
# INVESTIGATION OF VARROA RESISTANCE HONEY BEE BREEDING PROGRAMS IN THE UNITED STATES FOR APPLICATION IN AUSTRALIA

An International Specialised Skills Institute Fellowship.

**DR. JODY GERDTS**

Sponsored by Agribusiness

# Table of contents

# 1. Acknowledgements

I would like to thank the following organisations who generously provided me with the opportunity to undertake an Agribusiness International Fellowship.

## Awarding Body – International Specialised Skills Institute (ISS Institute)

The ISS Institute plays a pivotal role in creating value and opportunity, encouraging new thinking and early adoption of ideas and practice by investing in individuals.

The overarching aim of the ISS Institute is to support the development of a 'Better Skilled Australia'. The Institute does this via the provision of Fellowships that provide the opportunity for Australians to undertake international skills development and applied research that will have a positive impact on Australian industry and the broader community.

The International Specialised Skills Institute was founded 29 years ago, by a small group of innovators including Sir James Gobbo AC, CVO, QC, and former Governor of Victoria, who had a vision of building a community of industry specialists who would lead the up-skilling of the Australian workforce. The Fellowship program builds shared learning, leadership, and innovation across the broad range of industry sectors worked with. Fellows are supported to disseminate learning's and ideas, facilitate change and advocate for best practice through the sharing of their Fellowship learnings with peers, colleagues, government, industry, and community. Since its establishment, ISS Institute has supported over 450 Fellows to undertake skill and knowledge enhancement across a wide range of sectors which has led to positive change, the adoption of best practice approaches and new ways of working in Australia.

The Fellowship programs are led by our partners and designed in a manner which ensures that the needs and goals desired by our partners are achieved. ISS Institute works closely to develop a Fellowship program that meets key industry priorities, thus ensuring that the investment made will have lasting impact.

For further information on ISS Institute Fellows, refer to www.issinstitute.org.au

### Governance and Management

## Fellowship Sponsor - Agribusiness

Agrifoods Skills Australia was the Industry Skills Council for the Agrifoods Industry covering rural and related industries such as food processing (including beverages, wine, and pharmaceuticals), meat, seafood, and racing. The Fellow, and the ISSI team would like to thank them for providing funding support for this Fellowship.

I would also like to thank all the people and organisations that made this experience possible. In Hawaii, a huge thank you to David for meeting with me and opening your operation. Thank you to Bartjan Fernhout from Arista Bee foundation for making the connection and to the women who took time out of your days to share with me. In Washington, thank you to Sue Cobey and Dr. Tim Lawrence for the chats.

In Louisiana, a huge thank you to all the folks at the USDA-ARS Honey Bee Breeding and Genetics Laboratory for opening your arms to me, my questions, and ideas. Specifically, thank you to Drs. Bob Danka and Mike Simone-Finstrom for support and mentorship. Thank you to Phil Tokraz for access to and training on the real time PCR machine and help with sample prep and data analysis. Thank you to Garret for digging deep into VSH breeding, insemination techniques, and just being fun to tag along with. Thank you to Vincent, Adrian, Perot and everyone else for the chats, encouragement, and feedback on my work.

In Indiana, thank you to Dr. Brock Harper for opening your lab and for being a great springboard for ideas. Thank you to Krispn Given for sharing insights into breeding mite biting bees and caveats on selecting bees for this interesting behaviour.

Thank you to Dorothey Morgan and Dwight Wells for bringing people together for a special meeting in Kentucky and giving me the opportunity to share my work and learn about the amazing success you are having with selecting and maintaining a survivor stock population. Your ideas are Avant guard and against the grain of your industry. Keep up the great work.

Thank you to my husband Daniel Martin and my daughter Peita Martin for being such great travel companions. Thank you to my parents Wayne and Joan Gerdts for taking care of Peita for a stretch in Baton Rouge and for your continued support in my endeavours.

Thank you to ISS institute and the Victorian honey bee contingency fund for making this dream trip a reality.

This report and experience are dedicated to my father Wayne Gerdts who passed away shortly after I returned to Australia. He was my first beekeeping mentor and one of my best friends. I will forever be grateful for the time I was able to spend with him as a result of this Fellowship.


*Wayne and Jody Gerdts in a winter Wisconsin (USA) apiary circa 2003*

# 2. Executive Summary

## Background

Varroa mites are the foremost cause of honey bee colony losses globally impacting both pollination services and honey production. Australia remains the only country with a significant apicultural industry free of these devastating mites and although considerable resources have been dedicated to early detection and eradication, the threat of Varroa becoming established in Australia remains. Once established, the mite is projected to devastate Australia's honey bee reliant industries (pollination and honey production) by progressively destroying most to all feral colonies and placing an unprecedented demand on apiarists for managed colonies for pollination. Beekeepers will have to quickly learn how to manage Varroa within their hives in order to stay in business and provide pollination services. For the most part, managing the Varroa mite involves chemical control agents in the hive that are expensive, can harm the bees, taint hive products, and to which Varroa itself evolve resistance.

In small pockets around the world, however, honey bee populations have been able to survive these devastating mites though both natural and human accelerated selection. The goal of this Fellowship was to meet the people, programs, and bees that have broken through the devastating chemical cycle to strike a balanced relationship. This report details learnings from interviews with key people from operations and organisations in the United States that have been engaged with selecting Varroa resistant traits in honey bees for at least five years. Additionally, original research conducted whilst on Fellowship helped answer questions around virus transmission that are key to enabling future safe imports honey bee genetics into Australia from colonies demonstrating Varroa resistance overseas. The Fellowship was conducted from January 2019 to September 2019 with overseas travel between July and September 2019.

The Fellows' family has been keeping bees in the United States since the 1930's and Gerdts is the fourth generation to take up the passion. The Fellow moved to Australia from the United States in 2013 and is the founder and managing director of Bee Scientifics, an Australian company focused on honey bee breeding, education, and nutrition. Gerdts recently completed her PhD at La Trobe University studying a fungal pathogen in honey bees and continues to conduct honey bee focused research in Australia.

## Fellowship learnings

The five groups that were visited in undertaking this Fellowship employ different strategies for honey bee breeding and selection. Each operation has its merits and has faced problems ubiquitous to building a secure and sustainable bee breeding program; each operation has overcome those difficulties in their own unique ways. The varied solutions to common problems will help the Australian honey bee industry meet the challenges of establishing a cohesive bee breeding strategy where selective breeding can be successful.

Most importantly, this Fellowship bestowed hope and inspiration. The commonly accepted view is that Varroa devastates bees and there is nothing that can be done. This notion is simply untrue. The programs that were visited are living proof that given a chance, the host-pathogen relationship between the European honey bee and the Varroa mite will come into balance. The real finesse lies not in breeding bees that can survive varroa, but in maintaining commercially viable honey bee populations suited to beekeeping that can naturally keep mite populations at manageable levels. It is possible and the Australian honey bee and pollination reliant industries are in a prime position to learn from these successful programs.

## Personal, professional and sectoral impact

The learnings and relationships resulting from this Fellowship have had a profound impact on the Fellow's life and future work. It is her hope that this future work will have a positive influence on the resiliency of the Australian honey bee industry, now and into the future.

On a personal level, the relationships that were forged as a result of this Fellowship helped cement friendships and expanded her professional network in an exciting way.

### Impacts that have occurred

» Relationship with Arista Foundation for Breeding Varroa Resistant Honey Bees;

» Better understanding of the mechanics of honey bee breeding and selection for Varroa resistance;

» Better understanding of the mechanics of selecting for grooming and Varroa sensitive hygiene;

» Insight into how to structure focused bee breeding programs;

» Identification of key universal obstacles to sustaining a honey bee breeding program;

» Conducted novel research on virus transmission rates which helped inform a current germplasm importation project in Australia;

» Introduced international researchers to obstacles facing the Australian honey bee industry;

» Relationship with Heartland Honey Bee Breeding Cooperative key players which could eventuate in advanced training for Australian Beekeepers.

### Impacts that are planned

» Collaborating with researchers at Purdue University, the USDA, and Canada to investigate Varroa resistant genotypes in Australia and develop assays to select for resistance pre-varroa;

» Establish de-centralized honey bee breeding collectives to focus on breeding commercially suitable honey bee stocks;

» Educate bee breeders about different ways to select for Varroa resistance;

» Forge a plan of how to select for Varroa resistance once it becomes established in Australia;

» Prepare beekeepers and stocks for living with Varroa.

**Considerations / recommendations**

Three main recommendations have resulted from this Fellowship. The first two are targeted at Australian industry beekeepers and will lay the foundation for successfully navigating the path toward Varroa resistance in Australia. The third is directed toward the Government and University sectors to create a space for pollination-focused collaborative research and to train the scientists of tomorrow.

## Recommendations:

1. Establish decentralised honey bee breeding networks to promote technology, capacity, and genetic exchange;

2. Preparing for living with Varroa through continued selection and development of breeding lines and establish and maintain set-aside apiaries designated as treatment-free zones once Varroa is established;

3. Establish a Centre for Pollination Resiliency housed at an Australian university to address the scientific questions facing the beekeeping and pollination industries today and capacity build scientists of tomorrow.

# 3. Fellowship Background

## Fellowship Context

Varroa mites are the foremost cause of honey bee colony losses globally impacting both pollination services and honey production. Australia remains the only country with a significant apicultural industry free of these devastating mites and although considerable resources have been dedicated to early detection and eradication, the threat of Varroa becoming established in Australia remains. Once established, the mite is projected to devastate Australia's honey bee reliant industries (pollination and honey production) by progressively destroying most to all feral colonies and placing an unprecedented demand on apiarists for managed colonies for pollination. Beekeepers will have to quickly learn how to manage Varroa within their hives in order to stay in business and provide pollination services. This scenario has unfolded before in the United States (1980s) and New Zealand (early 2000s).

Of specific concern is the Varroa-virus complex where the blood sucking mite transmits deadly viruses to developing bees. These viruses can deform the bees wings as with Deformed Wing Virus or cause complete paralysis as with several different paralysis viruses. To date honey bees host around 25 different viruses and Varroa mite parasitism exacerbates the infection severely reducing colony health and productivity. Australia only is known to harbor around 7 of these viruses with two of the main perpetrators in colony losses, deformed wing virus and slow paralysis virus absent.

Chemical treatments called acaricides are routinely used to control Varroa mites in managed honey bee hives. If left untreated, colony death occurs within 6-18 months. These chemicals have been shown to reduce honey bee reproduction, contaminate wax and honey, and negatively impact colony health in connection with other agrichemicals. Additionally, due to Varroa's unique incestual reproductive strategy where brothers mate with sisters, once resistance to an acaricide is developed, the resistance is quickly spread through a population rendering chemical control methods unsustainable in the long term.

On a positive note, genetically linked traits such as grooming, tenacious cleaning (Varroa sensitive hygiene or VSH), and altered brood rearing cycles have enabled select populations of both managed and feral honey bees to naturally keep Varroa populations low in the hive without acaricides. However, Varroa resistance can be closely tied to adaptations linked with specific environmental cues and conditions and when those cues are absent resistance significantly decreases.

Other strategies bees employ for keeping Varroa levels low involve disrupting mite reproduction by uncapping and re-capping the cells where honey bee pupae and mites are developing or by altering the number of cells available for mites to reproduce in response to seasonal and climactic cues. These processes are much more difficult to understand and quantify since they are triggered by specific mite and environmental driven cues. Although it will be difficult to breed for these traits without the selective pressure of Varroa, Australian apiarists can develop a priori best-practice protocol available for deployment immediately upon Varroa establishment based on standard breeding procedures that have already been developed at the USDA Breeding laboratory in Baton Rouge.

The most viable solution to safeguard Australian honey bee and pollination reliant industries is to understand the Varroa resistance selection processes, adapt these techniques to Australia's unique beekeeping practices and environmental conditions, and begin to employ these techniques in Australian-based breeding programs.

Despite the awareness of the looming threat posed by Varroa in Australia, there has been little action in preparing for living with the mite. As previously mentioned, heritable genetic traits that help ameliorate the effects of Varroa on a honey bee colony are well known. Bees have a few physical responses to mites hitchhiking on the backs of adult bees; grooming and biting can injure or kill mites before they can reproduce, thus keeping mite levels low in a colony. Encouraging work is underway at Purdue University in Indiana to select for grooming and biting behaviour but intensive grooming has also been seen in Tasmanian honey bees when researchers were trying to glue radio frequency identification (RFID) tags to the backs of bees to monitor their movements. The fact that grooming behaviour is already seen in Australia is encouraging, but specific assays that can mimic mite infestation are essential to develop so Australian apiarists can pre-emptively breed for these important traits.

The objectives of this Fellowship were to investigate the skills, methodologies, and framework:

1. To identify and quantify honey bee traits associated with Varroa resistance

2. For the long-term cultivation, selection, and maintenance of these traits within a breeding population in Australia

# Fellowship Methodology and Fellowship Period

This Fellowship required significant travel consisting of both short visits and interviews with organisation leaders as well as a month-long research residency (Table 1, Figure 1). Organisations were chosen because of their reputation for success in breeding Varroa resistance or experience in bee breeding in general.

*Table 1. Organisations and programs visited during the Fellowship to study Varroa resistance and honey bee breeding in the United states between July and September 2019.*

| Organisation | Skills/ expertise | Model | Time visited |
|---|---|---|---|
| Hawaii Island Honey Company | Breeding commercially viable Varroa resistance | Private Company with Not-for Profit and Research collaborators | July 16-17 2019 |
| Susan Cobey | Honey Bee Breeding | Independent queen bee breeder with strong industry and research links | July 26, 2019 |
| USDA-Agricultural Research Centre | Honey bee breeding for Varroa Sensitive Hygiene and Russian Bees | Government research lab with extensive experience breeding Varroa resistant lines of bees and bee viruses | July 31-August 30, 2019 |
| Purdue University | Honey bee breeding for grooming and mite biting. | Engaged in citizen science to develop the mite biter bees. Maintains treatment free apiaries. Advocates of locally adapted stocks | September 6, 2019 |
| Heartland Honey Bee Breeders' Association (HHBBA) | Breeding for mite biting and survivor stock | Citizen science and grass roots organisation propagating from survivor stock, promoting localized stocks of bees | September 8-9, 2019 |


Layfayette, IN
Coupeville, WA
Frankfort, KY
Hilo, HI
Baton Rouge, LA
WASHINGTON
MONTANA
WYOMING
NEBRASKA
IOWA
United States
UTAH
MISSOURI
CALIFORNIA
Las Vegas
Los Angeles
San Diego
ARIZONA
NEW MEXICO
OKLAHOMA
Dallas
Ottawa
Toronto
NEW YORK
PENN
WEST VIRGINIA
Gulf of California
Gulf of Mexico
Cuba
Guatemala
Nicaragua
Caribbean

# Fellow's Biography

The Fellow have been involved with the apiculture (beekeeping) industry for over 15 years and from a fourth-generation beekeeping family. Gerdts recently completed her PhD through La Trobe University investigating a fungal disease in honey bees and continues to conduct research on honey bee nutrition, virus transmission, and genetic importation of honey bee germplasm.

Before moving to Australia in 2013, Gerdts worked at the University of Minnesota Honey Bee Research Laboratory, a global leader in honey bee health topics. Upon arrival in Australia, she has continued working in the apiculture industry with a focus on research, selective breeding, education, and training. The Fellows currently serve as the secretary of the Australian Queen Bee Breeders' Association (AQBBA) and Vice President of the Australian Pollinator Alliance.

In addition to research, Gerdts am the founder and managing director of Bee Scientifics, an Australian company that focuses on nutrition, breeding, and beekeeper education.

# Abbreviations / Acronyms / Definitions

**Artificial Insemination**
A breeding process used by honey bee breeders to control genetic crosses of honey bees where semen fis collected from male bees is collected and inseminated into Virgin queen bees yielding mated queens with known pedigrees

**Bee Breeding**
Breeding bees is the process of deliberate selection of certain characteristics and subsequent propagation of bees demonstrating desired traits.

**Bee Shed**
A shed in a beekeeping operation where beekeeping equipment is stored and where honey may be extracted.

**Cell Builders**
Strong colonies that have been manipulated by beekeepers to raise virgin queen bees.

**CSIRO**
Commonwealth Scientifics and Industrial Research Organisation

**Drone**
A male bee

**Feral Honey Bees**
Honey bees that survive without the assistance of human intervention

**Germplasm**
Genetic material e.g. semen and eggs.

**Land-Grant University**
An institution of higher education in the United States designated by a state to focus on the teaching of practical agriculture, science, military science, and engineering.

**Mite Counts**
A process of determining the infestation level of varroa mites in a honey bee colony. Usually reported as a ratio of mites per 300 bees.

**Open Mated Queens**
Virgin honey bee queens that have mated naturally on the wing with free flying drones. Once mated, the queen can lay fertilised eggs which become female bees.

**Polyandrous**
Referring to honey bee queens mating with multiple drones (males) leading to inter-colony genetic diversity.

**qPCR**
Quantitative Polymerase Chain Reaction used to determine absolute or relative quantities of a known sequence in a sample.

**Queen Bee**
The female reproductive member of a honey bee colony.

**Queen Bee for production**
Generally open mated queens whose colonies are used for pollination and/or honey production.

**Queen Bee for Breeding**
Generally artificially inseminated queen bees whose genetics have been selected and controlled for breeding purposes.

**SOP**
Standard Operating Procedures

**Survivor Stock**
Referring to honey bee colonies in an area creating a population able to survive without human intervention to manage pests, diseases, or the environment.

**Varroa mites**
Parasitic mites of honey bees implicated in colony decline and responsible for vectoring deadly viruses.

**VSH**
Varroa Sensitive Hygiene

**Worker Bee**
Female bees that perform tasks in the bee hive in accordance with their age and physiological development.

# 4. Fellowship Learnings

## Many Different Paths

The host-pathogen relationship is a complex and constantly shifting process where defences are built and circumnavigated, each organism striving to survive. When a new pathogen emerges in a species, the initial impacts often result in widespread host mortality. Given time, however, the natural course of this relationship favours less virulent pathogens and more resistant hosts where a balance in survival for both is forged. In the case of economically essential species such as the western honey bee, letting the host-pathogen relationship come into balance would have been devastating for the global food network. Consequent widespread chemical intervention has led to an increase in mite virulence and an overall decrease in honey bee fitness. Nonetheless, where a focused non-treatment selective breeding approach has been taken to favour resistant colonies, great success in non-treatment colony survivorship has been documented.

The five groups that were visited in undertaking this Fellowship employ different strategies for honey bee breeding and selection and the Fellow has been following their work for several years. Each operation has its merits and has faced problems ubiquitous to building a secure and sustainable bee breeding program and overcome those difficulties in their own unique ways. The varied solutions to common problems will help the Australian honey bee industry meet the challenges of establishing a cohesive bee breeding strategy where selective breeding can be successful.

The following section will explain the key aspects that were attractive about each of the organisations and details the learnings gleaned that are applicable to the Fellow's personal situation as well as to the Australian Honey bee Industry as a whole.

# Fellowship Destinations

## Hawaii Island Honey Company, Hilo Hawaii- Selection for VSH in a Commercial Apiary

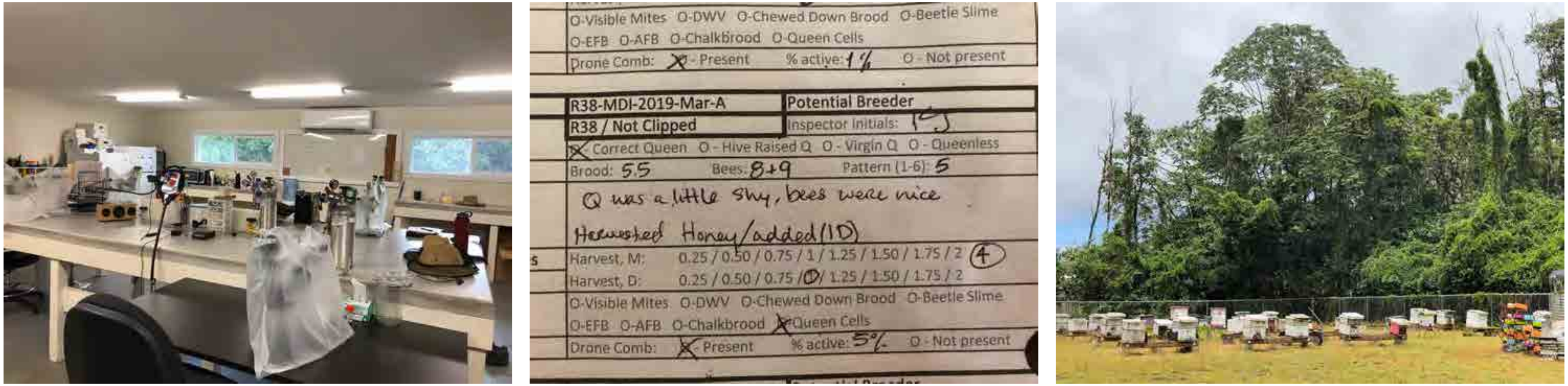



*Figure 2 Left- inside of the HUB working Laboratory. Middle-Example data recorded on breeder hives. Right-Breeder apiary with inseminated queens*

**Background**

Varroa mites became established on the Big Island of Hawaii in 2007-2008. Their arrival coincided with the arrival of another prominent pest of the honey bee: the small hive beetle. Varroa mites weakened colonies and small hive beetle took advantage of the Big Island's excellent breeding conditions (warm and humid) to proliferate. The two exotic pests worked in concert to devastate the Big Island's managed and feral honey bee populations.

Beekeeper intervention, using chemical Varroa acaricides and small hive beetle trapping systems were able to control the two pests in managed hives, but feral (wild) populations suffered great losses. This loss, however, proved advantageous to focused breeding efforts as there were fewer non-selected colonies to dilute the gene pool when reproducing queen bees/colonies.

Danielle Downey was Hawaii's apiary inspector at the time of Varroa establishment and is currently the executive director of PAm (Project Apis mellifera). Prior to her position in Hawaii, Danielle worked with beekeepers in a Varroa landscape and researched Varroa for her master's degree. She brought extensive knowledge about living with the pest to her role as a Hawaiian Apiary officer. David Thomas is one of the largest honey producers in Hawaii and wanted to find a way to breed Varroa resistance into his bees to avoid the chemical pathway, keeping his honey and wax pure and helping the bees help themselves. Dr. Bob Danka is the research leader and research entomologist at the United States Department of Agriculture's top bee breeding facility located in Baton Rouge, Louisiana. Dr. Danka has been involved with breeding Varroa resistant bees for the last 15 years.

Through a serendipitous breakfast meeting the HUB was born. The HUB is a ground-breaking project linking not-for-profits, a government research agency, and private enterprise together for a common goal: developing and breeding commercially viable Varroa resistant bees. Now, nearly six years in, the project has also linked in with Arista Bee Foundation from the Netherlands and is making substantial, measurable progress toward maintaining lines of commercially viable Varroa resistant honey bees. This is a first-in the world effort, a major success story, and a glimmer of hope for Australia (Figure 2).

### Learnings

The learnings from the visit to the HUB can be broken down into four categories: Infrastructure, Strategic breeding plans, Capacity, and Finances. Having experience with research labs, bee breeding, and running her own business, Gerdts had a unique perspective to ask strategic questions and make discerning observations about the program. Understanding intricate aspects of this novel approach to bee breeding are essential for developing a successful and sustainable breeding program in Australia.

### Infrastructure

The HUB is housed in a purpose-built field laboratory with apiary, laboratory, and office spaces. There are microscopes, computers, beekeeping equipment, lab consumables, bee breeding equipment, vehicles, and kitchen equipment. The HUB is located on David Thomas' property. David also financed the construction and outfitting.

The HUB facility is adjacent to David's commercial bee shed and cell builders. The breeding program consists of around 700 colonies and is connected to the honey production side of the business of between three and four thousand colonies in each of two locations: Hawaii and Louisiana. Queen lines are maintained through Artificial Insemination and the drone stock is sourced from open-mated queens that have naturally low mite levels in real-life field situations.

Apiaries are scattered around the Big Island (5km- 100km away) and visited regularly to collect bee samples for mite counts, evaluate for performance, and collect drones for replication of breeding stock.

### Strategic breeding plan

Honey bee breeding is a long process. Honey bees are polyandrous meaning one virgin queen mates with several (8-15) drones on her natural mating flight, a process essential to becoming the sole reproductive member of the honey bee colony. This type of mating results in extreme genetic diversity within a colony where most of the 50,000 workers are half-sisters, having the same mother and different fathers. Evolutionarily speaking, polyandry is a great advantage because it spreads the risk of having a genotype susceptible to a particular pest or pathogen across the colony so only a few members of the family will succumb to the disease, rather than impacting all individuals. For bee breeding, polyandry is extremely hard to navigate because the very diversity that promotes stability across the bee colony can interfere and dilute the selective breeding efforts of a beekeeper.


*Figure 3 Left- Drone flight cages to confine drones until maturity when they will be used to artificially inseminate breeder queens. Right- Example of ID tags used for breeder colonies*

The negative impact of polyandry can be overcome though careful, sustained selective breeding efforts with excellent record keeping to inform breeding crosses, acute attention to detail, and some luck. Without systems in place to record, organize, and analyse data necessary for measuring progress toward a goal, effective bee breeding is impossible.

HUB solved this problem through teaming up with Arista Bee Foundation and aligning with the USDA Bee Breeding Lab. Weekly video conference meetings between the HUB staff and BartJan Fernhout of Arista and the use of proprietary queen breeding software are essential to maintaining, collecting and analysing these data and are the foundation of the breeding program.

**Capacity**

Program capacity is a combination of peoples' individual skill sets and institutional memory developed as Standard Operating Procedures (SOPs) to create program continuity as people enter and leave the organisation. I arrived at the HUB on a very special day; it was Noe's last day on the job and two new staff were completing their second week of training. Noe had been the project manager for over two years and accepted another position in New Zealand. As such, much of the previous two months were dedicated to writing down all the processes that had been developed over the past four years as SOPs creating an operating manual and institutional memory essential for continuity in bee breeding.

*Figure 4 Jody and Alicia with cell builder colonies*

The skill sets of individuals engaged in a honey bee breeding program are unique and extremely rare. Some skills are transferrable across many different professions such as data handling, communication, organisation, proficiency in technology application. Some are developed quickly such as microscopy and various lab diagnostic procedures. However, some take years of practice to develop and refine, such as practical beekeeping skills, queen rearing, and artificial insemination (Figure 4).

Finding qualified people to fill the positions necessary to run the program has been challenging. As will be explained in the finances section, the program relies on extraordinarily skilled technicians but attracting and retaining such people can prove to be difficult.

**Finances**

Honey bee breeding is an arduous and expensive process conducted over many honey bee generations (Figure 5). Hawaii is uniquely situated having a climate favourable to beekeeping all year around allowing for more generations annually and benefits of breeding paying off earlier than colder climates with less opportunity for successive generations to be evaluated. As such, favourable breeding results are beginning to emerge from the program with open mated stock selected for Varroa sensitive hygiene performing as well as non-selected stock in a commercial apiary situation. This is the end goal- to develop man maintain commercially viable Varroa resistant stock.

*Figure 5 Artificially inseminated breeder queen with green ID disk on her thorax*

To get here, grant money through Project Apis mellifera contributed mainly by Costco has funded salaries, David Thomas funded the lab building and fit-out, bees, and some salary, the USDA and Arista have largely donated time and energy for data analysis and consultation and stock. All these contributors made it possible to getting the project up and running. An amazing effort by not-for profit, government and private enterprise enabled this cutting-edge program to evolve. For funding agencies, five years of funding may seem like a long time and a lot of money, but the bee breeding has only just begun. The challenge ahead for the HUB is to be able to pay the highly skilled staff a suitable wage to retain their capacity and continue to grow. The long-term vision is to sell the production and breeder queens on a commercial market to support the program; to use the start-up money to become self-sufficient.

The main problem about this vision is that currently there is not enough of a market for this Varroa resistant stock to fund the continuation of the program. This may sound ridiculous, but the truth is, Unites States beekeepers rely heavily on putting chemicals in their hives to fight Varroa. Using (either by using selectively bred stock or development of new lines from existing held stock) Varroa tolerant stock will not happen until chemicals no longer work. There are several factors driving the reluctance to uptake, but the two main factors are: lack of market incentive and fidelity to currently held genetics. Firstly, there is no market incentive for beekeepers to switch. Beekeepers that raise and sell queen bees commercially can sell everything they currently produce. When chemical no longer work to control Varroa, an increase in demand for Varroa tolerant stock will begin to drive the change. Second, many of the genetic breeding lines have been passed through generations of beekeepers. Queen producers and beekeepers have a certain fidelity to the breeding lines established in their operations. Although Varroa resistance can be developed in any line of bees, there is no current desire to select for Varroa tolerance in established lines nor is there a desire to fail to maintain proven and reliable breeding lines currently under selection.

Unless there is an organisation that sees the long-term benefits of maintaining a breeding program and is willing to fund the project or there is a market incentive for such detailed and expensive work, the HUB will struggle. It is accepted that start-ups take time and money to get off the ground, but the expectation is that at some point, the initial investment will pay off and the fledgling idea will be self-sufficient. Bee breeding is expensive and slow and until there is a market incentive to support it, this project will need propping up.

**Application in Australia**

Seeing how the HUB operated and learning about the struggles and successes gave great insight into what is necessary for programs in Australia to be successful and sustainable in the long term. Only long-term sustainable programs can meet the challenges associated with being chemical independent when living with Varroa. The lessons gleaned visiting the HUB have been fundamental in crafting the final recommendations from this Fellowship. Namely, breeding programs in Australia need to find solutions to key aspects of maintaining a breeding program. Infrastructure, Strategic breeding plans, Capacity, and Finances are all essential components to success and stability. However, something more esoteric that also needs to be established is buy-in through direct ownership or through support of the cause. This buy-in is essential and will be the main supporting pillar to a sustainable program. People must believe in the cause and be willing to dedicate time, money, energy, resources, and ideas to the project. Buy-in is a by-product of having an incentive for the project's success, which could be financial or ideological or both.

Australian honey and beeswax are considered some of the finest in the world because Australian apiarists can keep bees at large scales without contaminating hives with chemical acaricides. This status is critical to the value of our products and may be a driver for the early adoption of developing Varroa resistant lines of bees. If there is a widespread demand for Varroa resistance traits in honey bees the market incentive will allow queen bee breeders and queen producers to focus on developing and maintaining this important trait.

## Sue Cobey, Coupeville Washington- Queen Bee Breeder

**Background**

Sue Cobey is an international authority on honey bee instrumental insemination and bee breeding. She established and currently maintains a closed population breeding program for the New World Carniolans, a population with source stock from the carniloian honey bee's native ranges in Eastern Europe. This breeding program has been running for 39 years and is recognized as an industry standard and model program. Sue teaches specialized skills classes focused on instrumental insemination of queen bees designed to teach the skills necessary for the selection and maintenance of honey bee stocks.

**Learnings**

Although the Fellow's visit with Sue was short, she found it informative and inspiring. It was the last day of a three-day intensive workshop in Queen Bee Insemination. The six participants were from a pool of around 50 applicants to the course. Entry is competitive and expensive, and the classes are always full. The participants came from all corners of the United States and were hand-picked based on the value estimated they would receive from the course and how building bee breeding skills could further their beekeeping aspirations and enterprises. Many of the participants already ran successful commercial beekeeping operations and were striving to become independent from commercially available production queens (Figure 6).

This is in direct contrast to the story that unravelled in Hawaii: the major queen producers in the United States are not adopting Varroa resistant stocks because there is no market incentive. Here, the Fellow met smaller scale commercial apiarists disillusioned with the lack of progress toward Varroa resistance in commercially available stocks who are initiating their own breeding programs to select for Varroa resistance!

This realisation contributed further to understanding one of the key elements necessary for a successful bee breeding program: capacity. Instrumental insemination of queen bees is fundamental to any breeding project, but the skill is gained slowly through practice, training, and working with proficient mentors. These participants were chosen because of the likelihood that this skill will be further developed and applied to future continued stock enhancement programs.

**Application in Australia**

While we have several people with the expertise to inseminate queens, there are limited training pathways for further skill development or for interested people to learn this difficult skill. There are also currently no suppliers or distributors of insemination equipment making access to the tools and materials difficult. Increasing the availability of training and materials would expand Australia's bee breeding capacity into the future.

*Figure 6 Left participants in a course to learn artificial insemination techniques for breeding honey bees. Right- Honey bees guarding a space in the lid with Sue Cobey in the distance*

## United States Department of Agriculture Honey Bee Breeding Genetics, and Physiology lab, Baton Rouge Louisiana- Development of VSH and Po-line Lines of Bees

### Background

The USDA-ARS bee lab (for short) is a global leader in breeding Varroa resistance, understanding the Varroa-virus complex, and monitoring colony health in large-scale field settings. The lab consists of around 6-8 research scientists with 1-2 technicians dedicated to each researcher as well as general apiary and office support personnel. The facility is equipped with the most up-to-date genomics equipment and collaborates with other government and university research institutions to work on large-scale, complicated questions concerning honey bee health, pathogenesis, and bee-pest interactions (Figure 7).


*Figure 7 A branded frame inside a USDA honey bee colony*

### Learnings

The Fellow's tenure at the USDA-ARS bee lab afforded her the opportunity to learn practical laboratory skills, participate in pioneering genomics research, be introduced to novel ideas in bee nutrition, and engage with honey bee research scientists and talented technicians. These skills, ideas, and connections have informed and supported her current and future work.

### Practical Laboratory Skills

**Vertical transmission assessment of target viruses**

Gerdts spent about a month at this lab conducting research to inform an importation project being proposed by herself, Dr. John Roberts from CSIRO, and David Briggs a Fellow queen bee breeder. Specifically, she investigated virus levels in colonies with low mites derived from open mated lines bred for Varroa Sensitive Hygiene. Australia is free from two important viruses implicated in colony death associated with Varroa. The goal of the proposed project was to test Australian importation protocols to determine if honey bee germplasm (queens and drone semen) that is selectively bred for Varroa resistance can successfully be imported while safeguarding Australia's Virus-free status. A report recently published showed that if a honey bee population has a moderate level of Varroa resistance within the genetic pool, honey bees and Varroa can find a balance through natural selection. However, if the background level of resistance is low, natural selection alone will result in dramatic colony losses and leading to a great decrease in genetic diversity within the population (van Alphen and Fernhout, 2020).

*Figure 8 Ten honey bee eggs on the tip of a fine paint brush. These eggs will be analysed for viruses*

Vertical transmission occurs when a virus is passed from one generation to the next through reproductive materials, either through eggs with the case of queens or though semen as with drones. Although vertical transmission of viruses is reported to occur (Chen et al., 2006), little work on how mite levels and consequent virus status of a colony influence the virus load of the reproductive material (Figure 8). Elucidating the relationship between a colony's varroa/ virus status and the likelihood of reproductive material containing virus was essential to inform prospective germplasm importation efforts in Australia.

For this study, the Fellow selected colonies with naturally high and low Varroa mite levels and looked for virus in eggs, larvae, pupae, and adult worker bees. She also looked for virus levels in drones and semen from colonies with low mite levels. Through this process, the Fellow was trained on Quantitative Polymerase Chain Reaction (qPCR) processes, protocol and data interpretation. The results showed that low mite levels may be able to be used as a proxy for low virus levels and potential negligible virus risk when importing germplasm into Australia (Figure 9).

*Figure 9 Left-Honey Bee Drones from low mite colonies to check drones and semen for viruses. Middle-A worker bee suffering from Deformed Wing Virus. Right- Labortory work to analyse viruses*

**Assessing Brood Mite Levels and Reproductive Potential**

Determining the number and reproductive capacity of brood nest mites is fundamental to selecting for Varroa Sensitive Hygiene-type resistance. VSH is a specific type of hygiene performed by house bees where the brood cappings covering pupating bees are removed, the pupae inspected for reproductive mites, and either the cap is re-sealed or the parasitized pupae and associated mites are removed from the nest (Harris et al, 2010) (Figure 10). Although the process of determining brood infestation levels and mite reproductivity is relatively easy, the work is technical requiring attention to detail and practice to master. At present, this type of selection is the only proven and effective method to select for this behaviour and something that will needed to be mastered by queen breeders in Australia when breeding for varroa resistance.

*Figure 10 Left-Uncapped honey bee pupae being examined for Varroa mites. The cell on the far left contains a white male mite while an adult female mite is in the upper right of the frame. Right- A frame of sealed honey bee brood with prepupae and pupae removed to ascertain brood infection rates and mite reproductive capacity*

**Pioneering Genomics Research**

One of the most rewarding aspects of the Fellow's tenure at the Baton Rouge bee lab was to participate in ongoing research. The major focus of the lab whilst she was there was collecting bees performing hygienic behaviour toward a Varroa mite infected honey bee cell. This small component was part of a large collaborative project across several research institutions. The bees were collected performing hygienic behaviour and immediately preserved in liquid nitrogen. The cell the bee was working on was marked with a pin and inspected later for the presence of Varroa mites. Bees that were performing hygienic behaviour on infested cells were then sent to another university where they will be analysed for genes up-regulated while performing the task (Figure 11, Figure 12). This project joins the global imitative to discern and identify genetic markers associated with Varroa resistance. Genetic markers are used as breeding tools across Agriculture and Horticultural industries world-wide.

*Figure 11 Left- microtubes prepared to hold bees flash frozen in liquid nitrogen collected whilst performing hygienic behaviour. Right- watching bees in observation hives for performing hygienic behaviour*

Having markers to assist with selecting for Varroa resistance in honey bees could drastically change how bee breeding is conducted by making it easier to select bees that can keep Varroa levels low and help decrease the reliance on chemicals in the hive. For Australia, being able to select on markers would give Australian apiarists an enormous head-start when living with Varroa, enabling the preservation of genetic diversity of the Australian honey bee population and help the bees find a natural host-pathogen balance sooner than otherwise possible.

*Figure 12 Left- microtubes prepared to hold bees flash frozen in liquid nitrogen collected whilst performing hygienic behaviour. Right- watching bees in observation hives for performing hygienic behaviour*

**Novel Ideas in Bee Nutrition**

One of the most surprising and immediately applicable research projects the Fellow learned about in Baton Rouge was the use of Spirulina as a feed substitute for honey bees. In nature, bees derive protein, amino acids, sterols, lipids, fatty acids, and nutrients from pollen; pollen is what builds the bees. Nectar is the source of carbohydrates- it is what fuels the bees. When natural high-quality pollen is not available, beekeepers must supplement their bees' diets with a pollen supplement. Pollen supplements can be made from a variety of different sources but usually have a soy bean or pea bulk base for high protein with additions of a variety of different ingredients such as whey, vegetable oils, yeast and egg to supply amino acids and additional nutrients. While these pollen substitutes are essential to keep bees healthy, many formulations are not providing a complete nutritional profile for bees.

Dr. Vincent Ricigliano has been studying the impact of nutrition on bee health for a number of years and is currently experimenting with feeding bees spirulina, a blue-green microalga considered to be a superfood for humans and gaining traction in the livestock feed realm. Dr. Ricigliano's lab is filled with fish tanks and grow lights pumping green water, growing spirulina. Some of his recent work has shown spirulina to have "significant potential as a pollen substitute or pre-biotic diet additive to improve honey bee health" (Ricigliano and Simone-Finstrom, 2020).

*Figure 13 Top-Garret surveying Pol-Line breeder colonies. Middle- Hunter collecting pupae for virus screening. Bottom-Daniel and Bob chatting about VSH selection*

In Australia, Gerdts manufactures a pollen substitute called Bee Build Sausage. Equipped with this new information, she has developed and field-tested two new spirulina-based products for the Australian market to help beekeepers provide nutrition to their bees. Australian made quality supplemental feed products are especially important during drought and fires as seen in the summer of 2019-2020.

**Engage with Honey Bee Research Scientists and Talented Technicians**

The bee lab team consists of individuals from diverse backgrounds and expertise and held together through their interest in some aspect of honey bees. Chatting with the various research scientists brought dry, analytical and sometimes difficult information conveyed in scientific literature to life. The Fellow learned about the messy, candid and fascinating side of the researcher's scientific endeavours. These chats shed true, human light on the complex and difficult process of scientific enquiry and gave her confidence in her own process. Their stories, willingness to answer her questions, and passion about their own areas of interest helped her reflect on science communication and how complex issues can be delivered even in a non-formal setting (Figure 13).

The technicians at the bee lab are some of the un-sung heroes of the work. They are the cogs behind the results published in scientific journals without which, the research scientists would be lost. Many of the technicians have worked at the lab for over a decade and have been instrumental in the development of procedures, data collection, manual labour, and tedious tasks necessary to conduct good science. Each of the technicians are masters of their small component of the process and learning various skills from them was an absolute honour for the Fellow.

**Application in Australia**

Most directly, the original research conducted while at the bee lab has had an important impact on the current importation project in Australia. The data generated demonstrated that the likelihood of vertical transmission of viruses through semen and eggs was low, but possible. The research team has used this information to generate sampling plans to safe guard Australia's honey bee virus status. Another direct and immediate application was the development of spirulina containing bee feed products for the Australian market. Given the major impact of drought and bush fires on honey bee food resources, the development of products known to have a positive impact on honey bee health has been advantageous. Learning how to select for the VSH trait in honey bees, participating in research projects and building her professional network have longer term, but potentially more further reaching impacts. These all contribute to future capacity and will undoubtedly prove to be useful for the Fellow in the coming years.

## Purdue University, Lafayette Indiana- Indiana Mite Biters

*Figure 14 The Purdue honey bee research field lab*

**Background**

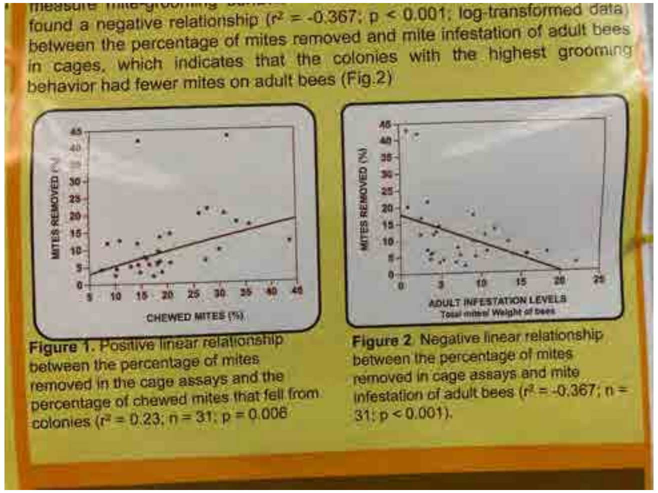
Honey bee researchers at Purdue University have worked for the past 20 years to understand develop a different mechanism for Varroa resistance called grooming (Figure 14). Colonies that are excellent groomers are aggressive toward phoretic mites, biting their legs and feet off. Colonies that exhibit over 50% mite biting behaviour have an increased likelihood of survival. Mite biting percent is measured by counting the number of mites dropped on a sticky mat with chewed legs compared to those that don't have chewed legs.

The development of the Indiana mite biter bees commenced in 1997. The source population was derived from commercial queen stock, a VSH and a Russian queen, and other "Survivor Stock" queens from the area. Each year the breeding population consisted of about 100 colonies. The goal for the first 10 years was to purely select for survival and in 2007, selective breeding focused on mite biting behaviour was initiated. The stock was further developed and selection assays fine-tuned from 2007 to 2014 (Figure 15).

In 2014, a beekeeper stock evaluation was initiated through a blind study where beekeepers were provided a queen from the Purdue breeding stock and a commercially sourced queen. Beekeepers were asked not to treat for mites and report back whether the colony survived or not. The beekeepers reported that the Indiana bees survived longer, made, more honey, had fewer mites and were a bit more aggressive than the commercially sourced queens. Although this trial was limited in scope (102 queens to 39 beekeepers) the idea of incorporating citizen science into the program is progressive (Figure 16.)

For a full background on the development of the Indiana Mite Biter please read this fascinating article: https://www.beeculture.com/breeding-mite-biting-bees-to-control-varroa/

*Figure 15 Left-Krispn pointing out some bees with DWV on the ground of the breeding apiary. Middle-A poster showing the relationship between grooming, mite biting, and adult infestation. Right-Inside the field lab with artificial insemination equipment*



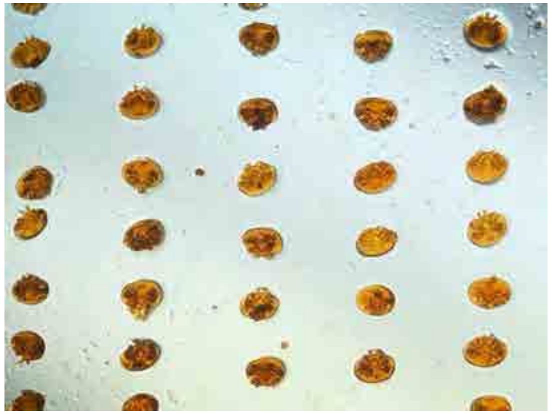



*Figure 16 Left- Close up of mounted mites examined for damaged legs. Below-one hundred mites mounted to a slide. This measurement is used to determine percent chewing behaviour for a colony*


**Learnings**

The Fellow has been following the progress of the Purdue bee lab for the past decade attracted to their focus on breeding from locally adapted survivor stock and cooperation with local beekeepers and queen bee breeding groups. As part of a Land-Grant university, a major focus of the lab is extension related education and training providing the platform for community and industry engagement. Specifically, they have worked closely with the Kentucky Bee Breeders associated and related organisations to increase capacity through Artificial insemination courses and replicating breeding lines from Survivor Stock.

Gerdts was surprised to learn that aside from engaging with beekeepers, the bee lab historically did not collaborate much across universities or other research institutions. Currently, they maintain Varroa resistant breeding lines and although they have been selecting for mite chewing behaviour, there is little known about other mechanisms (e.g. VSH) that might be contributing to survival. Additionally, not much is known about how the mite drop count related to the phoretic or brood mite levels. Coming from the perspective of studying several different resistance mechanisms, it would be assumed people engaged in the breeding work would also be curious to know if and how these mechanisms work in concert with one another. However, this lack of information may be about to change: the Purdue Bee Lab is now under the guidance of Dr. Brock Harper. Dr. Harper is an enthusiastic evolutionary biologist that brings an interest and expertise in the relationship between genotype and phenotype, in other words- he wants to understand the relationship between what the bees have the genetics to do and what they actually do. Dr. Harpers' curiosities will most likely drive the development of a whole new understanding of Varroa resistance and how to breed for it.

The lack of engagement in the broader research community may be partially due to the "stay at home" focus. Krispn Given, the main bee lab technician and an invaluable member of the breeding team, is astutely focused on breeding locally adapted stock. One of Krispn's mottos: "The best bees are the ones in your own back yard." His work has supported the formation of MicroBreeder Cooperatives and suggests that to develop locally adapted stock, building a history of at least 5 years with 100 colonies is a good place to start. The idea of local adaptation is extremely important in Indiana as they experience long and cold winters. Bees must be hearty, have mechanisms to withstand long winters, and build up quickly to take advantage of the relatively short spring and summer. These ideas have contributed significantly to my understanding of key components for sustainable breeding programs.

**Application in Australia**

Australia is in prime position to learn from the experiences of others and prepare now for living with Varroa. Although there is not currently a way to test Australian colonies for mite grooming behaviour, a new assay is being developed that tests individual bees for their grooming efficacy (Morfin et al., 2020). Knowing grooming is effective against mites and that the trait exists in every population of honey bees could provide a pathway to pre-select Australian stock for Varroa resistance. Additionally, Australian beekeepers can learn from the idea of developing and maintaining "set aside" apiaries where bees can become adapted to a certain set of climatic circumstances. The development of locally adapted stock will go a long way to providing a solid robust base stock that can be selected further for Varroa resistance when the time comes. Lastly, creating microbreeding networks is essential. Increasing capacity across the industry where more people can select and maintain breeding lines will go a long way to improving local adaptation and survivorship.

## Heartland Honey Bee Breeder's Cooperative, Frankfort Kentucky


*Figure 17 Logos of organisations belonging to the Heartland Honey Bee Breeders' Cooperative*

**Background**

The Heartland Honey Bee Breeders Cooperative (HHBBC) was formed in 2013 and involves the cooperative sharing of information, techniques and disease-resistant genetics between queen producers in the states of Indiana, Ohio, West Virginia, Pennsylvania, Kentucky, and Illinois. Each year in June, certified HHBBC queen producers bring virgin queens to Purdue University where semen is harvested from Indiana Mite Biter drones and used to inseminate the new queens.

The newly inseminated queens return to each state's queen breeding program and are evaluated for the following year for Varroa resistance, temperament, production, disease resistance, and localization. Although facilitated by a few of the same people, two other initiatives: Chasing Feral Honey Bees and the Honey Bee Recovery Alliance play a significant role in sourcing and selecting locally adapted Varroa resistant honey bee colonies (Figure 17).

At the heart of this enormous effort is a core group of dedicated individuals. The main activities of this group are stock sourcing though maintaining their own apiaries and trapping feral swarms, Varroa resistance trait identification which focuses determining percent mite chewing behaviour, and educating Fellow beekeepers about the importance of locally adapted Varroa resistant stock. Accordingly, an intricate network of information and skill exchange has developed around some thoughtful, innovative, and clever systems. This group is completely grassroots and against the grain of the American beekeeping industry. They insist beekeepers not to buy commercially produced queens or packaged bees and instead join a local revolution that works more closely with bees' natural habits. They encourage stock sharing and are committed to make the stock they work with accessible to anyone who wants to keep bees within their region. HHBBC et. al.'s dedication is impressive and commendable; their success is inspiring (Figure 18).


*Figure 18 Top-Dorothey Morgan helping a beekeeper look at a sticky mat for mites that have been chewed. Middle-Dorothey and Dwight Wells setting up the digital microscope to look for chewed mites. Bottom-Dwight's license plate BEEIPM stands for integrated pest management*

**Learnings**

Most of the Fellow's time was spent with Dorothey Morgan and Dwight Wells (Figure 19). Each is retired from their professional working lives and now dedicate an enormous amount of time and resources toward their shared passion. Dorothey and Dwight are natural teachers have been successful in creating an open sharing and learning environment uniting Fellow beekeepers around a common cause: healthy bees. The five main components that the HHBBC and associated groups focus on are swarm trapping and nutrition, determination of mite biting percent i.e. is the colony suitable for breeding stock, reproduction through artificial insemination, and replication from and access to genetics from the breeding stock for production use. The HHBBC and associated groups use social media to share videos recorded at different club meetings and workshops to build a library of resources accessible to anyone in the world. Although they are focused mostly on their geographical area, the east central United States, many of the techniques and systems they have worked out are transferrable and applicable to other regions of the world.

The most impressive aspect of the work done by the HHBBC is the grass-roots level cooperation and astute practical beekeeping knowledge that is fundamental to their success. They have solved some of the key problems for successful breeding programs by de-centralizing and developing some organizational memory in the way of the teaching videos and recorded presentations. However, much of the work is a labour of love with individuals contributing significant amounts of time, money, and energy to the project without direct financial compensation. This type of program will continue to be successful if people are continuously engaged, knowledgeable, and passionate about the progress of the program. Additionally, a succession plan would be helpful to identify a pathway for key skills, capacity and knowledge that is essential for the program to be passed along participants in the event of people leaving and or entering the group.

**Application in Australia**

The work by the HHBBC is wholly applicable to Australian beekeeping. Recognizing and maintaining feral or wild populations of honey bees in Australia is essential to provide the genetic diversity necessary to build a successful post-Varroa population of honey bees. One caveat here is that many feral bees currently in Australia do not have the gentle temperament to tolerate beekeeping practices. With this in mind, apiarists in Australia should consider working toward developing locally adapted stocks that are also managed or at minimum selected for beekeeper friendly traits.

Given the lack of a funded focused honey bee research program in Australia, the breeding progress will largely come from stakeholders and invested individuals. The framework of HHBBC's breeding cooperative along with the systems of sourcing, identifying, replication, and distributing desired stock will be fundamental to Australia's success in breeding Varroa resistant honey bees.

*Figure 19 From Left to right: Dwight Wells, Daniel Martin, Jody Gerdts (Fellow), Peita Martin, and Dorothey Morgan*

# 5. Personal, Professional and Sectoral Impact

The learnings and relationships resulting from this Fellowship have had a profound impact on the Fellow's life and future work. She hopes that this future work will have a positive influence on the resiliency of the Australian honey bee industry, now and into the future.

On a personal level, the relationships that were forged as a result of this Fellowship helped cement friendships and expanded her professional network in an exciting way.

## Impacts that have occurred

» Relationship with Arista Foundation for Breeding Varroa Resistant Honey Bees;

» Better understanding of the mechanics of honey bee breeding and selection for Varroa resistance;

» Better understanding of the mechanics of selecting for grooming and Varroa sensitive hygiene;

» Insight into how to structure focused bee breeding programs;

» Identification of key universal obstacles to sustaining a honey bee breeding program;

» Conducted novel research on virus transmission rates which helped inform a current germplasm importation project in Australia;

» Introduced international researchers to obstacles facing the Australian honey bee industry;

» Relationship with Heartland Honey Bee Breeding Cooperative key players which could eventuate in advanced training for Australian Beekeepers.

## Impacts that are planned

» Collaborating with researchers at Purdue University, the USDA, and Canada to investigate Varroa resistant genotypes in Australia and develop assays to select for resistance pre-varroa;

» Establish de-centralized honey bee breeding collectives to focus on breeding commercially suitable honey bee stocks;

» Educate bee breeders about different ways to select for Varroa resistance;

» Forge a plan of how to select for Varroa resistance once it becomes established in Australia;

» Prepare beekeepers and stocks for living with Varroa.

# 6. Recommendations and Considerations

## Sustainable Honey Bee Breeding Networks

While this Fellowship initially focused on understanding selecting for specific traits in honey bees that increase survivorship in a Varroa landscape, it became abundantly clear that these efforts must be conducted within a well-defined breeding structure. The Australian beekeeping industry has recognized the need for and value of collaborative breeding programs for decades initiating several projects at local and national levels in both private and public sectors. Despite the ongoing effort, no collaborative sustained breeding effort has lasted the test of time or has included the rigor necessary to accomplish the difficult task ahead of maintaining commercially viable Varroa resistant honey bee stocks.

Building a collaborative honey bee breeding network consisting of multiple self-sufficient, self-organized breeding collectives prior to Varroa establishment will help Australian apiarists develop locally adapted, commercially viable stock while creating a framework for implementing Varroa resistance selection techniques when the time comes. Creating a sustainable breeding network must, therefore, be our first objective in Australian when preparing for living with Varroa.

## Key Elements of a Sustainable Breeding Collective

Successful honey bee breeding programs have 5 key elements: Resources, Finance, Framework, Capacity, and Facilities (Figure 20). Each of these elements have sub requirements and specializations necessary for success. In a honey bee breeding collective, each of these elements would be handled by multiple operations/organisations, each with a specialized skill set. Distributing the work and asset responsibility across several stakeholders allows people to specialize in various aspects, not only spreading the workload, but ensuring the best qualified person/ people are attending to the required job. For example, a participating beekeeper may provide apiary sites, extraction services, and transportation of breeding stock while another may perform replication (queen rearing and artificial insemination of breeding stock), while another stakeholder handles data collection and synthesis, breeding cross determination and communicates results. Identifying key elements necessary for a sustained breeding collective ensures capacity to achieve breeding goals and allows for continuity across time regardless of stakeholder turnover (Figure 21).

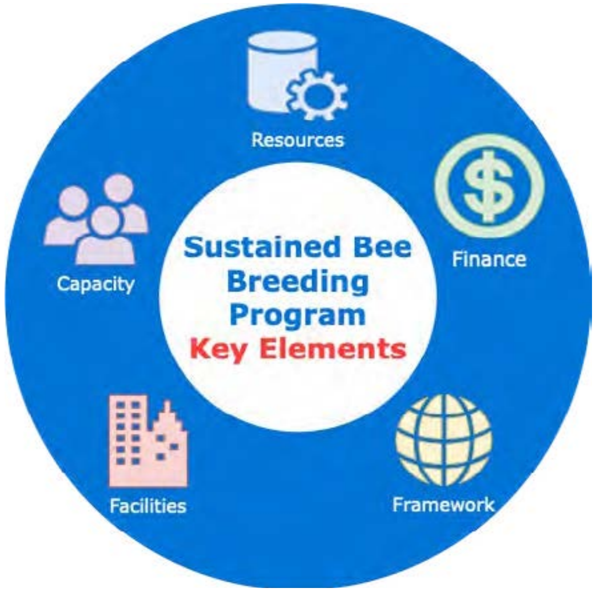
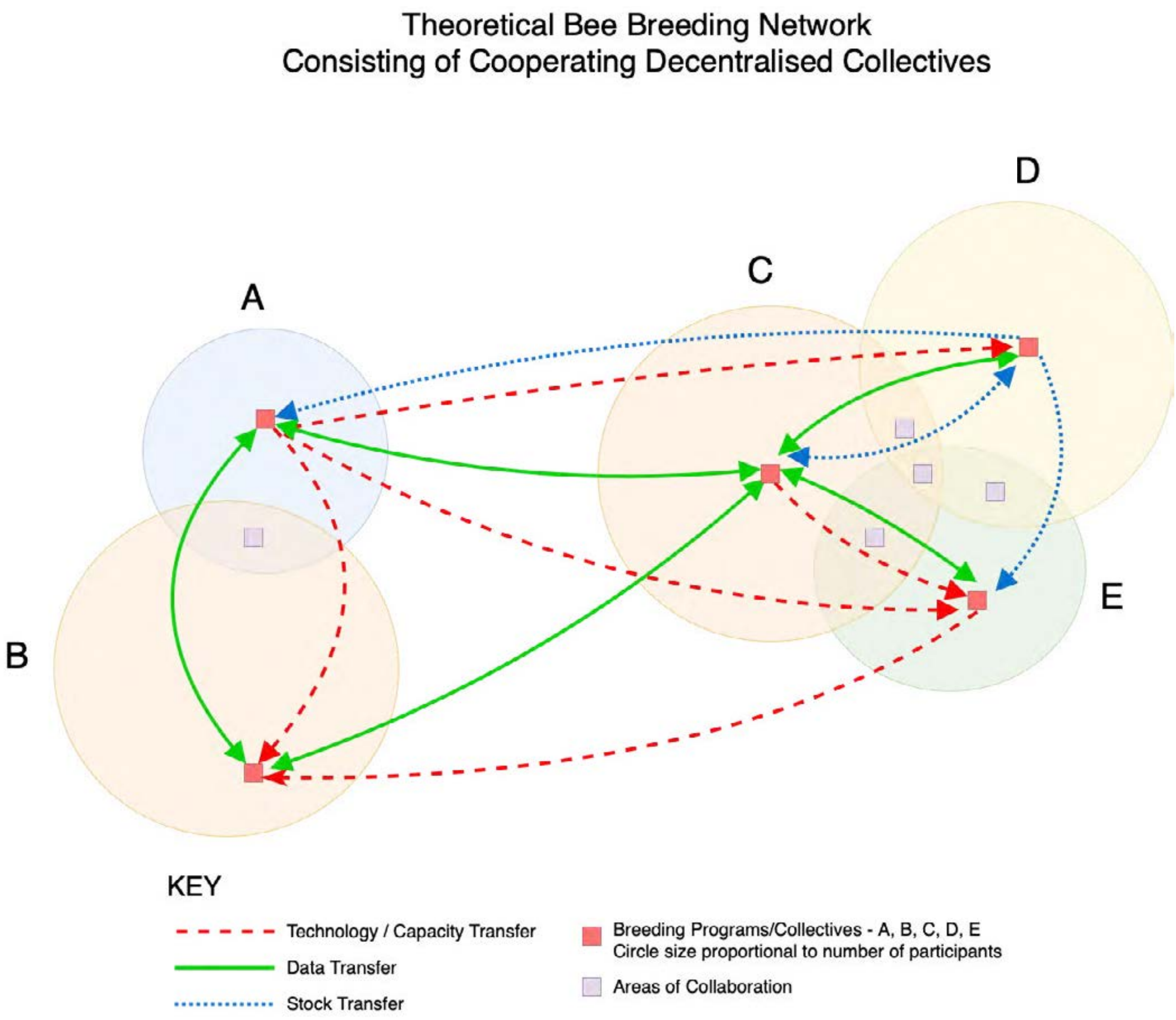



*Figure 20 Key components necessary to address when building and maintaining a sustainable honey breeding program*

Honey bee breeding is costly in both time and resources regularly yielding little short-term return on investment. In the public sector, the lack of on-going grant funding for retaining qualified staff and resources has greatly hindered breeding efforts while in the private


*Figure 21 A detailed view of various aspects of key elements for sustained and successful honey bee breeding programs*




sector the major breakdown in many breeding programs has been due to stakeholders unsuccessfully navigating the onerous job of honey bee breeding while meeting the demands of a beekeeping enterprise. Too often, the rigor required by the selective breeding process in sacrificed because the beekeepers engaged in such efforts must also maintain a livelihood. Establishing breeding collectives united by a breeding network provides a sustainable, unified, and collaborative approach to stock enhancement regardless of the traits under selection or the identity of the participants (Figure 22).

*Figure 22 A visual model of a theoretical honey bee breeding network consisting of multiple de-centralized breeding collectives*

## Preparing for Living with Varroa

## Continued selection and development of maintained stock

Currently, selecting for Varroa resistance is a time-consuming process requiring mites, skill, and experience. Globally, researchers are working a simple, easy, and effective way to select for Varroa resistance. This could be accomplished through selecting on genetic markers associated with Varroa resistance or through an alternative phenotypic assay triggering behaviours known to limit mite growth in colonies (e.g. grooming and brood hygiene). If and/or when these selection tools are proven, Australian queen bee breeders should begin selecting Varroa resistant associated traits within proven domestic stock. In lieu of such tools, continued selection for hygienic behaviour is recommended as is the maintenance of genetically diverse breeding populations to increase the likelihood of resistance associated alleles in the future

**Establish and maintain set-aside, non-treatment apiaries**

Learning from the experiences of Purdue University and the HHBBC, developing locally adapted stock is essential to the continued success of honey bee colonies and beekeepers. Establishing multiple decentralized set-aside apiaries across the nation will increase the likelihood of bees being suited to their environment and promote underlying genetic diversity essential to combat Varroa with commercially viable honey bees. This genetically diverse population undergoing beekeeping associated selective pressures (temperament, honey production, disease resistance) where natural selection has assisted in establishing a host-pathogen balance will be a precious resource to the Australian and global beekeeping industries.

## Establish a Centre for Pollination Resiliency Housed at an Australian University

**Address questions of today**

Currently pollinator research in Australia is conducted by several universities through various level research projects. While helpful, there are no direct and consistent industry ties which is damaging on two fronts: 1) important findings are not communicated and promoted to industry so uptake of helpful information is limited and 2) money is spent on research that has either been conducted before or is not valuable or relevant to the beekeeping/ pollination industries. Additionally, the disjointed nature of pollination/ pollinator related research projects lacks continuity necessary to build understanding about large-scale problems facing pollination security in Australia.

**Build capacity scientists of tomorrow**

Working in the pollination system and especially working with honey bees takes years to decades of experience to master. Currently in Australia, young scientists do not have a place to turn to have contact with pollination specialists or apiarists. There are no programs on offer where students can learn about honey bees through an evolutionary perspective, or as a model organism for understanding eusocial behaviour in insects. To build pollination security in Australia, we need to foster young scientists that have exposure to pollination networks and have experience with field and lab techniques specific to working with honey bees. We need to foster an appreciation and passion for the foundation of our food security and provide the scientists of tomorrow with the tools to tackle future threats. A centre for pollination resiliency would tie together the currently disjointed pollination research focus, provide a platform to build on understanding, and incubate the next generation of scientists who may hold the key to our food and biodiversity future. It is time.

# 7. References


Chen, Y., Evans, J., Feldlaufer, M., 2006. Horizontal and vertical transmission of viruses in the honey bee, Apis mellifera. J. Invertebr. Pathol. 92, 152–159. https://doi.org/10.1016/j.jip.2006.03.010

Harris, J. W, Danka, R. G, & Villa, J. D. 2010. Honey Bees (Hymenoptera: Apidae) with the Trait of Varroa Sensitive Hygiene Remove Brood with All Reproductive Stages of Varroa Mites (Mesostigmata: Varroidae). Annals of the Entomological Society of America, 103, 146. https://doi.org/10.1603/AN09138

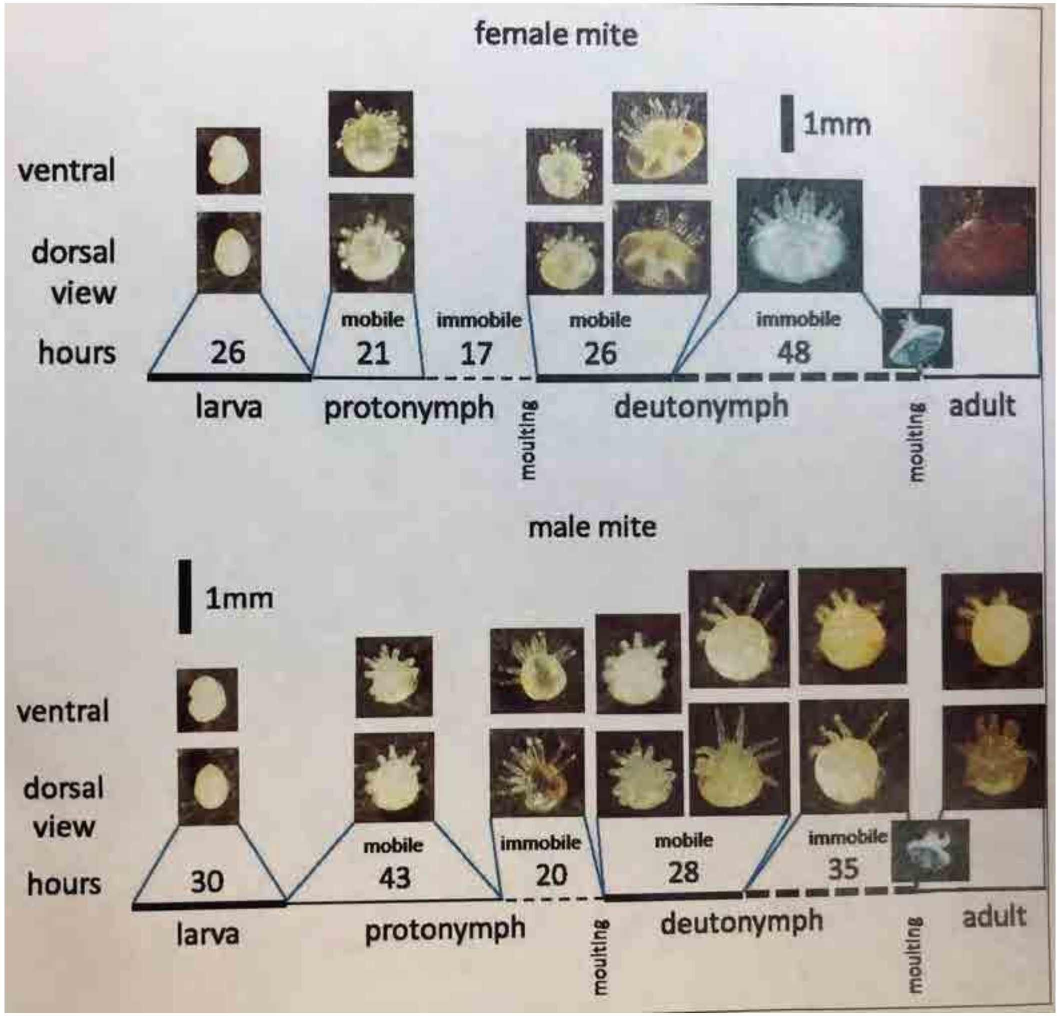
Morfin, N., Espinosa-Montaño, L.G., Guzman-Novoa, E., 2020. A direct assay to assess self-grooming behavior in honey bees (Apis mellifera L.). Apidologie. https://doi.org/10.1007/s13592-020-00769-y

Ricigliano, V.A., Simone-Finstrom, M., 2020. Nutritional and prebiotic efficacy of the microalga Arthrospira platensis (spirulina) in honey bees. Apidologie. https://doi.org/10.1007/s13592-020-00770-5

van Alphen, J.J.M., Fernhout, B.J., 2020. Natural selection, selective breeding, and the evolution of resistance of honeybees (Apis mellifera) against Varroa. Zool. Lett. 6. https://doi.org/10.1186/s40851-020-00158-4

# 8. Appendices

*Figure 23 Developmental stages of male and female mites. Determining the developmental stage of the mite in relationship to the developmental stage of the pupae determines the reproductive capacity of the mites in the cells. One way to supress mite levels in a colony is to supress mite reproduction capacity*



International
Specialised
Skills
Institute

**ISS Institute**
Level 1, 189 Faraday Street
Carlton VIC 3053

**T** 03 9347 4583
**E** info@issinstitute.org.au
**W** www.issinstitute.org.au

Published by International Specialised Skills Institute, Melbourne | www.issinstitute.org.au