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Rural Industries Research and Development Corporation

Pollination Aware

Raising the Profile of an Undervalued Service

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Foreword

The contribution to Australia's agricultural output from crops and commodities that are responsive to pollination by insects is significant and has the potential to grow strongly. The complement of insect-pollination-responsive crops includes many that provide high value utilisation of limited resources such as water and soil fertility.

Whilst many different insects can effect pollination of one or another of these responsive crops, the European honey bee has for many reasons become the predominant pollination agent of choice in most parts of the world including Australia and producers of responsive crops have come to depend on the services provided by honey bees to achieve economically viable productivity.

In Australia, possibly more so than in other comparable agricultural economies, producers of pollination-responsive crops tend to rely on incidental pollination by either feral honey bees or bees managed for honey production rather than on paid services by bees specifically managed and provided for pollination purposes. This reliance on unmanaged services could well result in sub-optimal levels of pollination and come at a cost to both the yield and quality of the crop.

The risks associated with relying on incidental pollination are compounded by the threat posed by exotic pests and diseases of honey bees, and the varroa mite in particular. In the event of an incursion of varroa it will be the unmanaged bee colonies and the feral bee population in particular that will be hardest hit, along with producers who rely on them to pollinate responsive crops.

The research reported here has as a primary objective the consolidation of available information on pollination in Australia at commodity/industry, regional/state and national levels, to provide a base for more detailed decision making on the management of pollination at all these levels, as well as at the level of the individual pollination-responsive enterprise.

In pursuing this objective, the work has highlighted the risks associated with a heavy reliance on incidental pollination; identified significant deficiencies in the information available to producers of pollination-responsive crops on the responsiveness of their crops and the pollination levels required to achieve optimal yield and quality; and, for what is believed to be the first-time, provided a reasonably comprehensive representation of the temporal and geographic spread of pollination-responsive crops in Australia.

This, in turn, has allowed an estimate to be made of the capability required to service Australia's total pollination task and identified issues that would be associated with maintaining a managed honey bee population sufficient to both service the pollination needs of the country and exploit Australia's honey production potential.

This research should assist producers of insect-pollination-responsive crops to optimise the management of their enterprises and aid apiarists and those providing pollination services, in particular, to manage their businesses whether or not varroa is present in Australia. The work should also be of benefit to researchers, advisors and regulators servicing the pollination and honey bee industries in identifying priority areas for attention and investment.

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.. Information on the Pollination Program is available online at www.rirdc.gov.au

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.

Tony Byrne
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Executive Summary

Almost without exception, the world's agricultural, horticultural and silvicultural industries are based on the growth of one or another of the seed plants (gymnosperms and angiosperms), and in turn the reproduction of these plants and the production of commercially valuable outputs from them relies in most cases, on the fertilisation of an ovule by pollen which occurs after pollination.

In some important agricultural species pollination is effected by the wind. For most other commercial species the intervention of insects, and particularly honey bees, is required for effective pollination. In many countries, pollination of commercial plant species that are responsive to pollination by honey bees is effected by the deliberate introduction of honey bees to the crop at flowering, either by the grower of the crop or by an apiarist as part of a commercial arrangement with the grower.

Whilst pollination by bees is as important in Australian agriculture as it is anywhere else in the world, this country's large population of feral honey bees and extensive honey producing industry mean that pollination of commercial crops by bees often occurs without any deliberate intervention from and at no cost to, the producer of the commodity. As a result of this widespread incidental pollination, the use of commercial pollination services and the level of awareness of the importance of pollination by bees to Australia's rural output are lower than might be expected given the importance of pollination-responsive commodities to Australia's rural industries.

The contribution from incidental and 'free' pollination services is substantial and very important to Australia, but there is insufficient research-based information available to determine whether or not the level of pollination achieved is sufficient to realise the full potential of a specific crop in terms of yield and quality, or to determine the uniformity of its effect across a crop, plantation or orchard. Logic and the limited research and anecdotal information available would suggest that by and large Australia's bee-pollination-responsive crops are not being pollinated at economically or biologically optimal levels. The absence of detailed research means it is difficult to make a conclusive judgement on the matter and impossible to assess what yield or quality benefit (that would result from optimal levels of pollination) is being foregone.

This lack of knowledge and the consequent inability to appropriately manage such an important process represents a risk to pollination-responsive enterprises and industries and should be a priority for research and management attention. In the case of Australia's pollination-responsive agricultural industries, two factors exacerbate the risk posed by this state of affairs.

First, should the honey bee pest, varroa mite, enter and become established in Australia, the contribution from incidental pollination could diminish to insignificance in the space of five to ten years, almost certainly resulting in significant reductions in the yield and quality of pollination-responsive crops. Second, as international competitive pressures and rising costs of production squeeze the margin between costs and returns enjoyed by the producers of pollination-responsive commodities, the inability to measure or manage losses in output and revenue resulting from sub-optimal levels of pollination could be the element that causes an enterprise to fail.

At the level of industry or government, the same limitations on knowledge of and ability to manage a process such as pollination make it very difficult to determine appropriate levels of investment in research or risk reduction programs, and the priorities for such investments.

This study is intended as: first, an attempt to consolidate the current knowledge of best-practice management of pollination under Australian conditions; second, a basis for programs to raise awareness of the importance of pollination to optimal productivity in responsive commodities; third, a foundation for determining priorities for research to improve the knowledge and management of pollination; and fourth, a basis for investing in programs to manage the risks posed by varroa and other exotic honey bee pests and diseases.

The study comprises:

- a review of pollination and the factors that determine its success as a biological process
- a consideration of pollination in agriculture and horticulture with a particular focus on the circumstances applying in Australia, including the risks facing those with an interest in pollination in this country and the possible impacts of those risks should they be realised
- an analysis of the pollination process and its management in a range of pollination-responsive commodities produced in Australia. This information is presented in both summary form and as 35 case studies, each dealing with a single pollination-responsive commodity or a small group of commodities that are either closely related genetically or that have much in common in the management of their pollination.
- a consolidation of the information for each of these commodities into a overview of the pollination supply-demand relationship as it is currently understood and applies in Australia, and how that relationship might be affected by an incursion of varroa or some other serious pest or disease of honey bees.

Whilst there is much information on pollination accessible through the literature this study reveals that:

- there are significant gaps in the available knowledge
- the information that is available is often not always conclusive nor is it always consistent
- much of the information available is drawn from international experience and its direct relevance and applicability to Australia circumstances may be questionable.

Apart from a relatively small number of highly pollination-responsive and specialist industries, such as almonds and seed crops where pollination is well managed, it is likely that the importance of insect pollination is not fully appreciated and as a result is not optimally managed by the majority of producers.

In particular, the apparent reliance on incidental pollination by feral bees or other insects for most moderately pollination-responsive commodities probably means that the pollination of many of these crops is not at economically optimal levels. Further, as individual plantings of responsive commodities get larger the contribution from incidental pollination will be reduced to essentially an edge effect, leaving an even greater proportion of these crops sub-optimally pollinated.

In summary, the information presented here indicates that in 2005/06 the total area of pollination-responsive crops, including both annual and perennial species, grown in Australia exceeded 970,000 hectares. Further, it also indicates that in the peak month of September and in the absence of any significant contribution from feral bees or other insect pollination agents, optimal pollination of economically responsive crops requiring pollination in that month would have required more than 480,000 colonies of honey bees to be available to be deployed for this purpose.

Whilst the basis for the methodology used here to derive insect-pollination capacity requirements in the event that varroa effectively eliminates feral honey bee populations may be subject to review and improvement upon more and better information becoming available, the indications from this study are that the total capacity requirement to achieve optimal pollination under such circumstances will be significantly greater than might previously have been anticipated.

The authors recognise that given the limits on the information used to derive the pollination capability requirements in the presence of a bee pest or disease that eliminates feral bees in Australia, the derived information is itself subject to significant margins for error. Further, because there is no evidence that the prime candidate pest or disease, varroa, is present in Australia, the conclusions drawn here are necessarily hypothetical and speculative.

In recognising these limits, the authors nonetheless believe that the information presented in this report and the conclusions drawn have a value in that they satisfy objectives of the study, which are:

- to assist pollination service users and providers to better understand aspects of the scale, geography and seasonality of demand for pollination services, and thereby enhance their decision making, planning and risk management in regards to pollination-service-related business activities

- to assist industries with an interest in honey bee pollination and their advisers to better understand the current and potential market dynamics associated with the provision and use of pollination services and in particular to better understand the potential impacts of an incursion of varroa or some other severe pest or disease on their industry, and thereby plan to mitigate these effects

- to similarly assist national and state government agencies with interests and responsibilities of relevance to the pollination industry in comprehending the scale and complexity of the industry in a 'post-varroa' scenario, and planning to discharge their responsibilities and preserve their interests in such a scenario

- to provoke and hopefully assist researchers in relevant scientific, social and economic fields to identify and address the deficiencies in knowledge revealed by this analysis.

The particular information required to be collected and/or researched to enable better management of the pollination task at all levels in Australia includes:

- current, locally relevant information on the responsiveness of key crops and commodities to pollination and the stocking rates and management practices required to achieve economically optimal pollination under Australian conditions. Particular attention should be paid to the management of pollination for what might be termed 'moderately' and 'marginally' responsive crops, including pome fruit, stone fruit, soybeans, lupins and sunflower. This would include information concerning interactions, if any, between pollination and other management variables that influence the yield and quality of produce from responsive species

- reliable information on the contribution to the pollination task made by feral honey bees and non-honey bee insect pollination agents, and the circumstances and conditions that favour these insects and thereby enhance their contribution

- more specific and direct information on annual honey production in Australia, including aspects of the seasonality and geography of honey production and the number of colonies committed to honey production in any month

- more readily accessible information on the production of pollination-responsive commodities in Australia, particularly in those instances where pollination-responsive species are grouped with non-responsive commodities for the purposes of data collection

- information that would assist in the incorporation of melliferous species into future environmental tree planting and revegetation projects to expand the resources available to apiarists and in particular to provide resources to maintain and build the strength of colonies in the period from April to July each year when other resources are least available. This would include information on the development of supplementary feeding formulae and management programs to assist apiarists to maintain and build colony condition during the same period each year

- determination of the key components of a pollination quality assurance protocol to improve the confidence of both service providers and users in the provision of commercial pollination services.

This study, first, tentatively concludes that the current perception of the contribution to pollination services from incidental sources including feral bees and non-honey bee pollination agents is probably significantly overstated. Second, whilst the study includes no specific recommendations with regards to biosecurity management to reduce the likelihood and impact of an incursion of varroa or some other exotic bee pest or disease, there should be no inference other than that such an incursion would:

- have strong negative impacts on the apiary and pollination industries resulting in a significant deterioration in the international competitiveness of both
- warrant all reasonable endeavours on the part of governments and industry participants to:
  - exclude the entry of these pests and diseases and in particular varroa
  - implement practices and protocols to enhance the prospects of early detection of such an incursion should it occur
  - develop and test plans to eradicate, control or manage an incursion
  - provide all interested parties with the information, training and materials to mitigate the effects of these pests and diseases should any one of them become established in Australia.

Indeed, a conclusion of this study is that an enhanced interest in, awareness of, capability and capacity for and provision and use of managed, commercial pollination services should constitute a significant element of a comprehensive strategy for managing and mitigating the consequences of the incursion and establishment of varroa or other exotic pests and diseases of honey bees.

1. Background

The Rural Industries Research and Development Corporation (RIRDC) commissioned Strategen Environmental Consultants Pty Ltd (Strategen) to undertake a study of various aspects of the pollination industry in Australia. Strategen is a mid-sized consultancy based in Perth. Dr Robert Keogh, the General Manger of Strategen, has extensive experience across a wide range of agricultural industries in various parts of Australia, and was a principal researcher and author of the report, *Pollination Australia: Biosecurity risk management* (Brous and Keogh 2008), prepared for RIRDC.

This pollination project is managed by RIRDC as part of its Pollination R&D Program, and is jointly funded by RIRDC and Horticulture Australia Limited (HAL). HAL has amongst its members industries relying on the cultivation of crops responsive to insect pollination to achieve optimal productivity.

A primary objective of the project is to consolidate available information on pollination in Australia at commodity/industry, regional/state and national levels to provide a base for more detailed decision making on the management of pollination at all these levels, as well as at the level of the individual pollination-responsive enterprise.

The study is also intended to enhance awareness of pollination and its importance at all the levels referred to above amongst the producers of pollination-responsive commodities and the beekeepers that service their needs, as well as amongst researchers and advisers to these industries and politicians and bureaucrats in state and federal governments.

The study has been approached within the context of the threat posed to, and potential impact upon, Australia's apiary and pollination-responsive industries by the varroa mite and other pests and diseases of honey bees. Varroa is universally regarded as one of the most serious pests of honey bees. Currently Australia is the only significant honey producing/pollination-responsive nation in which varroa is yet to become established.

In recent years RIRDC has funded a number of studies addressing different aspects of the pollination industry in Australia and the risks posed to it by varroa including:

- *Pollination Australia: Biosecurity risk management* (Brous and Keogh 2008)
- *Pollination Australia: Education and Training* (Brous 2008)
- *Pollination Australia: Research and Development Priorities* (Clarke 2008)
- *Valuing Honey Bee Pollination* (Gordon and Davis 2003)
- *Analysis of the Market for Pollination Service in Australia* (Monck et al. 2008)
- *Improving Lucerne Pollination with Leafcutter Bees – Stage 2* (Anderson 2006b)
- *Cross Pollination in Olive Cultivars* (Guerin and Sedgley 2007)
- *Commercial Beekeeping in Australia (Second Edition)* (Benecke 2007).

RIRDC has also been instrumental in fostering the recent establishment of Pollination Australia, an alliance of the various industry organisations representing those with an interest in pollination either as providers or consumers of pollination services.

2. Introduction

Approach to the study

Any consideration of the future of the apiary and related industries in Australia, including those producing honey bee-pollination dependant agricultural and horticultural commodities, must take into account the significant threat posed by pests and diseases of honey bees currently exotic to this country. Of particular concern is the varroa mite that has devastated honey bee populations in most parts of the world, and which now occurs in our three nearest neighbouring countries, Papua New Guinea, Indonesia and New Zealand.

By any analysis (e.g. Hitchens 2008 as reported in RIRDC 2008), the risk posed by varroa in regards to both the likelihood and the consequences of an incursion is High to Extreme, and risk management protocols such as Australian Standard 4360 direct that High risks require intervention, and Extreme risks require urgent attention.

The responses available to manage such risks fall into two groups – those intended to reduce the likelihood of an incursion, and those intended to reduce the consequences of an incursion.

Australia has in place a range of pre-border and at-the-border arrangements to detect and prevent incursions of exotic pests and diseases, including those that might affect honey bee related industries. These arrangements have been and continue to be the subject of occasional review and adjustment. As a result, other than noting the severe consequences of a quarantine failure resulting in varroa becoming established in this country, this matter is not considered further in this study.

A key driver for this study is the need to ameliorate the consequences of an incursion, should it occur. In particular, this study is intended to address a strong perception that the development of amelioration strategies is severely constrained, first, by a poor awareness and understanding of pollination and its role in agriculture and horticulture, often on the part of people with a significant interest in it and second, by an absence of reliable and coherent information on the pollination task in Australia.

This report represents an effort to consolidate, present and interpret the available information pertaining to pollination in Australia, including an inventory of the commodities that are responsive to pollination by honey bees; it presents an outline of key aspects of pollination management in this country and a summary of the pollination task in Australia covering geography, timing and the numbers of honey bee colonies required to perform the task.

This information is intended to be used by those with an interest in the pollination industry to improve awareness of the importance of pollination to rural productivity and understanding of the consequences of an incursion by varroa or some equivalent honey bee pest or disease. It could also assist the development and implementation of strategies to prepare for and to mitigate the impact of such an incursion should it occur. Finally, the information presented here is intended to assist in identifying significant gaps in our understanding of pollination in Australia as a means of prioritising research and extension efforts to address these knowledge gaps.

Pollination in nature

There are three processes critical to the production of fruit and/or seed in higher plants (gymnosperms and angiosperms): the development of a fruiting structure (a flower in angiosperms and a cone in gymnosperms); pollination; and fertilisation of the ovule.

Pollination is the transfer of pollen which contains the male gamete to the female organs of seed plants. In flowering plants (angiosperms, or ‘covered seeds’), the female gametes (ovules) are located within carpels, and pollination is effected when the pollen contacts the stigma through which the ovules are accessed. In contrast, non-flowering seed plants (gymnosperms or ‘naked seeds’) have uncovered ovules to which the pollen is transferred directly.

Fertilisation is the process by which the male and female gametes contact one another, adhere to each other, their cells fuse and, finally their nuclei fuse to form the embryo and seed. Pollination is the essential process precedent to fertilisation and subsequent seed and fruit development.

With pollination being such an important step in their life cycle, seed plants have evolved an array of designs and methods by which pollination is effected to match the diversity of ecological niches they occupy. The combinations and permutations of the arrangements by which pollination is achieved can be understood by considering three factors in the process, described as follows.

Fertilisation types

Fertilisation types describe the compatibility between male and female gametes. Combinations include:

- cross-fertilisation: the female gamete is only compatible with male gametes from another plant of the same species
- cross- and self-fertilisation in same plant or species: the female gamete is compatible with male gametes from either the same plant or from another plant of the same species
- self-fertilisation in a single plant: the female gamete is only compatible with male gametes from a flower on the same plant
- self-fertilisation in a single flower: the female gamete is only compatible with male gametes from the same flower.

Pollination pathways

Pollination pathways describe the structural route traversed by the pollen tube to reach the ovule. The two routes are as follows:

- pollen is transferred by a pollinating agent from an anther to a compatible stigma, with the pollen grain then germinating on the stigma and the pollen tube subsequently growing through the stigma, style and ovule into the embryo sac
- the pollen grain germinates within the anther in which it was produced, with subsequent growth of the pollen tube through the anther wall and ovary wall into the ovule and embryo sac. No pollination agent is required to effect pollination in such plants, and this route only applies in certain self-pollinating species where the female gamete is compatible with male gametes from the same flower.

Pollination agents

Where effective pollination requires that the pollen be transferred across a distance to a compatible stigma or ovule on the same or another plant, different plant species utilise different agents for pollen transfer. Pollination agents include:

- wind
- water
- bees

- flies
- birds
- beetles
- butterflies and moths
- bats and other mammals.

Of these, the two most common agents are the wind (all grass species including cereal crops, are wind pollinated) and the various insect pollinators, including in particular the European honey bee (*Apis mellifera*).

3. Pollination in Commercial Agriculture and Horticulture in Australia

Given the centrality of seed plants to agriculture, the importance of pollination to rural industries in Australia and worldwide cannot be over-estimated. Most producers of highly pollination-responsive commodities, those engaged in the breeding of pedigree seed, and the apiarists who service their pollination requirements, appreciate the value and importance of effective pollination and manage the process accordingly.

In agricultural industries with lower levels of pollination responsiveness, the depth of understanding and quality of management of pollination is sometimes inconsistent with the benefits of effective pollination to productivity and product quality or conversely the costs of sub-optimal pollination to those industries.

In some of the very largest agricultural industries such as cereal cropping, where wind pollination dominates, attempts to manage or manipulate the pollination process would not appear to be feasible given the scale of the enterprises, especially as there are many other production variables that are more easily managed and provide greater relative returns.

Whilst there are a number of interesting and important exceptions that will be canvassed later in this report, honey bees are the major pollination agents for most pollination-responsive agricultural commodities other than those that are wind pollinated. In these non-wind-pollinated crops, the degree to which pollination improves yield and/or quality may not be easily appreciated against a background of large variations in yield and quality due to seasonal and other factors.

A particular issue confounding the appreciation of the importance of pollination in Australia is the incidental pollination performed in the course of their foraging and at no cost to the grower, by feral honey bees which are widespread and active at most times of the year and by bees from commercial and hobbyist hives located in the vicinity and being managed for honey production.

Pollination by bees and other biological agents can be important to commercial agriculture at three different scales.

Large scale

For commodities where the commercial product is the fruit or seed, for example, almonds, apples and melons, pollination is important to yield and/or quality at the scale of whole enterprise and industry.

For some large-scale grazing enterprises where pollination-responsive clover species are an important element of the pasture base, pollination is important to seed-set and therefore the maintenance of the clover content of the pasture and as a consequence of this, the quality of the feed on offer and the fertility of the soil.

With few exceptions the predominant pollination agent for these crops at this scale is the European honey bee.

Medium scale

For commodities where the commercial product is the root, tuber, corm, stem or leaf, for example onions, carrots, lettuce, and cabbage, pollination may not directly affect yield or quality of commercial crops but it may be essential to the production of viable seed for future plantings. In such commodities the production of seed is generally conducted as a separate enterprise to the production of the item that appears on supermarket shelves. The area devoted to the production of seed is typically only a small fraction of that sown to the commercial product. For these commodities only the seed crops require pollination, and commercial pollination services if used are confined to the seed crops.

For some other commodities such as tomatoes and cut flowers that are grown in enclosed facilities such as glasshouses, pollination may be very important to yield, quality and/or shelf life, and it is the relatively small scale of the production enterprise that locates such services in this category.

Whilst the European honey bee is the most common biological pollination agent used at this scale there are a number of other insects that can be effective pollination agents where the crops are grown over a relatively small area or grown in confined spaces. Other agents utilised include various Australian native bee species, leaf-cutter bees and flies. In Tasmania (but not in mainland Australia) and in some other countries, bumble bees are used as pollinating agents.

Micro scale

For many commodities, tightly controlled pollination conducted at the level of a small number of plants is important in cross-breeding to produce new varieties. This is often independent of whether or not pollination is important to the yield or quality of the commercial product. At this scale honey bees and the other insects may be used or pollination may be performed by hand.

There are also a relatively small number of circumstances in commercial agriculture where pollination and consequent seed production may have detrimental impacts on the quality of the commodity. One example is in the citrus industry, where pollination leads to the formation of seeds in seedless Mandarins, reducing the value of the fruit. Pollination may also be detrimental in the cut flower industry, where pollination and fertilisation result in the senescence of the flower reducing the vase life of the product.

In such cases producers take steps to exclude pollination agents from accessing the flowers at critical times.

Honey bees as commercial pollination agents

The European honey bee has a number of important characteristics that make it an attractive agent for use in a commercial pollination enterprise, especially where large-scale services are required. These include:

- its effectiveness as a pollination agent across a wide range of agricultural and horticultural commodities
- its effectiveness across a wide range of climatic regions
- the range of other commercial uses to which it can be put to supplement income from pollination, such as honey production
- its relatively low maintenance requirement and significant capacity to sustain itself when providing pollination services
- the flexibility to match the magnitude of pollination services required by varying the number of hives deployed to a particular service contract
- its status as a social insect which makes it:
  - convenient to manage
  - possible to deliver an intense pollination capability in a small area

– possible to move colonies over large distances from one pollination service contract to another or to other activities.

Whilst in certain specific and relatively specialised circumstances there may be another insect that is superior to the honey bee as a pollination agent for that particular species of plant, it is unlikely that any individual insect species or collection of species could in the foreseeable future replace the honey bee as the primary agent for the provision of pollination services across the broad sweep of commercial agriculture and horticulture in Australia.

Given this and the threat to the European honey bee posed by its pests and diseases and varroa in particular, Australian horticulturalists and agriculturalists have no real alternative and every incentive to improve their understanding of the pollination process and increase their awareness of the critical determinants of successful utilisation and management of pollination by honey bees in commercial crops in Australia, in order to contribute to ensuring the biosecurity of Australia's honey bee populations.

The apiary industry in Australia

In addition to providing honey, beeswax and several other apiary products, the European honey bee *(Apis mellifera)* has also played an important role in pollination of horticultural and agricultural crops since its introduction to Australia in the early 1800s.

There are currently close to 10,000 registered beekeepers in Australia operating a total of just less than 572,000 hives. A large proportion of registered beekeepers are located in NSW and QLD, with around 31% of the national total located in these two states (Crooks 2008).

The honey bee industry is important to Australia with an estimated gross value of honey and beeswax production of $75 million in 2007/08 (Crooks 2008). Whilst honey is the main commercial output of the Australian honey bee industry, other products and services add to the income of beekeepers, particularly the provision of paid pollination services. An estimated average of 28% of honey bee businesses provided pollination services of some type and more than three-quarters of these businesses (approximately 20% of the total number) received payment for pollination services provided in 2006/07(Table 3.1).

Table 3.1 Pollination service provision 2006/07

	Proportion of honey bee businesses providing pollination services (%)	Number of businesses providing pollination services	Number of businesses receiving payment for pollination services	Proportion of businesses providing pollination services that receive payment for pollination services (%)
South Australia	52	100	66	66
Tasmania	47	15	15	100
Victoria	39	132	132	100
Queensland	29	107	62	58
Western Australia	35	33	33	100
Southern NSW	26	78	51	65
Northern NSW	4	16	5	32
Total	**28**	**481**	**363**	**76**

Source: Crooks 2008

In addition to the managed hives there are innumerable colonies of feral honey bees established in most parts of the continent, largely due to the benign climate and abundant melliferous resources amongst the native Australian flora.

During the daily routine of foraging for nectar and pollen, both managed and feral honey bees come into contact with numerous flowering plants, and in doing so assist fertilisation of those plants through the transfer of pollen. Honey bees are thought to be the most efficient pollinators across a wide range of plants compared to other insects, birds and animals due in large part to the nature and intensity of their foraging.

There are some plants with flowers specifically adapted to pollination by agents other than bees, and in such cases honey bees are irrelevant to the pollination process. A striking Australian example of this is the Kangaroo Paw (*Anigosanthus* spp). The flowers of these plants are adapted to pollination by certain native bird species, and the stamens are too distant from the nectary for bees to contact them when foraging for nectar. The commercial significance of these species is of course limited.

The possibility has been raised that the nature and intensity of foraging by honey bees can be disruptive to the flower in some plant species where the flower has evolved for pollination by more subtle agents, but to date this has not been confirmed.

The production of honey and other products by honey bees is widely known, readily comprehended and greatly valued. The pollination services provided by honey bees in Australia and elsewhere, being less tangible, are sometimes less well appreciated even though the importance and value of these services is arguably much greater.

Whilst recognising the limits of anthropomorphism, it is worth noting that the plant has a stronger and more direct interest in pollination than does the honey bee. The honey bee's 'intention' in visiting flowers is to collect nectar and/or pollen. The fact that in the course of doing so it may transfer pollen from one flower to another and thereby initiate the fertilisation process is, from the honey bee's perspective, purely coincidental.

From the perspective of the plant the reverse is true and the provision of nectar is the 'price' it must pay to lift the probability of pollination occurring to evolutionarily sustainable levels.

Lucerne represents a circumstance where these related but varying interests are finely balanced. European honey bees (which are unlikely to be the natural pollinators of lucerne) with no previous experience of lucerne will visit flowers to collect nectar and in doing so will effect pollination. Bees with previous experience will, if alternatives are available, avoid lucerne because of the force with which the keel of the flower strikes them when tripped. Forceful tripping of the keel is an adaption in lucerne that improves the chances of pollination occurring. Where alternative nectar sources are not available experienced bees will draw nectar from the side of the lucerne flower thus avoiding the keel and defeating the plant's interest in having pollen exchanged.

Humans have a strong interest in both aspects of the relationship between honey bees and pollination-responsive flowers. Apart from the honey resulting from bees gathering nectar, it is said that one in every three mouthfuls of food that we consume comes to us through the aid of pollination by honey bees (CSIRO 2007). For some crops (such as almonds) the responsiveness is almost absolute and very little fruit would set without honey bee pollination. For other fruits such as apples significant production would occur without intervention by honey bees; however quality and yield increase to varying degrees as a result of pollination by honey bees. Table 5.1 in Section 5 (and case studies listed in Appendix 1) indicates the degree to which different commodities rely on or respond to pollination by honey bees.

The benefits of honey bee pollination whether by managed hives or feral colonies accrue directly to the agricultural sector, and indirectly through sales (domestic and export) and the utility value of the food and fibre produced, to the entire Australian community.

The medium-term prospects are that, as producers of commodities that show marginal responses to pollination manage and optimise the other variables that influence the output and quality of their crops in their search for ways to improve their competitiveness, they will become aware of and seek to realise the benefits available to them from the optimal use of pollination services.

This, together with increases in areas planted to commodities with high pollination responsiveness, will drive an increase in the requirement and demand for managed pollination services. To ensure adequate capacity is available to provide the pollination services required by the agriculture sector the honey bee industry must have the capability to grow and develop with the increasingly diversified demand, and may well undergo a significant restructuring that results in a change in the balance between beekeeping for honey production and beekeeping for the provision of pollination services.

Factors that could contribute to such a re-alignment of the industry by negatively affecting the economics of honey production include increased competition in export and domestic honey markets, competition for and restrictions on access to native floral resources, and the possible incursion of one or more severe bee pests or diseases that could decimate the feral bee population and have severe impacts on the costs of managing and maintaining commercial honey bee colonies.

Australia is currently alone amongst the significant honey producing countries of the world in being free of what is considered to be amongst the worst of the pests and diseases of honey bees, the varroa mite.

Until very recently only one type of varroa mite (*Varroa destructor)* was known to be parasitic on and pathogenic to the European honey bee. *Varroa destructor* has in recent decades spread to most of the significant beekeeping countries in the world, and caused widespread damage to the apiary industry wherever it has occurred.

In 2008 a survey of honey bee populations in Papua New Guinea detected for the first time anywhere in the world a second species of varroa mite, *Varroa jacobsonii,* parasitising European honey bees (Anderson 2008, reported in Cunningham et al. 2009). Whilst the details of the biology of this new type of varroa are not currently available, there is the possibility that this species could be as harmful as *Varroa destructor* has been elsewhere in the world (Anderson 2008, reported in Cunningham et al. 2009).

If introduced to Australia, varroa (*V. destructor* or possibly the new species *V. jacobsonii*) has the potential, demonstrated in other countries and described below, to quite rapidly decimate the feral (unmanaged) honey bee population. Commercial and hobbyists' honey bee colonies would be similarly affected unless they are carefully managed by paying close attention to hive vigour and hygiene combined with regular treatment with appropriate chemicals (Somerville 2009).

In the event of such an incursion, the incidental pollination services provided by feral bees would progressively diminish to the point of extinguishment. Commercial apiarists would be reluctant to risk allowing their bees to come into contact with bees of uncertain health status, which would result in an inevitable increase in charges for pollination services, reflecting the increased demand for and management costs of providing these services.

The risk of varroa being introduced and becoming established in Australia is considered to be high. The disease is present in both New Zealand and Papua New Guinea. New Zealand and Australian experience with small hive beetle (SHB) indicates that a pest is likely to be well established before it is detected, and no country has been successful in eradicating varroa once it has become established.

Given the likelihood and the likely impact of a varroa incursion, the cost-effective use of commercial honey bee pollination services will become very important to producers of pollination-responsive commodities.

As with any input to production, the break-even point for the use of pollination services is where the projected additional income due to increased yields or improved quality from using an additional unit of pollination service equals the cost of providing the additional unit of pollination service. As neither component of this equation is currently well understood in Australia, a significant and urgent research effort to elucidate these matters is warranted if pollination-responsive industries in Australia are to be able to respond appropriately to the incursion of a pest or disease that makes the use of commercial pollination services the only option available to them.

Pollination services or honey production? – A dilemma for commercial apiarists

Whilst the stock involved and the biological processes they perform are the same, from a commercial point of view, optimal management of bees for the commercial provision of pollination services is quite different to that for the commercial production of honey. Analogous sets of circumstances apply to the management of cattle for dairy or beef production or of sheep for wool or meat production.

The commercial imperative for a pollination enterprise is to have sufficient hives of a suitable strength and condition available to perform the pollination services at the time and place required by the client. This requirement is, unlikely to be entirely compatible or consistent with the demands of optimal honey production. The key points of difference in the management of the two enterprises relate to:

- **Timing:** The provision of pollination services requires that the honey bees be available when the crop in question requires servicing. In the case of some crops such as almonds, this occurs at a time (July/August) when in the normal annual beekeeping cycle colonies are at a low point in their levels of activity. The period for which the bees are required is confined to the flowering of the target crop which is usually of the order of only one month and may be as little as two weeks.

  As Figure 3.1 illustrates, a four-week pollination service contract can, when preparation and recovery times are taken into account, exclude a hive from performing other services, including optimal honey production for a period of more than three months.

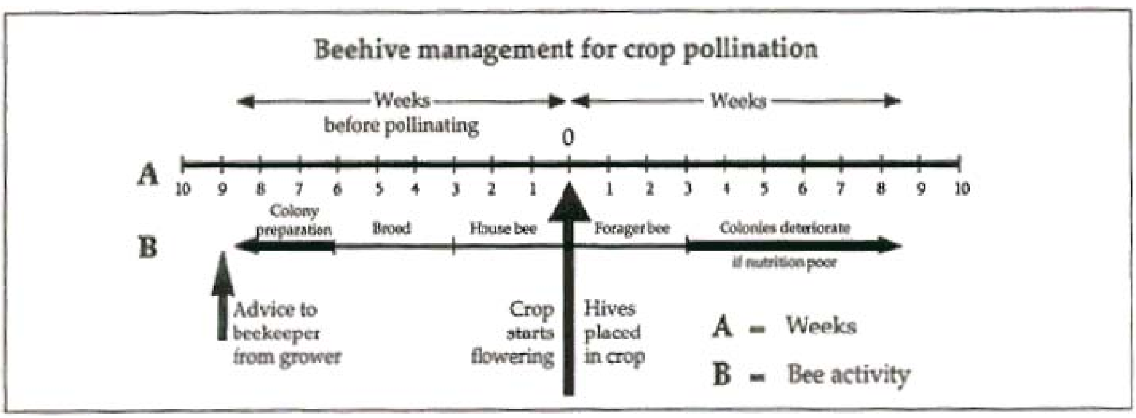

Figure 3.1 Beehive management for crop pollination – a beekeeper's view (Parker 1989)

- **Location:** Crops requiring pollination are occasionally located far removed from the areas normally frequented by apiarists focused on honey production, and may even be in areas that are climatically not within the honey bee's normal range. Melon crops on the Ord River scheme represent a case in point.

- **Quality of floral resource:** Many crops requiring pollination provide bees with little or poorly balanced nutrition when compared to those floral resources favoured for honey production and/or conditioning bees for honey production. Indeed, some pollination-responsive crops are so unattractive to bees that they will only service these crops if there is no alternative foraging target available. As a result of these factors, bees that have completed a pollination service contract may be in worse condition than at the time they were introduced to the crop, and as a result may not be fit for optimal honey production or a further pollination contract until they have been able to recover through access to high quality and balanced foraging.

For an apiarist with a commercial interest in optimal honey production, servicing unattractive or low nutrition crops is unlikely to be acceptable as the resources required to support the recovery of a colony that has completed pollination on an unfavourable crop represent a loss of honey production in two ways. First, because the colonies are in sub-optimal condition they are not able to forage to maximum effect, and second, the resources they consume in their recovery are not available to be harvested as saleable honey.

- **Colony condition:** To adequately perform pollination services a colony must contain a large number of mature bees, with a large proportion actively foraging. A measure often used to ascertain whether a hive is in suitable condition to perform a pollination service is five to seven full depth brood frames, 50% full of brood in all stages of development. Typically an apiarist whose business is directed to providing pollination services might expect only 60% of hives to be in such condition at any given time.

  Depending on the time at which the pollination service is required, a hive intended for honey production may not be in suitable condition to perform the service. Conversely, depending on the nature of the crop that has just been serviced, a colony having completed a pollination service may not be in optimal condition for honey production even if good nectar flows are available.

- **Marketability of products:** Regardless of the quantity or nutritional quality of the honey derived from some pollination-responsive crops, the palatability of the honey to humans may be low, making it either unsaleable or subject to a significant price discount relative to that from other sources. Examples of plant species producing low-palatability honey include almonds and carrots. Canola, while an attractive resource for building colony strength, can pose problems for the beekeeper because the honey tends to candy which makes it difficult to extract and unattractive to consumers.

  An enterprise with a commercial focus on honey production would be compromised if its output included significant quantities of unpalatable honey obtained in the provision of pollination services.

- **Stocking density:** To ensure adequate pollination coverage of the target crop, stocking densities of three to five hives per hectare are usually required. At such densities it is unlikely that a colony will harvest sufficient nectar to be acceptable to a commercial honey production enterprise. Typically, where honey production is the commercial objective, stocking densities closer to one hive per hectare would be expected on the same floral resource.

- **Preparation:** To meet the requirements for providing pollination services, especially for early (July and August) flowering crops such as almonds, an apiarist must begin preparing colonies in the preceding March and April, by directing the autumn honey flow that might otherwise be harvested for honey production into building and maintaining the condition of the colony for the forthcoming pollination service. June and July are normally periods of lowest activity for the bees, but if a colony is to be fit to undertake the early pollination tasks activity must be maintained at unseasonably high levels. It may even be necessary to provide supplementary feed to ensure that the colonies meet condition requirements before they are deployed to the pollination task.

Where honey production is the objective, March and April are the time of an important secondary harvest from the honey flows from autumn-flowering native flora. Following this harvest, honey-producing colonies are usually allowed to go into a period of low activity over the winter months.

- **Risk:** The provision of commercial pollination services offers apiarists a lower risk – reward profile than applies to honey production. Providing pollination services to established horticultural industries has higher income security with respect to the timing of income flows when compared with the risks a honey producer faces from the unpredictability of the timing and magnitude of annual honey flows, and uncertainty as to honey prices, as they are dependent on volatile domestic and international supply and demand factors.

  In seasons of strong honey flows and good prices a honey producer is likely to enjoy an income well in excess of that of a pollination service provider with as many hives but is likely to suffer in comparison when either honey flows or prices are low and particularly so when both are in the lower quartile of expectations simultaneously.

  This is not to say that pollination providers are insulated from the factors determining the prosperity of honey producers. The terms of trade facing honey producers will effectively set benchmarks for pollination service providers in pricing their services and will dictate the point at which apiarists might switch from one activity to the other.

Given the extent to which the factors outlined above might compromise optimal honey production, an apiarist whose business is built around honey production may have difficulty in finding a commercial justification for providing pollination services at a price that would be attractive to the user of the pollination services.

Other things being equal therefore it might be expected that as the use of pollination services becomes more sophisticated, and particularly in the event that an incursion of a pest or disease such as varroa eliminates the contribution to pollination from the feral honey bee population, apiarists will tend to specialise in either the provision of pollination services or in honey production, and the requirement for specialist pollination service providers will far exceed that of the present time.

Whilst switching from one of these two enterprises to the other could be achieved at relatively low cost and may not take many months to effect, it is unlikely that frequent switching would be commercially ideal. It is also difficult to see how an individual could practicably and efficiently operate a business that sought to optimise both commercial honey production and commercial pollination service provision from the same set of hives.

Given these factors an ideal scenario for the future may well appear be that commercial apiarists either concentrate exclusively on producing honey and/or other bee products or concentrate on providing pollination services with the production of some honey as an inevitable by-product.

Information presented in this study, however, would suggest that, whether or not there was an incursion of a pest or disease that eliminated the pollination contribution from feral bees, were the use of paid pollination services to approach the optimal levels indicated in the case studies, specialisation as either a pollination service provider or a honey producer may not be practicable for other than a minority of apiarists.

A key factor making specialisation as a pollination service provider particularly difficult would be the nature of the annual cycle of demand for pollination services. The concentrated peak of demand in September and October and the protracted period without a significant requirement for pollination services between February and July each year would oblige a would-be pollination specialist to use the autumn honey flow to sustain the colonies and the income from honey production to sustain the business.

Whilst the problems facing a specialist honey producer would be less, in circumstances where demand for pollination services reached its full potential, the co-incidence of the peak pollination period in spring (September and October) with the major annual honey flows which usually occurs at about the same time could present a dilemma.

The demand for pollination services in spring would likely be so great as to require a significant proportion of the bee population managed primarily for honey production to be redirected to the provision of pollination services. This would push prices for these services to a point where honey producers would be tempted to forego the honey flow for the relative certainty associated with providing pollination services. This in turn could leave the honey flow under-exploited.

Conversely in autumn the specialist honey producer would face very high competition for floral resources from pollination specialists looking to use the autumn flow to sustain his/her stock in preparation for the up-coming late winter pollination services.

These timing-induced tensions have the potential to become significant challenges for Australia's apiary and pollination industries, and these challenges would be exacerbated by an incursion by varroa or some other major pest or disease of honey bees.

Threats to the protagonists –biological and chemical

Australia's relative freedom from many of the debilitating pests and diseases of animals and plants that affect other countries is of considerable benefit to its competitive position in areas such as agricultural production and trade (ABARE 2006). This advantage has been maintained over the years through the country's relative isolation as an island continent, and through significant investment in quarantine measures to protect against incursions of exotic pests and diseases (ABARE 2006). Significant increases in trade volumes, international travel and agricultural intensity as well as demographic and environmental changes have resulted in an increased threat to Australia's biosecurity and to the apiary industry amongst others.

Varroa

The varroa mite, *Varroa destructor*, is widely regarded as the most serious pest of the honey bee and currently infects honey bees in every major beekeeping area of the world, except Australia (Anderson 2006a; Cunningham et al. 2002). The threat of varroa mite incursion is real and while reasonable efforts are being made to prevent an incursion into Australia, it is generally accepted that it is more likely than not that varroa will eventually become established in this country (Anderson 2006a; Cunningham et al. 2002).

V. destructor is one of a small number of species of varroa mites known to parasitise bees of the genus *Apis.* Another species of these mites is *V. jacobsonii* which occurs less widely but has been observed in regions to the immediate north of Australia including Papua New Guinea and parts of Indonesia. Until recently it was believed that only certain 'types' of *V. destructor* could affect European honey bees, whilst there were types of both *V. destructor* and *V. jacobsonii* that could parasitise the Asian honey bee (*Apis cerana*). In 2008 a survey undertaken by Denis Anderson in Papua New Guinea, and subsequently extended to Indonesian Papua, detected a type of *V. jacobsonii* parasitising European honey bees in those areas; apparently to the same destructive effect as *V. destructor* (Anderson 2008).

Given this information, it is reasonable to conclude, as does Anderson (2008), that an incursion of *V. jacobsonii* into Australia would have the same consequences as an incursion by the better known *V. destructor* mite. Whilst this discovery might not change the consequences of a varroa incursion, the presence of the mite in Papua does increase the likelihood of an incursion (Anderson 2008).

On this basis, regardless of which of the two types of varroa were to become established, if left untreated, a hive infested with varroa will die out entirely within two or three years. In the event of a varroa incursion into Australia, it is therefore likely feral bee colonies and poorly managed hives will effectively be wiped out in a period of five to ten years.

The life cycle of varroa begins when the female mite enters a honey bee brood cell. As soon as the cell is capped by nurse bees, the *Varroa* mite lays eggs on the larva. The female mite may lay up to six eggs at intervals of about 30 hours. The first egg develops into a male mite and the rest are female (Somerville 2009).

The young mites (nymphs) hatch in about the same time period as the young bee develops, and they feed on the growing bee larva. Once mites reach maturity they mate, the males die, and the females leave the cell with the host and attach to adult bees and feed by sucking their blood (DAFF 2009). On average, 1.5 daughter mites emerge from a worker cell and 2.5 daughter mites emerge from a drone cell along with the mother mite; the male and undeveloped female mites die inside the cell (Somerville 2009).

There can be 24–30 breeding cycles for the mites in a year. It is believed that female mites will breed up to three times. Thus, as long as honey bee brood is present, the mites will breed and their numbers will increase. If drone brood is present, then the mite population will increase even faster (Somerville 2009).

A heavily infested colony may have mites on one-third or more of adult bees or brood. Unfortunately, mites are very good at concealing themselves on adult honey bees. It is generally agreed that to observe adult mites on adult honey bees is very difficult and totally unreliable as a diagnostic tool (Somerville 2009).

In spring and summer when breeding conditions are ideal most colonies rear large numbers of drones. Drone bees drift from hive to hive and even between apiaries. They are certainly able to move varroa mites around. Foraging worker bees will come in contact with other bees when visiting blossom for nectar and pollen.

Adult mites are quite capable of living for more than five days without the presence of honey bees, and so can also be moved around on used beekeeping equipment, including extracted combs.

A colony can appear to be populous with healthy looking brood one week and be all but extinct the following week. Attack by varroa mite weakens bees, shortens their lives, or causes death from virus infections that would otherwise cause little harm. In severely attacked colonies bees may have stunted wings, missing legs or other deformities. Unless urgent action is taken, the vitality of bees in the colony declines until all are dead (DAFF 2009).

For the keepers of managed hives a varroa incursion would necessitate very careful and continuous management. Detection and treatment of mites would be required before the mite burden reaches critical levels. Replacement of infected colonies with fresh colonies before their condition deteriorates to a level where hives may become commercially ineffective may also be necessary.

Upgrading the management of hives to the standard required to maintain productivity in the face of a varroa incursion will inevitably incur costs to the beekeeper in both time and materials required to accomplish the necessary monitoring and intervention.

Based on the experience of the USA and New Zealand, it is likely that an incursion that resulted in the establishment of varroa in Australia would cause significant changes in the local apiary industry. Estimates from these countries are that, following the incursion of varroa, implementation of control measures added upward of US$25 (AUD$35) per hive to the beekeeper’s annual costs, well above any other cost traditionally associated with keeping bees.

The introduction of varroa to the USA and its detection in New Zealand saw initial increases in the fees charged to pollination service users well in excess of that which might be attributable to the additional costs incurred by the apiarist. With the passage of time as new supply-demand balances have become established prices being charged and paid have settled at levels that more closely reflect the additional management costs.

Australia's agricultural industries are worth approximately $30 billion annually (DAFF 2007), with $1.8 billion responsive to honey bee pollination to some degree (CIE 2005). Because a significant proportion of pollination is provided by feral bees, the introduction of varroa and the consequent decimation of the feral bee population could be expected to have large economic impacts across the responsive industries, with some ramifications for the broader agricultural sector.

An ongoing port surveillance program, now managed by Animal Health Australia and implemented through the various state primary industry departments, is intended to assist in the early detection of varroa and other pests and diseases of honey bee, and thereby aid to the maintenance of Australia's varroa-free status.

Arguably the most significant impact of a varroa incursion will be the destruction of all untreated honey bee colonies across the landscape, both managed and feral. This would lead to a serious reduction in the pollinating capacity available to a wide a range of horticultural, broadacre crop and pastoral plants relying on incidental pollination by feral bees in particular, with potentially dramatic impacts on the quantity and quality of production from these industries unless the loss of this incidental pollination capacity is made good through the increased use of managed hives.

The prospect facing the pollination industry in Australia in the event of a threat such as varroa becoming established is that:

- Over a period of two to five years, populations of feral bees would be decimated to the point that they could no longer be considered a significant or reliable provider of incidental pollination services.

- Whilst an incursion of varroa might decimate feral hives to the point where their contribution to pollination is negligible; it is highly unlikely that the feral population would be totally wiped out. The persistence of even a small population of feral bees and the likely occasional recruitment to the feral population of swarms originating from managed hives would mean that in the absence of some breakthrough development in control or management technologies, varroa, once established, would persist within these populations even in the face of the widespread implementation of the most stringent control measures in the managed honey bee population. The existence of such a disease reservoir would require apiarists to apply high levels of monitoring, hygiene and control on an ongoing basis to maintain the condition and effectiveness of their stock.

- Apiarists would immediately incur significantly increased costs in monitoring, managing and maintaining colony strength in the presence of the disease.

- The decimation of feral populations and the increase in management costs could have counter-acting impacts on commercial honey production in Australia. The higher costs of maintaining colonies would negatively impact the economics of honey production and would of itself lead to a reduction in the number of managed hives providing incidental pollination services.

  The decimation of feral colonies should increase the floral resources available to commercial beekeepers and lead to an increase in the number of managed hives and the attendant incidental pollination but it is unlikely that this would represent anything other than a partial replacement of the contribution currently provided by feral bees.

  The ultimate net impact will be determined by the relationship between the additional costs of maintaining managed colonies and the price paid for honey at any given time. This net effect is likely to take a significant time to be fully realised. The evidence from other countries is that the initial impact will be strongly negative.

The incursion and establishment of varroa in Australia is therefore very likely to lead to serious short and probably medium and long-term problems for the supply and availability of bees for pollination services (Cunningham et al. 2002).

As discussed under Integrated Pest Management, below, there is nationally accumulating evidence that there may be some scope to reduce the impact of varroa by selecting bees for resistance to the pest. Such resistance is usually manifest in the cleaning behaviour of the bees in a colony that results in a higher proportion of the mites being removed from the hive as part of the cleaning routine, which has the effect of slowing down the rate at which varroa burdens increase within a colony.

There is no evidence that such behaviour can completely illuminate the pest from a colony. Further, it is difficult to envisage a means by which such characteristics could be selected for in the absence of the pest particularly if as seems to be the case that such behaviours come at a cost to the intensity of foraging and honey production.

Small hive beetle

Small hive beetle (SHB) (*Aethina tumida*) also has the potential to cause apiarists significant economic losses by damaging wax comb, by spoiling stored honey, pollen and brood, and by causing bees to abandon hives (Fletcher and Cook 2005). Primary damage to apiaries and stored honey by SHB is through the activity of the larvae that feed on brood, pollen and honey causing it to ferment and give off an odour like sour oranges. Stored supers of honey or extracted frames can also be ruined by infestation with adult beetles and larvae. The beetles have been reported to be capable of destroying strong honey bee colonies in a matter of weeks. Feral colonies of bees are also susceptible to SHB and provide a significant haven and reservoir for re-infection and spread.

Previously exotic to Australia, SHB was first detected in Australia at Richmond in the western outskirts of Sydney in October 2002 (Fletcher and Cook 2005). Subsequent investigation identified the beetle in 103 apiaries in NSW and 11 in Queensland. The level of infestation in the affected apiaries and historical reports subsequently indicated that SHB may have been in NSW for more than a year before being detected.

The most severe initial impact of the presence of the SHB in Australia has been the subsequent movement restrictions placed on owners of hives detected with the pest during the initial investigation into the incursion, and on the live bee export industry which had its access to some markets withdrawn following detection of SHB in Australia (Fletcher and Cook 2005). The medium to long-term impact on the commercial apiary industry cannot be quantified due to a lack of information, but is likely to be manifest as increases in management time and costs to maintain the hygiene and condition of hives.

Other biological threats

While varroa mite is the most potent exotic threat to honey bees in Australia, and SHB is a severe pest that may be yet to reach its full destructive potential in the Australian environment, the honey bee is also vulnerable to a range of other pests and diseases, including fungal, viral, protistan and bacterial diseases.

Pests and diseases not yet established in Australia

The vulnerability of honey bees to pests and diseases is associated with their highly social behaviour which predisposes them to the rapid spread of pathogenic organisms within and between colonies, despite the hygiene and housekeeping practiced by healthy honey bee colonies.

Understanding the diseases of honey bees and their management is essential for successful beekeeping. The heavy reliance of Australian agriculture on a single pollinator species and incidental rather than managed pollination services makes pollination-responsive industries potentially more vulnerable to outbreaks of disease within Australia’s honey bee population.

The impact of pests and diseases other than varroa on the management of honey bee colonies and the impact on cost and delivery of pollination services would be of a similar nature to that of varroa, but probably to a lesser degree in terms of effects on individual colonies, both feral and managed. This less sever feral honey bee population reduction could mean that the feral colonies continue to make a considerable contribution to pollination. However, such a population would serve as a reservoir for continuing re-infection of managed apiaries, ensuring that beekeepers would have ongoing costs to manage the impact of these pests and diseases on their hives.

Important pests and diseases of honey bees that are not yet established in Australia are summarised below.

Tropilaelaps mite

Tropilaelaps mite (*Tropilaelaps clareae*) is a parasite of brood only, and causes brood mortality or reduced longevity of adult bees that survive the parasitised brood stage. It will breed and survive in bee colonies as long as brood is present. Its presence in Australia would result in widespread losses of honey bee colonies causing serious economic hardship to apiarists and growers of those crops which require honey bee pollination to achieve viable production.

The mites can be transferred between colonies and between apiaries through normal apiary management practices.

The life cycle of the mite is synchronised with that of the host and they will only persist in a hive with adult bees and live brood. Adult mites are not able to survive more than 2–4 days away from bee brood and have been observed to drop off adult bees in swarms and packaged bees after two days away from the brood.

Asian bees

There are a number of species of honey bees native to various parts of Asia including the Asian honey bee *(Apis cerana*), giant honey bee *(A. dorsata*), dwarf honey bee *(Apis. florea*), and four more recently identified species of which little is known: *Apis andreniformis*, *Apis koschevnikovi*, *Apis nigrocinta*, and *Apis nuluensis*.

The better known Asian honey bee species (*A. cerana* and *A. dorsata*) exhibit behavioural traits that make them unsuitable for commercial management, such as frequent swarming behaviour and low honey production. These bees represent a threat to the Australian honey bee industry because their tendency to rob honey from other hives can disrupt *A. mellifera* colonies and more importantly because it is possible for them to carry and transmit serious diseases and pests including the varroa and Tropilaelaps mites.

Tracheal mite

Tracheal mite (*Acarapis woodi*) is an internal parasite that infests the respiratory system of adult honey bees. This mite is responsible for causing acarine disease or acariosis. The European honey bee, the Africanised honey bee (*Apis mellifera scutellata*), and the Asian honey bee (*Apis cerana*) are the only known hosts of this pest. Drones, workers, and queens may be infected. The entire mite life cycle is spent within the trachea or breathing tubes in the thorax of adult honey bees except for brief migratory periods. Mites are also occasionally found in air sacs in the thorax and abdomen. Within the trachea, the mite reproduces and feeds. Mites penetrate the breathing tubes with their mouthparts and feed on blood.

The impact of tracheal mites is exacerbated if the host is under stress and so can be worse in colder areas.

Bee viruses

There are a range of viral diseases of honey bees including Acute Bee Paralysis Virus (ABPV or APV), Israel Acute Paralysis Virus (IAPV), Kashmir Bee Virus (KBV), Black Queen Cell Virus

(BQCV), Chronic Paralysis Virus (CPV), Cloudy Wing Virus (CWV), Deformed Wing Virus (DWV) and Sacbrood Virus (SBV). These diseases are not known to occur in Australia.

Africanised bees and Cape honey Bees

Africanised bees **(***Apis mellifera scutellata* and its hybrids) and Cape honey bees (*Apis mellifera capensis*) represent threats to the honey bee industry in two ways**.** First, like other exotic bees they have the potential to be the means of introduction and spread of exotic pests and diseases to and throughout Australia. Second, they can also interbreed with the European Honey bee with the potential to introduce undesirable behaviours and characteristics into the honey bee population. Africanised honey bees are sometimes known as 'killer bees' and have behaviours that are entirely unsuited to management for commercial purposes, while Cape honey bees are less productive as the worker bees have the ability to lay fertile eggs, so can replace the role of the queen bee and disrupt the genetics of the colony.

Braula fly

The braula fly (*Braula coeca*), which is currently found in Tasmania but not on mainland Australia, is a tiny commensalate wingless fly found in colonies of the honey bee, where it lives on the bodies of the bees and literally steals its food out of the mouth of its host. The larvae of *Braula* are problematic because they damage the appearance of comb honey by burrowing under the cappings.

Pests and diseases currently established in Australia

Pests and diseases already established in Australia are summarised below.

Nosema

Nosema apis and *Nosema ceranae* are host specific microsporidian parasites of the adult European honey bee. *N. apis* is an endemic pest of honey bees throughout the world (Rice 2001). Anderson and Giacon (1992) found that the presence of *N. apis* may significantly reduce pollen collection by honey bee colonies, leading to reduced fruit/seed set as a result of inefficient pollination.

Giersch et al. (2009) detected *N. ceranae* in samples of honey bees taken from four Australian states. There is a view (Cannon 2009, pers. comm.) that *N. ceranae* is displacing *N.apis* in the Australian bee population and probably represents the greater threat to the local industry.

American foulbrood

American foulbrood (AFB) is a brood disease of honey bees caused by the bacterium *Paenibacillus larvae* ssp. *larvae*. It is a particularly virulent brood disease because the bacteria form heat and drought-resistant spores. Honey bee larvae become infected by eating infectious spores in contaminated food given to them by nurse bees in the hive. It is a notifiable disease that is controlled in all Australian mainland states by destroying the bees from infected colonies and burning or irradiating hive material (Oldroyd et al. 1989).

Effectively managing such a contol program is resource intensive and can be particularly difficult in horticultural areas where even a small number of poorly managed hives can represent a source of continuing re-infection for well-managed commercial hives providing pollination services to crops in the area. Keepers of well-managed hives have little chance of avoiding infective bees or of managing them at source.

European foulbrood

European foulbrood (EFB), caused by the bacterium *Melissococcus plutonius*, is an economically important honey bee brood disease that affects colonies throughout much of the beekeeping areas of

Australia. Infected colonies may become poor honey producers and unsuitable for crop pollination (Oldroyd et al. 1989).

Chalkbrood

Chalkbrood of honey bees is caused by the fungus *Ascosphaera apis* and has been recognised in Australia since the early 1900s, where it was first reported in 1993 from south-east Queensland (Hornitzky 2001). Despite a broad range of experimental work to develop chalkbrood control strategies, a specific strategy that has been universally adopted or accepted by beekeepers around the world remains to be seen (Hornitzky 2001).

Colony collapse events

Colony collapse events are little-understood phenomena, in which worker bees from a colony abruptly disappear. These events were originally observed in European honey bee colonies in the USA in late 2006. Hypotheses of the cause or causes of these events include environmental change-related stresses, pathogens including combinations of some of those listed above, or chemical exposures. Given this uncertainty as to the cause and the variability in the symptoms, describing them collectively as a syndrome or ascribing the name Colony Collapse Disorder (CCD) may not be appropriate as it implies a consistency in cause and effect that has not been demonstrated.

Chemical threats

Chemicals used for insect control in crops may pose a threat to honey bees located or working in the vicinity of treated crops. The bees can be killed or otherwise adversely affected by many commonly used agricultural chemicals. The conflict between chemical use and insect pollinators requires careful attention to the choice of chemical and the timing and method of application. For example in spring 1998, drift from aerial spraying with dimethoate in a Western Australia barley crop damaged honey bee populations in more than 100 hives brought in to pollinate an adjacent canola crop.

Managed hives can be moved to avoid insecticide problems if timely advice is given, but wild insect populations are more vulnerable. Most poisoning occurs when pesticides are applied to flowering crops, pastures and weeds. Pesticides should be kept to a minimum while hives remain in the vicinity.

The other threat associated with the use of agricultural chemicals is the contamination of products including honey by such chemicals, either as a result of applications made to the plants from which the bees source the products or from chemicals applied to control pests or diseases of the bees themselves.

Integrated Pest Management (IPM)

Integrated Pest Management (IPM) is a generic approach to managing pests, weeds and diseases in a wide range of agricultural and horticultural situations. IPM is intended as an environmentally sensitive approach to pest management that aims to reduce the impact of undesirable organisms to sustainable levels without necessarily eliminating the pest. This enables avoidance of both long term and short term adverse impacts that are often associated with a total reliance on agricultural chemicals targeted at eliminating pest organisms.

IPM programs seek to combine the manipulation of multiple aspects of the environment, including natural predator and competitor organisms, with minimal, timely use of chemicals to disadvantage a specific pest organism thereby limiting both its population and its impact on the enterprise in question. Effective IPM relies on current, comprehensive information on the life cycles of pests and their interaction with the environment (Delaplane et al. 2005; Anon 2009; Calderone 1999; Tew 2001).

Whilst honey bees are often counted amongst the collateral damage arising from the use of agricultural chemicals, and it might seem that IPM techniques would always favour honey bees and improve their productivity, there may be circumstances where the predators and competitors of the target organism of an IPM program also predate upon or compete with honey bees, compromising their effectiveness as pollinators or honey producers.

In addition, some IPM programs manipulate pest populations through the cultivation or encouragement of other plant species amongst or adjacent to the commercial crop. This can sometimes act as a distraction or deterrent to honey bees, compromising their effectiveness in pollination or honey production.

IPM as a means of managing pests and diseases in crops has amongst its advantages a reduction in the risk of unintended adverse impacts on nearby honey bee populations from the use of pesticides. In crops that can be pollinated by insects other than honey bees, IPM can also help to maximise the contribution to pollination from these other agents.

Therefore, whilst the development of IPM strategies is likely to be positive in an overall sense for honey bees and the pollination services they provide, apiarists and the users of pollination services should be aware that there may be particular circumstances where the benefits may be compromised, in part at least.

The development of IPM strategies to manage or respond to incursions of pests and diseases of honey bees themselves is not well advanced and is generally not viewed as relevant in the time-frame of the threat currently posed by varroa to the Australian honey bee and pollination industries.

In countries where varroa has become established, such as the USA and Europe, IPM approaches are being used to mitigate the impact of the pest. In general an IPM response to varroa has the objective of reducing the frequency with which colonies must be replaced and has four common components:

- close monitoring of mite burdens in the colonies to determine threshold levels at which actions should be taken
- selective use of miticides
- application of diverse approaches to reduce mite populations and the rate at which they increase, including:
  - selection of bee strains with mite resistant queens and/or hygienic behaviours and/or suppressed mite reproduction (it should be noted that some of these desirable characteristics are associated with other traits that reduce the productivity of the colony)
  - removal of drone brood (varroa burdens are higher on drone brood so removing the brood eliminates a larger number of mites)
  - use of screen hive floors
- replacement of colonies when the mite burden exceeds the threshold at which commerciality is compromised.

Whilst research into IPM is continuing in regions where varroa is well established, the understandable focus of efforts in places such as Australia (where particular pests or diseases do not yet occur or have not become established) continues to be on the use of appropriate pesticides, the selection and breeding of resistance or avoidance characteristics in honey bee populations, and/or the development of alternative pollination agents that are not susceptible to the pests and diseases of honey bees.

Relationship of honey bees with Australian native flora and fauna

The commercial apiary industry is unusual amongst the rural industries of Australia in that the producers (the apiarists) rarely own the land and the vegetation from which their products are derived or the apiary sites on which their hives are located. The viability of the Australian apiary industry therefore depends heavily on apiarists having continued access to areas of nectar and pollen yielding flora.

The availability of pollen and nectar in the native vegetation of Australia in its natural condition is very high by any standard (Cunningham 2009, pers. comm.). Paton (1996) reports that more than 200 species of native Australian plants, representing about 75 families, have been recorded as being visited by European honey bees. It is not possible to determine in all cases the purpose of these visits, or to draw any firm conclusions as to the quality or quantity of pollen and/or nectar if any provided by particular species, nor whether these visits have a role in pollinating the plants. There is, however, conclusive evidence in many cases that the pollen and nectar are highly attractive to the bees and that pollination of the host plant may result.

Plants of the family *Myrtaceae*, particularly the eucalypts, represent the bulk of commercial honey and pollen resources in Australia. For example in Victoria, the apiary industry derives at least 75% of the annual honey crop from these species, while in NSW 70% of the annual crop relies on eucalypt species (Goodman 2001; Somerville and Moncur 1997). Other native flora including the *Proteacea* as well as introduced species including canola, lucerne, clovers, citrus and a variety of weeds contribute lesser but significant quantities of nectar and pollen to the annual honey crop (Goodman 2001).

The apiary industry is heavily dependent on access to native floral resources, particularly the eucalypts occurring on public lands, such as state forests, national parks, other conserved forests, stock routes and other land managed by government. Commercial beekeepers practise a migrating beekeeping pattern following significant flowerings, primarily of the various *Eucalyptus* species. To work the range of floral resources as they come into flower it may be necessary for beekeepers to move loads of bees four to six times per year, often within a 200km radius of their base, and occasionally further afield – sometimes up to 1200km (Somerville and Moncur 1997). The future of the industry may be somewhat uncertain if access to traditional floral resources is constrained.

The placement of European honey bees in native vegetation is the source of some controversy in various parts of Australia. Those opposed to it have concerns that it has deleterious impacts on the natural ecology. These concerns relate to three aspects of the behaviour of European honey bees. First, it is contended that by virtue of the vigour and intensity of their foraging, honey bees compete with and often outcompete, native birds, insects and small mammals that depend on the same resources for their survival. Second, there is a view that in accessing the nectar and pollen of some species of native plants honey bees can cause damage to or the destruction of, the flowers they are foraging upon, and disrupt the production of fertile seed thereby compromising the survival of those species. Third, there is a concern that feral bee colonies may displace native birds and mammals and insects from nesting, roosting and breeding sites in tree hollows and other suitable and in doing so interfere with the breeding and survival of these animals.

A fourth aspect of concern to some is the impact of and threats posed by, beekeepers accessing sites within native woodlands to deliver, recover and service their hives. These concerns relate particularly to the spread of weeds and diseases that may damage the host ecosystems.

The scientific literature on these matters is not conclusive with some reports indicating damaging impacts and others concluding that honey bees have no or negligible negative effects (Paton 1993, 1996, 1999). Paton (1996) provides a comprehensive summary of the relevant literature on this subject and represents the range of views as to the impact of honey bees on the natural environment. It would seem from this summary that it is not possible to generalise on whether the impact is positive or negative.

It is apparent that any conclusion as to the impact of European honey bees can only be drawn when the particulars of an interaction are considered, including the plant species concerned, the presence or absence of other pollination agents, other amendments to the ecological system involved, and aspects of the time of year and seasonal conditions prevailing.

Despite this uncertainty, in recent times and in various jurisdictions there has been mounting community pressure exerted on governments to exclude apiarists from crown lands and reserves in particular. Whilst so far it has only been in Queensland that apiarists face exclusion (commencing in 2012), in most other jurisdictions access has been or is to be restricted to a greater or lesser extent.

The loss of access to native nectar and pollen sources is recognised as a major threat confronting the beekeeping industry in Australia. Remnant vegetation is crucial for the survival of feral populations of European honey bees as it provides hollows for colonies to become established in as well as access to a diverse array of important food plants (Cunningham et al. 2002).

Areas including national parks, local reserves, conservation areas, and remnant bush blocks contain the majority of remaining native forest on which the apiary industry relies. These areas also provide much of the network of apiary sites which the industry needs to access in order to harvest the honey flows which occur irregularly and for short periods. Native forests on public lands also provide a ‘safe harbour’ and clean rehabilitation area which is needed to rebuild the strength and health of hives.

Remnant native vegetation in the vicinity of pollination-dependant crops is also important in supporting populations of native insects that pollinate some specialty crops such as cashew and macadamia (Cunningham et al. 2002).

The destruction of remnant vegetation through clearing and diseases like dieback also threatens the level of incidental pollination services available from not only feral honey bees but from native bee populations as well.

In addition, as many pollination-responsive crops do not provide good quality pollen and nectar resources for the honey bees pollinating them, apiarists providing pollination services to such crops, require access to the good quality foraging provided by the native vegetation to restore and maintain the condition of their colonies. Without this access they will struggle to rebuild and maintain their colonies for future pollination services (Cunningham et al. 2002).

Restricted access to conserved native vegetation is only one threat to beekeepers. Government policy, land clearing, firewood cutting, pests and diseases, forestry activities, reduced flooding and increase salinisation of the land may all contribute to the reduction in the floral resources available to beekeepers and affect the commercial beekeeping industry.

Climate change is also likely to impact the distribution and seasonality of pollination-responsive crops and pollen and nectar resources, as well as having an impact on the honey bee itself, its pests and diseases and other pollination agents. Determination of such effects is likely to be difficult given the number of organisms involved and the complexity of their interactions. This report does not attempt to anticipate the nature and scale of any impacts but recognises that these could significantly affect both honey production and the provision of pollination services and, as a result, warrants the attention of both the pollination and honey industries and researchers serving them.

In 1989, a national workshop of apiary industry personnel and scientist was convened in Canberra to discuss issues relating to commercially managed honey bees in the Australian environment. One of the key recommendations of the workshop was that each state should conduct a survey to determine the value and use of apiary sites, and then establish a comprehensive database to record this information (Goodman 2001).

Various land tenure, e.g. those held by state forests and national parks, are placing considerable pressure on beekeeping usage of these lands. Without a comprehensive and detailed report on the value of various floral types across Australia, it is very difficult for the industry to adequately and professionally argue their case to the relevant authorities.

The growing interest in revegetation of agricultural lands as an offset for carbon dioxide production and other environmental impacts has the potential to provide new floral resources for exploitation by the apiary industry if the species planted as part of these revegetation projects include those that are favourable and attractive to bees. Engagement of the apiary and related industries with those interested in revegetation activities as early as possible in the process would seem appropriate, first to ensure that any requirement for pollination services to assist the revegetation processes are recognised, and second to influence the composition and management of revegetation processes to provide where possible and appropriate an additional floral resource that might be accessible to the apiary industry.

Paton (2008) suggests that if the honey bee industry is to respond to changing resource levels and take a proactive role in revegetation programs that may secure floral resources in the medium and long-term then three pieces of information are needed:

- more accurate information on the suite of species used by the industry when key nectar-producing plants are flowering
- information that will allow predictions as to how floral resources might change through time
- information on how planting densities and arrangements of plants in revegetation programs may influence tree shape and eventual productivity of individual plants.

Other floral resources

Whilst the native flora are the key resource for apiarists in Australia there are some other introduced plant species that are of significance to beekeepers at certain times of the year and in certain regions of the country. If beekeepers are excluded from some of these native flora resources at some time in the future, these other resources could assume greater importance to apiarists, first, as a source of honey, and second, and of greater relevance to this study, for their potential to provide the nutrition required to ensure that colonies are in a condition to provide services to pollination-responsive agricultural industries.

Regardless of any pollination benefit that may accrue to the farmer, canola crops can provide a valuable resource for building up colony strength at a time of the year, leading into spring, when other resources may not be in flower.

Paterson's curse (*Echium plantagenium*), a widespread and prolific weed in the southern agricultural areas of Australia, provides nutritious pollen and nectar early in spring, and as such represents an opportunity for beekeepers to prepare colonies for either spring honey flows or for spring pollination services and also provides an initial honey flow.

Paterson's curse is regarded as an important weed because of its abundance and the fact that it is poisonous to livestock and is the subject of attempts to control and/or eradicate it including by the use of biological control measures. Its capacity for survival and prolific growth would, were it not toxic, make it an attractive and valuable pasture species. Beekeepers may have an interest in research to breed non-toxic varieties of this plant as a means of supplementing or replacing other floral resources.

Similarly, in southern parts of Australia, capeweed (*Arctotheca calendula*) is a prolific and widespread annual weed of pastures in particular that is an attractive and nutritious source of pollen and nectar for bees in late winter/early spring. Its potential role in the management of bees for pollination does not appear to have been considered in any depth.

Managing bees for pollination

The use of honey bees to pollinate various agricultural and horticultural commodities has been demonstrated to be an efficient means of improving fruit and seed set in responsive species.

Achieving the best results from the use of honey bees for this purpose requires careful management on the part of both the service provider (beekeeper) and the producer of the commodities to be pollinated (orchardist/farmer).

Furthermore, as discussed above, the management of honey bees for pollination services is not necessarily entirely compatible with optimal honey production. Attempts to achieve both objectives may lead to conflicts in priorities that result in sub-optimal outcomes and diminished returns.

Managing bees for the purpose of pollination is not a simple task and requires attention to the preparation and maintenance of hives prior to and during pollination service periods and in many instances providing for colonies to recover strength after the service is completed. The following paragraphs summarise the issues associated with some of the key factors to be considered when managing honey bees for pollination.

Hive strength

The more adult bees within a colony, the more field bees are potentially available for pollinating the target crop. Each hive needs a minimum number of bees in the hive proper for housekeeping duties, such as taking care of young developing larvae, feeding the queen and maintaining the correct temperature. Bees above this minimum number are then available for foraging duties. The weaker the colony the fewer bees available to carry out field work.

In most cases the ideal hive used for pollination should contain the equivalent of five to seven full depth brood frames, 50% full of brood in all stages of development and a prolific queen and bees covering 8–10 frames with sufficient honey stores for the term of the pollination contract.

Pollination productivity depends on an expanding brood nest. The expanding brood nest has a high demand for pollen and nectar that stimulates the colony to actively forage on the crop to be pollinated.

For commodities that flower in late spring and summer it may not be a particular problem for a beekeeper to provide hives in such a condition because that is where colonies normally are at that time of year. For early crops like almond which in Australia blossom in mid-July to mid-August when honey bee colonies are normally in a cyclical low in their activity, successful pollination requires that the apiarist diverges from the normal beekeeping cycle to ensure that large and vigorous colonies are available to perform the pollination service.

Growers of pollination-responsive crops who rely on honey bees for pollination are concerned about future availability of bees as well as increasing costs for pollination.

Maintenance/supplementation

A supply of water must be available to bees at all times. A lack of it adversely affects the nutrition, physiology, brood rearing, and normal behaviour of the bees. If a natural source is not readily accessible to bees, an artificial source must be provided. In favourable conditions water within 500m may be adequate but in the peak of summer the optimal range may be as little as 100m or less. The water must be of an appropriate quality and in particular must be free of contaminants that may adversely affect the health of the bees.

Large brood nests require significant quantities of high quality pollen which is rarely available with commercial crops, canola being the exception. At times of the year when pollen of suitable quality is not readily available, beekeepers may need a supplement to feed to their colonies to prepare them for pollination services or honey production.

Such supplements may offer commercial operations, queen breeders and hobbyist beekeepers a tool to boost colony strength, population, and brood productions, resulting in a more effective pollination season and higher honey yields.

Honey bees can be fed various foodstuffs to supplement inadequate supplies of pollen or nectar?. In the USA several highly balanced protein supplements have been developed specifically for the honey bee industry. These supplements have been designed to improve honey bee health and overall life expectancy.

Throughout the USA pollination brokers, grower associations and government departments of agriculture have established and enforce minimum colony strength standards. This practice ensures growers of strong pollination units and establishes quality expectations.

The science and economics of supplementation have not been conclusively demonstrated. The anticipated growth in demand for pollination services and the possibility of beekeepers being excluded from some of the floral resources they have relied on to reach and maintain optimal condition of their bees could mean that natural resources are not adequate or accessible to meet the demands of pollination service provision. In such circumstances a clear understanding of the science and economics of supplementary feeding would be required.

Hive placement

Whilst it may seem that the ideal placement of honey bee hives for optimal pollination effectiveness might be equidistant placement throughout the field, and possibly in an irregular layout pattern with hives spaced apart and facing different directions, there are many factors to be considered that are likely to dictate distribution patterns.

First, for practicality, convenience and access, hives are often grouped together, either on the pallets used to transport them or to facilitate the work of the beekeeper and/or the grower. If bees have to fly further than 500m to service the entire crop, hives should be split up and placed at appropriately spaced intervals.

Micro-climatic factors can influence the level of activity of a colony, and this also influences hive placement choices. Where possible, hives should be placed in elevated positions with a warm sunny aspect and protected from prevailing winds, to maximise bee activity. In wet and cold conditions bees only forage short distances from their hives. Hives should not be placed in long rows, for example along a fence line. This may lead to increased drifting and non-uniform colony strength.

Other points to be considered in locating hives within a crop to be pollinated include:

- temperature
- vehicle access
- whether the area is subject to flooding
- nuisance to public and farm workers, i.e. near sheds, roadways, stockyards
- disruption to bees from passing traffic – machinery and livestock movements reduce pollination activity
- sunlight/warm locations increase honey bee foraging times
- shade in spring is necessary to encourage maximum activity on target crops but shade early in the season will lessen bee activity (especially in almonds)
- slope – it is preferable to place hives on flatter ground
- ground cover – it is preferable to mow site before delivering the bees as tall plants may inhibit bee access to hives

- proximity of non-target flowers which might distract bees from target pollination crop
- water – bees must have access to sufficient water of a suitable quality.

From a pollination service provider's viewpoint, all-weather vehicle access to the crops to be serviced is essential. Hives should not be placed within 100m of gates, lanes, stock-troughs and sheds to minimise disruption to the flight activity of the bees from human, vehicular and stock movement and to protect the comfort of people and livestock. Whatever the placement that optimises the efficiency and effectiveness of pollination, all hives must be readily accessible to the beekeeper, not only for placement and recovery but for monitoring and servicing as required.

Timing/hive replacement or rotation

Timing is crucial for efficient pollination. Growers want bees on the crop during the pollination window but they also want them removed soon after bloom is finished so that they will not interfere with other tasks. Bloom periods may range from no more than a few days, up to several months.

While the consequences of being late in moving hives in to a bloom may be obvious, several problems can arise when hives are moved into a bloom too early. For example moving bees in too early will encourage bee to forage other floral sources rather than the targeted species. Non-target species may include ground flora in the form of weeds, as well as various eucalypt species that may also be particularly attractive to foraging honey bees. Bees show remarkable fidelity in their foraging and as a result may continue to service those non-target species even after the commercial crop comes in to bloom.

When services are required over an extended pollination period, rotation/replacement of hives may be required. The poor nutritional value of many horticultural crop species may result in declining hive health, hence the need for replacement or rotation of hives in order to achieve best pollination coverage. Healthy colonies with a strong developing brood are more efficient pollinators, hence replacement of weak colonies with strong colonies results in increased pollination efficiency.

Where servicing lucerne crops the bees often quite quickly learn to avoid tripping the lucerne flowers, or find other species to forage thus reducing the effectiveness of the service being provided. Rotating hives through the crop will ensure that there are always naive bees that have not yet learned to avoid the target species when foraging in the lucerne.

For crops such as almonds the most effective approach is to gradually increase the number of hives in the crop as the flowering progresses to its peak, then reduce the hive density as the number of flowers to be serviced declines.

Hive densities

Hive densities ultimately determine the number of honey bees working the target flower bloom. Stocking rates for honey production may vary from as little as four up to twelve hives per hectare depending on the crop to be pollinated. For most pollination purposes, the stocking rate should be at four to six active hives per hectare so that the area is saturated with bees to maximise the potential for pollination. At these stocking rates, however, the bees may not be able to gather sufficient honey to meet the nutritional requirements of the colony, let alone generate a surplus for collection and sale. In such circumstances nutritional supplements may be required, colony condition will decline and commercial honey production will not be feasible. A decline in colony condition may not impede pollination effectiveness provided it is closely monitored and is not for a prolonged time. It is also important that the bees have the opportunity to recover on nutritionally adequate foraging as soon as the pollination contract is completed.

Non-honey bee pollination agents

As is indicated in Section 2, there are a large number of biological and other agents that can contribute to the pollination of commercial and other plant species.

Wind pollination is critical to cereals which collectively represent Australia's largest agricultural sector. For other commercial plant species there are many hundreds of insects apart from European honey bees with the potential to mediate the pollination process. In Australia about 1500 species of native bees have been identified.

Most of these bee species are solitary creatures many of which come from one of nine genera including *Xylocope* (carpenter bees); *Exoneura* and *Braunsapi* (reed bees); *Amegilla* (blue-banded and teddybear bees); *Megachile* (leaf-cutter and resin bees); *Homalictus*; *Amphylaeus*; *Hyleaus* and *Meroglossa*. There are also a number of stingless social bees from the genera *Austroplebeia* and *Trigona* that form and service hives and brood (Anon 2009).

Whilst there is no doubt that that these insects contribute to the pollination of both the native and introduced flora of Australia including key pollination-responsive commodities, the scale and importance of this incidental contribution is not well understood. Jones (2009) reports unspecified studies that indicate 10–15% of visits to un-named pollination-responsive flowers are made by native bees, with 80% being made by European honey bees.

The circumstances under which these observations were made are unknown and it is likely that the activity of these agents will be affected by environmental conditions and the intensity of visits will be related to the presence of and distance to suitable vegetative habitat in the vicinity of the crop being pollinated.

In a study undertaken in New Zealand, Rader et al. (2009) demonstrated that there were other insects including the bumble bee that were as efficient as the European Honey Bee in transferring pollen, but not as effective in that the frequency of visits made to flowers by insects of these other species was much lower than that observed for honey bee. This they concluded was a function of the larger populations of honey bees in the area.

Research in Australia into the use of bees other than European honey bees for commercial pollination is limited. Leaf-cutter bees (*Megachile*) have been introduced under controlled conditions and demonstrated to be effective in pollinating lucerne crops (Anderson 2006b), and the bumble bee (*Bombus terrestris*) which has become endemic to Tasmania is sometimes used in the pollination of green-house crops in that state. Amongst the native bees, work has been done on the use of some *Trigona* species and blue-banded bees for pollinating small-scale commercial crops (Anon 2009).

4. Case Studies

Section 3 above outlines the generic issues confronting apiarists and the producers of pollination-responsive commodities in managing bees and responsive crops for optimal pollination efficiency.

In reality the management requirements for each of the pollination-responsive commodities are different, and within some commodities there are even finer details that need to be managed differently depending on the particular circumstances under which the commodity is being produced and market segments for which it is intended.

Factors that influence the finer detail of pollination management include:

- degree of responsiveness of the crop on pollination to achieve commercially viable yields
- time of year at which the pollination service is required
- variety of the crop
- intended market for the crop
- quantity and nutritional quality of the pollen and nectar produced by the crop in question
- attractiveness of the crop to honey bees
- environment and location in which the crop is grown
- production method used in growing the crop (broadacre, orchard, glasshouse).

Table 4.1 shows more than 50 different agricultural, horticultural and other commodities grown in Australia and summarises their responsiveness to pollination. A series of 35 case studies (listed in Appendix 1) considering and summarising specific pollination management issues has been done for many of these commodities; each study deals with a single pollination-responsive commodity or a small group of commodities that are either closely related genetically or that have much in common in the management of their pollination.

The case studies also indicate, based on the best available information, the hive density required to achieve optimal pollination outcomes, assuming no contribution to pollination from other sources. This information is then used as the basis for estimating the total pollination capacity that would be required to provide optimal pollination in the absence of any contribution from outside sources including feral honey bees, for the entirety of Australia's pollination-responsive commodities (this information is summarised in Appendices 2 and 3).

Table 4.1 Commodities which are responsive to pollination

Commodity	Group	Commodity	Group
Pollination required for seed production only (all covered in a single case study)			
Asparagus	Vegetable	Eucalyptus	Tree crops
Broccoli	Vegetables	Garlic	Herbs
Carrot	Vegetables	Gladiolus	Cut flowers
Cauliflower	Vegetables	Onions	Vegetables
Chrysanthemums	Cut flowers	Potato	Vegetables
Commodities requiring insect pollination for optimal production (case studies presented for most of these)			
Almond	Nuts	Lupin	Broadacre
Apple	Tree crops	Lychee	Tree crop
Avocado	Tree crops	Macadamia	Nuts
Blueberry	Vine crop	Mango	Tree crops
Canola	Broadacre	Melons[b]	Ground crops
Capsicum	Vegetables	Nashi	Tree crops
Cherry	Tree crops	Olives	Tree crops
Chestnuts	Nuts	Papaya	Tree crops
Chickpea	Vegetables	Passionfruit	Vine crops
Citrus	Tree crops	Pear	Tree crops
Clover	Broadacre	Persimmons	Tree crops
Coconut	Tree crops	Pistachio	Nuts
Cotton	Broadacre	Pomegranate	Tree crops
Cucurbits[a]	Vegetables	Rubus[c]	Vine crops
Custard apple	Tree crops	Soybean	Broadacre
Faba beans	Broadacre	Strawberries	Ground crops
Field peas	Broadacre	Sugar plum	Tree crops
Kiwifruit	Vine crops	Summerfruit[d]	Tree crops
Legumes	Broadacre	Sunflowers	Broadacre
Lentils	Broadacre	Table grape	Vine crops
Longan	Tree crop	Tomato	Tree crops
Lucerne	Broadacre		
Commodities depending on pollination by non-biological agents (no case studies prepared)			
Barley	Broadacre	Rice	Broadacre
Maize	Broadacre	Sorghum,	Broadacre
Oat	Broadacre	Wheat	Broadacre
Pasture grasses	Broadacre		

a Includes Pumpkin, Cucumber Squash, Zucchini
b Includes Honeydew, Rockmelon, Watermelon
c Includes Boysenberry, Raspberry, Loganberry, Youngberry
d Includes: Apricot Nectarine, Peach, Plum

5. Synthesis

General

As the essential precursor to the production of fruit and seed, pollination is a fundamental process in the biology of all flowering plants. For the vast majority of those flowering plants that have been adapted as horticultural and agricultural commodities, pollination is an important determinant of yield and quality.

For a significant portion of agricultural plant species, including in particular the cereals, pollination appears to be adequately effected by the wind. For the remainder, the intervention of some biological vector such as an insect, bird, or mammal is required for pollination to occur.

Of the biological pollination agents none is more important to commercial agriculture and horticulture in Australia or world-wide than the European honey bee. Indeed, 65% of horticultural and agricultural crops introduced into Australia since European settlement require honey bees for pollination (Jones 1995, cited in Gibbs and Muirhead 1998). The importance of honey bees in this role is due in large part to the efficiency of their foraging activities (Gibbs and Muirhead 1998), and the convenience of managing them due to their highly social behaviours. The beneficial impacts of pollination by honey bees has been repeatedly demonstrated in trials involving comparisons of yield and quality produced by plants from which access by honey bees has been excluded with those plants to which honey bees have had full access.

The importance of primary industries with some reliance on pollination by honey bees to the Australian economy makes it almost certain that the value of pollination services carried out by honey bees substantially exceeds the value of honey and other apiary products generated by honey bees in this country. However, a significant proportion, if not the majority of these pollination services are currently performed either by feral bees, or as an incidental by-product of the foraging by bees managed for honey production. This means that the monetary value of bee pollination accrues at no cost to the producer of the commodity alone and is therefore unlikely to be fully appreciated or carefully managed by any party to the process.

Despite the repeated demonstration of the benefits of adequate pollination, and probably also because of the widespread provision of ‘free’ but uncontrolled and unmanaged incidental pollination services by feral bees and/or those managed for honey production, it is likely that there are many instances in a variety of pollination-dependant commodities where yield and/or quality are forgone due to sub-optimal pollination.

The mere observation of honey bees on or around the flowers of a pollination-dependant crop does not constitute evidence of that crop having been adequately pollinated. The timing and number of visits by bees to a flower, the presence of suitable polliniser cultivars (if required), and the climatic conditions under which the pollination occurs are some of the determinants of pollination effectiveness, and are factors that must be managed in order to achieve optimal yield and quality outcomes.

The value of pollination services currently provided from all sources, and the cost in terms of the yield and quality foregone as a result of the presumed sub-optimal use of pollination services, are difficult to quantify, and have not been the subject of comprehensive research in Australia. They are however of sufficient importance in several crops to warrant investigation.

For so long as the disease status of Australia’s honey bee population remains favourable the first element of this valuation equation (the current value of the pollination services provided) is of mainly academic interest. In the face of continuing cost/price pressures on most agricultural and horticultural commodities, however, the opportunity cost of sub-optimal pollination could be of commercial significance, and should be better understood if producers of pollination-dependant commodities are to make informed decisions as to the management of their crops.

A deterioration in the disease status of honey bees in this country could have a dramatic impact on the prosperity and prospects for the producers of pollination-responsive commodities, and on the demand for and importance of reliable information upon which they might make management decisions about the use of managed pollination services.

If one or more of a number of candidate organisms were to become established in Australia the health status of the honey bee population would deteriorate significantly, with potentially severe impacts on the level of 'incidental' pollination by feral bees in particular.

Foremost amongst these biosecurity threats is the varroa mite. In recent years this pest has proven highly destructive to bee populations in all countries where it has occurred, and it has spread rapidly within and between beekeeping countries around the world. Australia is now the only such country that has yet to record a detection of varroa. Elsewhere in the world wherever varroa has been detected it has proved impossible to eradicate and costly to manage.

Varroa poses a high risk to Australia's honey bee population responsive industries, given its presence in New Zealand and Papua New Guinea, its propensity for rapid spread, and its capacity to destroy honey bee colonies. Such a risk demands the development and implementation of management actions to reduce the likelihood and/or the consequences of an incursion. The actions that might be undertaken to manage this risk include:

- a review of pre-border and border quarantine and detection arrangements
- enhanced monitoring of hives to improve the chances of early detection should an incursion occur
- the development of management strategies to retard the spread of the pest and to maintain effective and productive colonies should it become established in Australia
- targeted research to address and where possible to anticipate priority exposures to varroa and its consequences.

Management of pollination services

Risk management actions must be cost effective in both nature and the degree to which they are pursued. The problem facing Australia's biosecurity authorities, beekeepers, and pollination-responsive industries in undertaking a cost/benefit analysis of any proposed action(s) is the dearth of widely accepted and credible information upon which to base such analysis. The three aspects of the value of pollination to each pollination-responsive commodity are:

- the maximum return (yield/quality) achievable when pollination capacity is unlimited
- the minimum pollination capacity required to achieve the maximum return
- the proportion of the maximum return achieved in the absence of any pollination.

Without this information it is difficult to quantify the risk to industries using honey bee pollination should Australia's honey bee populations be subjected to, for example, an incursion of varroa mite. This information is also critical in determining the point at which investments in varroa exclusion or mitigation programs would cease to be cost-effective.

Apart from its importance to the development of a coherent and economically feasible response to an event such as a varroa incursion, information should also be relevant to the efficient management of pollination-responsive crops whether or not varroa becomes established in Australia.

As improvements in the management of other variables that impact the yield and quality of agricultural commodities (such as choice of plant variety, soil moisture and fertility) lead to smaller and smaller responses to additional expenditure on managing these variables; as information and technology improve; and as pressure on margins due to competition from overseas producers intensifies, the optimisation of pollination as a determinant of yield, quality and profitability will become increasingly important.

Without a clear understanding of the responsiveness of commodities to pollination and astute management of the factors that affect pollination outcomes, producers of pollination-responsive commodities will be unable to manipulate the costs and benefits of pollination services to maximise their commercial returns. The consequences of inadequate information on inputs that affect yields and quality are either unnecessary expenditure on excessive use of an input, or a reduction in yield and/or quality due to the inadequate use of the input.

Further, as understanding of the importance and management of pollination increases and producers seek to optimise their usage of pollination services, an awareness of the demand for and supply of these services will in itself become important information for producers and service providers alike. Without such information producers of responsive commodities and service providers will find it more difficult and expensive to access or provide pollination services when and where required.

The information needed to effectively manage the provision and use of commercial pollination services has spatial and temporal dimensions, and is influenced by the wide range of commodities that may respond to those services. Factors that will influence the cost and availability of pollination services to a producer of a pollination-responsive commodity will include:

- the location of the responsive enterprise relative to the suppliers of pollination services and their stocks, and relative to other potential users

- the time of the year when the producer requires the services, and the competing options available to apiarists at that time including deploying honey bee stocks to the collection of honey

- the other producers and commodities requiring services at that time and their financial capacity to pay for such services. For example, with all other things being equal, a producer of a high value, highly pollination-responsive commodity will be prepared to pay more for pollination services than will a producer of a low value, low pollination-responsive commodity when supply of the services is limited.

- other issues including the accessibility and hygiene of the producer's crops, the attractiveness of the crops to bees, the quality and quantity of any by-product honey that the service might provide the apiarist, as well as the strength, condition and disease status of any bees offered by the pollination service provider.

This study provides important baseline information to enable a better understanding of all of these factors, and should assist the producers of responsive commodities, the suppliers of pollination services, their industry organisations, researchers and governments make informed decisions about the requirements for pollination services in Australia, and about biosecurity, particularly in the face of the threat from varroa and other pests and diseases.

A prime objective in researching, collating and presenting this information has been to provide a concise but comprehensive summary of the available knowledge pertaining to pollination and its management for each of the commodities covered by these case studies.

It has become apparent during the course of this study that there are significant deficiencies in the availability and accessibility of information relevant to the management of pollination in Australia. The deficiencies identified tend to be one or the other of two types. Either there is an absolute lack of conclusive information on one aspect or another of pollination in a some commodities, or the relevance of the informational available to conditions prevailing in Australia is uncertain.

In the absence of credible and relevant crop (even variety)-specific information, decisions about pollination services, their use, and the threats facing service providers and users may be reduced to little more than speculation. In Australia at present such crop or variety-specific information exists or is readily accessible for a relatively small number of highly responsive species. The efficiency of ill-informed decisions is almost invariably low, and the outcomes may occasionally be catastrophic.

Pollination responsiveness

A key consideration in understanding the pollination service requirements of pollination-responsive commodities at a crop, enterprise, regional and national level is the proportion of the maximum yield for that commodity that can be achieved in the absence of any biological pollination agent.

A variety of references are available that provide estimates of the pollination responsiveness of one or more commodities, and several include extensive lists. The reliability of the estimates provided is uncertain and there are inconsistencies in the estimates provided in the different references.

Table 5.1 below represents a consolidation of the relevant information on the pollination responsiveness of as many commodities as could be accessed from the literature in the course of this study. There are three important qualifications that should be made in regards to this list.

First, the list refers only to the responsiveness to pollination by biological pollination agents. Commodities such as cereals, which are dependent on wind pollination, are assumed to have a zero responsiveness to pollination by biological agents and not included in the list.

Second, for a significant number of species pollination responsiveness relates only to the production of viable seed rather than the commonly traded commodities for that species. In these species the commonly traded commodity is some vegetative component of the plant such as a root as is the case with carrots; a tuber such as potato; a corm in the case of onions; a leaf such as with lettuce and spinach, or an unfertilised inflorescence as is the case with cauliflower and broccoli. In such cases pollination services are only required for that part of the crop (usually a very small proportion of the total) that is grown to produce the seed required for future plantings. In Table 5.1 such crops are designated as ‘seed production’.

The third qualification is that programs for breeding new varieties of commodities that may be shown as having no responsiveness to biological pollinators for commercial scale production may require the use of biological agents (including human intervention) to effect the cross-pollination needed to generate the genetic combinations from which new varieties are selected.

Table 5.1 Pollination responsiveness of selected crops (as percentage of yield)

Commodity	Responsiveness (%)	Commodity	Responsiveness(%)	Commodity	Responsiveness (%)
Tree crops		**Ground crops**		**Seed production**	
Almond	100	Peanuts	10	Beans	10
Apple	100			Broccoli	100
Apricot	70	**Broadacre crops**		Brussel sprouts	100
Avocado	100	Canola	15	Cabbage	100
Cherries	90	Cotton	10	Canola seed	100
Citrus[a]	0–80	Soybeans	10–60	Carrot	100
Grapefruit	80	Sunflower [a]	30–100	Cauliflower	100
Lemon & lime	20			Celery	100
Macadamia	90	**Vine crops**		Clover	100
Mandarin	30	Blueberry	100	Lucerne	100
Mango	90	Cucumber	100	Mustard	100
Nectarine	60	Kiwi	80	Onions	100
Orange	30	Pumpkin	100		
Papaya	20	Rockmelon	100		
Peach	60	Squash	10		
Pear[a]	50–100	Watermelon	70		
Plum & prune	70				

a Depends on variety
Source: Modified from Gill (1989) by Monck et al. (2008)

Pollination dependence or responsiveness

Because for many of the plant species considered in this report significant production of the commodity in question occurs in the absence of insect mediated pollination, and to avoid the need to make an arbitrary distinction as to the point at which a species should be considered to be ‘dependent on’ rather than ‘responsive to’ insect-mediated pollination, the term responsiveness rather than dependence is used throughout this report. Conceptually, the use of ‘responsiveness’ aligns the management of pollination as an input to a system of production more closely to other inputs such as fertilisers for which the concept of economic optimisation based on the responsiveness to increments in the input is well understood and widely applied.

Potential demand for pollination services

A second important objective of this study has been to quantify the potential demand for pollination services in Australia in circumstances where first, the contribution from feral bees had been eliminated by a disease such as varroa and, second, all pollination-responsive commercial crops were serviced at the optimal rate indicated in the literature.

This objective has been set based on the view that information on the potential demand for pollination services in a ‘post-varroa’ Australia will serve four purposes:

- to assist pollination service users and providers to better understand aspects of the scale, geography and seasonality of demand for pollination services, and thereby enhance their decision making, planning and risk management in regards to their pollination-service-related business activities

- to assist industries with an interest in honey bee pollination and their advisers to better understand the current and potential market dynamics associated with the provision and use of pollination services, and in particular to better understand the potential impacts of an incursion of varroa or some other severe pest or disease on their industry, and thereby plan to mitigate these effects

- to similarly assist national and state government agencies with interests and responsibilities of relevance to the pollination industry in comprehending the scale and complexity of the industry in a 'post-varroa' scenario, and planning to discharge their responsibilities and preserve their interests in such a scenario

- to provoke and hopefully assist researchers in relevant scientific, social and economic fields to identify and address the deficiencies in knowledge revealed by this analysis.

Methodology

An estimate of the potential demand for pollination services in Australia has been developed using the following methodology:

- **Identification of pollination-responsive commodities**: Based on consultation with pollination stakeholders including consumers and providers of pollination services and researchers with an interest in the industry as well as detailed review of the relevant literature. More than 50 different commodities for which production is responsive to pollination principally by the European honey bee a greater or lesser extent, were identified, and are listed in Table 4.1. Table 5.1 indicates the degree of responsiveness to pollination for many of these commodities.

- **Determination of optimal hive density**: The optimal hive density for each crop has been determined by reference to the literature. Typically this has resulted in a range of stocking densities and in such cases a conservative mid-range value has been applied. The values applied are as shown in Table 5.2.

- **Area of pollination-responsive crops:** Information from the *Agricultural Commodities: Small Area Data, Australia, 2005-06 (Reissued)* (ABS 2008) based on the ABS Agricultural Census conducted at 30 June 2006 was used as the estimate of the area over which each of the pollination-responsive commodities identified above is grown in Australia. This data was collected and in this report has been interpreted at the level of Statistical Local Area (SLA).

- In cases where this data is reported as other than hectares of the commodity (e.g. for some tree crops it reported as numbers of trees) a conversion to hectares has been made based on conversion factors derived by reference to the literature. This information is summarised at a national level in Table 5.3 (a).

- **Pollination period:** For each commodity the month in which pollination occurs was determined by reference to the literature and state agricultural agency websites. In many cases pollination was assigned to a single month regardless of where the crop might be grown. In some cases, such as apples, where the crop is grown over a wide geographical range, the period of pollination might be assigned to different months for different states or groups of states.

This data is detailed in map and tabular form in Appendices 2 and 3. Each of the maps shows the distribution of hives at a SLA level required to provide the optimum stocking density for each of the commodities that are pollinated in a particular month. The information is also summarised at a national level in Table 5.3 (b).

Table 5.2 Hive density (number of hives per hectare) recommended for efficient pollination of selected crops, densities used in calculations of pollination service demand

Commodity	N° of hives per hectare	Commodity	N° of hives per hectare	Commodity	N° of hives per hectare
Tree crops		**Broadacre crops**		**Seed production**	
Almond	6	Canola	0.5	Beans	11
Apple	3	Cotton	0.6	Broccoli	11
Apricot	3	Soybeans	4	Brussel sprouts	11
Avocado	3	Sunflower	4	Cabbage	11
Cherries	3	Lucerne	4	Carrot	11
Citrus	1			Cauliflower	11
Macadamia	7	**Vine crops**		Celery	11
Mango	12	Blueberry	3	Clover	3
Nectarine	2	Cucurbits	4	Mustard	11
Papaya	3	Kiwifruit	6	Onions	11
Peach	2	Melons	3		
Pear	3				
Plum & prune	3				

Table 5.3(a) Potential demand for pollination services in Australia (area in hectares of bee-pollination responsive crops requiring pollination in each month derived from 2005/06 ABS Census)

State	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
ACT								6	7	1			**14**
NSW	1449		68633					107940	97626	6665	5371	20617	**308301**
NT	70	3			612				2111	17	51	70	**2935**
Qld	7793	2717		8392		1205	4347	10398	5899	46831	1845	9548	**98974**
SA	108	105					4530	74318	19095	3134	3530	16142	**120961**
Tas	497							103	151	2038	910	122	**3821**
Vic	3780	145					7674	102004	24898	10859	1949	1261	**152569**
WA	186				1269			219311	57802	2319	481	1477	**282844**
Total	**13883**	**2970**	**68633**	**8392**	**1881**	**1205**	**16551**	**514080**	**207588**	**71862**	**14137**	**49237**	**970418**

Table 5.3(b) Potential demand for pollination services in Australia (number of hives required at optimal stocking densities based on 2005/06 ABS Census)

State	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ACT								3	18	3		
NSW	5668		274532					109341	176284	22688	5599	83683
NT	280	12			1836				25334	52	51	300
QLD	31172	10868		33568		21690	13041	50832	54732	78333	1845	37198
SA	324	420					27178	38195	40728	9907	10193	64426
TAS	5467							252	452	5667	2855	485
VIC	14972	580					46043	61968	57842	33125	2502	6497
WA	558				3807			110799	127268	7001	498	6244
Total	**58441**	**11880**	**274532**	**33568**	**5643**	**21690**	**86262**	**371388**	**482657**	**156775**	**23543**	**198833**

Limitations of the data

Each element of the data has its limitations as indicated below:

- **Identification of pollination-responsive commodities**: For most of the commodities listed in Table 5.1 the literature indicates a range of responsiveness to pollination, and the circumstances under which the responsiveness has been determined is not standardised between the various sources. There are numerous variables that could influence the responsiveness of a crop, including location, weather conditions, effective stocking rate, condition of colonies, management of the crop including the presence and nature of pollinisers if required, and varietal differences in responsiveness within the one species. For example the ABS information used consolidates all citrus varieties in a single value. The responsiveness of citrus is known to vary between different species and varieties of citrus and it has not been possible to distinguish between them from the information provided. For the purposes of deriving a potential demand for this group of fruit a single, conservative factor has been applied across the whole area reported for the industry.

- **Optimal hive density**: As with responsiveness to pollination, the literature can indicate quite a diversity of optimal hive densities for the one crop. In preparing this report a conservative but not the lowest value, has been used. It is also recognised that as for pollination responsiveness, optimal hive density will be influenced by location, weather conditions, effective stocking rate, condition of colonies, management of the crop including the presence and nature of pollinisers if required, as well as varietal differences in responsiveness within the one species. In addition, for tree crops in particular, as trees mature the density of hives required varies with the age and size of the tree.

  Further, the economic 'optimality' of a given stocking rate will vary with the unit price of the commodity and the cost charged by the apiarist for a hive; other things being equal the optimal stocking rate will be higher as the price received for the commodity increases and will be lower as the cost of a hive increases.

  Additionally, due to the limited information relevant to this study available on lupins and 'low alkaloid' Paterson's curse, these species have not been included in the calculation of potential pollination demand even though case studies for each have been prepared and are presented. The decision to exclude white lupins from consideration in the development of the potential demand tables and maps also takes into account a preliminary cost-benefit analysis that suggests that the density of hives required to achieve the yield increases demonstrated in trials is not economically feasible.

- **Area of pollination-responsive crops:** As well as the limitations imposed by the census information collection methodology, the data used are for a single year (2005/06), and the extent to which it may be representative of other years, in particular future years, is uncertain. Further, in at least a couple of instances responsive commodities are grouped with unresponsive species, for example, lucerne and faba beans. In the case of lucerne, specific data have been sourced from elsewhere and included in the table and the maps; no provisions for faba beans have been included in either the maps or the tables even though a case dtudy is presented and they have been demonstrated to be responsive.

- **Pollination period:** As with pollination responsiveness and hive density, in the literature and in practice, views on the optimal pollination period vary more than might be indicated in the tables and maps presented in this report. Key sources of variation between years are likely to be seasonal conditions, crop management, crop location and crop variety.

Despite these and other limitations it is believed that this information, as well as representing the best currently available, will serve as a very useful tool to those with interests in the pollination industry in providing a visual representation of the distribution of potential demand for pollination services and the logistical challenges that the pollination and apiary industries are likely to face.

Issues arising

This study and the information presented in this report raise a number of issues that warrant close consideration by those with an interest in the pollination and apiary industries in Australia. These matters are addressed below as discreet items. This is done solely for convenience and should not obscure the fact that many of them are related, interdependent or different facets of the same issue.

Whilst the threat posed by varroa and other exotic pests and diseases of honey bees makes consideration of and action on these issues pressing to the point of urgent, they are by and large matters that should, in the interests of the efficiency and prosperity of the affected industries, be addressed anyway.

Quality and relevance of information available to Australia's pollination and apiary industries

Whilst a key objective of this study is to consolidate the currently available information of relevance to pollination in Australia, and the authors believe that this objective has largely been achieved, in the course of this study it has become apparent that there are severe deficiencies in the information available on some key issues and that much of the information that is available is based on research undertaken outside Australia thereby devaluing the applicability of this information to Australian conditions.

Key information deficiencies relate to:

- the population of feral honey bees in Australia – the number of colonies, their distribution on a large-scale and meso-scale, and the strength and condition of feral colonies
- the responsiveness to pollination of various crops and commodities when grown under Australian conditions
- the stocking rate (hive density and hive strength) required to achieve optimal pollination
- the current and potential contribution to pollination from non-honey bee pollination agents and management means by which this may be enhanced.

Interest in and awareness of the importance of pollination amongst potentially affected parties in Australia

The anecdotal evidence from informed visitors to this country is that Australian producers of all but the most pollination-responsive commodities have little awareness or apparent interest in pollination as an important process in optimising the management and productivity of these commodities.

Explanations for this apparent indifference may lie in one or more of the following:

- a view that either the responses to pollination are perceived to be too small to be economic in absolute terms or relative to those that might be achieved by a similar investment in managing some other yield-related variable
- seasonal variations are so great relative to the response to pollination that the cost of pollination represents an unacceptable risk in the face of uncontrollable seasonal factors
- that populations of incidental pollination agents including feral bees, are sufficient to achieve adequate levels of pollination.

There is also anecdotal evidence (Cannon 2009, pers. comm.) that some producers have tried paid pollination services and have been dissatisfied with the apparent response and/or the condition of the colonies made available by the pollination service provider.

A clear challenge/opportunity for the pollination industry lies in raising interest and awareness of the importance of pollination amongst the producers of moderately responsive commodities.

The two conditions precedent to success in this endeavour are, first, credible and relevant research that demonstrates the responses that can be achieved and that achieving them is economically rewarding and, second, the development and deployment of extension methodologies that are meaningful to and effective within, the target audiences.

Adequacy of levels of pollination currently being achieved in Australian agriculture and horticulture

Despite the absence of conclusive statistics, the usage of managed pollination services appears to be growing in Australia. This usage however seems to be largely concentrated in either very highly responsive commodities such as almonds; very high value specialty situations such as vegetable and lucerne seed crops, or crops such as canola where there is a strong offset benefit to the service provider in the melliferous resource.

There has been some penetration of the use of paid pollination services into the second tier of pollination-responsive commodities such as apples, pears, cherries and other stone fruit. This penetration is probably not as deep as in other comparable industries internationally, and it is apparent that many producers of these second tier and moderate to low pollination-responsive crops rely on incidental pollination by feral bees, bees from colonies managed for honey production and/or other insects.

Whilst no specific research to support the view has been published, the circumstantial evidence available to the authors of this report would suggest that in most circumstances where incidental pollination is relied on it is unlikely that the pollination service being provided from these sources approaches that which might be optimal for the crop in question, and as a result yield and/or quality are being forgone.

The circumstantial evidence that informs this opinion has a number of elements relating generally to the smaller populations of pollination agents within and around the crops in question, and therefore lower frequency of visits to flowers by these insects when compared to that achieved where optimal numbers of managed hives in good condition are used. These elements include the following:

- **Density and strength of hives:** Contributions to pollination can come from hives from a number of sources including:
  - *Feral bees*: Available information on feral bee populations in Australia (e.g. Paton 1996) indicates that colony densities in the general Australian landscape are less than one per hectare and often less than half that, and that while colony populations vary with the seasons and from year to year, numbers of individuals in a feral colony are likely to be of the order of 10,000. These estimates contrast with the hive densities recommended for optimal pollination of two to eight or more hives per hectare and with hive strengths of 50–60,000 individuals. Indeed a hive with a population of 10,000 individuals is probably at the minimum sustainable level and has very few bees available for foraging for pollen and nectar and thereby performing pollination services and probably reflects a low background level of floral resource available to the feral colonies.
  - *Hives managed for honey production:* Where bees are being managed for honey production optimal stocking densities are likely to be about one per hectare, each with a population of 20–30,000 individuals. The pollination potential of this arrangement is also likely to be an order of magnitude less than that required for optimal pollination, meaning that producers of pollination-responsive commodities who rely on this incidental source of pollination are likely to be severely under-serviced.

- *Other insects:* As noted elsewhere in this report, studies on visits to flowers by insects capable of effecting pollination, other than European honey bees, account for 10–15% of the total, with honey bees accounting for the other 85–90%. As with the observation that populations of feral bees are generally lower than that required to achieve optimal pollination of commercially responsive crops, it is likely that the populations of non-honey bee pollination agents are geared to the background availability of appropriate floral resources which are likely, over the course of a year to be significantly less than that represented by a pollination-responsive commercial crop.

- *Combined impact*: When the contributions to pollination from these three sources are considered together, and compared with that which might be achieved from a paid pollination service involving four strong hives per hectare, a generous estimate of the combined incidental pollination service might be 30% of that delivered by the paid service. This comprises up to 5% from feral bees (0.5 hives/ha at 20% strength); 10% from bees managed for honey production (1 hive/ha at 50% strength) and 15% from other insects. This estimate takes no account of the other elements considered below which would further dilute the effectiveness of the incidental pollination.

- **Proximity and distribution of hives**: As reported in Section 3 the proximity of the populations of pollination agents to and their distribution amongst the target crop is an important factor in determining pollination effectiveness. In most instances the ideal requires populations to be position close to and preferably within, rather than peripheral to the crop or orchard to be pollinated, and to have them distributed more or less uniformly and 150–300m apart.

  Almost by definition it is unlikely that any of the colonies from which honey bees providing incidental pollination services originate will satisfy these criteria. Occasionally where the crop in question is a favoured source of nectar for the production of honey an apiarist may locate hives within the crop, but generally colonies will be outside the perimeter of the crop and probably some distance removed.

  It is even less likely that populations of non-honey bee pollination agents will satisfy these criteria.

  From this point of view the outcome of a reliance on pollination from incidental sources is likely to be non-uniform, with plants at the edge of the crop receiving the highest level of service and those within the crop receiving progressively less, as their distance from the edge increases.

  A common trend in agriculture and horticulture has been towards ever larger individual plantings; as this continues, the location and distribution of pollination agents within a crop will grow in importance and distortions to the uniformity of pollination will intensify unless dedicated and managed pollination resources are used.

- **Alternative targets**: As is also noted elsewhere in this report many pollination-responsive crops are not highly attractive to bees or other insects as sources of pollen or nectar. Management of the timing of introduction to and placement of hives within such crops can effectively force the bees to forage amongst the target crop. No such control exists where pollination is performed by insects from incidental sources and there is a high risk that the target crop will be avoided by foraging insects in favour of more attractive species if such are available in the vicinity.

- **Other factors**: Issues such as access to adequate water, avoidance of disruptions from traffic and stock movements, and exposure to herbicides and insecticides are all issues that can impact the effectiveness of pollination by bees. Management associated with the use of paid pollination services provides some protection against such negative impacts whilst reliance on incidental pollination carries all these risks.

In summary, where the optimal pollination capability of a commodity is more than the equivalent of about one hive per hectare, circumstantial evidence would suggest that it is likely that a reliance on vectors other than honey bees specifically managed to provide pollination services will result in yield and/or quality being foregone and in the event of an incursion of varroa the opportunity cost of the forgone output will increase significantly.

Potential demand for pollination services in Australia

Based on the information outlined and analysed earlier in this section, and presented in the maps (Appendix 2) and in Table 5.3, a conservative estimate indicates that the potential demand for pollination services in the absence of a contribution from feral colonies could reach a peak of about 480,000 hives or more in the month of September, and approach or exceed 200,000 hives for most of the months during the period from August to the following March each year, before declining to very low levels in April, May, June and July.

Taking into account that in any apiary at any time only about 60% of hives will be in a condition suited to providing pollination services (Monson 2008, pers. comm.), the number of hives required to be committed to meeting this peak demand would be about 750,000.

This number compares with a current total apiary industry capability of about 500,000 hives; 400,000 or more of which are probably not currently involved in the provision of paid pollination services but are used exclusively for honey production.

Seasonality of demand for pollination services and honey production in Australia

Figure 5.1 compares the seasonality of potential pollination demand with that of honey deliveries – the latter being a surrogate for honey production. In this graph potential pollination demand is represented by the number of hives that could be required to meet the total Australian pollination demand in the absence of feral bees and with all producers of pollination-responsive commodities using optimal stocking rates as shown in Table 5.2. Honey production is indicated by monthly honey deliveries to a major honey-packing enterprise represented as a percentage of the total annual harvest in a 'typical' year (2005/06).

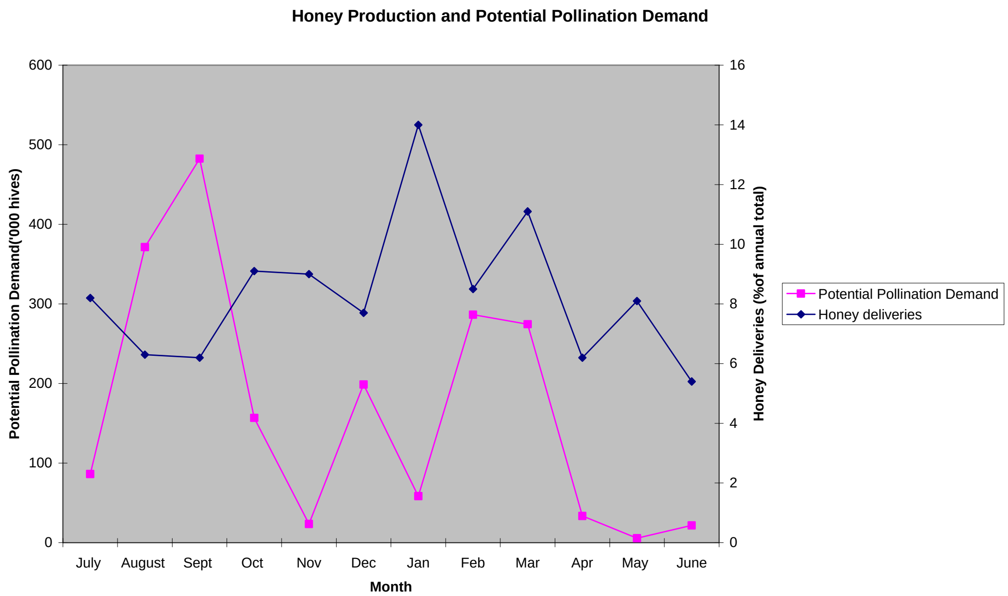

Figure 5.1 Monthly potential pollination demand and monthly honey deliveries

It is recognised that both measures are indicators only. The pollination demand is based on an extrapolation of information from ABS census data for 2005/06 and various literature sources. Honey deliveries to a packer are necessarily a lag indicator of honey production (deliveries in one month probably roughly equate to production in the previous month). In the absence of any more reliable information from other sources this is the best available indicator of the monthly pattern of honey production.

If the potential demand for pollination services is ever realised it will give rise to two distinctly different periods of tension between the two principal apiary activities. In the period from September to December inclusive and possibly continuing into March when pollination demand and honey production are both at high to very high levels there will be a competition for colonies to service the two different activities. In the period from April to July inclusive when there is no demand for pollination services and honey production is declining there will be competition for declining floral resources.

Currently such tensions can be seen in microcosm in Tasmania, where the onset of the Leatherwood honey flow in mid-January each year partially overlaps with a period of elevated demand for pollination services from that state's specialist seed producers. This results in the producers of late seed crop facing high pollination service charges and the apiarists servicing them forgoing at least part of the state's premium honey flow (Bourke 2009, pers. comm.).

The Australian apiary industry in a high pollination scenario

A national apiary industry that had the capacity to simultaneously service the peaks in pollination demand and honey production that would occur in the last quarter of each calendar year would need to comprise in excess of one million hives. An industry of such a large size would give rise to intense competition for the floral resources required to sustain the national honey bee population through the second and third quarter of each calendar year when there is little or no demand for pollination services. The result of this competition for resources could be that much of the nectar from the autumn flow that currently arrives at the packers as honey would be consumed in the field by colonies being held over for the next pollination season.

If the national apiary industry were to optimise its total stock at a level that matched the floral resources available during autumn and early winter, there would be severe competition for colonies to service the dual peaks of pollination demand and honey production in spring and summer each year. The result of such severe competition could be very high prices for pollination services and/or less than full exploitation of the available melliferous resources and therefore lower honey production.

Managing and maintaining colonies for pollination service provision

The likely outcome of this dilemma would be an industry that had a total capacity approaching that required to service both pollination and honey production at the peak, some elevation of pollination services charges at this time, and the development of supplementary feeding regimes and formulae to carry colonies (principally those used for pollination services) over the lean autumn and early winter period.

Quality assurance for pollination services

A key factor in the use and effectiveness of paid pollination services by producers of pollination-responsive commodities is the quality of the colonies supplied by the service provider. Established pollination service providers report frequent instances where producers are resistant to suggestions that they should use paid services on the basis of previous unsatisfactory experience with under-strength colonies (Cannon 2009, pers. comm.; Monson 2008, pers. comm.).

Realisation of the full benefits of pollination and the potential for the use of pollination services will depend on users and potential users having confidence that the service they are provided with is of an appropriate standard. The apiary industry's quality assurance system, B-Qual, does not presently cover the quality assurance aspects of pollination service provision.

At least two informal or semi-formal quality assurance systems are in operation in Australia that are increasingly being applied as the de facto quality assurance standard. The more formal of these is the Code of Practice developed by the Tasmanian Crop Pollination Association Inc., and the less formal is that applied by the major pollination broker to the almond industry when selecting hives for use in servicing the almond industry (Monson 2008, pers. comm.).

Both these systems have elements that apply to the provider and to the user. For the service provider they cover aspects such as the strength and condition of hives, their biosecurity status, delivery, and maintenance and inspection standards. User aspects include access to the crop, crop condition, and provision of water. The use of agricultural chemicals in the vicinity of the target crop is of concern to both the service provider and the user.

Given the importance of the quality assurance to future of the pollination industry in Australia, the development of a formal and widely endorsed industry standard for the provision and use of pollination services should be addressed as a matter of priority, and the systems referred to above would appear to represent a sound basis for the development of such a standard.

Adequacy of and competition for floral resources in a high pollination scenario

As discussed above, a significant issue facing the apiary industry if the use of paid pollination services grows towards its potential will be the adequacy of, access to and competition for floral resources in the period from April to August each year which is when there is little or no demand for pollination services, but also when the condition of colonies that will be required for the provision of services in the following spring must be maintained and developed.

During this period these colonies will be competing for floral resources with those used for the production of honey from the autumn honey flows. Whilst in the event of that varroa becomes established, the elimination of feral bees may mean that the floral resources available to managed colonies will increase, it is unlikely that this will be sufficient to meet the increased overall demand. The problem for beekeepers could be exacerbated if the recent trend in some states to exclude managed hives from certain nature reserves and other public lands continues.

The growth in tree-plantings for the sequestration of carbon and other environmental purposes may provide the apiary industry with an opportunity to access new floral resources. To be most effective for the apiary industries such plantings must include melliferous species, and in particular those that flower at a time of the year when other resources may be limited. Achievement of any meaningful contribution to the security of the apiary and pollination industries from these sources will require the affected industries to engage effectively and early with those who might be interested in establishing such plantings to ensure that the interests of apiarists, including the mix of species planted and access to the resources, are provided for.

Enhancing the contribution to pollination from non-honey bee pollination agents

The contribution to pollination from agents other than the European honey bee appears to be minor at 10–15%, and the trend in modern agriculture to larger and larger plantings will reduce the contribution from these agents to the pollination of larger-scale crops and orchards. However, there are situations where these non-honey bee agents can make a significant contribution, and in the event of a varroa incursion producers may need to manage conditions to favour them.

The situations where non-European honey bee pollination agents are likely to be most effective are smaller-scale plantings in close proximity to vegetation attractive as a habitat to the insects of interest. Given this, the contribution from these insects will be enhanced by the planting and/or encouragement of favoured species of vegetation in the vicinity of the crop-lands, gardens or orchards, the provision of other favoured or required elements such as access to water, and the avoidance as far as possible of practices that deter or are detrimental to them, particularly the choice and use of agricultural chemicals.

Conclusions

A number of matters of significance to the pollination and apiary industries arise from work reported here.

Whilst there is much information on pollination accessible through the literature it reveals:

- there are significant gaps in the available knowledge
- the information that is available is often not consistent nor is it conclusive
- much of the information available is drawn from international experience and its direct relevance and applicability to Australia circumstances may be questionable.

Apart from a couple of highly responsive and specialist industries such as almonds and seed crops where pollination is well managed, it is unlikely that the importance of insect pollination in less responsive commodities is fully appreciated, and as a result is not optimally used or managed by the majority of producers.

The reliance on incidental pollination from feral bees or other sources is probably not well founded and it is therefore highly likely that Australia’s agricultural and horticultural industries are suffering lower yields and poorer quality harvests than would be the case were pollination to be optimised.

As individual plantings of responsive commodities get larger the contribution from incidental pollination will be reduced to essentially an edge effect, leaving the largest portions of these crops severely sub-optimally pollinated.

These factors would suggest that the potential use of pollination services, particularly in the event of a varroa incursion that eliminated the contribution to pollination services from feral honey bees, could require up to 480,000 colonies of European honey bees to be available for the provision of pollination services in the month of September each year.

Achievement of this potential will rely on:

- there being appropriate information to enable the producers of pollination-responsive crops to recognise that pollination is economically feasible for them and to determine the optimal stocking density to use to achieve optimal pollination

- effective extension of such information to potential users

- appropriate quality assurance arrangements within the pollination industry to provide users of these services with the confidence that the benefits of pollination will be realised.

Realisation of the potential for the use of paid pollination services would produce significant challenges for the apiary industry in Australia relating to:

- the availability of sufficient colonies to meet the springtime peak in demand for pollination services and take advantage of the co-incident peak in honey flows without causing the cost of providing pollination services to exceed what is economically feasible for the producers of pollination-responsive commodities

- the availability of adequate floral resources to sustain the increased national bee population through the autumn–early winter period when the demand for pollination services is low and the competition for floral resources is at a peak

- the development of suitable business models for the management of bees for pollination and/or honey production under the circumstances of a nationally managed bee population of about one million hives

- the availability of adequately trained and capable human resources to manage and service a much larger and more complex apiary industry.

As this study is heavily predicated on the assumption of the incursion and establishment in Australia of varroa or some other equally destructive pest or disease of honey bees, it must be emphasised that the apiary industry has nothing to gain from such an incursion and the industry should have as its highest priority the continued exclusion of destructive exotic pests and diseases.

The industry must have access to methods, materials, knowledge training and commitment to manage and maintain apiaries for pollination or honey production in the presence of varroa or other pests and disease. Indeed, there is potential for a significant increase in demand for paid pollination services with all the attendant opportunities and challenges for the apiary industry in the absence of varroa.

The derived information and interpretations provided in this study represent the best that could be realised given the limitations of the information currently available as noted above. This study is published as a starting point for further work to address the deficiencies and uncertainties that constrain the development of the pollination industry in Australia and exacerbate the threat posed by varroa and other exotic pests and diseases of the European honey bee.

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Appendix 1. Case Studies

Case studies prepared for the report:

1	Almond	19	Macadamia
2	Apples	20	Mango
3	Apricot	21	Melons
4	Avocado	22	Papaya
5	Blueberry	23	Passionfruit
6	Canola	24	Paterson's curse
7	Capsicum	25	Peaches and Nectarines
8	Cherry	26	Pear and Nashi
9	Citrus	27	Persimmon
10	Clover	28	Plums and Prunes
11	Coffee	29	Pomegranate
12	Cotton	30	Rubus
13	Cucurbits	31	Soybean
14	Faba beans	32	Strawberries
15	Kiwifruit	33	Sunflower
16	Lucerne	34	Tomatoes
17	Lupins	35	Vegetables for seed
18	Lychee and Longan		

Individual case studies are available at ____________________.

Crops not pollinated by honey bees

Several crops studied as part of the *Pollination Aware* investigation were found to be non-responsive to honey bee pollination. Information contained in various literature sources indicated that these crops show no response to honey bee foraging and were pollinated by other processes including wind and/or self pollination. Non-responsive crops studied included:

- Olives
- Pistachios
- Walnuts
- Grapes
- Lentils
- Chickpeas
- Chestnuts
- Linseed.

In addition to these, the major cereal crops, wheat, barley, oats, maize and sorghum are well known to be pollinated by wind and to show no response to insect pollination, so were not considered further in this study.

Appendix 2. Maps of Pollination Demand by Month and by Statistical Local Area (SLA)

Appendix 3. Tables of Calculated Pollination Requirements by Month and by State

January	State	Capsicums	Cucurbits	Soybeans	Tomatoes	Vegetables for seed	Grand Total
	New South Wales	384			5284		5668
	Northern Territory			280			280
	Queensland			31172			31172
	South Australia	324					324
	Tasmania					5467	5467
	Victoria	444	1536		12992		14972
	Western Australia	558					558
	Grand Total	1710	1536	31452	18276	5467	58441

February	State	Sunflower	Tomatoes	Grand Total
	Northern Territory		12	12
	Queensland		10868	10868
	South Australia		420	420
	Victoria	580		580
	Grand Total	275112	11300	286412

March	State	Sunflower	Grand total
	New South Wales	274532	274532
	Grand Total	274532	274532

April	State	Sunflower	Grand total
	Queensland	33568	33568
	Grand total	33568	33568

May	State	Melons	Grand Total
	Northern Territory	1836	1836
	Western Australia	3807	3807
	Grand Total	5643	5643

June	State	Strawberries	Grand Total
	Queensland	21690	21690
	Grand Total	21690	21690

July	State	Almonds	Melons	Grand Total
	South Australia	27178		27178
	Victoria	46043		46043
	Queensland		13041	13041
	Grand Total	73222	13041	86263

August	State	Almonds	Apricots	Avocados	Canola	Macadamias	Nectarine	Peaches	Plums and prunes	Grand Total
	Australian Capital Territory				3					3
	New South Wales	8804			48595	45067	1681	1636	3558	109341
	Queensland		173	14090	226	36343				50832
	South Australia				36865		531	338	460	38195
	Tasmania						37	79	136	252
	Victoria				47742		4936	5729	3561	61968
	Western Australia				109274		955	571		110799
	Grand Total	8804	173	14090	242703	81410	8141	8353	7714	371388

September	State	Apple	Apricots	Avocados	Blueberries	Canola	Cotton	Macadamias	Mangoes	Plums and prunes	Strawberries	Grand Total
	Australian Capital Territory	15				3						18
	New South Wales			4489	1536	48595	118479		2016		1170	176284
	Northern Territory	0							25334			25334
	Queensland	4974				226			49532			54732
	South Australia			1583	30	36865					2250	40728
	Tasmania		452									452
	Victoria			1328	348	47742					8424	57842
	Western Australia			4074	3	109274		14	7664	2946	3294	127268
	Grand Total	4989	452	11474	1917	242703	118479	14	84545	2946	15138	482657

October	State	Apple	Apricots	Blueberries	Canola	Cherries	Cotton	Cucurbits	Kiwi fruit	Nashi	Papaya	Pear	Grand Total
	Australian Capital Territory										0	3	3
	New South Wales	7818	235			3967		9984	396	21		267	22688
	Northern Territory										52	0	52
	Queensland					54	77837		222		1	219	78333
	South Australia	4317	1115			1594		1928	48	80		825	9907
	Tasmania	4689		84	892					2			5667
	Victoria	13986	2108			2683			1098	1256		11994	33125
	Western Australia	5121	206			238			90	80	0	1266	7001
	Grand Total	35931	3664	84	892	8537	77837	11912	1854	1438	53	14574	156775

November	State	Cherries	Citrus	Papaya	Raspberries	Sunflower	Vegetables for seed	Grand Total
	New South Wales		5296	69	234			5599
	Northern Territory		51					51
	Queensland		1845					1845
	South Australia		2617		36	1380	6160	10193
	Tasmania	2481			374			2855
	Victoria		1791		711			2502
	Western Australia		476		23			498
	Grand Total	2481	12076	69	1377	1380	6160	23543

December	State	Capsicums	Cucurbits	Melons	Lucerne	Soybeans	Tomatoes	Vegetables for seed	Grand Total
	New South Wales			5217	12000	61824		4642	83683

	Northern Territory	24	232					44	300
	Queensland	6132	29416					1650	37198
	South Australia			426	64000				64426
	Tasmania		452	9			24		485
	Victoria			1269		2280		2948	6497
	Western Australia		4316				1400	528	6244
	Grand Total	6156	34416	6921	76000	64104	1424	9812	198833

State	**Jan**	**Feb**	**march**	**April**	**May**	**June**	**July**	**August**	**Sept**	**October**	**Nov**	**Dec**	**Total**
Australian Capital Territory								3	18	3			23
New South Wales	5668		274532					109341	176284	22688	5599	83683	677795
Northern Territory	280	12			1836				25334	52	51	300	27865
Queensland	31172	10868				21690	13041	50832	54732	78333	1845	37198	299710
Queensland				33568									33568
South Australia	324	420					27178	38195	40728	9907	10193	64426	191371
Tasmania	5467												5467
Tasmania								252	452	5667	2855	485	9710
Victoria	14972	580					46043	61968	57842	33125	2502	6497	223528
Western Australia	558				3807			110799	127268	7001	498	6244	256175
Grand Total	58441	11880	274532	33568	5643	21690	86262	371388	482657	156775	23543	198833	1725213