THE WINSTON CHURCHILL MEMORIAL TRUST OF AUSTRALIA

Report by TIFFANE BATES

2009 Churchill Fellow

AUSTRALIA, THE LAST HONEYBEE OASIS: BREEDING HONEYBEES RESISTANT TO VARROA MITES.

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Signed: Tiffane Bates Dated: 10 October 2010

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INTRODUCTION

"Let our advance worrying become advance thinking and planning"
Sir Winston Churchill

The honeybee[1] is under threat throughout the world. World bee populations are in trouble for many reasons and at the forefront of these is the parasitic mite *Varroa destructor*. Australia is now the only country remaining with a large bee industry which is free of varroa. It is only a matter of time until it arrives. We need to get prepared. This parasite will decimate both feral and commercial bee colonies. Food producers will no longer be able to rely on passive pollination from feral colonies and commercial beekeepers will struggle to keep up with pollination demands. Countries which have relied on chemical treatments are finding many problems including mite/chemical resistance. People are turning to breeding resistance. This project investigates current breeding programmes in several varroa infested countries around the world and provides recommendations as to how we in Australia can prepare for the inevitable arrival of a pest which will radically change the way we conduct agriculture in this country.

ACKNOWLEDGEMENTS

Firstly I would like to thank the Winston Churchill Memorial Trust for the incredible opportunity that is my Fellowship experience. In particular Meg Gilmartin and Helen Bolton for their support and never ending humour.

I can hardly express my gratitude to every person who showed me around, shared their research, time, food, ideas, precious energy, laughs and contacts. Thank you to everyone I visited, it was an absolute pleasure to work with you all and I hope to have the opportunity again soon. And a particular thanks to the families that I stayed with, your patience with another bee conversation is much appreciated.

Natarsha Bates, gets a special 'Ta'. Without her this report would never have seen the light of day. Her help and care throughout my entire Fellowship earns her the title of 'cast of thousands'.

Huge thanks to the uncountable people in the bee industry who have enthusiastically encouraged me to embark on this journey as they do in all the madcap ideas I put forward. Especially, but certainly not limited to; Rob Manning and Boris Baer for their glowing references; and for their letters of recommendation; Des Cannon, John Davies, Peter Detchon, Dave Leyland, Doug Sommerville and Max Whitton.

Whilst I was away two hardworking guys were taking care of my girls for me. Big thanks to Ron Clark and Colin Fleay for caring for my bees during the winter.

My trip would not have been possible without the patience of my personal journey planners, Qantas agents Melissa Hanley and Sue Crockett.

And a huge thanks to my friends and my Tom, your love and presence during this madness that is running a bee business is more valuable than I can say. Special thanks to Tom Salmon, Lisa Brideson, Jamie van Egmond and Sebastian Jones who went above and beyond the call to help my shift my beehives before I left Australia.

[1] Any reference to bees or honeybees in this report refers to the European honeybee, *Apis mellifera*

Executive Summary

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This project investigates current honeybee breeding programmes in several countries infested with parasitic mite *Varroa destructor* and provides recommendations as to how we in Australia can prepare for the inevitable arrival of a pest which will radically change the way we conduct agriculture in this country.

Highlights

- New Zealand was my first experience of beekeeping with varroa mites.
- Hawaii, home to world famous queen producers Kona Queens: I watched them send 5,000 queens in one afternoon. Varroa mite has just been discovered on The Big Island.
- I worked in the northern US and Canada with Sue Cobey, Liz Huxter and Marla Spivak, very dynamic and inspiring beekeepers involved in bee breeding research.
- Exploring vast acres of almond orchards in California with Randy Oliver whilst covering topics from epigenetics to how to manage bears in your beeyard.
- The overwhelming wealth of knowledge of my Baton Rouge USDA lab hosts. Being part of a fantastic conversation with researchers Jeff Harris and Bob Danka about the meaning of success.
- A month in Europe and the UK opened my eyes to what can be done through extensive European wide research projects and long term national breeding programmes.
- In France Gilles Fert introduced me to the concept of a beekeeping consultant.

Recommendations

- We need to learn from overseas mistakes, not repeat them. Especially in relation to chemical dependence and use. Getting on the 'chemical treadmill' should be carefully considered
- We must develop a strategy to most effectively and efficiently get varroa resistance into a commercially viable bee population which is then utilised by the industry
- We should improve the hygienic behaviour and general disease resistance of our existing Australian bee stocks
- It is critical that we improve understanding between science and industry
- We can prepare Integrated Pest Management techniques
- A change in public perception of the value of bees for Australia would benefit future planning
- Importing semen or any germplasm should be considered very carefully in view of disease transfer (eg viruses) and ecotype suitability

Dissemination and Implementation

- Since my return to Australia I have:
    - participated in an industry and research gathering in Canberra on non-chemical and minimal chemical use options for varroa management
    - been involved in the development of a Honey Bee Industry and Pollination Continuity Strategy for Australia in anticipation of a possible varroa incursion.
    - given presentations on my Fellowship experiences and findings at CIBER and SymbioticA at the University of Western Australia
    - been invited to speak with Professor Lyn Beazley, The Chief Scientist of Western Australia about the threats to honeybees in Australia.
    - sent virgin queens to Rottnest Island as part of the Better Bees WA breeding programme
    - I will continue to be involved with breeding and research within Australia

THE JOURNEY

Figure 1 Countries visited

PROGRAMME

March 2010 New Zealand

- Mark Goodwin & Michelle Taylor, Horticulture & Food NZ
- David Yanke, Daykel Apiary
- Jane & Tony Lorimer, Hillcrest Apiaries

April 2010 Hawaii

- Maria Derval (Didi) Diaz, University of Hawaii
- Gus Rouse, Kona Queens
- Michael Krones, Hawaiian Queen Co.
- Richard Seigel, Volcano Island Honey
- Ethel Villalobos, University of Hawaii
- Darcy Oishi, USDA Hawaii

May 2010 North America; California, British Columbia & Louisiana

- Randy Oliver, Scientific Beekeeping
- Ray Olivarez, Olivarez Honey Bees
- Eric Mussen & Sue Cobey, University of California, Davis
- Liz & Terry Huxter, Kettle Valley Queens
- Andony Melathopoulos, Agriculture & Agri-Food Canada, Beaver Lodge

- Tom Rinderer, USDA Honey Bee Breeding, Genetic & Physiology Research Unit

June 2010 USA (Minnesota), Germany, Portugal, France

- Marla Spivak, University of Minnesota, USA
- Darrel Rufer, Rufer's Bees, Minnesota, USA
- Ralph Büchler & Marina Meixner, Kirchhain Bee Institute, Germany
- Fernando Duarte, Quinta das Ferrarias, Portugal
- Yves le Conte, INRA, France
- John Kefuss, Independent researcher & beekeeper, France
- Jean-François Mallein, Independent apiculturist, France
- Gilles Fert, Beekeeping Consultant, France

July 2010 UK

- William Hughes, University of Leeds
- Bill Cadmore, Yorkshire Beekeepers Association
- Clive de Bruyn, BBKA Committee Member, Essex
- Sandra Kinchin, FERA National Bee Unit, York
- John Whent, Pear Tree Honey Farm, Richmond

AUSTRALIA, THE LAST HONEYBEE OASIS: BREEDING HONEYBEES RESISTANT TO VARROA MITES[2]

THE IMPORTANCE OF HONEYBEES

Imagine a world without bees. A terrible prospect certainly for those of us who love honey, and the families making their living from these hard working insects, but is it so serious for everybody else?

It has been estimated that the European honeybee, *Apis mellifera* is involved directly or indirectly in 65% of agricultural production in Australia alone (RIRDC, 2010). A third of all we eat comes directly or indirectly from bee-pollinated crop plants (Graham, 2005). This includes crops such as almonds and canola, as well as honey and pollen. Stock fodder plants including alfalfa and clover also require pollination by bees. This list of massive dependence on bees does not even include the textile industry or native flora requirements.

The value of the honeybee contribution to horticulture and agriculture worldwide is close to $US60 billion per year (Benjamin & McCallum, 2008). Honeybees are currently a crucial component in the human food chain. And let us not forget the cultural and historical importance of this small companion which has, for so many thousands of years been our supply of candle light and sweetness. Remember also the unending fascination with the humming mystery that is 'the Hive'.

HONEYBEES UNDER THREAT

There are reports from many countries of massive and inexplicable losses of bee colonies over the past few years. There is a great deal of research going into the cause of these colony collapses. Most scientists now agree that it is more likely that interactions between different pressures are 'overloading' the bees and there is not just one reason for the high mortalities (Moritz, Miranda, Fries, Le Conte, Neumann, & Paxton, 2010).

Figure 2 Honeybee with parasitic mite *Varroa destructor* on its thorax (Photo USDA Photo Unit)

Meanwhile the known diseases and pathogens are intimidating enough, *Nosema apis, N. ceranae, Varroa destructor*, American and European Foul Brood, Small Hive Beetle, to name just a few. In addition we are not just expecting our bees to while away their hours collecting honey in a back garden as natural selection takes care of their disease resistance. Bees are now farmed on a huge scale and only those colonies with the highest honey production and gentlest temperament are chosen. Consequently loss to disease is not economically viable and colonies are, in general treated with synthetic chemicals against loss to pathogens. Many bees are now dependant on beekeeper management and some countries have little or no wild bee populations.

[2] Any reference to bees or honeybees in this report refers to the European honeybee, *Apis mellifera*

Varroa destructor

This small parasitic mite is widely considered the most serious threat to profitable beekeeping. It is an external parasite which feeds on adults and larvae (Figure 2). The mites weaken the colony by reducing the fitness of individual bees and therefore the colony, as well as acting as a vector for various potent viruses.

The Asian honeybee, *Apis cerana* is the original host of varroa and the mite has switched to the European honeybee only in the last 60 years (Solignac, et al., 2005). The host parasite relationship of *A. mellifera* and varroa has not yet properly developed and most colonies are killed by the parasite.

Worldwide the mite is predominantly controlled by treatment with synthetic chemicals. There are several other varroa management strategies which will be discussed later in this report.

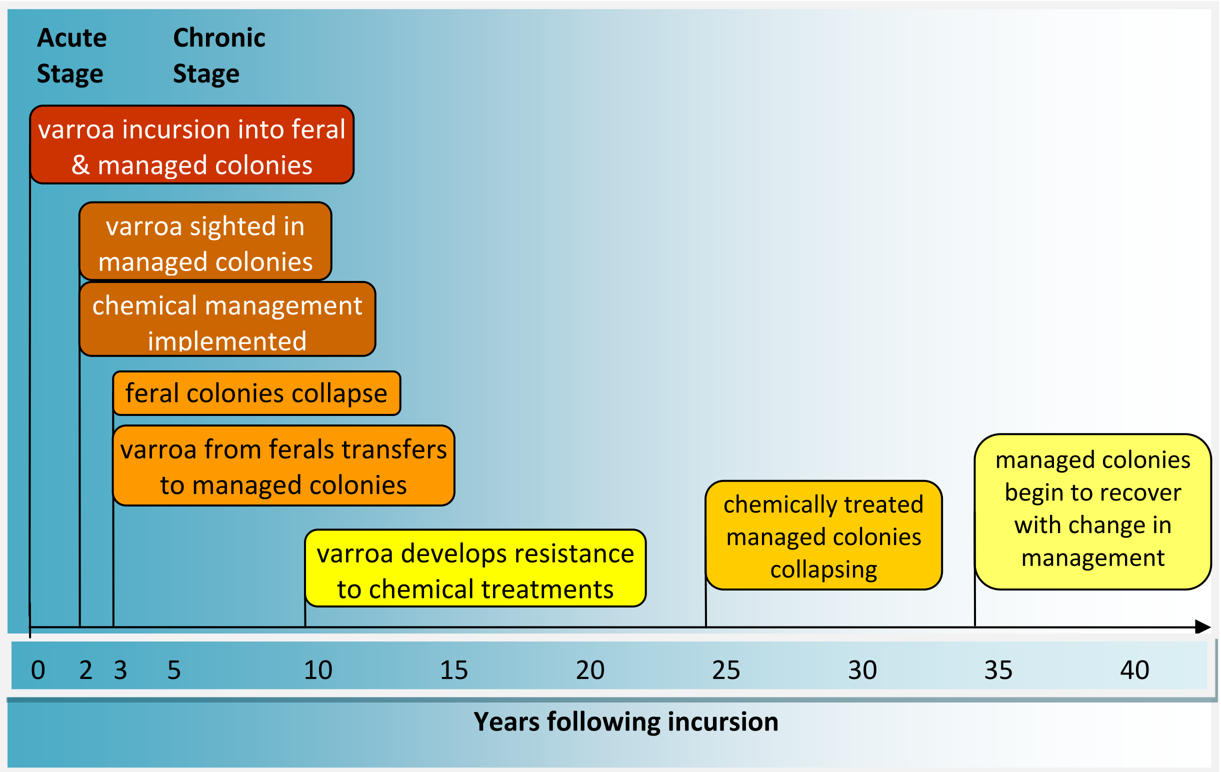

Figure 3 Industry response following varroa incursion and chemical management (timing is approximate and dependent on multiple factors)

AUSTRALIA: THE LAST OASIS

Varroa has spread throughout the world and now threatens bee populations on every continent except Australia (Figure 4). Through luck and excellent biosecurity measures Australia is, as far we know, free of the varroa mite. However, with our closest neighbours infested with varroa and the very isolated islands of Hawaii recently affected, we are feeling the pressure. Exactly how varroa invades each country is not known but the arrival of swarms into Australia via sea traffic is disturbingly real. A often repeated quote from eastern states honeybee researcher Ben Oldroyd states "it is unlikely that Australia will remain free of the mite" (Oldroyd, 1999).

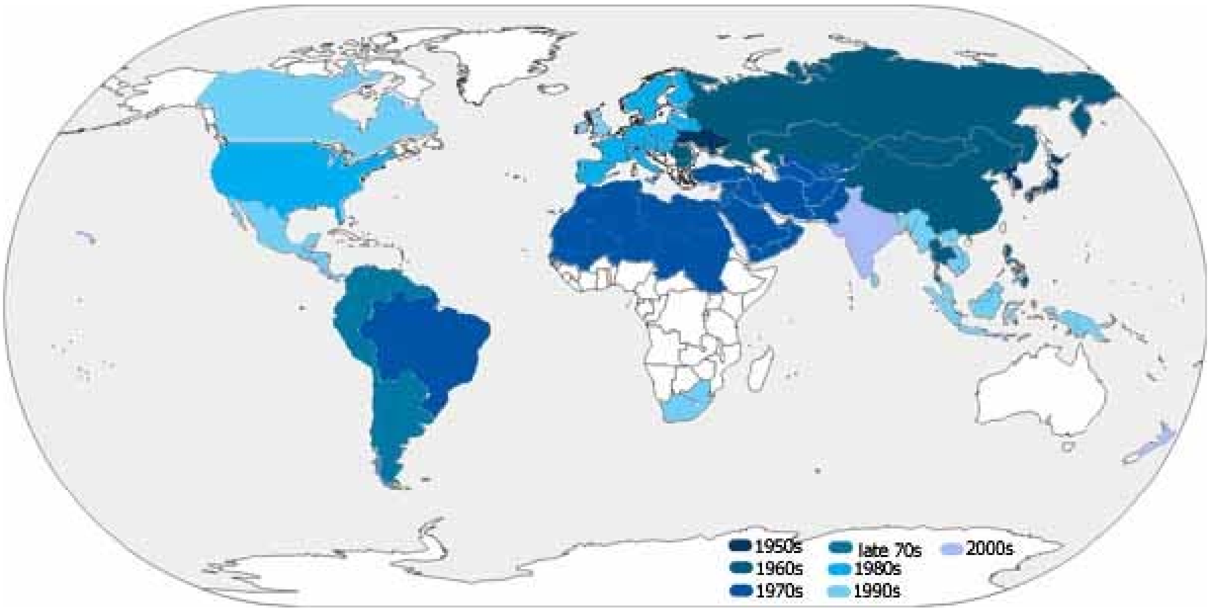

Figure 4 Global incursion of *Varroa destructor* onto *Apis mellifera* since 1950s[3]

The importance of honey bees has become very apparent in the last few years as world bee populations are threatened. In 2008 the Federal government released a report 'More Than Honey' which encapsulated the value of the bee industry to Australia and recommended $50 million be invested in the future of apiculture in Australia (House of Representatives Standing Committee on Primary Industries and Resources, 2008). This position was reiterated in August 2010 in another report 'Pollination Aware,' which also described the threat to Australian crops by exotic pests and diseases of honeybees (RIRDC, 2010).

Australia is currently the only continent on which a large feral population of honeybees still supplies passive or incidental pollination to agricultural crops and other flora. Other countries pay for hives to do this work. The beekeeping industry in Australia is relatively small and if ferals were to be eradicated by a pest such as varroa, it is possible that there would not be enough managed bee colonies available to provide adequate pollination to all crops in peak seasons (RIRDC, 2010).

According to many of our overseas colleagues, in Australia we live in a beekeeping paradise with a huge floral nectar supply from our *Eucalyptus* species, very long seasons and of course as yet, no varroa.

MY INTEREST

As a beekeeper in Australia, I am aware that it is only a matter of time before we are faced with varroa in this country. I therefore applied for a Churchill Fellowship with the intention of learning about the global experience with breeding resistance to varroa and bringing this information home. Obviously the subject is extremely broad; spanning over 50 years since the first infestation of *A.*

[3] (Allsopp, 2006; Navajas, et al., 2010; Solignac, et al., 2005; Anderson & Trueman, 2000; Zhou, et al., 2004; Abrol, et al., 2006)

mellifera, with thousands of beekeepers involved, and a comprehensive study is unmanageable in a 3 month period. So I framed the question to my own area of interest, queen bees. I am a fourth generation beekeeper and have been working in WA with bees off and on for over 15 years. I now have my own bee business called Bee Herd and spend time mating and breeding queen bees. I am also the research apiary manager with the Collaborative Initiative for Bee Research (CIBER) at the University of Western Australia and act as an intermediary between the researchers and various beekeepers.

WHY BREED FOR RESISTANCE TO PESTS AND DISEASES?

What does it mean to breed for resistance to varroa mites and why should we breed when the chemicals are available to treat this pest?

There are various registered chemicals with which beekeepers can treat their colonies for varroa mites. Early on these synthetic miticides were very effective (Le Conte, Ellis, & Ritter, Varroa mites, 2010). However, in the last twenty years two problems have arisen: in many cases the mites have developed resistance to the chemicals, and secondly residues of these chemicals are accumulating in the wax, pollen and even in the honey. These residues can result in a decrease in colony health (Frazier, Mullin, Frazier, & Ashcraft, 2008; Johnson, Ellis, Mullin, & Frazier, 2010). Another concern perhaps is that many cosmetic products contain wax, pollen or honey and therefore possibly chemical residues. With this in mind, the challenge is to find traits and or bee stock that can survive varroa infestation and produce healthy, active colonies whilst reducing chemical use. Crucially these bees must also be commercially viable in terms of production and temperament.

TOLERANCE OR RESISTANCE?

Disease resistance in honeybees can be defined as 'the ability of a bee population to survive without therapeutic treatments in a given environment and management system (Büchler, Berg, & Le Conte, 2010). The concept can also be referred to as disease tolerance; 'the ability of a honeybee colony to co-exist with an infestation of the mite' (in this case) (Goodwin & Taylor, 2007) Breeding for 'tolerant' bees and 'resistant' bees seem to be interchangeable terms around the world. As the most commonly used term is resistance in the literature, I will use that term from here on.

LEARNING FROM PEOPLE IN THE THICK OF IT

Each country and person I visited offered a different learning opportunity and way of looking at the question of 'how to breed a varroa resistant bee'. My observations ranged from individual beekeepers using natural selection to large scale government funded operations with impressive resources and decades of research on the subject. No single place had found the ultimate answer to suit all situations; every place had amazing ideas, knowledge and innovations. The brief description I give here in no way does justice to the vast amount of information, time and patience contributed by every person I met.

This section describes the approaches and my general experience of each location. It also gives my reasons for visiting. I have not expressed opinions given by individuals unless backed up by published research. I have also not given my opinion as to whether or not the work is successful, as this is complex and subjective. I have rather grouped my opinions and observations at the end of this section and in the conclusions and recommendations. In addition there were so many more places I 'should' have visited; it felt like an avalanche of possibilities once I was on my way.

NEW ZEALAND

I visited New Zealand because it is our closest, culturally similar neighbour and bee breeders here gave me an insight into how we might react to and manage the coming of Varroa. New Zealand has had varroa for around 10 years, which was the time it took the USA mites to develop resistance to the main chemical treatments used for mite control (Figure 3). There are rumours that this is starting to happen in the North of New Zealand.

Not all news in New Zealand post varroa is bad: people spoke of 30% increases in honey yield due to removal of feral colony competition. New Zealand also experienced a marked increase in pollination revenue for the beekeeper as crops such as kiwifruit require 100% pollination by insects and feral bees were no longer available to do this. The high market value of Manuka honey has also helped the economic survival of the NZ industry. (Somerville, 2008)

The two major groups involved in breeding for varroa resistance in NZ are The Horticulture and Food Research Institute (HortResearch) near Hamilton and Daykel Apiaries in the far north. There is also a group in the South Island starting up a breeding programme in preparation for the arrival of varroa in the southern South Island. I visited the two former organisations as well as a commercial honey producer involved in the HortResearch project.

The Horticulture and Food Research Institute

At the request of the NZ bee industry the Horticulture and Food Research Institute are currently running a breeding programme to identify varroa resistant stock. Bee stock was collected from a selection of breeders within the country. The mating occurs via both artificial insemination (AI) and natural closed population mating on a remote island off the Coromandel Peninsular (Figure 5).

Figure 5 Participating in closed population mating in New Zealand

Daykel Apiaries

Daykel Apiaries in Northland is run by commercial queen producer David Yanke. David has bred queens in NZ for over 30 years and after the arrival of varroa decided to commit part of his business to breeding bees with varroa resistance. He utilised Russian bee stocks known as 'Primorsky,' which have developed natural resistance to varroa in reaction to the mite's presence in Russia since the 1960s (Figure 4). David imported semen from this stock and carefully combined the genetic material with a test population from his own apiary. He uses artificial insemination for the breeding programme, but mates his production queens naturally.

Hillcrest Apiaries

Jane and Tony Lorimer are honey producers who breed their own queen bees. Jane, a longstanding president of the National Beekeepers Association of New Zealand, is aiding HortResearch with their research into varroa resistance.

United States of America

The USA is home to the some of the largest beekeeping operations in the world, with some operations of well over 50,000 beehives. The country has experienced huge bee losses over the last five years and is now in a situation where varroa mites are generally resistant to the majority of legal miticides (Figure 3).and chemical residues in wax, pollen and honey are at alarmingly high levels

Similar to Australia, North America is not the natural home of the honeybee. Now that their borders area closed to queen importation, the few-large scale queen producers supply much of country from a few breeder queens. This is reducing the genetic diversity of the bee population and possibly the ability of the bees to defend against pathogens and changes in climate (Le Conte & Navajas, Climate change: impact on honey bee populations and diseases, 2008).

Hawaii

A premier site of world queen bee production, Hawaii was only invaded by varroa in the last two to three years. There are three large queen bee producers on the Big Island of Hawaii and various other honey harvesters (Figure 6). The other islands, including Oahu, are home to hobbyists and small scale operations.

Figure 6 A Hawaiian Queen Co. breeding apiary

In 2009 existing Hawaiian stock was tested for the varroa resistant trait, Varroa Sensitive Hygiene (VSH), by the Baton Rouge research lab on the mainland (referred to later). The lab found that some level of this trait is already in existence on the Big Island (Danka, Harris, & Villa, 2010), which could greatly benefit their breeding programmes as these bees will already be adapted for the Hawaiian climate.

Hawaiian beekeepers are attempting to manage varroa without the use of synthetic chemicals. They have received permission from the USDA to use a version of formic acid specially formulated for hot climates. The queen breeders; Kona Queens, Hawaiian Queens Co. and Olivarez Honey Bees are participating in breeding strategies which involve importing semen from resistant lines on mainland USA and combining it using AI with their existing stock. The University of Hawaii is involved in these projects and is working with the Hawaiian Department of Agriculture to ensure beekeepers receive the best advice and assistance. The results of this approach will be tested when the feral colonies start to collapse in the third or fourth year after incursion (Figure 3). It will be very useful for Australia to watch what happens as the Hawaiian climate poses challenges similar to our own (refer to the section on Challenges for Australia).

California

California is an excellent place to be a beekeeper: a nice climate, good resources and access to some of the country's oldest queen producing families. It is also the site of the legendary vast monoculture that is the California almond industry, which only exists because of honeybees. Utilitsing over a million beehives a year, the almond pollination attracts beekeepers from all over the country (Pettis & Delaplane, 2010) (Figure 7). Hundreds of packages of bees are also imported annually from

Australia for almond pollination. Could production of this size be maintained without the use of chemicals? This is a question asked by many concerned about varroa management in the USA.

Whilst in California I visited a small scale commercial beekeeper, a large queen bee producer and the University of California honeybee research department. I barely scraped the surface of the knowledge base in this state. Unfortunately restricted by time, I could only take advantage of the following experiences.

Figure 7 Large scale beekeeping & mass transportation in California

Scientific Beekeeping, Grass Valley

The small northern town of Grass Valley is home to beekeeper and entomologist, Randy Oliver, from Scientific Beekeeping. He is on a self declared mission to do as much, learn as much and educate as much as he can. I could not possibly encapsulate all the areas in which Oliver is involved in this report so will summarise with a quote from his website: "...bee scientists in general are telling us that we need to move beyond the numbskull beekeeping practice of throwing a mite bomb into our hives once a year until it's ineffective, but rather start practicing smart beekeeping, or IPM, centered around fightin' bees that kick mite butt with only occasional help from us" (Scientific Beekeeping). IPM is integrated pest management and will be discussed later. Oliver is also becoming involved with bee epigenetics investigations (see Glossary).

University of California, Davis

UC Davis is the site of research of some of the great bee science minds of our time. Researchers at Harry H. Laidlaw Jr. Honey Bee Research Facility are among other things, currently addressing concerns about California's almond industry and national bee health. I met with Dr Eric Mussen, Extension Apiculturalist who believes that resistant stocks are a better long term solution than currently available short-term fixes (University of California). Mussen has been in his role for many years and is on the pulse of what is happening in the US industry

Some weeks later I travelled to Canada with Sue Cobey of UC Davis who is a world leader in artificial insemination of honeybees. Sue has been developing the New World Carniolan strain of bee since the 1980s, using stock from all over the USA. It has proved to be productive, hardy, gentle and highly disease resistant. Generally Sue is involved at UC Davis in identifying, selecting and improving honeybee stocks showing good disease resistance (University of California).

Olivarez Honeybees, Orland

Brothers Ray and Russell Olivarez have queen bee operations in Hawaii and California. They have hundreds of breeder queens and sell thousands of production queens a month. They currently treat their colonies with the commonly used varroa chemicals but are also working with Marla Spivak from the University of Minnesota to improve their varroa monitoring techniques and therefore widen their knowledge for stock selection.

USDA, Baton Rouge, Louisiana

Baton Rouge, Louisiana is home to the USDA Agricultural Research Service, Honey Bee Breeding, Genetics and Physiology Laboratory. The lab is involved in a plethora of research projects aimed at minimising problems that threaten honeybee productivity, and improving bee stocks for beekeeping (USDA Honey Bee Breeding, Genetics & Physiology Research Unit, 2010). They also aim to devise solutions based on genetic resistance to specific parasites.

One such parasite is *Varroa destructor*. Two breeding approaches were adopted by the lab more than 20 years ago: The Russian Honeybee Program and the Varroa Sensitive Hygiene (VSH) Program. The former utilised existing stock from Russia which showed evidence of resistance to varroa. The Varroa Sensitive Hygiene (VSH) Program isolated and identified this particular measurable characteristic of varroa resistant bees (Harbo & Harris, 1999). These two research projects have produced bees which require significantly reduced varroa treatments (Rinderer, Harris, Hunt, & de Guzman, 2010).

University of Minnesota

Figure 8 Science/Industry collaborations: Darryl Rufer and Marla Spivak

Using a different approach, the team at the University of Minnesota have developed bees which have greatly reduced varroa loads compared to others under similar conditions (Spivak & Reuter, 2008). Since 1994 lead researcher Marla Spivak and colleague Gary Reuter have been working in collaboration with local beekeepers including Darryl Rufer to breeding resistance in bees via hygienic behaviour (Figure 8). One benefit of this characteristic is that it is simple to measure in the field.

This research group is now working towards refining efficient and simple monitoring techniques, developing certification for specific traits such as hygienic behaviour and aiding beekeepers with sampling so they can make more informed breeding choices.

CANADA

Kettle Valley Queens, British Columbia

Figure 9 Mixing bees to make homogenised packages for varroa resistant experiments: Terry Huxter and Tiffane Bates

Following a well timed phone call by Randy Oliver I found myself driving with Sue Cobey, researcher at UC Davis, to Grand Forks, British Columbia. A collaborative project is underway in Grand Forks between Agriculture and Agri-Food Canada, represented by researcher Adony Melathopoulos, Beaver Lodge, Alberta and local beekeepers Liz and Terry Huxter from Kettle Valley Queens. Sue Cobey was asked there to contribute her artificial insemination skills and I participated as a curious and enthusiastic assistant (Figure 9).

To trial potentially Varroa resistant stock combinations in the field, this collaboration between science and industry was making full use of the Huxter's commercial operation and the research know-how of the Agriculture and Agri-Food Canada lab. One of the stock traits being selected for was the VSH trait identified by the Baton Rouge lab.

EUROPE

The honeybee is endemic to the majority of European countries and has correspondingly adapted to a broad range of different conditions. There is therefore a much higher capacity within the population for honeybees to adjust to changes in conditions, whether climatic or via pathogen introduction (Le Conte & Navajas, 2008). As Büchler, Berg and Le Conte (2010) suggest this diversity provides a rich source of material from which to select for varroa resistant stock.

Generally beekeepers in Europe have small numbers of hives and can consequently undertake highly intensive beekeeping management, enabling them to reduce their reliance on chemical treatments. Europe is home to many long running breeding programmes, both at the individual and large scale, national level. In response to large colony losses the focus of many of these programmes has in recent years shifted from economics and beekeeper convenience, to disease survival and colony fitness (Büchler, Berg, & Le Conte, 2010).

COLOSS (Prevention of COlony LOSSes Network)

The COLOSS Network is worldwide and involves 53 countries.[4] The Network was set up in response to large colony losses worldwide and its scientific members are attempting to identify and investigate why this is occurring. Its aim is to find the best ways to develop and disseminate sustainable management strategies. I have included COLOSS in the European section because it came to my attention there and so far the majority of the organisational roles are filled by Europeans.

The **COLOSS genotype environment interaction test** was of particular interest to me. This European wide collaboration aims to trial different bee strains under variable conditions to test their resistance and vitality (Network). Colonies from 17 different European countries are assigned to variable locations, and predetermined management and selection tools are repeated by each participant on the various strains they receive (Figure 10). Colonies are monitored closely and survival rates and a myriad other information is recorded (Büchler, Berg, & Le Conte, 2010). Colonies from both the German lab at Kirchhain and from Yves Le Conte's experiments are involved in the trials (discussed below).

Figure 10 Staff at Kirchhain Bee Institute monitoring bees for the COLOSS genotype programme (Ralph Büchler and assistant)

[4] www.coloss.org

Germany

Germany has a long history of national bee breeding programmes. Mating stations occur throughout the country where beekeepers can bring their virgin queens to be naturally mated on location by drones from colonies managed by the bee institutes. I was taken to several of these stations by researcher Ralph Büchler from the Kirchhain Bee Institute. The German bee monitoring project (*Arbeitsgemeinschaft Toleranzzuht*) is a recent long term study undertaken to understand periodically high winter losses of honey bee colonies in Germany (Genersch, et al., 2010). Refer to Kirsten Traynor's excellent article in the November 2008 ABK for a full description of this programme.[5]

Kirchhain Bee Institute, Hessen

Figure 11 Mating nucleus hives and drone colonies at Kirchhain Bee Institute, Hessen, Germany

The Kirchhain Bee Institute is involved in multiple areas of bee research as well as training, disease monitoring and raising public awareness. Their research covers such subjects as breeding, bee immunity and pesticide tolerance (Figure 11). Director Ralph Büchler plays a significant role in the German and European breeding programmes and in research into bee health in Europe. Researcher Marina Meixner heads the Diversity and Vitality Section of COLOSS and amongst other activities works with beekeepers on varroa management.

Whilst in Kirchhain I also spoke to Tilly Kuhnert who was the AI expert involved with the West Australian Department of Agriculture and Food bee breeding programme in the 1980s. I was pleased to be able to tell Tilly that the programme is still running but now in private hands.

Quinta das Ferrarias, Aljezur, Portugal

During the Fellowship I took a two week detour to southern Portugal to visit my father. After 40 years as a beekeeper himself, my father could not resist accompanying me to investigate a beekeeping operation (Quinta das Ferrarias) in the nearby town of Aljezur. The owner of Quinta da Ferrarias, local Fernando Duarte, runs 2,000 honey production colonies in and around the south of Portugal, harvesting mainly wild lavender. The bees are the local Spanish/Portuguese race. The colonies are treated biannually for varroa with a rotating application of synthetic chemicals.

Portugal is involved in the previously mentioned COLOSS programme via researcher Antonio Murilhas.

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[5] (Traynor, 2008)

France

National Institute for Agricultural Research, Avignon

The French National Institute for Agricultural Research (INRA) is world renown for their work on varroa resistant bees. Bee research, under the Directorship of Yves Le Conte, is divided amongst three teams: Biology, ecology and pathogens; Pollination; and Ecotoxicology. Since 1994 Yves Le Conte has been collecting French feral or abandoned honeybee colonies that have survived without varroa treatment. Yves believes that the natural selection process is advantageous as it selects for sustainable host-parasite equilibrium (2007). A breeding programme has been running for many years and Yves now has colonies which have survived without treatment for more than a decade. The bees bred by Yves are part of the COLOSS programme previously discussed.

John Kefuss, Toulouse

Fifty kilometres outside Toulouse James Bond is at work in the bee industry. Beekeeper John Kefuss initiated a breeding strategy in 1993 which he has christened **'The Bond Test'**. This "live or let die" approach selects colonies which survive varroa without treatment. The beekeeper can then improve colony production and temperament from the resulting stock.

John also promotes the 'soft Bond test' for those beekeepers without a financial buffer to survive the loss of a large number of colonies to varroa. This 'soft' version enables the beekeeper to select a proportion of their colonies for sacrifice to the 'test' based on the cost of sampling, and not experience a crippling loss to varroa.

John sells breeder and production queens and semen all over the world.

Jean-Francois Mallein and Philippe Huau, Giroussens

Close by in Giroussens, Jean-Francois Mallein and Philippe Huau are slowly building a queen breeding operation. These two young men are starting out in the industry when so many are throwing up their hands in despair at the challenges in modern beekeeping. The business is run using 'Buckfast' stock (Figure 12) and insemination experts are regularly brought to France from Poland to help with stock maintenance and improvement. Mallein and Huau use synthetic chemicals for varroa treatment.

Figure 12 Tending 'Buckfast' bees treated with synthetic chemicals, bred for gentleness and honey production

Gilles Fert, The Pyrénéss

Gilles Fert has been breeding and producing queen bees in the Pyrénéss Mountains for over 25 years. He is also a beekeeping consultant, with part of his business dedicated to advising apiarists all over the world. Gilles believes that the quality of the queen is the major determinant for the dynamism of the colony (Fert, 2008). Twenty years ago he imported Caucasian bees from Georgia, Russia and in the last two years has been using 'Primorski' stock which is advertised as resistant to varroa. Gilles only treats with 'soft chemicals' and is a firm advocate of adequate nutrition for bee health.

United Kingdom

The UK has had varroa for less than 20 years. There are many enthusiastic advocates of breeding for varroa resistance in Britain; most recently in August of this year, Swindon beekeeper Ron Hoskins publicised his development of a varroa resistant British bee (Devon Beekeepers Association).

University of Leeds, Yorkshire

The University of Leeds houses a group of dedicated social insect scientists headed by Dr William Hughes. Honeybee projects include investigation of disease transmission by Kat Roberts and looking for evidence of wild bee populations in the UK. The apiary at the University is run by Bill Cadmore, Vice Chairman of the Yorkshire Beekeepers Association.

Figure 13 English honey bee on thistle

Whilst in Leeds I attended The Great Yorkshire Show and was invited on a fieldtrip by National Bee Unit agent Sandra Kinchin. The National Bee Unit is part of The Food and Environment Research Agency (FERA) which carries out extensive bee monitoring, sampling and research throughout the UK. Sandra also took me to meet John Whent of Pear Tree Honey Farm**.** John is one of the UKs largest honey producers. He took us to see a yard of bees which he has never treated for varroa and which he is now monitoring. The most successful colonies from his observations will be utilised in his future bee stocks.

Clive de Bruyn, Essex

It was recommended that I visit Clive de Bruyn whilst in the UK. A well travelled beekeeper, Clive was in Yorkshire at the time and willing to go to the pub for a chat. A beekeeper of some 50 years, he has studied varroa in the UK since their arrival in 1992. Clive was advisor to the National Bee Unit for many years and on the committee of the British Beekeeping Association. In 1993 he co-wrote *The New Varroa Handbook*, but told me that much has changed in varroa management in the since then.

Beekeeping with varroa

How are people coping with the day to day and the big picture?

In the previous section I described some visionary projects and folks who are committed to sustainable, long term ways of approaching bee health and management. These approaches take time and money and are therefore are not possible for everyone.

So what are other people doing? So far the varroa mite is predominantly managed in the same way as any other stock disease, that is, with synthetic chemicals such as coumaphos and fluvalinate. Until recently only those people who preferred not to use chemicals or believed that this was not a long term solution concentrated on any other option. However it is becoming clear that that as mites become more virulent and chemical residues in hives increase it is no longer possible to rely on government registered chemicals as the only means of varroa management.

THE PRESSURES OF LIVING WITH VARROA

Figure 14 The first time I saw varroa in NZ (Photo Katie Lee)

As a beekeeper, the first time I saw varroa it was inconceivable to me that working with *that* in my hives could become normal and manageable (Figure 14). However, for much of the world this is just how it is. There is a whole generation of beekeepers who have never worked any other way. It is now no longer possible for beekeepers to just harvest honey or check colonies once a year; varroa has eradicated passive beekeeping. This section describes the extra pressures these beekeepers live with and how these pressures affect treatment decisions.

Economics

In some ways varroa can be seen as an economic disease. Many beekeepers will be reluctant to integrate a bee stock into their operation, no matter how varroa resistant, if the bees are sting a lot or are less productive. Similarly, when business owners make decisions about management, the cost of changing the way things are done or implementing another time heavy practice such as varroa sampling is often not economically viable.

It has taken some time for governments to acknowledge the importance of the beekeeping industry to the economic health of a country. Lack of value for this relatively small agricultural industry has often resulted in low funding for research and assistance for beekeepers in crisis periods.

Viruses

Figure 15 varroa mite which has been feeding on bee pupa (Photo USDA photo unit)

The effect of varroa on a bee colony is quite complex. The presence of varroa alone rarely kills a colony except at very high populations. Unfortunately varroa can also transmit viruses such as Deformed Wing Virus (DWV) from bee to bee when the mite feeds on the bee's haemolymph (Oldroyd, 1999)(Figure 15). This added stress can reduce vigor and longevity, meaning the difference between a colony surviving through the winter or not (Le Conte, Ellis, & Ritter, Varroa mites, 2010).

Myriad other diseases

Of course varroa is not the only disease bees have to survive and manage. Each country has an individual collection of diseases, each with different colony threshold effects depending on climate and beekeeping styles.

Colony Collapse Disorder (CCD)

For the last four years Europe and America have been losing colonies in huge numbers. This mysterious phenomenon has been termed CCD. More and more research is pointing to colony collapses resulting from interactions between different stressors. (Le Conte, Ellis, & Ritter, Varroa mites, 2010)

Large scale industry

In some places beekeeping businesses have become very large; in the Americas particularly, 70,000 beehives are being run by one business. In these cases colony stress can be increased by long distance travel, high competition in apiaries and unskilled apiary labour. The challenges of disease management for these large scale operations are amplified.

Chemicals: Resistance, residues and cocktails

The synthetic chemical treatments which made varroa just another management issue for so many years are now almost useless in many places because the mites have developed resistance to these chemicals (Figure 3). In desperation for their businesses some beekeepers have resorted to using very high levels of chemicals or even mixing up their own concoctions. In countries such as New Zealand and Portugal which have had varroa for less time than others, these chemicals appear to be still effective.

Figure 16 Bees harvesting sunflower nectar and pollen in France. The golden valleys are very beautiful, but the beekeeper moved his hives because he was nervous that the chemical treatments on this crop were poisoning his bees.

Chemical residues have been found even in hives which have only ever been treated with the correct and legal chemical treatments. In most cases residues are in the wax and pollen (as the treatments are fat soluble), but are sometimes even in the honey (Figure 16) (Mullin, et al., 2010). Beekeepers in countries with varroa now need to replace their comb much more regularly than in the past. This has the dual purpose of reducing contaminated wax and disease build up in the comb.

VARROA MANAGEMENT TOOLS

Living with varroa is difficult and requires management; this is certainly clear. Fortunately there are many ways to be a successful and satisfied beekeeper with varroa. Unfortunately they all come with some cost in time, money or both. The next section provides a brief look at the variety of treatments available. There are many published works on varroa treatments so I will be brief for the most part. The main focus of this section is on breeding as a management tool.

Chemical treatments

The chemical treatments include synthetic or 'hard' chemicals, and 'soft' chemicals. The former include fluvalinate, flumethrin and coumaphos. 'Soft' chemicals include formic acid, thymol and oxalic acid. Many of the 'soft' chemicals are complicated or dangerous to use, require very specific climatic conditions and must be used in conjunction with mite monitoring. Some of these treatments can damage the colony if used incorrectly and there are still unanswered questions about their long term effect on the colony (Mullin, et al., 2010).

Biotechnical treatments

There are many simple and successful methods of biotechnical varroa treatment involving the physical manipulation of a hive to reduce the varroa population. The most common version is brood removal, particularly drone brood which is more susceptible to mites (Goodwin & Taylor, 2007). Mites are trapped in the brood and killed following removal. Such biotechnical treatments are often very time consuming.

Doing nothing / Natural selection

Varroa and *A. mellifera* have not been in relationship for very long and we have inhibited natural selection by using chemical treatments. It is rare therefore for honeybees and varroa to have found a balanced host-parasite equilibrium such as exists between *Apis cerana* and varroa (Le Conte, Ellis, & Ritter, Varroa mites, 2010). However, there is evidence of bees with naturally occurring varroa resistance (Le Conte, de Vaublanc, Crauser, Jeanne, Rouselle, & Bécard, 2007).

Breeding

I discussed earlier in the report why I chose to investigate breeding and why I believe it is the only long term option for varroa treatment. Resistant bees can and have been successfully bred and used in conjunction with other treatments or ultimately alone. My goal here is not to advocate for a specific breeding programme, most have advantages and disadvantages. Here I will aim to give an overview of what is possible and the pros and cons of different breeding strategies.

Figure 17 Experimental queen, Baton Rouge USDA

The complications of breeding honeybees

Honeybees are not a simple animal to breed. It is difficult to control their diet or foraging behaviour, and interactions between bees within the colony are very complex. Added to these are the difficulties of any other animal breeding programme: economic costs, loss of some characteristics by the selection of others, and the pressures of industry politics.

The breeding tools

Many different breeding programmes are running in the world, each with a slightly different goal, method and challenges. However, many of the same basic tools are available. The use of these may depend on money, time, location and politics. Artificial insemination is commonly used in the initial phases of a breeding programme and often in an ongoing way to maintain traits and stock. This is especial critical if a closed population is required. AI is also very useful for 'fast tracking' a trait with single drone inseminations.

Many breeding programmes also utilise offshore islands to benefit from natural mating and still ensure stock integrity, including Rottnest Island in Western Australia, Mercury Island in New Zeland and Norderney in the North Sea.

Why are colonies resistant to varroa?

Bees around the world have developed a variety of ways by which they live successfully with varroa in the colony. Varroa resistant colonies inhibit the growth of the varroa population to such a degree that the colony is able to survive long term in a healthy, productive way without treatment. Few if any of the mechanisms of resistance are fully understood but many can be selected for in a breeding population. These mechanisms include: grooming of adult bees; regular swarming; damaged brood removal (hygienic behaviour and VSH (Figure 18)); early hatching of worker bees or drones; low mite population growth and reduced mite reproduction. Selecting for bees with virus resistance would also improve a colony's ability to thrive regardless of varroa infestations.

Figure 18 Evidence of VSH in Kettle Valley: brood which has been uncapped and is being resealed

There is a great deal published detailing these mechanisms and related breeding programmes. I recommend the Apidologie review articles by Ralph Büchler and Tom Rinderer (Büchler, Berg, & Le Conte; Rinderer, Harris, Hunt, & de Guzman) for further information on this subject.

Strategies for resistance breeding

There are three conceptual approaches to selecting bees for a breeding programme:

- Select colonies with a specific trait
- Focus on a stock of bees with known resistance and develop this for your requirements,
- Select colonies which survive varroa untreated over a long period from within managed or feral populations.

What's working in resistance breeding

Various breeding programmes have produced colonies which can survive for many years without varroa treatment (Büchler, Berg, & Le Conte, 2010; Rinderer, Harris, Hunt, & de Guzman, 2010; Goodwin & Taylor, 2007). Stock from many of these is being widely utilised by the beekeeping community. A number of methods used to achieve this result stood out on my Fellowship including:

1. Closed breeding programmes such as Sue Cobey's New World Carniolian line. Selection for either a specific trait or stock line is achievable within a closed breeding programme. One of the down sides of this style of breeding is the high level of resources required initially and for maintenance of the stock over time.
2. Selecting for a specific characteristic with an accompanying sampling technique also improves the tool box for Integrated Pest Management (see the IPM section below).
3. Utilising existing resistant stock via queen or semen importation can speed up and help to focus the breeding process. Time is crucial when facing a varroa crisis.

Figure 19 Varroa infected bee (Photo Rob Manning)

Unfortunately importation of genetic stock carries the risk of unknown pathogens or traits coming with the stock. In addition the benefit of using bees adapted to their region (ecotypes) may be important for resistance.

4. Varroa breeds and multiplies on the larvae of bees. An absence of capped larvae in the hive reduces the breeding period of the varroa and shortens the time over which the mite population can expand. Regions with a cold climate have the advantage of a period in winter when the queen no longer lays eggs. In parts of Germany an extra broodless period is artificially initiated partway through the year as part of their management practice.
5. It follows also that bee behaviour which reduces the amount of brood in a colony or makes the colony broodless for a period, is an advantage when resisting varroa. There are some honeybee races which show higher levels of natural tolerance than others due in part to such behavioural characteristics. Africanized bees for example swarm very readily and Carniolan queens lay more conservatively than queens of other races.

Such natural selection is a useful strategy in breeding. Two of the beekeepers I visited have taken advantage of naturally selected mite resistance in their breeding populations. Yves Le Conte has identified surviving wild colonies and bred from these and John Kefuss has allowed his colonies to manage varroa without treatment and then bred from the survivors (the 'Bond Test') (Kefuss, Vanpoucke, Bolt, & Kefuss, 2009; Le Conte, de Vaublanc, Crauser, Jeanne, Rouselle, & Bécard, 2007). A similar method has also been successfully adopted by Ingemar Fries in Sweden (Büchler, Berg, & Le Conte, 2010). However the 'Bond Test' can be expensive in terms of money and morale, as managed colonies have often been selected for high production and gentleness at the cost of hardiness.

Anyone who runs a successful breeding programme with specific goals must decide how to utilise the resulting stock. For some breeders it is enough to have bees which do not require varroa treatments. Others want or need to involve the wider community in their accomplishment. This of course involves many factors, one of which is dispersal of stock. The sale of inseminated queens and production daughters is one way to distribute stock to the industry, as was done by Marla Spivak with her hygienic bees (Spivak & Reuter, New Direction, 2008). Another is for the beekeeper to mate their own queens with the drones from resistant breeder colonies with the added advantage of not completely replacing the beekeeper's own bees. Beekeepers can do this themselves by buying a breeder queen and using her drones to mate with their virgins. National initiatives such as the German mating stations appear to be very effective.

Challenges

Bees exist that can survive without treatment for varroa mites. However, beekeepers may not utilise such resistant stock for various reasons. Most often the reason is economic, sometimes political, sometimes practical, and often involves what I call 'the science industry void' (see below). It is not a coincidence that chemical treatments have been the varroa management tool of choice. They are usually easier, cheaper and give faster results than breeding. Selecting stock from surviving colonies can present a problem as colonies can be healthy for over two years and subsequently collapse (Le Conte & Navajas, Climate change: impact on honey bee populations and diseases, 2008)(Figure 3).

Breeding takes a lot of time, patience and resources; three things which are not always available when trying to run an economically viable business. Even if the breeding is done by someone else, changing management practices to incorporate resistant stock or implementing IPM can be a challenge for many people. The following are some of the reasons why a beekeeper might choose to continue to use their existing varroa management system even if presented with bee stock that is resistant in the apiaries of the breeder:

- The resistant stock produces less honey or pollen
- The bees tend to be more aggressive
- The beekeeper does not want to compromise the breeding stock they have developed
- The resistant stock is from apiaries with very different climates

Unknowns

It is now coming to light that there may be other challenges to add to the above list, such as ecotype specific resistance is one. I heard many stories backed by research on my Fellowship of bee stock that was highly resistant to varroa. I often heard a corresponding story from someone who had used that same stock in a different area which did not survive varroa infestations. This experience was repeated to me anecdotally again and again around the world. How this will affect the dispersal of resistant bee stocks is not yet clear.

Beekeepers also seemed unsure as to why some resistant stocks had survived for nearly a decade without treatment then suddenly experienced large losses to varroa. It is possible that an extra stress such as a climate fluctuation occurred and the colonies couldn't cope. Nobody had an absolute answer for this question.

Figure 20 Trapping drones with a helium balloon and queen pheromone in the former East Germany to determine the percentage of marked experimental drones represented in the mature drone stock.

There is now a significant amount of research showing that high levels of chemical residues exist in the wax of most colonies in varroa infested countries (Mullin, et al., 2010). There is some concern about the potential impact this is having on developing bees (Frazier, Mullin, Frazier, & Ashcraft, 2008). Bee breeders are starting to ask questions about the effects of these residues on queen and drone viability. Similar questions could be posed regarding the effects of 'soft' chemical treatments such as formic acid (Johnson, Ellis, Mullin, & Frazier, 2010).

Research is being undertaken at the Kirchhain Institute into the quantity of drones needed in an area to get a sufficient proportion for genetic transfer of traits (Figure 20). There is less feral interference in Germany than Australia but a much higher density of managed colonies.

Another layer of colony complexity that is only just starting to be understand is the effect on bee colonies of epigenetics (where non-genetic factors cause the organism's genes to express differently). Nutritional cues present in royal jelly have been shown to alter gene expression (Kucharski, Maleszka, Fort, & Maleszka, 2008). What this translates to in the colony is that a fertilized bee egg can become either a queen or a worker depending on what she is fed. How many other changes are happening in the hive that we cannot understand?

Integrated Pest Management

Integrated Pest Management (IPM) is a tool used generally in agriculture when a farmer wants to minimise their chemical use (The Food and Environment Research Agency, 2009). IPM utilises a variety of techniques to keep pest populations at a level which does not have a detrimental economic effect; this can also include using resistant bee stocks. Colony monitoring is a critical part of successful IPM (Figure 21), leading to the farmer only treating stock when certain pest thresholds are reached (Goodwin & Taylor, 2007). Using IPM could also benefit beekeepers who are working in places where varroa is resistant to the approved chemicals.Many beekeepers are now using this form of management and it is proving to have huge potential for the future of varroa control worldwide.

Figure 21 Naturally occurring drone brood in a colony with varroa destructor: a good way to check for mites is to break open drone broad

2010 Churchill Fellow Daniel Martin from Victoria will go to the USA this year to investigate IPM for varroa control.

AND NOW IN AUSTRALIA

Australia is the last beekeeping oasis. However it is now accepted that the question of **if** we get varroa is long redundant; it is now just a matter of time.

CHALLENGES FOR AUSTRALIA

Each country has complex political, economic and cultural climates which influence decisions about their futures. One of Australia's biggest challenges will be to negotiate all these complex factors so that the decisions we make about varroa will be realistic and successful. As I have previously discussed the arrival of varroa will bring with a whole gambit of problems some of which are particular to Australian conditions:

- We now face the challenge of preparing our bee populations for varroa. Selecting for resistance to a pest we do not yet have is a unique test of queen breeder innovation. No 'varroa free' testing techniques currently exist for the majority of the varroa resistant traits as there are for other diseases.
- A large proportion of our industry (particularly in Western Australia) uses the Italian race of bee. Italian colonies have shown to be particularly vulnerable to varroa as the queens are prolific brood producers and have a long laying period (Tarpy & Lee, 2005). These traits are of course fantastic for production but will also encourage large varroa population. Unfortunately the races which are naturally more tolerant of varroa (eg Caucasians, Carniolans) are generally not heat tolerant (Graham, 2005).
- Many beekeepers in Australia do not have a broodless period in their hives as the winters are not particularly harsh or long. Again, this results in a long breeding period for varroa.

- The extreme heat in many areas could make it difficult to use currently available 'soft' chemicals as such as Formic acid which are most effective in cooler climates (Wright & Villalobos, 2009).
- It is also important to note that many treatments and management techniques which work in one climate and with one race of bee, do not necessarily work with another. Mark Goodwin of HortResearch NZ reminded us of this at a talk he gave in Canberra last month.
- The combination of a reduced or stressed bee industry and crashing feral colonies may result in insufficient pollination availability for agricultural crops, particularly during peak periods.
- Raising much needed funds for a pest that has not yet arrived presents its own challenges, as does motivating the beekeeping and pollination industries to prepare for varroa when they have so many other pressures on their businesses.
- In addition we may get a strain that is already resistant to the current chemical treatments.

THE GOOD NEWS

Rarely is it such a benefit to be last: we are in an unusual position of being forewarned about the arrival of a major agricultural pest. Compared to the countries which received varroa twenty or even ten years ago, we have a plethora of varroa 'tools' available for our use. These include:

- Many examples of what not to do
- Several alternatives to synthetic chemicals
- Varroa resistant bee stocks
- Varroa resistant bee traits and breeding research
- Integrated Pest Management techniques
- Sampling techniques
- Threshold concepts
- A mapped bee genome
- Knowledge of viruses (particularly regarding semen imports)
- A partially mapped varroa genome
- Incursion plans

The good news is that some of the alternatives to synthetic chemicals are economically viable in other parts of the world. We have the opportunity to learn from other people's successes as well as mistakes and time to tailor this knowledge to our Australian climatic and beekeeping requirements. Australia may benefit from being a relatively small industry which may make it a little easier to communicate and make decisions. Individual businesses are also relatively small which may enable more beekeepers to use more complex management tools are the owner is more often the operator in these cases and will take more care.

Just to remind us that there is a silver lining, the arrival of varroa has also had advantages for some; beekeepers get higher honey yields without competition from feral colonies, they are paid higher rates for pollination contracts, and many who were not up to the extra management challenge have left the industry. The latter point may not seem like an advantage, but it ultimately benefits the industry as a whole.

And the best news is that people are starting to move already, prior to the crisis and chaos.

What are we doing already?

Of course our first defence against a varroa incursion is the vigilant biosecurity programmes running in each state. There are also training courses, brainstorms, and research projects going on all over the country. These include:

- Testing Australian stock for varroa resistance at the USDA Baton Rouge lab (Oldroyd/Rinderer, current project)
- Finding hygienic lines of bees in existing breeding programmes (e.g. Manning, RIRDC 2008)
- South Australian beekeeper Ben Hooper's work with varroa management supported by a 2010 Nuffield Scholarship
- The *Better Bees for tomorrow* project run through CIBER in WA supported by a 2010 ARC linkage grant with Better Bees WA

There is a big push to increase public and political awareness of the impacts varroa will have on the whole country and through this an understanding of the value of bees to Australia. I am hopeful that we will learn from the mistakes and assistance of other countries and come through a varroa incursion with a strong bee industry.

Conclusions

What is Success?

There are now various populations of bees in the world that do not require treatment for varroa mites. However, nowhere is there wholesale acceptance of these stocks by the bee industry. Perhaps we have been asking the wrong question and been satisfied with the wrong indicator of success. Maybe we need to change the question, focus on a different end point: it does not appear to be enough to breed a bee which can survive varroa mite. For the whole bee industry to thrive we might need a different question, specifically "**how do we most effectively and efficiently get varroa resistance into a commercially viable bee population?"**

The Science Industry Void

I believe one of the reasons that resistant stocks are not utilised by the industry is a phenomenon I have coined 'the science industry void'. Different motivators between science and industry seem to create a slightly different focus when it comes to resistance breeding usually related to the economic viability of the bees. Beekeepers think that scientists don't understand the big picture and scientists think the same of beekeepers. Time and again I had conversations which involved a beekeeper or a researcher saying "what scientists/beekeepers just don't understand is..."

There will never be a silver bullet or super bee which can fulfil everyone's requirements under all conditions. In my opinion it is crucial for the success of a varroa management programme that the understanding and focus of all stakeholders are as closely aligned as possible, including questions of what is success and what are healthy bees.

What about Australia

Based on what has and is happening throughout the world, it is tempting to say that chemicals should not be used and bees could then find a natural balance with varroa over time. The strongest will survive and we are currently selecting for weak bees by treating disease with chemicals. This is certainly true. However, this does not consider the reality of human nature, business survival and food supply for the country involved. If beekeeping is your business and you are faced with colonies looking like the one in Figure 22, not treating them at all would be a hard action to carry out. If you are a government employee and are faced with the decision to let a few years of crops fail whilst the bee populations recover, you would need to have a very good back up plan to propose.

Figure 22 Frame of bees with parasitic mite syndrome (PMS) caused by heavy varroa infestation and a weak colony

I think that encouraging Australians to follow the path of synthetic chemical use is very unwise. However, I am realistic about the pressure we will be under when varroa hits the chronic phase and our managed colonies start to die in large numbers (Figure 3). I am hoping we will have some alternative options to present at that time. It is important to note that if something doesn't work the first time, people remember that for decades. How a product or issue is presented can make or break its future.

Finally two things really stood out during my Fellowship:
1. IPM has great potential to reduce reliance on chemicals; and
2. easy and standardised sampling systems must be used in conjunction. This enables beekeepers to treat for the disease not for fear of the disease.

DISSEMINATION

Since my return to Australia:

- I have participated in an industry and research gathering in Canberra on non-chemical and minimal chemical use options for varroa management.
- I am involved in the development of a Honey Bee Industry and Pollination Continuity Strategy for Australia in anticipation of a possible varroa incursion.
- I have given presentations on my Fellowship experiences and findings at CIBER and SymbioticA at UWA.
- I have been invited to consult with Professor Lyn Beazley, Chief Scientist of Western Australia about the threats to honeybees in Australia.
- I have sent virgin queens to Rottnest Island as part of the Better Bees WA breeding programme.

There is so much interest in bees at this time and I plan to continue to disseminate the possibilities for disease resistance and opportunities for Australia through presentations, industry and research consultations and publication. I will also continue to be involved with breeding and research within Western Australia and hopefully further afield.

RECOMMENDATIONS

We need to learn from overseas mistakes, not repeat them,
especially in relation to chemical dependence and use.
Getting on the 'chemical treadmill' should be carefully considered

We should improve the hygienic behaviour and general disease resistance of our existing Australian bee stocks

We need to develop a strategy to most effectively and efficiently get varroa resistance into a commercially viable bee population which is utilised by the industry

It is critical that we improve understanding between science and industry

We can prepare Integrated Pest Management techniques

A change in public perception of the value of bees for Australia would benefit future planning

Importing semen or any germ plasm should be considered very carefully in view of disease transfer (eg viruses) and ecotype suitability

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GLOSSARY

Acute stage The initial stage of varroa mite infestation in a population of honey bee colonies. Large numbers of feral colonies act as a major source of mite invasion to managed hives. Invasion results in rapid increases in mite numbers in hives (Goodwin & Taylor, 2007)

Africanised bee hybrid of the African honey bee with various European honey bees. These bees are far more aggressive than the European subspecies. Common in Central and South America (Animal Health Australia, 2010)

AI Artificial insemination

Apiary colonies, hives, and other equipment assembled in one location for beekeeping operation

Apis mellifera The European honey bee

Apis cerana The Asian bee, the original host of varroa

Artificial insemination (AI) The mechanical introduction of selected drone semen into the oviducts of a virgin queen using special instruments

Asian honey bee *Apis cerana*

Those colonies which survive are resistant to the mite through natural selection.

Brood juvenile bees not yet emerged from the cell: eggs, larvae, and pupae

Buckfast bee strain of *A. mellifera* originally bred and developed by Br. Adam at Buckfast Abbey, England; resistant to tracheal mite *Acarapis woodi*; low resistance to varroa (de Guzman, Rinderer, Delatte, Stelzer, Beaman, & Kuznetsov, 2002)

Carniolan bee Gentle grayish-black honey bee originally from Carniolan Mountains in or near Austria.

Caucasian bee Gentle black honey bee originally from Caucasus area of Russia

Chemical resistance Where a pest such as varroa becomes more and more able to withstand a pesticide that is being used, so that the chemical no longer kills most of the pest population. Varroa has developed resistance to a range of chemical control substances (Goodwin & Taylor, 2007)

Chronic stage The stage of varroa mite infestation in a population of honey bee colonies following the acute stage. Die-off of feral and untreated colonies results in less mite invasion and more predictable increases in mite numbers in managed hives (Goodwin & Taylor, 2007)

Closed population mating controlled mating of queens and drones in an environment that is closed to genetic material from the outside; often occurs on an island

COLOSS Network Prevention of COlony LOSSes Network

Disease resistance The ability of an organism to avoid a particular disease; primarily due to genetic immunity or avoidance behavior

Ecotype a genetically distinct geographic variety, population or race within species, which is adapted to specific environmental condition

Epigenetics inherited changes in phenotype (appearance) or gene expression caused by mechanisms other than changes in the underlying DNA sequence; non-genetic factors cause the organism's genes to behave (or "express themselves") differently.

European honey bee *Apis mellifera*

FERA The Food and Environment Research Agency, UK

Feral wild or unmanaged bee colony

Formic acid an organic acid used as a varroa control substance. It is highly volatile, so must be applied in forms that prolong evaporation (Goodwin & Taylor, 2007)

Genotype (1) The genetic makeup of an individual. (2) The combination of genes at a single locus or at a number of loci. Geneticists speak of one-locus genotypes, two-locus genotypes, and so on.

Germ plasm: All the hereditary material that can potentially contribute to the production of new individuals.

Haemolymph the circulating fluid or "blood" of insects

'Hard' chemical synthetic chemicals; eg fluvalinate, flumethrin and coumaphos

Hygienic behaviour The uncapping and removal of dead larvae and pupae by adult bees (Spivak & Reuter, New Direction, 2008)

INRA French National Institute for Agricultural Research

Integrated Pest Management (IPM) a pest control strategy that uses a variety of complementary strategies including: mechanical devices, physical devices, genetic, biological, cultural management, and chemical management. These methods are done in three stages: prevention, observation, and intervention. It is an ecological approach with a main goal of significantly reducing or eliminating the use of pesticides while at the same time managing pest populations at an acceptable level.

Incursion the arrival of an organism, especially a pest or disease, within a country after it has crossed the border

IPM Integrated Pest Management

Italian bee A common race of bees, *Apis mellifera ligustica*, with brown and yellow bands, from Italy; usually gentle and productive, but tend to rob.

Miticide A chemical or biological agent which is applied to a colony to control parasitic mites

Natural selection Selection that occurs in nature independent of deliberate human control; evolutionary mechanism

New World Carniolans A breeding program originated by Sue Cobey to find and breed honey bees from the US with Carniolan and other commercially useful traits.

Organic chemical In relation to mite control substances, chemicals found in nature; 'soft' chemicals; formic acid, thymol and oxalic acid (Goodwin & Taylor, 2007)

Primorski bees strain of honey bees from the Primorsky region of far-eastern Russia with strong resistance to varroa (Rinderer, et al., 2001)

RIRDC Rural Industries Research and Development Corporation, Australia

Russian bees Primorski strain of *A. mellifera*

Science Industry Void Phenomenon of misunderstanding between industry and science

'Soft' chemicals Organic chemicals; eg formic acid, thymol and oxalic acid

'Soft Bond Test'

Stock

Synthetic chemical In relation to varroa control substances, chemicals not found in nature; 'hard' chemical; eg fluvalinate, flumethrin and coumaphos (Goodwin & Taylor, 2007).

Temperament

Tolerance In association with varroa, the ability of a honey bee colony to co-exist with an infestation of the mite without perishing, or at least harbour a higher population of mites without damage (Goodwin & Taylor, 2007)

Treatment

Varroa destructor external parasitic mite of *A. cerana* and *A. mellifera*; original host *A. cerana*

Varroa Sensitive Hygiene (VSH) hygienic behaviour trait identified by Baton Rouge (Harbo & Harris, 1999)

VSH Varroa Sensitive Hygiene

UC University of California, USA

USDA United States Department of Agriculture

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