a specified period of time (30 years) with and without surveillance. The difference between these simulations effectively represents the benefits potentially produced through surveillance measures.

The use of random number generators to simulate chance or random events is common in risk analyses modelling natural systems with high parameter uncertainty and variability. This is the approach we adopt. Parameters are stated within an abstract model as probability distributions rather than point estimates, and a Monte Carlo algorithm used to sample from each of these distributions (Cook and Matheson 2008).

To summarize the Cook et al. (2007) model, production loss per unit of area (d), spread area (A), population density (N) and the numbers of satellite sites in each time period (St) are with the probability of entry and establishment (p) in an expression of probability-weighted, or expected damage over time. Given a discount rate $\alpha$, the present value of expected damage after n time periods ($PV(ED_n)$) is (Cook et al. 2007):

$$PV(ED_n) = \sum_{i=0}^{n} (1 + \alpha)^{-i} \sum_{j=1}^{S_i} p.d.A.N.$$  

(1)

Separate models were run simultaneously for each of the mite species simulating likely impacts of incursions over a 30-year period. The areas affected in each iteration were then summed for each time period and capped at the total crop area (given in Table 6).

Discounting is used because a dollar available for investment in the present is more valuable than a dollar that will not become available until a later period. The future dollar has an opportunity cost associated with it (i.e. investment opportunities we have had to forgo while we wait for it to become available for spending) (Cook et al. 2007). The expression in (1) provides a probability-weighted estimate of pest-induced revenue losses amongst plant industries in present value terms. It is a measure of expected damage taking into account uncertainty in the likelihood of arrival and establishment, severity of production effects, and change in abundance and distribution of honeybee pests over time.

Let us firstly look at the no surveillance case. Simulating potential losses to plant industries resulting from pollination declines is difficult. Cunningham et al. (2002) and Free (1993) provide estimates of the total proportion of regional yield gains attributable to pollination services, but the resultant yield change in the absence of feral *A. mellifera* is a matter for speculation. The process of defining the “supply shocks” indicated in Table 6 in response to a pest-induced feral *A. mellifera* decline is not dissimilar to those used in Gill (1989b). However,
the magnitude of change is assumed smaller since other changes to management behaviours
serve to soften the impact.

Table 6  Crop statistics, production cost increases and yield losses

<table>
<thead>
<tr>
<th>Crop</th>
<th>Area (Haa)</th>
<th>Annual Gross Value of Production (5-Year Average)a</th>
<th>Percentage of Total Pollination Services Delivered by Insectsb</th>
<th>Additional Hives Required Per Hectare in the Absence of Feral Apis melliferac</th>
<th>Percentage Yield Loss in the Absence of Feral Apis melliferac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almond</td>
<td>4,430</td>
<td>$41,759,605</td>
<td>100</td>
<td>2 - 5</td>
<td>10 - 30</td>
</tr>
<tr>
<td>Apple</td>
<td>13,260</td>
<td>$378,444,535</td>
<td>90</td>
<td>2</td>
<td>0 - 20</td>
</tr>
<tr>
<td>Apricot</td>
<td>1,085</td>
<td>$31,490,850</td>
<td>70</td>
<td>1 - 2</td>
<td>0 - 10</td>
</tr>
<tr>
<td>Avocado</td>
<td>4,000</td>
<td>$78,740,005</td>
<td>100</td>
<td>2</td>
<td>10 - 30</td>
</tr>
<tr>
<td>Blueberry</td>
<td>510</td>
<td>$26,823,780</td>
<td>100</td>
<td>1 - 2</td>
<td>10 - 30</td>
</tr>
<tr>
<td>Canola</td>
<td>1,909.73</td>
<td>$1,502,672,850</td>
<td>15</td>
<td>0</td>
<td>0 - 5</td>
</tr>
<tr>
<td>Cherry</td>
<td>1,270</td>
<td>$42,829,140</td>
<td>90</td>
<td>1 - 2</td>
<td>0 - 20</td>
</tr>
<tr>
<td>Cucumber</td>
<td>1,205</td>
<td>$16,530,650</td>
<td>100</td>
<td>1 - 2</td>
<td>0 - 20</td>
</tr>
<tr>
<td>Field Pea</td>
<td>422,675</td>
<td>$98,764,290</td>
<td>50</td>
<td>0</td>
<td>0 - 10</td>
</tr>
<tr>
<td>Lemon &amp; Lime</td>
<td>1,785</td>
<td>$24,523,360</td>
<td>20</td>
<td>0.5</td>
<td>0 - 5</td>
</tr>
<tr>
<td>Lupin</td>
<td>1,347.18</td>
<td>$272,872,360</td>
<td>10</td>
<td>0</td>
<td>0 - 5</td>
</tr>
<tr>
<td>Macadamia Nut</td>
<td>14,000</td>
<td>$50,675,680</td>
<td>90</td>
<td>2 - 5</td>
<td>0 - 20</td>
</tr>
<tr>
<td>Mandarin</td>
<td>4,895</td>
<td>$86,286,200</td>
<td>30</td>
<td>0.5</td>
<td>0 - 5</td>
</tr>
<tr>
<td>Mango</td>
<td>2,650</td>
<td>$100,964,215</td>
<td>50</td>
<td>2</td>
<td>0 - 10</td>
</tr>
<tr>
<td>Nectarine</td>
<td>985</td>
<td>$114,537,870</td>
<td>60</td>
<td>1 - 2</td>
<td>0 - 10</td>
</tr>
<tr>
<td>Orange</td>
<td>30,560</td>
<td>$297,818,985</td>
<td>30</td>
<td>0.5</td>
<td>0 - 5</td>
</tr>
<tr>
<td>Peach</td>
<td>1,885</td>
<td>$84,923,755</td>
<td>60</td>
<td>1 - 2</td>
<td>0 - 10</td>
</tr>
<tr>
<td>Pear (Not Nashi)</td>
<td>3,025</td>
<td>$106,191,015</td>
<td>50</td>
<td>2</td>
<td>0 - 10</td>
</tr>
<tr>
<td>Plum</td>
<td>835</td>
<td>$44,197,390</td>
<td>70</td>
<td>1 - 2</td>
<td>0 - 10</td>
</tr>
<tr>
<td>Pumpkin</td>
<td>8,995</td>
<td>$59,762,785</td>
<td>90</td>
<td>1 - 2</td>
<td>0 - 20</td>
</tr>
<tr>
<td>Rockmelon</td>
<td>3,940</td>
<td>$104,172,020</td>
<td>100</td>
<td>1 - 2</td>
<td>0 - 20</td>
</tr>
<tr>
<td>Strawberry</td>
<td>905</td>
<td>$150,867,890</td>
<td>40</td>
<td>0</td>
<td>0 - 10</td>
</tr>
<tr>
<td>Sunflower</td>
<td>161,545</td>
<td>$50,798,325</td>
<td>100</td>
<td>2 - 5</td>
<td>10 - 30</td>
</tr>
<tr>
<td>Watermelon</td>
<td>4,950</td>
<td>$68,058,840</td>
<td>100</td>
<td>1 - 2</td>
<td>0 - 20</td>
</tr>
<tr>
<td>Zucchini</td>
<td>1,955</td>
<td>$32,249,965</td>
<td>100</td>
<td>1 - 2</td>
<td>0 - 20</td>
</tr>
</tbody>
</table>


b  Based on pollinator reliance figures in Cunningham et al. (2002) and Free (1993).

c  Based in part on Ministry of Agriculture and Forestry (2000).

Following Cook et al. (2007) we placed twenty five affected crops in one of four categories
roughly proportional to pollinator reliance, as Table 6 indicates. A conservative approach has
been adopted in that expected yield loss is much smaller than pollinator reliance (since
commercial pollination services are assumed to offset losses). By assuming yield losses remain
positive we imply that purchases of commercial pollinators will not be sufficient to avoid a decline in yield in the absence of feral *A. mellifera* hives. The number of hives required per hectare in the absence of feral *A. mellifera* for specific crops have not been estimated on the basis of feral hive equivalents in relevant land areas. For instance, the average density of feral hives may not necessarily be between one and five per hectare of sunflowers currently grown in Australia, but in order to receive sufficient pollination growers must pay for that number of hives. However, commercial pollination services are assumed to be an imperfect substitute for wild pollinators.

While an increased level of quantitative research has been witnessed across many disciplines in recent years, it is often not the case in the biological and natural resource management fields. A lack of basic data prevents the same level of quantification being achievable in analytical work compared to other fields such as engineering (Nunn 2001). This presents a major limitation when examining potential impacts of invasive species over time when one considers that entry and establishment probabilities tend to be highly sensitive (Cook et al. 2007; Cook and Matheson 2008).

As a substitute for rigorous quantitative risk analyses reporting the probability of species arrival, we have used the semi-quantitative categorisation system outlined in Biosecurity Australia (2001). This involves uniform (or rectangular) distributions being used to represent uncertainty in the probability of entry and establishment. The probability of each of the three bee mite species (*V. destructor*, *Varroa* (PNG variant) and Tropilaelaps) entering Australia is estimated as high. According to the Biosecurity Australia (2001) categorisation system, this can be represented by a uniform distribution with a minimum value of 0.7 and a maximum value of 1.0 (i.e. Uniform(0.7, 1.0)). The choice of risk category in this analysis is subjective. The probability of establishment conditional on entry already haven taken place is categorised as moderate, represented as Uniform (0.3, 0.7). Hence, the combined probability of entry and establishment is given by Uniform (0.2, 0.7).

The honeybee mite spread module of the model is largely unchanged from Cook et al. (2007), reflecting the view that the newly discovered Varroa (PNG variant) and the Tropilaelaps mites are likely to exhibit similar behaviour to *V. destructor*. The only exception is the assumed rate of spread of the Tropilaelaps mite, which is believed to be slightly higher than that of the other two mite species (Wilkins and Brown 2005). These and other species-specific assumptions underpinning the biological module of the model are provided in Table 7. The spread of honeybee mites (and consequent wild pollination decline) is assumed to follow a Verhulst-Pearl logistic function, as is the density of mite infestations within a given area of crop. Satellite infestations can also occur randomly in any given year via a logistic process dependent on the total area affected in the previous year. For a full description of these parameters and the complete model see Cook et al. (2007).
### Table 7 Biological parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Varroa destructora</th>
<th>Varroa (PNG Variant)</th>
<th>Tropilaelapsa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop area (Ha) affected upon incursion</td>
<td>PERT(10,30,50) (Cook et al 2007) b</td>
<td>PERT(10,30,50)</td>
<td>PERT(10,30,50)</td>
</tr>
<tr>
<td>Maximum crop area (Ha) affected</td>
<td>UNIFORM(82000,100000) (Bourke &amp; Harwood 2009) c</td>
<td>UNIFORM(82000,100000)</td>
<td>UNIFORM(82000,100000)</td>
</tr>
<tr>
<td>Population growth rate</td>
<td>PERT(0.20,0.35,0.50)</td>
<td>PERT(0.20,0.35,0.50)</td>
<td>PERT(0.50,0.60,0.70)</td>
</tr>
<tr>
<td>Population density upon incursion</td>
<td>PERT(5.0%,7.5%,10.0%)</td>
<td>PERT(5.0%,7.5%,10.0%)</td>
<td>PERT(5.0%,7.5%,10.0%)</td>
</tr>
<tr>
<td>Carrying capacity at maximum density of infestation</td>
<td>PERT(70%,85%,100%)</td>
<td>PERT(70%,85%,100%)</td>
<td>PERT(70%,85%,100%)</td>
</tr>
<tr>
<td>Maximum attainable no. satellite sites</td>
<td>PERT(30,40,50)</td>
<td>PERT(30,40,50)</td>
<td>PERT(30,40,50)</td>
</tr>
<tr>
<td>Minimum no. satellite sites</td>
<td>PERT(0,5,10)</td>
<td>PERT(0,5,10)</td>
<td>PERT(0,5,10)</td>
</tr>
<tr>
<td>Intrinsic rate of satellite generation</td>
<td>PERT(1.0×10⁻³,3.95×10⁻³,1.0×10⁻²)</td>
<td>PERT(1.0×10⁻³,3.95×10⁻³,1.0×10⁻²)</td>
<td>PERT(1.0×10⁻³,3.95×10⁻³,1.0×10⁻²)</td>
</tr>
</tbody>
</table>

a All parameter values are taken from Cook et al. (2007) unless otherwise stated.

b The term “PERT” is an acronym for the Program Evaluation and Review Technique, used to form a special case of the beta distribution using lower boundary (minimum), modal (most likely) and upper boundary (maximum) parameters (Vose 2000).

c The term “UNIFORM” refers to a rectangular distribution specified using a lower boundary (minimum) and an upper boundary (maximum).

We use 5,000 iterations of the model in which one value is randomly sampled across the range of each distribution. The advantage of using this approach is that it provides an indication of the complete set of possible damage scenarios. However, since we have assumed the complete independence of parameters, the tails of the expected damage distribution may be over-stated in the results. Nevertheless, for the purposes of this discussion we simply acknowledge this to be the case.

Taking the mean of the distribution of expected damage costs over a 30-year simulation (i.e. PV(EDₙ)/n) without surveillance measures, we estimate that the average damage to Australian plant industries that could occur as a result of honeybee mite incursions over the next 30 years is $72.3 million per annum. This is equivalent to a loss of 2.5% of the annual combined GVP of all crops included in the model. Due to the uncertainty and variability of the parameter estimates used in the model our confidence intervals are broad. Results indicate a 90% likelihood of damages between $43.5 million (1.5% of GVP) and $102.2 million (3.5% of GVP) per annum. Figure 1 presents the relative frequency distribution for average annual damage over the 30-year period following establishment.
Our assumptions imply the spread of honeybee mites through wild European honeybee colonies will occur slowly at first before accelerating rapidly. Figure 2 plots the crop area affected by decreased bee pollination over time. This diagram suggests insect pollination services will remain largely unchanged until approximately year 15. This inflexion (or threshold) point in the area curve corresponds to a sudden rise in the predicted mite populations after an initial incubation period during which populations gain a foothold in the natural environment.
Figure 2  Estimated area affected by honeybee mites in Australia over time in the absence of surveillance

Translating the affected area data into economic losses in Figure 3, we see a broadly similar pattern to Figure 2 with the periods of highest impact expected to occur 15-25 years into the future. Thereafter, the effects of discounting erode damage estimates. Note also that this figure illustrates the uncertainty surrounding the predictive model. The values expressed in this figure are in current value terms (i.e. PV(EDₙ) from expression (1)).
Figure 3  Estimated loss of Plant Industry production over time attributable to honeybee mite incursions

![Graph showing estimated loss of plant industry production over time attributable to honeybee mite incursions.]

Because plant industries are not currently signatories to any cost sharing agreement relating to bee mites, the pollination benefits accruing to them following the successful removal of any future incursion represent a large positive externality\(^7\). While the public and apiculture industries would provide necessary funding for an eradication campaign against an incursion (under the EADRA) should it happen tomorrow, other private beneficiaries are not obliged to pay anything. Hence, economic justification of a future eradication campaign may prove difficult. The omission of such a large externality in benefit cost analyses places a strong negative bias on the calculated net benefits expected to result from the successful eradication of an outbreak.

As Figure 4 indicates, by far the largest benefits are enjoyed by the sunflower industry, followed by the avocado, apple and strawberry industries. Of the 25 crops used in the simulations, 18 derived notional benefits from bee mite freedom of over $1 million per year. Technical model limitations prevented the inclusion of other crops and pastures, but the implication is nevertheless clear.

\(^7\) Recall that the EADRA lists the \textit{V. destructor} and Tropilaelaps as category 2 species, and \textit{V. jacobsoni} as a category 4 species. For each of these pests, the apiculture industry is obliged to meet all private costs of future eradication campaigns.
Thus far, our analysis has presented a scenario in which there is no surveillance effort devoted to bee mite exclusion. In effect, it presents a worst-case scenario for Australian plant industries. It is important to now consider what the likely impact on our results would be if surveillance (regardless of the form it may take) were to successfully lower the probability of mite establishment. This would have the effect of lessening the expected loss of pollination services to crops over time. But, how large or small will the change be?

To answer this question, we considered a hypothetical situation in which surveillance measures are introduced that lower the probability of each mite species becoming established in Australia from moderate (under the Biosecurity Australia (2001) categorisation system) to low (represented by Uniform (0.05,0.30). This will shift the distribution of average damage (shown in Figure 5) to the left. The extent of this shift is shown in Figure 5. Here the distribution of expected damage under both the without surveillance (i.e. worst case) and the with surveillance scenarios are shown using distributions fitted with the @Risk software package. Both are Normal distributions specified with mean ($\mu$) and standard deviation.
The distribution of average yearly losses from bee mites without surveillance, shown in dark blue, has a mean of $73.2 million and standard deviation of $17.9 million (i.e. Normal (73236519, 17885207)). With surveillance measures in place which succeed in lowering the probability of mite establishment from Uniform (0.30,0.70) (moderate, Biosecurity Australia (2001)) to Uniform (0.05,0.30) (low) average damage, shown in red, is given by Normal (69371461, 17323952). By lowering the expected losses from bee mite incursions, surveillance is generating a benefit for plant industries (i.e. under a surveillance strategy plant industries can expect to suffer lower loss of pollination services as a result of mite incursions). Under our hypothetical assumptions the decrease in mean average production loss generated by surveillance is 5.3%, equivalent to $3.9 million per year.

Although highly uncertain, the predictive assessment can be used in a speculative benefit cost analysis framework to put the effects of surveillance into perspective. It is important for policymakers to determine if surveillance effort is likely to produce a net benefit for society over time, and what the likely size of this net benefit (or cost) is. For instance, if the probability of honeybee mite establishment can be lowered to the extent indicated above (i.e. approximately by one third of the ‘without surveillance’ probability of establishment) with an investment of $750,000/yr, the ratio of benefits to costs is 5.2:1. However, if such a reduction is impossible without the investment of $2 million/yr, the benefit cost ration falls to 1.9:1. For our hypothetical reduction in the probability of establishment, $3.9 million effectively represents a point of ‘break-even’ investment where the ratio of benefits to costs is 1. For investments over this value the costs of surveillance provision are likely to outweigh the prevented bee mite damage over time.

We consider estimating the efficiency of surveillance in the next chapter and return to the question of integration in Chapter 5.
4. Efficiency of Sentinel Hives for the Early Detection of Exotic Bee Mites

Introduction

For reasons given earlier in this report (see Chapter 1) this Chapter explores a simulation model to examine the potential efficiency of targeted surveillance for the early detection of exotic bees mites (*Varroa* and *Tropilaelaps*). The simulation approach concentrates on considering sentinel hives for the early detection of mites as these are at the heart of the current National Sentinel Hive Program (NSHP). It was necessary to consider a simulation approach, as there is insufficient data to do otherwise.

Simulation models are not directly predictive. Rather, they let the user logically structure their assumptions and determine the implications of these on the question at hand. They allow synthesis of available information and beliefs. In using them, it is important to remember that they are abstractions of reality rather than reality itself. Any decision made from them needs to consider the simulation results as an input rather than letting the results directly determine the decision.

An important implication of this discussion is that the complexity of the simulation model needs to be in proportion with the available data and to model the key features of the system. Models that are too complex cannot be parameterised by empirical data and thus lose their connection to the real world. A model that cannot represent a key phenomenon of the system cannot adequately represent the full behaviour of the system, and therefore cannot explore the full range of system outcomes.

In undertaking the modelling for this study, significant knowledge gaps were recognised. In the absence of empirical data it is necessary to rely on expert opinion. In this case expert opinion was initially sought from Dr Denis Anderson using his extensive experience of bee mites and bee behaviour and his knowledge of the literature. These opinions were scrutinised and endorsed by attendees at the workshop. Even given this approach, significant uncertainty still remained.

Physical set up of the simulation

The first choices we made for this model were on the spatial and temporal scales of the simulation. We chose to model what might happen at the hectare scale, as this would allow consideration of honeybee dynamics without introducing undue complications. A hectare is equal to 100m² or 0.01 km². We ran our simulation over a 36 km² area around a port on a monthly time-step. The area covered was enough to examine the dynamics of the invasion process. Several options were considered for the spatial scale including at the individual hive level (too dense) and the square kilometre scale (too sparse). In total we tracked what might happen in 3600 cells across our simulation region for the various experimental conditions explained below.

We further assumed that all actions occurred independently at each hectare – this includes ‘dying off’, detection (at sentinel hives), swarming and foraging. Assumptions related to each of these actions are discussed below. While this assumption may not fully hold in practice, it was
thought that in the absence of other information it would still allow useful conclusions to be reached.

It was assumed that individual hectare areas would have in the order of three to five hives present at any particular time. This was based on expert judgement in environments with a range of suitable hive sites. This was taken as a worst case to bind the probability of detection. In a port environment, active management of the feral population would potentially reduce this number and increase the probability of detection in time to apply appropriate management.

‘Dying off’ and detection

The hives in any hectare area are likely to die off in winter months for various reasons including food shortage, inclement weather and hive destruction. We incorporated this into our model by assuming hives died off with probability $P_{\text{die}}$ which we set at 0.2. We experimented with different settings for this term and found little effect overall. A $P_{\text{die}}$ value of 0.3 is associated with colony collapse disorder.

Different methods of surveillance will have different success rates at detecting a pathogen if it is present in a given hectare. We modelled this as $P_{\text{detect}}$, which was set to 0.05, 0.1, 0.2 and 0.5. The number and positions of the sentinel hives can be varied in the simulation to consider different effects if necessary in a particular application.

Swarming and Foraging

Hives in a given hectare will swarm during particular times of the year. The rate of swarming was set at several levels, and the number of swarms was assumed to follow a Poisson distribution with rate $\lambda$. The values of $\lambda$ were 0.25, 0.5, 1 and 2, representing uncertainty about the true rate. In Table 8 below we show the probability of no swarms, one swarm, two swarms and more than two swarms occurring for particular values of $\lambda$.

For example, for $\lambda = 0.25$ there is a 78% chance that no swarming will occur in a particular month for any of the hives in a given hectare. If the value of $\lambda$ increases to 0.5 the chance of there being no swarm drops to 61%. If $\lambda$ goes to 1 or 2 the chance drops further to 37% and 14% respectively.

Table 8  Swarm probabilities for various values of the rate parameter $\lambda$.

<table>
<thead>
<tr>
<th>$\lambda$</th>
<th>Pr(0 swarms)</th>
<th>Pr(1 swarm)</th>
<th>Pr(2 swarms)</th>
<th>Pr(&gt;2 swarms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lambda = 0.25</td>
<td>0.779</td>
<td>0.195</td>
<td>0.024</td>
<td>0.002</td>
</tr>
<tr>
<td>Lambda = 0.5</td>
<td>0.607</td>
<td>0.303</td>
<td>0.076</td>
<td>0.014</td>
</tr>
<tr>
<td>Lambda = 1</td>
<td>0.368</td>
<td>0.368</td>
<td>0.184</td>
<td>0.080</td>
</tr>
<tr>
<td>Lambda = 2</td>
<td>0.135</td>
<td>0.271</td>
<td>0.271</td>
<td>0.323</td>
</tr>
</tbody>
</table>

When bees swarmed in the model they travel a distance that is chosen at random from an unrestricted distribution with average distance 630m. The shape of this distribution is shown in Figure 9 in Appendix 2.

In any particular month, bees from one hectare will travel and interact with bees in other hives. We assumed bees travel on average 300m to forage, with probability decreasing exponentially
with distance (Figure 10, Appendix 2). The values of this curve show the probability of an interaction that leads to transmission of the pest for hives at the specified distance.

**Swarms that increase with age**

Following feedback from researchers and representatives of the honeybee industry we assume further that when a pathogen arrives in a particular hectare it takes time for the pathogen to settle into that hectare. The swarming rates for bees with pathogens were assumed to increase linearly from zero up to lambda over a time period of three years.

**Running a Simulation**

We selected values for Pdetect and lambda and simulated the arrival of a pathogen on the edge of our 6km by 6km grid, and modelled the subsequent movement and transmission of the pathogen through the grid on a monthly time-step. We recorded how long it took to detect the pathogen, how far the pathogen had travelled in that timeframe and how much of the grid was covered by the pathogen by the time it was detected. This process is repeated 1,000 times in total for each combination of Pdetect and lambda.

Appendix 3 shows an example where the progress of one simulation is shown for every two-month time-step until the pathogen is detected after eleven months. The series of images begin with Figure 14 and Figure 15 showing very little movement of the pathogen. By May in Figure 16 and July in Figure 17 the pathogen has started to move from the starting location. By September in Figure 18 and November in Figure 19 the spread of the pathogen is quiet extensive, at which point it is detected.

**Results of Simulation**

The table below indicates the average number of months that a pathogen was present in the grid before it was detected at the sentinel hives, under 16 experimental conditions. In general the less often that swarms occurred the longer it takes for detection to take place. Also, the time taken to detect a pathogen dropped as the ability to detect it increased.

**Table 9 Simulated average time to detect a pathogen under sixteen experimental model conditions.**

<table>
<thead>
<tr>
<th></th>
<th>Lambda=0.25</th>
<th>Lambda=0.5</th>
<th>Lambda=1</th>
<th>Lambda=2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pdetect=0.05</td>
<td>20.5</td>
<td>20.1</td>
<td>20.2</td>
<td>19.3</td>
</tr>
<tr>
<td>Pdetect=0.1</td>
<td>15.5</td>
<td>15.3</td>
<td>15.1</td>
<td>14.6</td>
</tr>
<tr>
<td>Pdetect=0.2</td>
<td>12.3</td>
<td>12.5</td>
<td>12.1</td>
<td>11.9</td>
</tr>
<tr>
<td>Pdetect=0.5</td>
<td>9.6</td>
<td>9.6</td>
<td>9.5</td>
<td>9.3</td>
</tr>
</tbody>
</table>
Table 10  Std. errors for average time to detection under sixteen experimental conditions via simulation.

<table>
<thead>
<tr>
<th>Pdetect</th>
<th>Lambda=0.25</th>
<th>Lambda=0.5</th>
<th>Lambda=1</th>
<th>Lambda=2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.31</td>
<td>0.29</td>
<td>0.31</td>
<td>0.29</td>
</tr>
<tr>
<td>0.1</td>
<td>0.18</td>
<td>0.19</td>
<td>0.18</td>
<td>0.16</td>
</tr>
<tr>
<td>0.2</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>0.5</td>
<td>0.10</td>
<td>0.11</td>
<td>0.10</td>
<td>0.10</td>
</tr>
</tbody>
</table>

The histograms in Figures 11, 12 and 13 in Appendix 2 highlight the simulation distributions for the time taken to discover the pathogen, the distance travelled and the area of the grid affected by the pathogen in that time. These histograms are plotted for each of the sixteen situations. Clearly in Figures 8 and 9 the limitations of the spatial dimensions of our simulation are apparent. In both sets of histograms for low values of Pdetect many there were many simulations that achieved the maximum values for distance travelled (6.71km) and 100% of area covered. For larger values of Pdetect this was not a problem.

The simulation code developed here and reported above can be used to simulate how long it would take for an incursion to be detected. Evaluations of real-life detection strategies can better inform the setting of the Pdetect term. Individual preferences for swarming and foraging behaviour can be substituted into our approach to model particular types of honeybees, pathogens etc. Larger simulations are also possible given appropriate computing facilities. All simulations were carried out using the R programming environment version 2.5.0 (2007). Code for this algorithm can be made available upon request to the first author.
5. Development and Use of the Risk-Based Framework

Introduction

The analysis presented in the previous three Chapters produced methodologies for assessing the efficiency of components of the surveillance process. In this section we have brought these pieces together to provide a logical framework for considering the benefits and costs of surveillance of exotic bee mites (Varroa and Tropilaelaps).

In this Chapter we also report feedback received at the workshop from the Reference Group. The attendees and agenda of the workshop are provided in Appendix 4.

Integrative framework

To integrate the pathway analysis, the economic analysis and the information on surveillance efficiency using a risk-based framework we proceeded as follows. The pathway analysis provides an assessment of the probability of entry, establishment and spread. If this is assessed as \( p \) based on all the trade, then we argue as follows. Assume that there are \( k \) locations (typically ports at this time but these could vary in the future) under threat from a pest in Australia. If we put surveillance at a subset of locations we need to assess the proportion, \( g \), of the threat that is covered by the surveillance. For instance, if 40% of trade from risk regions went to locations where there is surveillance then the proportion of the threat covered by surveillance is 40%. At each site assume we have designed a surveillance system with efficiency \( e \) calculated using the simulation tool and our beliefs about the efficiency of the eradication procedures. The efficiency is the probability that an incursion will be detected and successfully eradicated. In this case we can calculate the new probability of entry and establishment and spread, after surveillance is in place, as

\[
\Pr(\text{Incursion with surveillance}) = \Pr(\text{Incursion}) \Pr(\text{Occurs at port with surveillance|incursion}) \Pr(\text{Surveillance system doesn’t detect|Incursion and occurs at port with surveillance}) + \Pr(\text{Incursion}) \Pr(\text{Occurs at port without surveillance|incursion}) \Pr(\text{Surveillance system doesn’t detect|Incursion and occurs at port without surveillance})
\]

where \( \Pr() \) denotes probability and \( \Pr(A|B) \) is the probability of \( A \) given \( B \) has occurred. Based on the quantities defined above this is

\[
h = p \times g \times (1 - e) + p \times (1 - g)
\]

which is the expected probability of entry, establishment and spread after the surveillance system is implemented.

The values \( p \) and \( h \) can then be used in the economic model in Chapter 3 to calculate the expected return on the surveillance effort as an annual cost. This can be compared to the proposed cost of the surveillance system to determine the cost-benefit ratio, and this can then be used in the decision-making process.
We note that more complicated models could be considered but this would be inconsistent with the quality and extent of the available data. The approach provides a simple framework for transparently assessing the logic of abstract surveillance options. Decision-making needs to integrate these insights with the other knowledge and facts that are not integrated into the modelling before final decisions are made.

**Application to future pests**

Before considering the application of the framework it is important to highlight a number of issues. The workshop strongly endorsed the view that pre-border prevention is much more efficient than attempting post-border detection and then mounting an eradication attempt. Eradication is costly and its success uncertain. The active engagement of exporters, importers and shippers in ensuring that bees and their associated pests and pathogens do not have the opportunity to establish is vital. The group strongly endorsed AQIS continuing targeting of bees as serious threats to the Australian honeybee and horticulture industry. The workshop also saw further opportunities to strengthen port operations involvement to ensure an educated and proactive work force actively involved in achieving biosecurity for bee pests and pathogens.

As discussed in the Scope section of the report (Chapter 1) the following pests were identified as being worthy of further analysis:

- *Varroa destructor*
- *Varroa jacobsoni*
- *Tropilaelaps sp (T. clareae and T. koenigerum)*
- *Apis cerana*
- *Apis dorsata*

Chapter 2 provided a detailed assessment of the risk posed by these pests. There is a clear pathway for each of them and the likelihood of arrival is rated high for both *Varroa destructor* and *Varroa jacobsoni*. The majority of this risk occurs at international shipping ports. Thus there is a significant probability of one of the Varroa mites arriving in Australia via *Apis cerana* or *A. mellifera*. The probability of entry, establishment and spread of *Tropilaelaps* mites is rated as very low. Thus Varroa mites represent the major risk. This data is supported by international experience and was supported at the workshop.

For the pests considered in this analysis, the major impact will arise from the impacts on pollination services. Direct impacts on honey production costs will occur, but there will be potential benefits from new economic opportunities providing pollination services. In the economic analysis in Chapter 3 we have considered only the economic impacts on the pollination services. In this analysis the expected cost of a pest that would impact on *Apis mellifera* pollination services is detailed in Table 11 (below).
Table 11  Expected costs of pests that impact on *A. mellifera* pollination services

<table>
<thead>
<tr>
<th>Probability of entry, establishment and spread</th>
<th>Expected cost (Millions) per annum</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>47.1</td>
</tr>
<tr>
<td>Moderate</td>
<td>43.2</td>
</tr>
<tr>
<td>Low</td>
<td>33.5</td>
</tr>
</tbody>
</table>

The workshop considered the use of sentinel hives. There was a clear view among participants that the National Sentinel Hive Program represented a viable approach to early detection of some pests. In considering the potential costs and benefits of using sentinel hives the key assessment that needs to be made is that of their efficiency in detecting particular pests. While most surveillance systems will inevitably detect a disease at some stage after an incursion, if it occurs too slowly for successful management action it will not provide useful information. There is insufficient empirical data to objectively determine how soon pests need to be detected to mount a successful eradication. What is known is that eradication of pests and diseases are typically difficult, especially if there are non-managed populations or regions that can harbour the pest or disease. Recent examples in Australia include Red Imported Fire Ants in Brisbane and Asian Green Mussel and *Apis cerana* in Cairns. The wide distribution of feral bees in Australia and their significant density therefore represents a significant challenge to any eradication strategy for bee pests and diseases.

There was a range of views expressed at the workshop about the probability of eradication of any incursion of honeybee pests or pathogens. While the likelihood will obviously depend on the specifics of any incursion there was a general agreement that failure to detect an incursion at an early stage would lead to significant difficulties. From the results presented in the simulation studies reported here it is apparent that in the simulation presented (four sentinel hives) detection at greater than 12 months after the incursion would lead to movement of mites at least six kilometres. This would typically be beyond the port environment and potentially into residential or peri-urban areas, posing significant detection issues. Thus we propose setting a cut-off time of 12 months between the time of detection from initial incursion, for eradication to be possible. While it is technically attractive to formulate a mathematical relationship between the eradication probability and the time to detection, the lack of data cautions about overcomplicating the model. Realistically, other factors beyond the model mean that even if detection occurs within 12 months, eradication may not be feasible. This includes human mediated transport, misunderstanding of biology, system failure etc. Based on discussions at the workshop we estimate the likelihood of success if detected within 12 months to be 50%. This may seem pessimistic, but reflects experience that eradication of pests in non-managed environments is difficult.

Detection within 12 months can be achieved by a number of strategies. For example, the number of traps can be increased or the detection rate can be increased. It was the strong view of the workshop that major efficiency gains in the surveillance program could come from increasing the efficiency of detection. There was a range of concerns with the current approach. If a single chemical is used for controlling mites we might be building up resistance to that single chemical through our testing process. The protocol of using sticky mats for 48 hours seems inadequate based on the lifecycle of the mite. Treating for seven days would be necessary.
for any chance to observe one or two mites. Rubbish builds up on the mats if they are left for more than 48 hours, which makes it harder to identify materials captured. Some inspectors may not be adequately trained causing further difficulty.

Overall, there was a belief that more thought and experimentation needed to be done to optimise the National Sentinel Hive Program. This might include better training, experimentation in countries that possessed the relevant pest in order to determine the empirical performance of particular protocols, and for examining the spread rates of pests. In addition, genetic techniques could be developed to streamline the identification process and remove the need for extensive dissection/identification work. The feedback from the workshop was that the improvement of detection rates was one of the most important avenues for improving the current system. In the present context we can achieve detection within 12 months with four hives if the probability of detection within the sentinel hive is greater than approximately 20%. We note that, as an incursion is a spatial phenomenon, at some point there is no alternative but to increase the number of traps to provide adequate spatial coverage.

For Australia we consider a surveillance system that covers 95% of risk. Risk in this context relates to trade whose origin is infected with one of the species of mites. Origin in this case could be beyond the last port of call because the bees can persist. Achieving 95% coverage is potentially possible in Australia due to the concentration of trade in a limited number of ports. Appendix 5 contains cargo statistics for the 2006/2007 financial year. From these data we can feasibly cover 95% of the importation volume (in tonnes) by monitoring only 14 ports (but note the analysis in Boland (2005)). This analysis assumes that the total tonnage is a reasonable de-facto measure of risk. It assumes that the risk scales with the number of vessels arriving, as well as the weight of the cargo. In addition it rates all source regions equivalently. As vessels can visit a number of ports before they arrive in Australia this is a conservative assumption.

We calculate the change in the probability of entry, establishment and spread as follows. Indicatively, if we use .85 (the mid point of the high range) for the unrestricted probability we have:

\[ h = 0.85 \times (1 - 0.5) \times 0.95 + 0.85 \times (1 - 0.95) = 0.45 \]

Using the economic analysis summarised in Table 11 this leads to a reduction of risk from High to Moderate, which gives an expected reduction in cost of damage of $3.9 million per annum. Alternatively, we could analyse these results quantitatively using the model in Chapter 3. In this case we use the probability 0.45 in the model to form the cost distribution. The mean of this distribution is $42.7 million. From Table 11, the benefit is thus 47.1-42.7 = $4.4 million per annum. Given the scarcity of available data the qualitative analysis is probably sufficient.

The indicative cost of a sentinel hive has been costed at $1700 per annum per hive (Iain East, personal communication). This is costed as $1000 for diagnostic services and $700 for maintenance of the hive. Thus four hives at 14 locations gives 56 hives, which would cost, under this formula, $95200 per annum. This would obviously increase with administrative overheads, but is significant lower than the potential benefit. It would involve a modest increase to the current program (Iain East, personal communication).

The alternative was to consider the use of bait hives. Bait hives are hives that are either empty or baited with honey or a pheromone. It was noted that honey is impractical if other bees are in the vicinity, as robbing will quickly occur. For direct detection of *Apis cerana* and *Apis dorsata* sentinel hives were considered impractical and bait hives represent the only feasible, widely applicable alternative available at this stage. As was noted earlier, the efficiency of bait hives was considered by the experts rather than being explicitly modelled.
We have not been able to find relevant literature providing empirical evidence for the efficiency of bait hives. Expert’s views on the efficacy of bait hives were mixed. While many participants at the workshop saw them as useful, the probability that they would detect an incursion was unclear. There are a wide variety of locations for swarms to move to in the port environment, and a bait hive is simply one of those locations. Also, use of pheromones means that the hives would need to be emptied frequently in swarming season to remove feral swarms rather than new incursions. Sentinel hives for bee pests can benefit from interactions between bees, rather than requiring a complete swarm to find the location. There was general agreement that the bait hives needed to be targeted for different species. For example, *Apis cerana* favours hollow logs and these can be utilised as bait hives.

The integrated analysis for *A. cerana* and *A. dorsata* is much more speculative. We calculate the reduction in the probability of importation, establishment and spread over a range of values for detection efficiency as follows.

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>Calculation</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>( h = .85 \times .95 \times (1 - .05) + .85 \times (1 - .95) )</td>
<td>0.81</td>
</tr>
<tr>
<td>10%</td>
<td>( h = .85 \times .95 \times (1 - .1) + .85 \times (1 - .95) )</td>
<td>0.77</td>
</tr>
<tr>
<td>15%</td>
<td>( h = .85 \times .95 \times (1 - .15) + .85 \times (1 - .95) )</td>
<td>0.73</td>
</tr>
<tr>
<td>20%</td>
<td>( h = .85 \times .95 \times (1 - .2) + .85 \times (1 - .95) )</td>
<td>0.69</td>
</tr>
</tbody>
</table>

If bait hives are only 5% efficient (i.e. the chance that an incursion is detected by them and then successfully eradicated) we have only a marginal reduction in the detection probability. As a qualitative analysis it does not change the category, and as a quantitative analysis its effect is approximately $400K per annum. While 5% may seem pessimistic, it reflects the considerable uncertainty about their effectiveness. For larger efficiencies the benefit increases. At 20% efficiency there is a decrease in the likelihood category, and an approximate benefit of $1.6 million per annum. While considerably uncertain, a 20% efficiency would appear to be associated with a larger number of bait hives deployed per hectare than four or five.
6. Application of the model to the National Sentinel Hive Program

Introduction

The modelling framework provides an opportunity to explore potential options for the deployment of sentinel hives at chosen locations as part of the National Sentinel Hive Program. In order to gain perspective on ways of improving a detection system it would be useful to note the effects of:

- distance of hives to coast
- the number of sentinel hives and
- the sensitivity of the detection method at hives

on the overall time taken to detection an incursion. To address these questions we have run a number of simulated incursions based on the model presented in Chapter Four. In these simulations the following values were used as defaults unless they are varied as part of the investigation:

- parameter lambda (the average rate of swarming per hecatare is set to 0.5
- probability of hives dying off is 0.2
- probability of detection is set to 0.1
- distance from hive to coast is 0.5 km
- the number of sentinel hives is 4

Distances travelled during foraging and swarming are as noted in Chapter 4.

Effect of Distance of Hives to Coast

The distance of the hives was varied from 100m to 3km away from the coast in increments of 100m. For each distance, we simulated 250 incursions and record the time taken to detection. These values are plotted in Figure 6. Increasing the distance between the hives and the coast leads to increased time to detection however, the time to detection is not very sensitive to distance to the coast. Note that this effect would increase the further from the coast the traps where located and the area infected would increase exponentially.
Figure 6  Estimated change in time to detection as the sentinel hives are moved from the coast

**Effect of Number of Sentinel Hives**

The number of sentinel hives was varied between two and twenty in increments of two hives. For each value for the number of hives we simulated 250 incursions and noted the time taken to detection. These values are plotted in Figure 7. Increasing the number of hives leads to smaller detection times but, most of the possible gains in efficiency (reduction in detection time) was achieved once six to eight hives were deployed.
Effect of Sensitivity of Detection Method:

The probability of detection was varied between 0 and 1. This is equivalent to varying the sensitivity of the detection (trapping) system. We have generated 5000 values in this interval and for each one simulated a single incursion. The time taken to detection is plotted against the corresponding probability of detection in Figure 8. As the probability of detection increases, the time to detection of the incursions decreases. For poor detection methods (sensitivity less than 0.15), the time to detection can be extremely large. However, even if a highly sensitive detection method is employed, the time to detection can still be of the order of several months.

Discussion

In attempting to provide a practical assessment of Australia’s bee surveillance system, the National Sentinel Hive Program, a number of points should be noted. Firstly, the model and the results above are applicable to any trapping system eg. sentinel hives, log traps, bait hives, sticky sugar stations (a new technique developed by Biosecurity Queensland) but the efficiency of detection and transmission must be chosen appropriately for the particular pest, parasite or disease of interest. For example, log traps will not be applicable to detecting incursions of species other than *A. cerana* due to the particular pheromone lure used, and would therefore have a probability of detection of zero for other species.
Secondly, the results are not objective inferences because the model is dependent upon the input parameters. Whilst these input parameters have been estimated by expert opinion, they are still only opinion. The value of the model and the results is in the trend patterns reported in the results. Whilst a formal sensitivity analysis was not conducted, the results above show very little variation in the overall time to detection once the number of hives is at least six, the distance from the hives to the coast in less than 1.5 km and the sensitivity of the trapping system is at least 0.2. It should however be noted that even when these parameters are optimised, the time to detection is still likely to be of the order of 10 months after the incursion occurs.

Thirdly, the ability to detect any incursion is limited by other factors not included in the model including the chance that pathogens will be present in the sentinel hives when testing is carried out. For parasites that continuously occupy the hive such as Varroa, the sensitivity of the trapping system will still increase as time from the incursion increases eg. as the number of Varroa in a sentinel hive increases, the probability of detecting the Varroa will increase.
7. Discussion, Implications and Recommendations

Discussion

A major limitation of this analysis is the lack of clear empirical data about the efficiency of bee pest surveillance systems. Experiments should be performed outside Australia to determine the ability of sentinel hives to detect pest incursions, as well as the rate that this occurs over time. For example, uninfested hives could be placed at varying distances from infested hives and observed over time to track the process of infestation. Different detection systems could be used and contrasted to determine the most cost-effective regime. While this would be expensive it could be cost-effective when recurrent expenditure is considered.

The economic analysis could be further developed in a number of ways, particularly in terms of the way it could be communicated to the bee surveillance community and used in risk mitigation strategy formulation. There is always a danger in using probabilistic models for prediction, particularly when there are non-market goods that may be affected by policy decisions (i.e. environmental, social and cultural factors). In these circumstances probability models add limited value. However, given the significant pollination (i.e. private) benefits, there may be a case for revising the model to improve its explanatory power. A spatially explicit modelling approach may be more appropriate given the large geographic spread of honeybee surveillance beneficiaries. The full extent of inter-temporal benefits and costs also need to be clarified since the choice of time-frame over which surveillance activities are to be viewed has a large impact on results due, in part, to the process of discounting. Given this, it is important in any modelling exercise that all components reflect the overall quality of the information. It is typically unwise to have a very detailed model of one component of the system when other components are very uncertain. If this is the case, the impact of the uncertain component dominates and the additional effort may be wasted.

The analysis suggests that sentinel hives have the potential to deliver positive cost-benefit outcomes. This is consistent with the views of the participants at the project workshop. Bait hives appear more problematic and the reasoning behind their effectiveness is not as clear. As well, there is not a consensus among the experts that they will be an effective measure. More work needs to be done to consider the potential benefits of their use.

With finite resources there will always be competition for available funds. Other biosecurity programs/choices may also have positive cost-benefit outcomes and choices may need to be made between them. For instance, resources could be concentrated on pre-border activities if it was thought to be more efficient. Any attempt at establishing such a ranking is beyond the scope of this analysis.

An option that was considered and has not been discussed previously in the report was the use of honeybee exclusion zones. At their most extreme, these zones could be maintained by active poisoning of honeybees. They would thus provide a barrier to spread and ultimate establishment of invasive bee species and associated pests. Maintenance of a partial exclusion system would make it a more manageable task to investigate all hives found within the zone. While the workshop was unanimous in agreeing that bee exclusion zones would significantly improve surveillance systems, the general view was that it was unlikely to be practical to maintain such zones by chemical means. Concerns about potential impacts on wildlife and contamination of honey products for human consumption meant that it was unlikely to be a
general approach, but that it could be used in specialised circumstances after appropriate risk assessment and mitigation. Active management of bees within port areas, as already occurs in some locations, was seen as an achievable goal and was strongly encouraged.

The qualitative analysis used here has significant limitations. While it is the standard approach applied by Biosecurity Australia, its reliance on qualitative descriptors means that there is potential ambiguity in its meaning. Thus it is important that users consider carefully the indicative probability ranges to ensure the interpretability of the results of the analysis. The objective analysis of the costs and benefits requires clear communication of assumptions and meanings. All techniques that can limit the ambiguity should be considered. Note that this is not an argument against simple assessment, in line with the quality of the available data. It is an argument for clear communication.

**Implications**

This framework will assist in further design of strategies and procedures for protecting the Australian honeybee and horticulture industries.

**Recommendations**

- That the risk-based framework developed here be adopted as the mechanism for determining future costs and benefits of improved surveillance for honeybee pests and diseases.
- That the current National Sentinel Hive Program be maintained and improved for the early detection of exotic bee mites using information provided in this report.
- That the active management of honeybees within port areas, as already occurs in some locations, be strongly encouraged.
- That targeted studies be funded to obtain clear empirical data of the efficiency of sentinel hives to detect exotic bee mites. Experiments should be performed outside Australia to determine the sensitivity of sentinel hives to detect low numbers of bee mites.
- That surveillance for the early detection of *A. cerana* be re-examined urgently with the aim of developing a new surveillance system that can detect low numbers of bees at remote locations.
- That AQIS continue to target bees as serious threats to the Australian honeybee industry and other industries that depend on honeybees for pollination and that port operations be strengthened to ensure a well educated and proactive work force to safeguard biosecurity for bee pests and diseases.
Appendix 1  Assessment methodology

(From Pathway analysis for the entry of exotic bees and exotic bee pests into Australia)

Assessment of the probability of entry, establishment and spread

Details of how to assess the probability of entry, probability of establishment and probability of spread of a pest are given in ISPM 11 (FAO 2004). A summary of this process is given below, followed by a description of the qualitative methodology used in this impact risk analysis.

Probability of entry

The probability of entry describes the probability that a quarantine pest will enter Australia as a result of trade in a given commodity, be distributed in a viable state in the pest risk analysis (PRA) area and subsequently be transferred to a host. It is based on pathway scenarios depicting necessary steps in the sourcing of the commodity for export, its processing, transport and storage, its use in Australia and the generation and disposal of waste. In particular, the ability of the pest to survive is considered for each of these various stages.

The probability of entry is divided into two components:

1. **Probability of importation**: the probability that a pest will arrive at the quarantine boundary; and

2. **Probability of distribution**: the probability that the pest will be distributed in the PRA area and subsequently transfer to a susceptible host.

Probability of establishment

Establishment is defined as the ‘perpetuation for the foreseeable future, of a pest within an area after entry’ (FAO 2004). In order to estimate the probability of establishment of a pest, reliable biological information (lifecycle, host range, epidemiology, survival, etc.) is obtained from the areas where the pest currently occurs. The situation in the PRA area can then be compared with that in the areas where it currently occurs and expert judgement used to assess the probability of establishment.

Probability of spread

Spread is defined as ‘the expansion of the geographical distribution of a pest within an area’ (FAO 2004). The probability of spread considers the factors relevant to the movement of the pest, after establishment on a host plant or plants, to other susceptible host plants of the same or different species in other areas. In order to estimate the probability of spread of the pest, reliable biological information is obtained from areas where the pest currently occurs. The situation in the PRA area is then compared with that in the areas where the pest currently occurs and expert judgement used to assess the probability of spread.
Assigning qualitative likelihoods for the probability of entry, establishment and spread

The term ‘likelihood’ is used for the descriptors of probability of entry, establishment and spread. Qualitative likelihoods are assigned to each step of entry, establishment and spread. Six descriptors are used: high; moderate; low; very low; extremely low; and negligible. Descriptive definitions for these descriptors and their indicative probability ranges are given in Table 12 (below). The indicative probability ranges are only provided to illustrate the boundaries of the descriptors. These indicative probability ranges are not used beyond this purpose in qualitative PRAs. The standardised likelihood descriptors and the associated indicative probability ranges provide guidance to the risk analyst and promote consistency between different risk analyses.

Table 12 Nomenclature for qualitative likelihoods

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Descriptive definition</th>
<th>Indicative probability (P) range</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>The event would be very likely to occur</td>
<td>$0.7 &lt; P \leq 1$</td>
</tr>
<tr>
<td>Moderate</td>
<td>The event would occur with an even probability</td>
<td>$0.3 &lt; P \leq 0.7$</td>
</tr>
<tr>
<td>Low</td>
<td>The event would be unlikely to occur</td>
<td>$0.05 &lt; P \leq 0.3$</td>
</tr>
<tr>
<td>Very low</td>
<td>The event would be very unlikely to occur</td>
<td>$0.001 &lt; P \leq 0.05$</td>
</tr>
<tr>
<td>Extremely low</td>
<td>The event would be extremely unlikely to occur</td>
<td>$0.000001 &lt; P \leq 0.001$</td>
</tr>
<tr>
<td>Negligible</td>
<td>The event would almost certainly not occur</td>
<td>$0 \leq P \leq 0.000001$</td>
</tr>
</tbody>
</table>

The likelihood of entry is determined by combining the likelihood that the pest will be imported into the PRA area and the likelihood that the pest will be distributed within the PRA area, using a matrix of rules (Table 13). This matrix is then used to combine the likelihood of entry and the likelihood of establishment and spread to determine the overall likelihood of entry, establishment and spread.
<table>
<thead>
<tr>
<th></th>
<th>High</th>
<th>Moderate</th>
<th>Low</th>
<th>Very low</th>
<th>Extremely low</th>
<th>Negligible</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>Very low</td>
<td>Extremely low</td>
<td>Negligible</td>
</tr>
<tr>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
<td>Very low</td>
<td>Extremely low</td>
<td>Negligible</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>Very low</td>
<td>Very low</td>
<td>Extremely low</td>
<td>Negligible</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very low</td>
<td>Extremely low</td>
<td>Extremely low</td>
<td>Negligible</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extremely low</td>
<td>Negligible</td>
<td>Negligible</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 13  Matrix of rules for combining qualitative likelihoods
Figure 9  Distances travelled while swarming
Figure 10  Distances travelled while foraging
Figure 11  Histograms of time to discovery under sixteen situations
Figure 12  Histograms of distance travelled until time of discovery for sixteen situations
Figure 13  Histograms of area of grid affected by pathogen by time of discovery for sixteen situations
Appendix 3  Simulation Example

The following series of figures show a particular simulation run. The simulation is carried out on a monthly time step but we give figures from every two months starting in January. This particular simulation ends in November with detection. The colour of individual hectares indicates the age of the pathogen incursion at that hectare.

Figure 14  Example Simulation – January

Age of Infection (months) Jan
Figure 15  Example Simulation – March

Age of Infection (months) Mar

Distance inland (km)

Distance along Coast (km)
Figure 16  Example Simulation – May

Age of Infection (months) May

Distance along Coast (km)

Distance inland (km)
Figure 17  Example Simulation – July

Age of Infection (months) Jul
Figure 18  Example Simulation – September

Age of Infection (months) Sep
Figure 19  Example Simulation – November

Age of Infection (months) Nov
Appendix 4  Workshop Attendees and Agenda

Simon Barry, CSIRO
Iain East, Australian Government Department of Agriculture Fisheries and Forestry
Nick Annand, NSW State Representative
Lindsay Burke, Chair, Biosafety Committee, AHBIC
Denis Anderson, CSIRO
David Clifford, CSIRO
Rob Duthie, Kalang Pty Ltd
Gerald Martin, Agreresults Pty Ltd
David Dall, RIRDC
Michael Stedman, SA State Representative
Joe Riordan, VIC State Representative
Hamish Lamb, QLD State Representative
Doug Somerville, NSW State Representative
David Cook, CSIRO
Greg Hood, Australian Government Department of Agriculture Fisheries and Forestry
Bruce W, Member of RIRDC Honey Bee Research and Development Committee
WORKSHOP Tuesday 16 June 2009

Hosted by CSIRO Mathematical and Information Sciences, Australian National University, Canberra, ACT.

Background: A small team has been funded by RIRDC to consider a risk-based assessment of possible surveillance systems for pests and diseases of honeybees. The aim is to produce a framework such that policy makers can assess the risks and consequences of any decision. As part of this project a working group of relevant experts is to be convened and this workshop is the group’s first meeting. A proposed methodology will be presented for discussion.

Workshop aim: To assess a proposed methodology for estimating the costs and benefits of surveillance systems for bee pests and to identify data sources and expert knowledge for key parameters.

Agenda

10:00am Welcome and introduction (Simon Barry)

10:15am Policy background and existing programs (Iain East DAFF)

10:30am Project background and methodology (Simon Barry)

11:30am Pathway analysis (Rob Duthie)

12.15am Surveillance efficacy (David Clifford)

1.00 pm Lunch

1.45 pm Economic impacts of honeybee pests (David Cook)

2.45 pm Integration and summary of results (Simon Barry/All)

3.15 pm Afternoon tea

3.30pm Alternative approaches

5.00 pm Finish
# Appendix 5  National Cargo Statistics


<table>
<thead>
<tr>
<th>Port</th>
<th>Total import('000 $')</th>
<th>Total import(Tonnes)kg</th>
<th>Proportion of total trade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>133030516</td>
<td>77538252</td>
<td></td>
</tr>
<tr>
<td>Sydney</td>
<td>42916202</td>
<td>15687719</td>
<td>0.20232232</td>
</tr>
<tr>
<td>Melbourne</td>
<td>39960079</td>
<td>12191929</td>
<td>0.35959924</td>
</tr>
<tr>
<td>Brisbane</td>
<td>20373322</td>
<td>12025169</td>
<td>0.51464848</td>
</tr>
<tr>
<td>Fremantle/Perth</td>
<td>12437371</td>
<td>8947751</td>
<td>0.63044742</td>
</tr>
<tr>
<td>Darwin</td>
<td>1910455</td>
<td>5164451</td>
<td>0.69664994</td>
</tr>
<tr>
<td>Geelong</td>
<td>3372034</td>
<td>5120860</td>
<td>0.76269261</td>
</tr>
<tr>
<td>Townsville</td>
<td>1093761</td>
<td>4064398</td>
<td>0.81511094</td>
</tr>
<tr>
<td>Adelaide</td>
<td>3415874</td>
<td>2229086</td>
<td>0.84385915</td>
</tr>
<tr>
<td>Gladstone</td>
<td>588767</td>
<td>2126811</td>
<td>0.87128832</td>
</tr>
<tr>
<td>Port Kembla</td>
<td>384862</td>
<td>2103394</td>
<td>0.89841550</td>
</tr>
<tr>
<td>Newcastle</td>
<td>606919</td>
<td>1144133</td>
<td>0.91317123</td>
</tr>
<tr>
<td>Conf NT Ports</td>
<td>666964</td>
<td>1139939</td>
<td>0.92782786</td>
</tr>
<tr>
<td>Bunbury</td>
<td>154397</td>
<td>1094024</td>
<td>0.94198239</td>
</tr>
<tr>
<td>Port Hedland</td>
<td>497559</td>
<td>623739</td>
<td>0.95026614</td>
</tr>
<tr>
<td>Whyalla</td>
<td>75606</td>
<td>482013</td>
<td>0.95624306</td>
</tr>
<tr>
<td>Mackay</td>
<td>305382</td>
<td>472003</td>
<td>0.96230425</td>
</tr>
<tr>
<td>Dampier</td>
<td>1942952</td>
<td>451126</td>
<td>0.96814853</td>
</tr>
<tr>
<td>Portland</td>
<td>232499</td>
<td>357476</td>
<td>0.97275882</td>
</tr>
<tr>
<td>Cairns</td>
<td>344891</td>
<td>349848</td>
<td>0.97727078</td>
</tr>
<tr>
<td>Esperance</td>
<td>201777</td>
<td>321673</td>
<td>0.98141932</td>
</tr>
<tr>
<td>Launceston</td>
<td>213119</td>
<td>234993</td>
<td>0.98445003</td>
</tr>
<tr>
<td>Hobart</td>
<td>47370</td>
<td>180455</td>
<td>0.98677732</td>
</tr>
<tr>
<td>Port Lincoln</td>
<td>89693</td>
<td>132047</td>
<td>0.98848038</td>
</tr>
<tr>
<td>Burnie</td>
<td>138020</td>
<td>118177</td>
<td>0.9900443</td>
</tr>
<tr>
<td>Weipa</td>
<td>72570</td>
<td>114261</td>
<td>0.99147803</td>
</tr>
<tr>
<td>Broome</td>
<td>365382</td>
<td>113406</td>
<td>0.99294062</td>
</tr>
<tr>
<td>WA Offshore Terminals</td>
<td>15371</td>
<td>107602</td>
<td>0.99432834</td>
</tr>
<tr>
<td>Westernport</td>
<td>61870</td>
<td>81330</td>
<td>0.99537724</td>
</tr>
<tr>
<td>Wyndham</td>
<td>55646</td>
<td>80176</td>
<td>0.99641126</td>
</tr>
<tr>
<td>Port Walcott</td>
<td>57866</td>
<td>73364</td>
<td>0.99735743</td>
</tr>
<tr>
<td>Albany</td>
<td>37231</td>
<td>73328</td>
<td>0.99830313</td>
</tr>
<tr>
<td>Geraldton</td>
<td>259121</td>
<td>52264</td>
<td>0.99897717</td>
</tr>
<tr>
<td>Devonport</td>
<td>10540</td>
<td>34357</td>
<td>0.99942023</td>
</tr>
<tr>
<td>Other Ports NT</td>
<td>13393</td>
<td>18894</td>
<td>0.99966394</td>
</tr>
<tr>
<td>Wallaroo</td>
<td>5753</td>
<td>15025</td>
<td>0.99985772</td>
</tr>
<tr>
<td>Other Ports WA</td>
<td>46431</td>
<td>5920</td>
<td>0.99993407</td>
</tr>
<tr>
<td>Other Ports Vic</td>
<td>44094</td>
<td>1564</td>
<td>0.99995424</td>
</tr>
<tr>
<td>Port Pirie</td>
<td>445</td>
<td>1177</td>
<td>0.99996942</td>
</tr>
<tr>
<td>Bundaberg</td>
<td>5827</td>
<td>851</td>
<td>0.99998039</td>
</tr>
<tr>
<td>Thursday Island</td>
<td>5444</td>
<td>815</td>
<td>0.99999098</td>
</tr>
<tr>
<td>Other Ports NSW</td>
<td>241</td>
<td>248</td>
<td>0.99999410</td>
</tr>
<tr>
<td>Other Ports SA</td>
<td>2060</td>
<td>158</td>
<td>0.99999614</td>
</tr>
<tr>
<td>Port</td>
<td>import('000 $')</td>
<td>import(Tonnes)kg</td>
<td>Proportion of total trade</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------</td>
<td>------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>Total</td>
<td>133030516</td>
<td>77538252</td>
<td></td>
</tr>
<tr>
<td>Conf Aust Ports</td>
<td>0</td>
<td>96</td>
<td>0.999997382</td>
</tr>
<tr>
<td>Other Ports Qld</td>
<td>319</td>
<td>63</td>
<td>0.999998194</td>
</tr>
<tr>
<td>Carnarvon</td>
<td>286</td>
<td>47</td>
<td>0.999998801</td>
</tr>
<tr>
<td>Twofold Bay</td>
<td>382</td>
<td>36</td>
<td>0.999999265</td>
</tr>
<tr>
<td>Cape Lambert</td>
<td>29</td>
<td>32</td>
<td>0.999999678</td>
</tr>
<tr>
<td>Coffs Harbour</td>
<td>342</td>
<td>25</td>
<td>1</td>
</tr>
</tbody>
</table>
References


Biosecurity Australia, 2001, Guidelines for Import Risk Analysis, Agriculture, Fisheries and Forestry Australia/Biosecurity Australia, Canberra.


URL http://www.R-project.org


The Australian honeybee industry produces honey and other bee products for domestic consumption and export, through apiculture of *Apis mellifera*. The industry has an estimated GVP of A$80 million. In addition, the annual benefit of apiculture to general agriculture through plant pollination in Australia is estimated to range from A$4 to 6 billion.

Because of the significant value of this industry there is a need for effective biosecurity. A component of this is the use of surveillance. This report considers a risk-based framework for exploring the costs and benefits of surveillance for exotic honeybee pests and diseases.

This project is part of the Pollination Program – a jointly funded partnership with the Rural Industries Research and Development Corporation (RIRDC), Horticulture Australia Limited (HAL) and the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF). The Program is managed by RIRDC and aims to secure the pollination of Australia’s horticultural and agricultural crops into the future on a sustainable and profitable basis. R&D in this program is primarily to raise awareness to protect pollination in Australia.

Most of RIRDC’s publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.