POLLINATION NATION

Research Highlights from the Canadian Pollination Initiative (2009-2014)

NSERC-CANPOLIN
CANADIAN POLLINATION INITIATIVE

FOREWORD

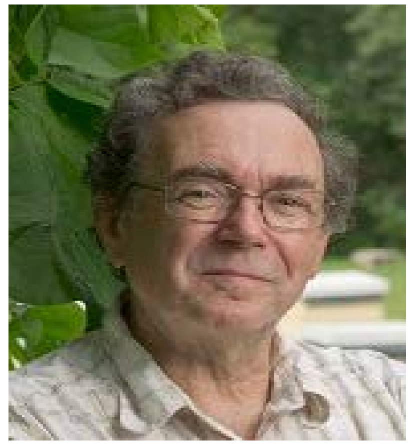
Welcome to "Pollination Nation", a compilation of research highlights from the Canadian Pollination Initiative (NSERC-CANPOLIN), a strategic research network funded by the Natural Sciences and Engineering Research Council from 2009-2014 to address the multifaceted problems facing pollinators and plant reproduction in Canada.

The CANPOLIN Network was truly national in scope, bringing together 44 researchers from 26 institutions across the country. Research activities fell into one of seven working groups: (1) Wild Pollinator Taxonomy, (2) Managed Pollinators, (3) Plant Reproduction, (4) Wind Pollination, (5) Ecosystems, (6) Prediction or (7) Economics. Many projects crossed working group and disciplinary boundaries, reflecting the highly integrative nature of CANPOLIN.

Immense progress was made over the life of the Network. At the time of writing, we have over 130 publications submitted or in print, and many more are still expected. But scientific output is just one way in which CANPOLIN was successful. The Network provided training for close to 150 graduate students, and has helped build a strong foundation for highly collaborative pollination research in Canada, one that I believe will serve the scientific community well as we continue to work to address the complex issues around pollination.

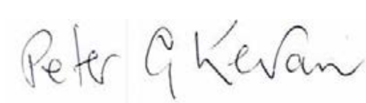
CANPOLIN would not have been possible without the dedicated efforts of our researchers and graduate students, working group leaders, and the members of our Board of Directors and Scientific Advisory Committee. See "Who's Who in CANPOLIN" on pg. 105 for a full list of Network members.

The Network is also indebted to its many partners and supporters, who generously helped leverage NSERC support almost two-fold.



The research stories highlighted in this digest are but a sample of some of the work that has taken place. A full list of projects can be viewed on pg. 96. To jump to a different story in the digest, readers may simply click on the navigation bar at right.

To learn more about CANPOLIN and its activities over last 5+ years, I invite you to visit our website.



Peter Kevan, Scientific Director, NSERC-CANPOLIN

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

TAXONOMY

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

KNOW YOUR POLLINATORS

Taxonomy is vital to the study of pollinators

Any study of pollinators – or attempt to conserve or protect them - requires accurate knowledge of the organisms are.

TAXONOMY

is the science of describing and classifying biological diversity. It is the very foundation of our understanding of biology, and our efforts to conserve biodiversity. In recent years, scientists have sounded the alarm about the growing "taxonomic crisis" - the fact that only a small fraction of the world's species have been described and species are going extinct faster than we can document them.

Thanks to the efforts of the wild pollinator working group (WG1), **we now know what CANADA's pollinators are.** A catalogue of 806 Canadian bee species has been successfully compiled – the fruit of many years of labour and exhaustive sampling across Canada, particularly by former CANPOLIN research associate Cory Sheffield. This effort also led to the discovery of some species not previously known in Canada, such as the masked bee *Hylaeus punctata*.

But knowing what bees are out there is just a first step. A major goal of CANPOLIN was to increase Canada's capacity in **pollinator identification.** This goal was essential not only to help fulfill the research objectives of the entire network, but also to support pollinator conservation programs in the long term.

The vast majority of Canada's bees are relatively inconspicuous and many species are extremely difficult to identify to species. WG1 researchers strove to break down the taxonomic barrier for Canadian pollinators through the creation of **user-friendly, online identification keys** that can be used by anyone with a microscope and a computer with internet access. Keys have been fundamental to insect identification since the field of taxonomy was born some 200 years ago, but traditional keys can be difficult to use, particularly for a non-expert. An old

The masked bee *Hylaeus punctatus*, a species not previously recorded in Canada *(photo by C. Sheffield)*

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

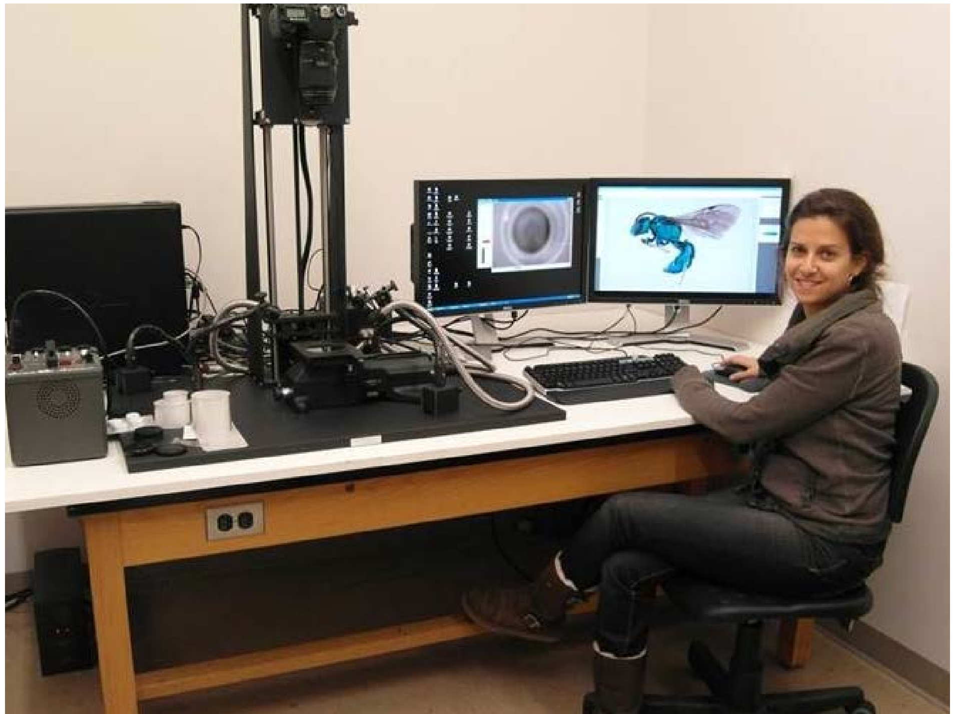
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

saying amongst taxonomists states that "keys are written by people who don't need them for people who can't use them."

To help rectify this problem, the WG1 team set out to build a series of keys that could be used by experts and lay-persons alike. These keys all share two important features: they are available freely online, and they are rich in high-quality images that help eliminate the need for a detailed knowledge of insect anatomy and terminology. Using the latest in imaging technology, WG1 researchers, graduate students and technicians have assembled literally thousands of high-resolution images of hundreds of anatomical features used to identify pollinators.



York University technician Sheila Dumesh compiles images for use in an identification key *(photo by L. Packer)*

Key development in CANPOLIN progressed in leaps and bounds. A key to all 56 genera of Canadian bees has been completed and tested, and is expected to be published in 2015. For the 42 genera that contain more than one species, WG1 efforts have resulted in species keys (either completed or nearing completion) for half of these. According to WG1 leader Laurence Packer, ongoing efforts by both CANPOLIN researchers and other colleagues outside the network will mean that Canadians can expect to have easy to use keys available for species in most of the remaining genera within the next few years. "Once these keys are complete, we will have the capacity to identify

Some of the bee genera for which identification keys are now available. From left to right: *Lasioglossum, Megachile, Bombus, Anthophora* *(photos by S. Marshall)*

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

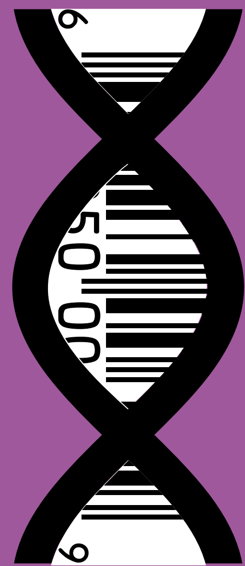
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

about 90% of our bees to species," says Packer. The rest, he cautions, are difficult genera that may take some time yet to crack.

As a supplement to the keys, WG1 also worked hard to **build the nation's DNA barcode library for pollinators**. DNA barcodes are small pieces of DNA that can be used to distinguish between species (much like barcodes are used to identify products in the retail industry). CANPOLIN funds have helped fill in many of the gaps that previously existed in the bee barcode library, and approximately three-quarters of Canada's bees species now have at least one DNA barcode sequence databased.



DNA BARCODES

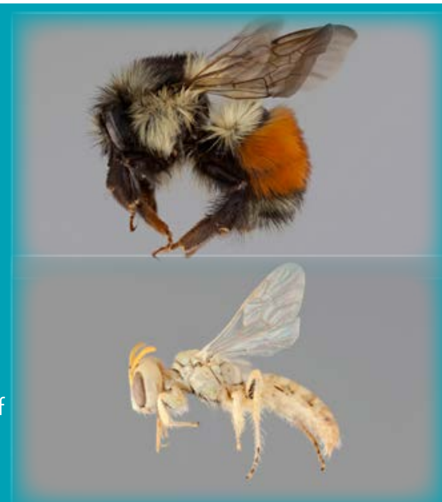
The usefulness of a DNA barcode library depends on how complete it is – the more species that are included in the library, the more likely you are to find an accurate match for a specimen you are trying to identify.

DNA barcodes are an exciting advance in insect identification, but the accuracy of barcode-based identifications is only as good as the state of the taxonomy of the specimens used in the database. While it cannot replace traditional taxonomy, barcoding can speed up identifications and help identify where additional morphology-based research is most needed.

AVOIDING MISIDENTIFICATION

Even with the best keys, users can sometimes arrive at an incorrect identification. To help avoid this, WG1 offers two useful tools. The first is a set of synoptic collections, each one a mini-collection of specimens representing the known bee fauna in a particular region. It allows an unknown bee with a tentative ID to be visually compared with a known specimen. WG1 researchers are providing synoptic collections to research labs across the country.

The second strategy is an ONLINE IMAGE BANK that includes whole-body images of different colour morphs, males and females, workers and queens for each Canadian bee species. The image bank will allow any user to confirm the identification of a particular specimen.



Images from the online image bank: female *Bombus melanopygus* (top) and a female *Perdita perpallida* (bottom)

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

THE "OTHER" POLLINATORS

Taxonomic advances for other important groups of insect pollinators

Not to be overlooked are the "other" major insect pollinators – flies, butterflies and moths. CANPOLIN researchers also set their sights on gaining a better taxonomic understanding of these groups.

The taxonomic and ecological diversity of flower visiting **FLIES** is probably greater than for any other group of insects, including bees. WG1's fly research team, led by Steve Marshall and Jeff Skevington, has made great strides in cataloguing the flower visiting flies of Canada, creating online keys to aid in identification of three major families (hover or flower flies, blow flies and cluster flies) and performing taxonomic revisions of several of the most important genera. Over 12,000 images of pollinating flies have been taken to aid in key building and other publications. And because DNA barcodes can also assist with identifying fly pollinators as well as bees, CANPOLIN researchers have built up the barcode library to include 1362 of 6000 species of Syrphidae, the most important group of flower visiting flies.

Marshall and Skevington also dug deep into the troves of information housed in insect collections at the Canadian National Collection in Ottawa, the University of Guelph and the University of Alberta. Each individual specimen stored in these insect museums is labelled with information about where the insect was found and when. With help from a large team of dedicated technicians, label information from about 165,000 specimens of Syrphidae have been digitally databased and geocoded, and can now be used by researchers to track changes over time in species distributions and phenology. (See p.86 to learn more about the value of historical insect specimens in research.)

WG1 researchers have revised the taxonomy of three genera in the flower fly family Syrphidae, including (from top to bottom) *Ocyptamus*, *Platycheirus*, and *Sericomyia (photos by A. Young)*

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

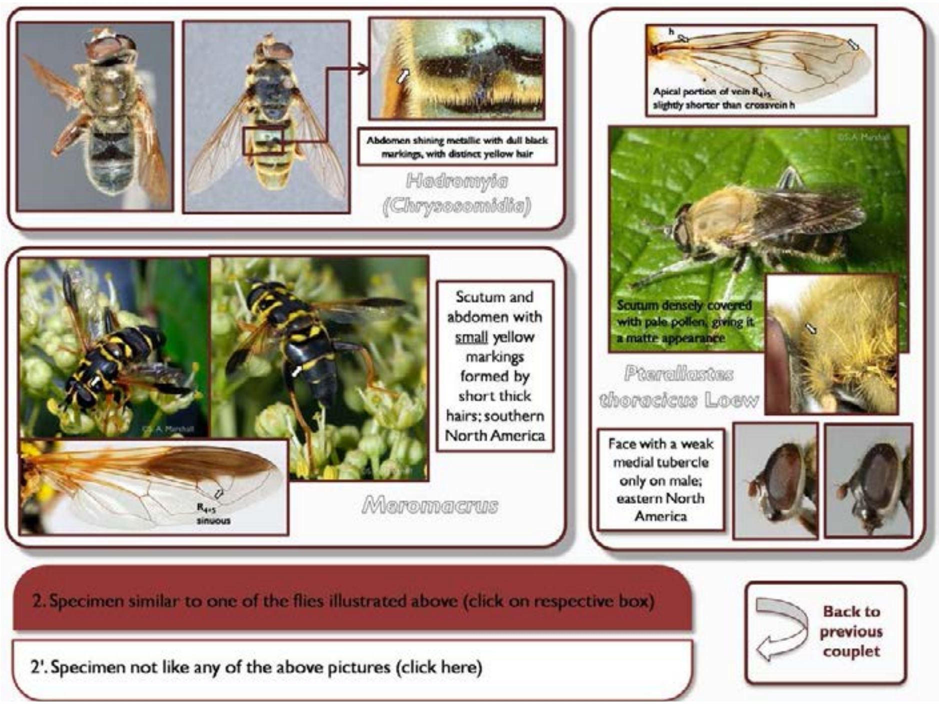
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

For expert and non-expert bug enthusiasts alike, the fly team is also producing a field guide to the flower flies of northeastern America. The guide will offer distribution maps, life history notes and vivid colour photographs of some 400 species, and is expected to be published in 2015.



A sample of the online, interactive key to Nearctic flower flies (*Syrphidae*) which is available through the Canadian Journal of Arthropod Identification

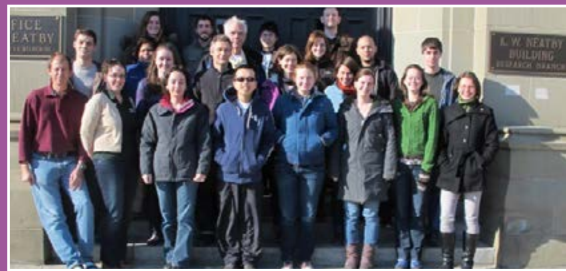
BUTTERFLIES and MOTHS are one of the most diverse insect orders, with over 4700 species known in Canada. Although they are among the most showy and charismatic groups of insects, many families can be difficult for non-experts to identify reliably. WG1 researcher Felix Sperling and graduate student Jason Dombroskie at the University of Alberta made a major step forward in enabling identification of this group by creating a matrix key to Canadian Lepidoptera. This interactive key, published in the Canadian Journal of Arthropod Identification, allows users to key moth or butterfly specimens to family, sub-family or tribe.

FLY OR **BEE?**

Many flower flies resemble bees, an act of mimicry that helps protect them from predators. Have you ever wondered why some flies make better bee mimics than others? WG1 researcher Jeff Skevington and colleagues believe that the answer lies in the size of the fly. "Smaller flower flies are less profitable as prey to predators, so there is less selection pressure on them to maintain a perfect bee-like appearance," explains Skevington. He and his colleagues arrived at this conclusion after conducting a comparative analysis of the evolution of bee mimicry in Syrphidae.

To read more about the study, see Penny et al. (2012), Nature 483: 461-464.

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits



BUILDING CAPACITY

CANPOLIN helped build pollinator identification capacity in Canada by offering two training courses for graduate students. Held at the Canadian National Collection in Ottawa, each two-week course offered training in both bee and fly identification and were instructed by taxonomy experts Jeff Skevington, Chris Thompson, Andrew Young, Michelle Locke, Cory Sheffield and Jason Gibbs. A total of 36 students participated in the training in 2010 and 2012 *(photos by J. Skevington)*

The parthenice tiger moth and the tiger swallowtail, two species included in the matrix key to families of Canadian Lepidoptera *(photos by J. Dombroskie)*

LOOKING FOR MORE INFORMATION?

[Canadian Journal of Arthropod Identification]

Additional keys and taxonomic revisions are available through the [CANPOLIN website].

See also the [Bees of Canada Image Bank.]

WHAT CAN **YOU** DO?

Two groundbreaking citizen science projects have made it possible to contribute to a continent wide effort to identify, track and conserve both bees and butterflies. All you need to participate is a camera and a computer.

Visit bumblebeewatch.org and ebutterfly.ca to learn more.

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

BEE HEALTH

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

NEW TREATMENT HELPS FIGHT BEE VIRUS

Feeding honey bees double stranded RNA can protect them against a destructive bee virus linked to colony losses

RNA interference or “silencing” is a revolutionary approach to treating disease in humans and animals. CANPOLIN researchers in working group 2 have now applied this innovative technique to an important bee pathogen, the Deformed Wing Virus (DWV), with promising results.

Honey bee infected with deformed wing virus
(photo courtesy of OMAFRA)

DWV is a common virus affecting bees in Canada. It is often associated with the parasitic mite *Varroa destructor*, which spreads the virus between bees. Bees infected with DWV are typically discoloured and have shrunken or crumpled wings, and die soon after they emerge as adults. Some bees may not show any physical symptoms, but they lack vigor and die prematurely. The virus has also been linked to severe winter mortality in bee colonies.

“With no single cause identified for ongoing colony losses around the world, it is important that we mitigate what stresses we can.” says Rob Currie, a WG2 bee health researcher at the University of Manitoba.

Knowing that RNA-interference has already shown some potential against other bee pathogens, Currie and graduate student Suresh Desai wondered if the technology could also be used to treat DWV.

To find out, Desai and Currie first extracted and replicated the virus, converting it to double-stranded (dsRNA) in the process. They then fed the dsRNA to honey bee larvae and adults in the lab before infecting the same bees with live DWV.

AFTER SEVERAL DAYS, ADULT BEES WHICH RECEIVED THE dsRNA TREATMENT HAD LOWER VIRAL LOADS THAN CONTROL BEES. TREATED BEES ALSO LIVED LONGER.

In dsRNA-fed larvae, the incidence of wing deformity after emerging as adults was similar to control larvae not infected with the virus. Although the dsRNA treatment did

FOREWORD

TAXONOMY
Know your Pollinators
The “Other” Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario’s “Green Arc”

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

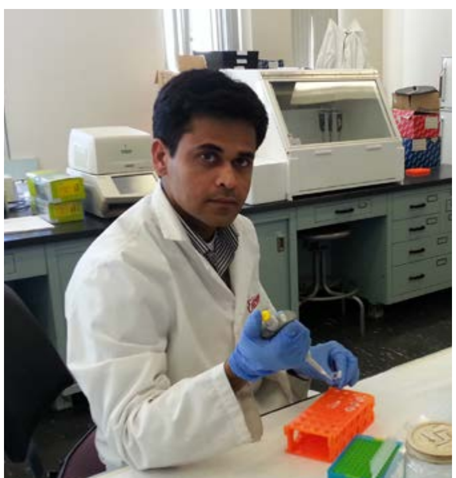
ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who’s Who in CANPOLIN
Partners
Credits

not increase the survival of larvae, Desai and Currie note that the improvements in viral load and adult longevity may offer a significant boost to overall colony health.

The researchers were also pleased to see that dsRNA was absorbed through the bee gut and transported to other tissues. This means that as a treatment, dsRNA could be easily applied to colonies through sugar syrup feeders, an effective and convenient way to reduce the stress on colonies associated with DWV.

With bees facing a multitude of serious threats to their health, the new treatment promises to be a valuable addition to the bee health toolkit.



Graduate student Suresh Desai at the University of Manitoba
(photo courtesy of S. Desai)

WHAT IS **RNA**?

DNA is familiar to most of us as "the stuff of life", carrying the genetic information for living organisms. But it has an important cousin, RNA, which also plays a vital role in biological systems. RNA transfers the genetic information from DNA to the rest of the cell, assembling the many proteins and enzymes that are the building blocks of life. There are many viruses, however, that have only RNA and no DNA. These are called RNA-viruses.

SILENCING A DISEASE

Some disease-causing RNA-viruses can be "silenced" through a technique called RNA interference. RNA from the virus is extracted and replicated, converted to double stranded RNA (dsRNA), and then introduced to the host. In its double-stranded form, the RNA blocks expression of the virus genes in the host cells, effectively silencing the virus and preventing disease in the host.

RNA interference is an exciting area of research, with potential applications in biotechnology research and human medicine.

LOOKING FOR MORE INFORMATION?

Desai, SD, Y-J Eu, S Whyard and RW Currie. 2012. Reduction in deformed wing virus infection in larval and adult honey bees (*Apis mellifera* L.) by double-stranded RNA ingestion. Insect Molecular Biology DOI: 10.1111/j.1365-2583.2012.01150.x

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

FUNGUS HELPS FIGHT DEADLY HONEY BEE PARASITE

A naturally-occuring fungus may provide dual protection from Varroa mites

The *Varroa* mite is a devastating bee parasite that can kill an entire honey bee colony if left untreated. Beekeepers typically treat their colonies with miticides to control *Varroa*, but resistance to miticides has become widespread, and some miticides can have negative impacts on the honey bee hosts. With *Varroa* identified by CANPOLIN reachers as a leading factor in the high winter mortality suffered by Canadian bee colonies in recent years (see Currie et al. 2010), the need for effective, bee-friendly treatments has never been more urgent.

WG2 researcher Ernesto Guzman at the University of Guelph believes that biological control, using natural mite pathogens, could be part of an effective treatment program against *Varroa*. There are several naturally-occurring fungal pathogens that attack the mite but are non-toxic to humans. They can also be mass-cultured, making them amenable to development as a treatment for bees.

The trick, of course, is finding a fungus that kills *Varroa* without harming the bees. Most insect pathogens attack a wide range of arthropod hosts and will not discriminate between mites and honey bees.

Working with research associate Mollah Md. Hamiduzzaman and graduate student Alice Sinia, Guzman looked at several fungal pathogens and identified one

The Mighty *Varroa* Mite

(photo courtesy of USDA)

It's no accident that the scientific name for this important honey bee pest is *Varroa destructor*. The tiny (~2 mm) mite packs a powerful punch, attaching itself directly to a bee and feeding on its haemolymph (blood). Several mites can feed on a single bee, weakening the bees and leaving open wounds that are susceptible to infection. The mites also transmit viruses and other serious bee disease. Once they infect a hive, mites can multiply rapidly and kill the entire colony.

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

Honey bee researcher Dr. Ernesto Guzman *(photo by Martin Schwalbe)*

strain of *Metarhizium anisopliae* that causes high mite mortality (over 90%) and relatively low bee mortality (24%). While the bee mortality is still higher than desired, Guzman and his team believe there may be other strains that are just as effective against mites but less harmful to honey bees.

A big part of the fungus' potential as a biocontrol agent lies in its two-pronged attack against Varroa. In addition to infecting the mites directly, the fungus appears to prevent the mites from suppressing the bees' own immune response.

EXPRESSION OF THREE IMPORTANT IMMUNITY GENES WAS 2-3 TIMES HIGHER IN BEES EXPOSED TO MITES INOCULATED WITH THE FUNGUS, COMPARED TO BEES EXPOSED TO REGULAR MITES.

According to Guzman, it may be possible to isloate the factors that trigger the enhanced bee immune response from the fungus. "These compounds could potentially be used to induce a natural defense against *Varroa* infections, avoiding some of the negative side effects associated with the live fungus.

LOOKING FOR MORE INFORMATION?

Currie, R, S Pernal, and E Guzman. 2010. Honey bee colony losses in Canada. Journal of Apicultural Research 49: 104-106

Hamiduzzaman, MM, A Sinia, E Guzman-Novoa and P Goodwin. 2012. Entomopathogenic fungi as potential biocontrol agents of ecto-parasitic mite, *Varroa destructor*, and their effect on the immune response of honey bees. Journal of Invertebrate Pathology 111: 237-243

A Varroa mite on a honey bee pupa *(photo by G. San Martin)*

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

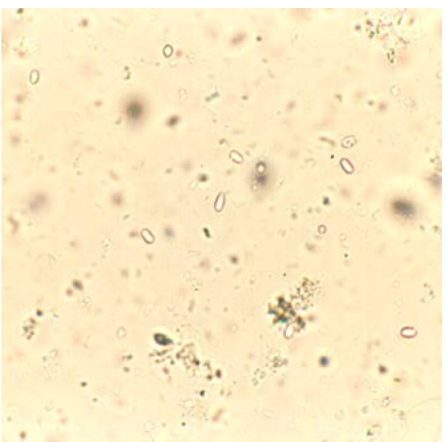
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

TAKING ON AN OLD FOE IN NEW FORM

Improving diagnostics and treatment options for a new species of Nosema in Canada

In Canada, the honey bee health crisis has meant devastating levels of winter mortality across the country. Poor survival of Canadian bee colonies has been linked to a number of interacting factors, including an array of pests and pathogens.

One high profile pathogen contributing to the global bee health epidemic is *Nosema.* The disease is a complex of two microsporidian parasites, *Nosema apis* and *Nosema ceranae.* Both parasites reproduce in the gut cells of honey bees, damaging them in the process, and produce infective spores that pass out in a bee's feces. Both species can shorten a bee's lifespan and reduce pollen foraging, colony reproduction and honey production; however, the two species can differ in their biology, symptoms, virulence, and potential for control.



Spores of *N. ceranae* and *N. apis* are indistinguishable *(photo by E. Guzman)*

The European honey bee is the traditional host of *Nosema apis,* while the host that *N. ceranae* was initially associated with was the Asian honey bee. But in 2005, natural infections of *N. ceranae* were discovered for the first time in the European honey bee in Spain. In only a few short years, the species has become widespread throughout Europe, Canada, the United States and other countries.

With the two species of *Nosema* now co-existing in Canada and elsewhere, it is imperative that beekeepers and bee researchers be able to distinguish between them. The challenge, however, is that the spores of the two species are virtually identical. "That means that the traditional method for *Nosema* diagnosis, a light microscope, is no longer adequate," explains WG2 researcher Ernesto Guzman from the University of Guelph.

Molecular diagnostic methods have been developed but they require multiple, time-consuming steps and/or expensive equipment that is not widely available. To rectify this problem, Guzman and research associate Mollah Md. Hamiduzzaman developed a new cutting-edge technique capable of detecting low levels of *N. ceranae* and *N. apis.* The DNA-based method can detect one or both *Nosema* species in a sample of just a single bee. It can also quantify the level of infection of *N. ceranae* even when the parasite is

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

present at very low levels – a critical factor given that just 32 spores are sufficient to cause an infection.

"THE NEW TECHNIQUE HAS MANY ADVANTAGES," SAYS HAMIDUZZAMAN. "IT IS BOTH MORE RELIABLE AND MORE SENSITIVE THAN PREVIOUSLY PUBLISHED METHODS."

As an added bonus, it is also faster and more economical, requiring only half of the "hands on" time to process a sample and costing one-tenth of the previous molecular methods.

But diagnosing *N. ceranae* is only half the battle, say CANPOLIN researchers. They also investigated best practices for preventing transmission between colonies, especially through contaminated apicultural equipment. WG2 member Stephen Pernal, a research scientist with Agriculture and Agri-Food Canada in Beaverlodge, AB, found that irradiation is the most effective method of disinfecting comb contaminated with *N. ceranae*

Spring hives used to test efficacy of fumagillin treatment *(photo by S. Pernal)*

spores. "Most chemical treatments for honey bee pests end up having a negative impact on the bees as well, and can end up in the honey stores. Irradiation offers an important non-chemical option for reducing or preventing transmission," says Pernal.

Hives with an active infection require treatment. The antibiotic fumagillin is the traditional treatment of choice for *N. apis*, but basic research on its efficacy against *N. ceranae* was lacking. Pernal and his team found that a spring application of a low rate of fumagillin can suppress an active infection of *N. ceranae* until autumn. An additional application at a higher rate in fall will continue to suppress the parasite over the winter, a period when honey bee hives are especially vulnerable to infection.

With the threat of pests developing resistance to known treatments always on the horizon, CANPOLIN researchers were also keen to investigate alternative therapies. Pernal tested several synthetic compounds for their effectiveness against *N. ceranae*, and while some show promise (including a synthetic analogue of fumagillin), traditional formulations of fumagillin remain the most effective antibiotic. Back at the University of Guelph, Guzman and graduate student Daniel Borges have examined several naturally-derived anti inflammatory products and found that some can reduce *Nosema* infection levels by over 50% and boost the natural immune response of the honey bee host.

Efforts by CANPOLIN researchers to improve diagnosis, treatment and prevention are an important step forward in the ongoing fight against this harmful parasite.

LOOKING FOR MORE INFORMATION?

Hamiduzzaman, MM, E Guzman-Novoa and PH Goodwin. 2010. A multiplex PCR assay to diagnose and quantify *Nosema* infections in honey bees (*Apis mellifera*). Journal of Invertebrate Pathology 105: 151-155

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

KNOW YOUR ENEMY: THE SMALL HIVE BEETLE

New exotic pest of bee hives isn't likely to survive cold Canadian climate

The movement of people and goods around the wold has always helped other species reach far flung parts of the globe. Many of these species reside in their new locales harmlessly, while others can become harmful invasives or destructive pests.

The European honey bee, itself a non-native species, has had more than its share of imported exotic pests. The most recent to appear is the small hive beetle (*Aethina tumida*), or SHB. Native to southern Africa, the SHB is a member of the sap beetle family. Given that sap beetles are typically attracted to sweet, sticky and fermenting substances such as rotting fruit, it is easy to see how an enterprising species such as A. *tumida* could invade bee hives and make a feast of the sugary honey stores.

SHB larvae in soil *(photo by M. Bernier)*

Adult small hive beetle *(photo by J. Moisan-Deserres)*

Adult beetles are active flyers and move frequently between colonies. The tiny beetles (4-7 mm in length) move quickly but stealthily through the hive as they feed and lay eggs in cracks and crevices. The larvae hatch and move into the comb, where they pollute the honey with their feces and damage the comb. When they are ready to pupate, the larvae leave the hive and burrow into the soil. Heavy infestation can cause bees to

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

abandon the hive altogether.

To add further insult to injury, the beetles also carry a species of yeast on their bodies that ferments honey, rendering the hive's stores useless for consumption by honey bees or humans.

The SHB adapts quickly to warm climates and has been established in the United States since the late 1990's. The beetle was first observed in Canada in 2002 in Manitoba, and has since been discovered in Alberta, Ontario and Quebec. However, it is not yet certain if the SHB can truly establish itself in our cold Canadian climate.

"If the small hive beetle were to spread, it could cause significant economic damage to an industry that is already under serious threat," says CANPOLIN researcher Valerie Fournier at Laval University.

Comb infested with SHB larvae
(photo by J. Ellis, Bugwood.org)

To assess how likely it is for the beetle to become established in Canada, Fournier and graduate student Martine Bernier worked with Laval colleague Pierre Giovenazzo to examine survival of pupae at different temperatures and soil moisture levels. "Pupation is the most vulnerable time in the life of the beetle, because in the soil they must contend with fluctuating temperatures and moisture as well as predators," explains Bernier.

THE TEAM FOUND THAT THE SURVIVAL OF PUPAE DROPPED MARKEDLY AT LOWER TEMPERATURES. AT A RELATIVELY BALMY 16°C (THE LOWEST TEMPERATURE TESTED), ONLY 23% OF THE PUPAE SURVIVED AT INTERMEDIATE MOISTURE LEVELS.

However, if the soil moisture was too wet or too dry, mortality was even higher. Based on their data, the researchers estimate that the small hive beetle requires a minimum temperature of 10-13°C to complete its pupal development.

Interestingly, soil moisture affected more than just survival of pupae. Moisture level also affected the sex ratio of newly emerged adults, with three times more females emerging from wet soils than males. The team also found that adults that pupated in wet soil lived only half as long as those that pupated in low to intermediate soil moisture.

The study provides important new knowledge about a potentially significant honey bee pest in a Canadian context, and suggests that the small hive beetle is not likely to become a serious pest in this country. "Based on our findings, we expect that Canadian honey bee colonies will benefit from at least some degree of climatic protection from this invasive pest," says Fournier.

LOOKING FOR MORE INFORMATION?

Bernier, M, V Fournier and P Giovenazzo. 2014. Pupal development of *Aethina tumida* (Coleoptera: Nitidulidae) in thermo-hygrometric soil conditions encountered in temperate climates. Journal of Economic Entomology 107: 531-537

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

BEES AND BIOMARKERS

Enzyme test can help determine if bees have been exposed to a toxic pesticide

How do you know if a bee has been sub-lethally poisoned by a pesticide, if the levels of pesticide in the bee are too low to be detected?

When it comes to the neonicitinoid family of insecticides, this is a question many bee health researchers would like to see answered. Neonicitinoids are the most commonly used type of insecticide around the world, and are toxic to honey bees at extremely low levels. They have been implicated in bee losses around the world, but there is no smoking gun that directly links colony losses to exposure to neonicitinoids.

Bees foraging on neonicotinoid-treated corn may be exposed to low levels of the pesticide *(photo by J. Conrad)*

WG2 researcher Madeleine Chagnon at the Université du Québec à Montréal says the answer may lie with what toxicologists call "biomarkers". Biomarkers are compounds that are affected by exposure to toxins and can be easily quantified. One such biomarker is the enzyme acetylcholinesterase, or AChE, which helps regulate the nervous system in animals. Insecticides that target the nervous system, such as organophosphates and carbamates, are known to cause a drop in AChE levels.

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

"Neonicitinoids also act on the nervous system, but they have a different mode of action," says Chagnon. "It is not known how these compounds affect AChE levels in honey bees, or if it could serve as an indicator of sub-lethal exposure."

Chagnon and her colleagues exposed bees in the lab to increasing but non-lethal doses of the neonicitinoid for ten days and then measured AChE levels. Unlike organophosphates, neonicitinoids caused the bees' AChE levels to increase.

The team also looked at levels of AChE levels in bees from hives placed in regular corn fields, organic corn fields and uncultivated fields. Bees were sampled weekly for four weeks. After two weeks of field exposure, bees in all three types of fields showed an increase in AChE levels – but the increase was highest in bees from hives placed in conventional corn fields.

"THIS IS THE FIRST TIME THAT AN INCREASE IN AChE HAS BEEN SHOWN IN HONEY BEES. IT SUGGESTS THE ENZYME ACHE MAY INDEED BE USEFUL FOR MONITORING EXPOSURE OF BEES TO NEONICITINOIDS," SAYS MONIQUE BOILY, THE TEAM'S ECOTOXICOLOGIST.

Boily cautions that further research is needed. "There are many factors that can affect the dose-effect relationship, such as the age of the bees, their genetic background, and other toxins they have been exposed to."

CANPOLIN researcher Madeleine Chagnon *(photo courtesy M. Chagnon)*

LOOKING FOR MORE INFORMATION?

Boily, M, B Sarrasin, C DeBlois, P Aras and M Chagnon. 2013. Acetylcholinesterase in honey bees (*Apis mellifera*) exposed to neonicotinoids, atrazine and glyphosate: laboratory and field experiments. Environmental Science and Pollution Research International 20: 5603-5614

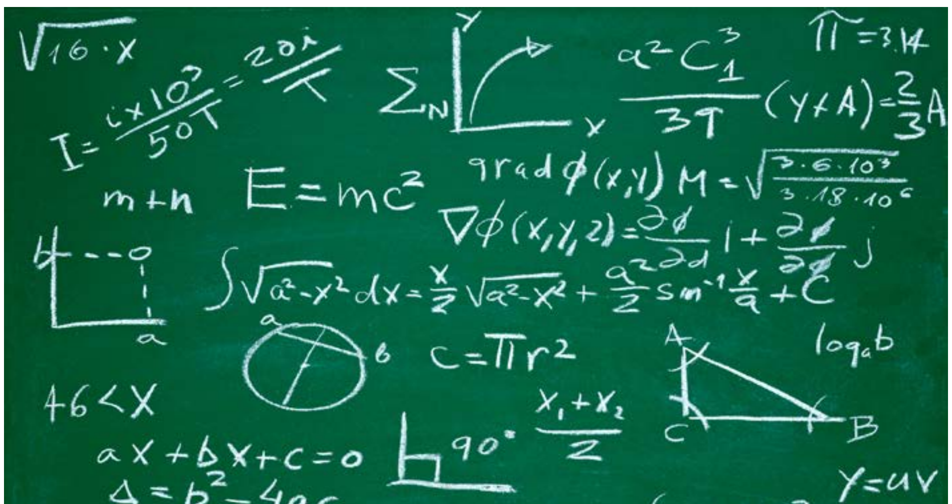
FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

BEES
AND MATH

Researchers develop novel approaches to help solve pollination problems

Scientific advances are almost always accompanied by new and improved mathematical models. These models act as simplifications of reality that allow researchers to elucidate complex problems, make predictions and ultimately solve real-world issues.

Mathematicians and statisticians have been an integral part of the CANPOLIN research network, applying their skills to examine a wide range of pollinator problems. For example, one of the greatest scourges of honey bees today are viruses. Many of these viruses are transmitted by the bloodsucking *Varroa* mite, itself a major contributor to poor colony health. Hermann Eberl, a mathematician at the University of Guelph, sought to develop a model that would examine the population dynamics of bees, viruses, and mites simultaneously to better understand their joint impacts on bee health.



Mathematic models can help solve real world pollination problems (stock image)

Eberl and graduate student Vardayani Ratti chose Acute Bee Paralysis Virus (ABPV) as the representative virus and modelled its population changes over time within the hive. The team used what is known as the susceptible-infected-removed (SIR) modelling framework, an approach used successfully in human epidemiology studies for the development of vaccinations and other disease control strategies. By manipulating factors such as colony size, birth and death rates for bees and mites, and the proportion of *Varroa* mites carrying the virus, Eberl and Ratti could see how the ABPV virus would progress under different conditions.

"ACCORDING TO OUR MODEL, IT IS POSSIBLE FOR BEES TO CO-EXIST WITH MITES IN HEALTHY,

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

New epidemiological models incorporate bee, mite and virus population dynamics in the hive *(photo by S. Humphrey)*

STRONG NUMBERS," SAYS EBERL. "BUT A VIRUS EPIDEMIC CAN TIP THE BALANCE. IT CAN HAPPEN OVER A PERIOD OF YEARS, WHERE THE VIRUS BUILDS UP SURREPTITIOUSLY AND THEN SUDDENLY THE COLONY COLLAPSES."

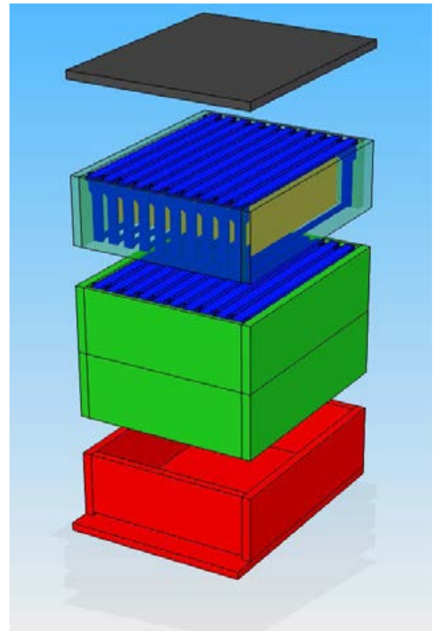
Future work on the model can examine the effects of other hive events, such as queen loss or swarming, and the impact of mite control on viral dynamics.

Eberl and his lab have also applied their mathematical prowess to improving hive design. The common "box" type of hive familiar to most, called the Langstroth hive, was designed in the 19th century for easy access by beekeepers, not necessarily to be the best structure for the bees themselves. In any type of hive, ventilation plays a critical role; it helps bees to keep warm in the winter and cool in summer, and to maintain the specific temperature required by the developing brood. It also helps ensure there is enough oxygen in the hive. In the wild, bees choose nesting cavities that will allow them to regulate their hive conditions as efficiently as possible.

Grad student Cody Thompson and post-doc Ranga Sudarsan worked with Eberl to examine the physical structure of the Langstroth hive to understand how ventilation, gas exchange and temperature regulation are related, and how hive design might be improved to make hive regulation more efficient. By reducing the amount of energy bees need to spend regulating the hive, the healthier bees will be to withstand other stresses.

To do this, the team took advantage of software normally employed by engineers for modelling ventilation in buildings and applied it to hives.

THE RESULTS SHOW THAT MODIFYING THE SHAPE OF BOTTOM BOARD AT THE BASE



A Langstroth hive with the bottom board shown in red. Above it are the brood chamber (green) and the honey supers (blue) (image by Koffr)

OF THE HIVE TO CREATE MORE AIRSPACE BENEATH THE BROOD CHAMBER CAN IMPROVE AIR EXCHANGE BETWEEN THE HIVE INTERIOR AND THE OUTSIDE ENVIRONMENT.

"Remarkably, but perhaps not so surprising given the ingenuity of nature, this is similar to the structure of wild hives in tree cavities, which have a large bowl-shaped structure below the entrance," explains Thompson. A novel bottom board for use with a traditional Langstroth

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

hive is currently in development, and promises to improve honey bee health by reducing energetic demands associated with heat and gas regulation.

Finally, novel mathematical approaches are also being applied by CANPOLIN researchers to better understand pollination networks, which are used to describe the interactions between all the plants and pollinators in a community (see pg. 79). Ayesha Ali, a statistician also at the University of Guelph, and her research team are applying innovative methods derived from econometrics (which studies how consumers make decisions) and artificial intelligence to improve the usefulness of pollination networks.

Statistician Ayesha Ali *(photo courtesy of University of Guelph)*

"Pollination networks usually assume that all individuals of a particular pollinator species will do the same thing," explains Ali. "But in reality, foraging behaviour depends on an individual's past experience, whether they are seeking out food for themselves or their offspring, and other factors."

BY USING NEW APPROACHES TO BETTER DEFINE THE "LINKAGE RULES" THAT HELP DETERMINE THE LIKELIHOOD A GIVEN POLLINATOR WILL INTERACT WITH A PARTICULAR PLANT, ALI SAYS THAT POLLINATION NETWORKS CAN BECOME EVEN MORE USEFUL AS A TOOL FOR POLLINATION ECOLOGISTS.

LOOKING FOR MORE INFORMATION?

Callaghan, L. 2012. An evaluation of latent Dirichlet allocation in the context of plant-pollinator networks. University of Guelph MSc Thesis, 174 pp.

Crea, C. 2011. On the robustness of Dirichlet-multinomial regression in the context of modeling pollination networks. University of Guelph MSc Thesis, 123 pp.

Ratti, V, PG Kevan and HJ Eberl. A mathematical model for population dynamics in honeybee colonies infested with *Varroa destructor* and the Acute Bee Paralysis Virus. Canadian Applied Mathematics Quarterly (in press)

Thompson, CG. 2011. A CFD study investigating the influence of bottom board geometry on physical processes within a standard honeybee hive. MSc Thesis, University of Guelph, 105 pp.

Sudarsan, R, C Thompson, PG Kevan and HJ Eberl. 2011. Flow currents and ventilation in Langstroth beehives due to brood thermoregulation efforts of honeybees. Journal of Theoretical Biology 295: 168-193

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

MANAGING POLLINATORS

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

BRAINY BUMBLE BEES

Bumble bees surprise researchers with their ability to learn from each other and solve problems

Bumble bees may have tiny brains, but they are capable of some remarkable learning feats, according to working group 2 researcher Peter Kevan and graduate student Hamida Mirwan at the University of Guelph. The pair made some fascinating discoveries while investigating the ability of bees to learn from each other through social learning.

"SOCIAL LEARNING IN ANIMALS USUALLY INVOLVES ONE INDIVIDUAL OBSERVING AND IMITATING ANOTHER, ALTHOUGH OTHER KINDS OF COMMUNICATION CAN ALSO BE INVOLVED," EXPLAINS MIRWAN.

To examine social learning in the bumble bee *Bombus impatiens*, Mirwan built artificial flowers from plastic tubes and discs.

Graduate student Hamida Mirwan sets up a bumble bee learning experiment *(photo by S. Humphrey)*

The flowers were constructed in such a way that the bees had to walk on the underside of the disc to reach a small hole in the tube where they could access a sugar syrup reward. A group of "experienced" bees then foraged on the artificial flowers for several days until they eventually became accustomed to feeding at them.

The next step was to see if other bees could learn from the experienced foragers. Mirwan confined a group of unexperienced or "naïve" bees in a mesh container near the artificial flowers. The arrangement allowed them to observe experienced bees as they foraged. The next day, the naïve bees were allowed to forage on artificial flowers. It took on average just over a minute, or about 70 seconds, for these bees to figure out how to access the syrup.

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

IN CONTRAST, BEES THAT HAD NOT OBSERVED OTHER BEES FORAGING ON THE FAKE FLOWERS SIMPLY COULD NOT FIGURE OUT HOW TO ACCESS THE SYRUP. IN FACT, MOST GAVE UP ALTOGETHER AFTER 30 MINUTES.

In a second experiment, Mirwan allowed naïve bees to observe dead bees with their heads placed in the access holes. Like the bees that watched live bee foraging, these bees were also able to figure out how to access the syrup. However, it took them a bit longer - about 15 minutes on average.

In a final test, Mirwan placed a group of experienced bees in a hive with their naïve sister bees. The latter were not given any opportunity to observe other bees (dead or alive) foraging on the artificial flowers, but they were allowed to interact with their experienced nestmates in the hive. When the naïve bees were allowed to forage on the artificial flowers, Mirwan and Kevan were surprised to see they were able to access the syrup in just 3½ minutes. "They took longer than bees that had observed other live bees in action, but they were much more adept at handling the flowers than bees that had just observed dead individuals," notes Mirwan.

Bumble bees feeding at artificial flowers used in social learning experiment at the University of Guelph *(photo by H. Mirwan)*

Behavioural science traditionally assumes that observation and imitation are at the heart of social learning, but social insects such as bees can also transmit information through touch, vibration and smell.

"WE CAN'T QUITE EXPLAIN HOW BEES THAT HAD NEVER EVEN SEEN AN ARTIFICIAL FLOWER WERE ABLE TO BECOME ADEPT SO QUICKLY AT FORAGING ON THEM, BUT CLEARLY SOME TYPE OF IN-HIVE COMMUNICATION TOOK PLACE," SAYS KEVAN. "IT SUGGESTS THAT SOCIAL LEARNING IN BUMBLE BEES IS EVEN MORE COMPLEX THAN WE FIRST EXPECTED."

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

PROBLEM-SOLVING BEES

In another set of experiments, Mirwan and Kevan tested the ability of bees to solve increasingly complex problems. Bees were faced with a series of ever-more challenging artificial flowers that required different strategies to access a sugar syrup reward. The simplest "flower" consisted of a tube with a cap that could be slid off easily. In more challenging flowers, the cap had to be moved to the left or right and/or straight upwards. In the most complex flower, the cap was cut in two halves and each half had to be moved separately.

When inexperienced bees were presented with the most complex flower first, they were unable to access the syrup reward and would stop trying. However, bees that were able to proceed through the series of increasingly complex flowers were able to successfully manipulate the most difficult flowers.

"Bees with experience are able to solve new problems," says Mirwan. "Whereas bees with no experience tend to just give up," says Mirwan. She and Kevan consider the study an example of scaffold learning, a concept normally restricted to human psychology where learners are taught through increasing steps of sophistication or complexity.

LOOKING FOR MORE INFORMATION?

Mirwan, HB and PG Kevan. 2013. Social learning in bumble bees (*Bombus impatiens*): worker bumble bees learn to manipulate and forage at artificial flowers by observation and communication within the colony. Psyche DOI:10.1155/2013/768108

Mirwan, HB and PG Kevan. 2014. Problem solving by worker bumble bees *Bombus impatiens* (Hymenoptera: Apoidea). Animal Cognition DOI: 10.1007/s10071-014-0737-0

FOREWORD

TAXONOMY
- Know your Pollinators
- The "Other" Pollinators

BEE HEALTH
- New Treatment Helps Fight Virus
- Fungus Combats Deadly Parasite
- An Old Foe in New Form: *Nosema*
- Know your Enemy: the Small Hive Beetle
- Bees and Biomarkers
- Bees and Math

MANAGING POLLINATORS
- Brainy Bumble Bees
- Super Bees and Biovectoring
- Bees in Space

PLANT REPRODUCTION
- Playing Darwin
- Evolution of Selfing in Plants
- High Cost of Self-Pollination

WIND POLLINATION
- Blowing in the Wind
- Pollination in Ontario's "Green Arc"

ECOLOGY
- From Dump to Diversity
- Thieving Bees
- Measuring Pollination Services
- Managing Forests for Pollination
- Native Bee Diversity on Farms
- Lowbush Blueberry Pollination
- Highbush Blueberry Pollination
- Nocturnal Pollination
- Pollinators at the Top of the World
- Alien Invasion
- Through the Eyes of a Pollinator
- Pollination Networks I
- Pollination Networks II

GLOBAL CHANGE
- Secrets of the Museum
- Pathogen Spillover & Bumble Bee Decline
- Keeping up with Climate Change

ECOMONICS
- Bee-conomics

APPENDICES
- List of Projects
- Who's Who in CANPOLIN
- Partners
- Credits

"SUPER BEES" PROTECT CROPS WHILE POLLINATING FLOWERS

New technology uses a bee's natural foraging behavior to distribute biological agents to control crop pests

Protecting crops from damaging pests without harming pollinators and other beneficial insects has long been a challenge for farmers. A new technology known as bee vectoring or "biovectoring" promises a safe, simple and cost-effective alternative to traditional pesticides.

Biovectoring takes advantage of a bee's natural foraging behavior as it moves from flower to flower collecting pollen and nectar. Before leaving the hive, the bee first picks up a powder containing beneficial microbes by passing through a special dispenser. These microbes may include fungi, bacteria or viruses that target plant pests such as insects, mites or disease-causing pathogens. The bees then disperse this protective "inoculum" throughout the crop as they forage.

A bumble bee picks up inoculum as it leaves a hive fitted with special dispenser *(photo by J. Sutton)*

CANPOLIN Scientific Director Peter Kevan first began exploring the use of bees as vectors for biocontrol over 20 years ago with John Sutton, a colleague and pathologist at the University of Guelph. Initial field tests showed the honey bees could suppress grey mould in strawberries by vectoring the naturally-occurring fungal endophyte *Clonostachys rosea*.

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

"The level of control was just as good as that provided by commercial fungicides," says Kevan. "We knew right away that we were on to something very promising."

Under the auspices of CANPOLIN, and with additional support from many partner organizations, Kevan and colleagues have made major advances in refining and expanding the technology. Bumble bee biovectoring has now been shown to reduce pests in greenhouse crops such as tomatoes, peppers and eggplant, and in outdoor crops such as lowbush blueberries, strawberries and sunflowers. Targeted pests include tarnished plant bugs, western flower thrips, whiteflies, aphids, cabbage loopers, mummy berry, the banded sunflower moth, *Sclerotinia* head rot, grey mold, whiskery rot and *Rhizopus*.

The results have been very promising. For example, the fungus *Botrytis*, which causes disease in many crops, can be controlled up to 50-80% in blueberry, 90% in strawberry, and almost 100% in greenhouse tomato

Testing the effectiveness of biovectoring for control of banded sunflower moth and *Sclerotinia* head rot in Ontario *(photo by J. Sutton)*

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

using bee-vectored biocontrol agents. Kevan and colleagues also found that biovectoring can provide an unexpected benefit: it also extends the shelf life of soft fruits.

The research team has also worked hard to improve the design of the dispensers used in the hive to maximize uptake by bees, and to adjust the formulation of the inoculum so that caking is minimized.

"It is important to ensure that the biocontrol agents, especially those that target other insects, don't harm either the bees or other beneficial insects," adds Les Shipp, an entomologicst with Agriculture and Agri-Food Canada and member of working group 2. Working with Kevan and other colleagues, Shipp recently published a study showing that bee-vectored *Beauveria bassiana*, an entomopathogenic fungus, was compatible with most other biocontrol agents typically used in greenhouses.

THE TECHNOLOGY WAS RECENTLY COMMERCIALIZED WITH THE LAUNCH OF A NEW COMPANY, BEE VECTORING TECHNOLOGY (BVT) INC., AND SHOULD SOON BE AVAILABLE TO GROWERS.

While results similar to those obtained by use of chemical pesticides can be achieved, bee-vectored biocontrol agents do require a longer period to take effect and thus must be implemented fairly early in the season. Still, it is compatible with both conventional and organic production, and can combine two highly valuable services to growers: pollination and crop protection.

"Biovectoring has enormous potential," says Kevan. "Ongoing research will see this exciting technology expand to large-scale crop production and to encompass an even wider array of crops and pests."

LOOKING FOR MORE INFORMATION?

Shipp, L, Kapongo, JP, Park, H-H and PG Kevan. 2012. Effect of bee vectored *Beauveria bassiana* on greenhouse beneficials under greenhouse cage conditions. Biological Control 63: 1130-1133

Reeh, K.W. and C.G. Cutler. 2013. Laboratory efficacy and fungicide compatibility of *Clonostachys rosea* against *Botrytis* blight on lowbush blueberry. Canadian Journal of Plant Science 93: 639 642

Using pollinators for crop protection. 2014. International Innovations, Issue 125 (January)

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

BEES IN SPACE

Bumble bees prove themselves as potential pollinators in space stations of the future

Scientists have spent years studying how to grow plants in controlled environments, anticipating the day when humans will need to grow their own food on long term space missions. Such "space greenhouses" will almost certainly operate at reduced air pressure – not only because it will reduce gas leakage and structural weight, but because it will also be cheaper to operate.

Previous research has identified several plants that will grow under low atmospheric pressures, but many candidate species - including as tomatoes, squash, pumpkins, melon and sunflower - require insect pollinators to produce a crop.

Bumble bees are already well established as greenhouse pollinators, explains CANPOLIN

Plants grown in enclosed spaces can be especially dependent on insect pollinators because there is no wind to transfer pollen *(stock photo)*

Long-term space missions of the future will require self-sustaining food production systems *(photo courtesy of NASA)*

graduate student Erika Nardone. "Unlike honey bees, they are happy to forage in enclosed spaces where there is no wind. The problem is that we don't know if if they will fly and forage in a low pressure environment that you will find in space."

To explore if bumble bees would provide adequate pollination services in an extraterrestrial setting, Nardone worked with with colleagues at the Controlled

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

Environment Systems Research Facility at the University of Guelph. The team placed a hive of bumble bees, *Bombus impatiens*, in a hypobaric chamber and exposed them to atmospheric pressures ranging from 30 kPa to ambient (about 97 kPa). Bees were videotaped as they foraged on artificial flowers filled with a sugar solution. The amount of time bees spent foraging, flying, walking or remaining stationary at each pressure was recorded.

At 50 kPa or higher, bees spent around 35% of their time foraging, and less than 15% not moving – similar to their activity at ambient pressure. In contrast, below 50 kPa, bees spent less than 10% of their foraging. Bees also had far less control in their flight take-offs and landings at the lower air pressures. The team also looked at what happened when the amount of oxygen was increased. A boost in the partial pressure of oxygen led to

CANPOLIN graduate student Erika Nardone photographing Earth-based bees *(photo courtesy of E. Nardone)*

a dramatic increase in foraging at the 40kPa treatment - to a level similar to what was observed in the ambient air treatment.

At 30kPa, however, flight stopped nearly altogether - even if extra oxygen was added.

"At this low pressure, it appears there are simply not enough air molecules for the bees to push against to sustain flight," notes CANPOLIN researcher and Scientific Director Peter Kevan, who also participated in the study.

A REMARKABLE RESULT OF THE EXPERIMENT, SAYS NARDONE, WAS THAT BUMBLE BEES CONTINUED TO FORAGE AT REDUCED ATMOSPHERIC PRESSURES EVEN WHEN THEY COULDN'T FLY.

"If they couldn't fly, they walked – movement to and from the hive was maintained. Only when oxygen became limiting was their foraging activity significantly reduced. This shows an amazing level of determination to get the job done."

With NASA recommending a pressure of 52 kPa for extraterrestrial facilities, the study shows that bumble bees could soon help man boldly go where no man - or bee - has gone before.

LOOKING FOR MORE INFORMATION?

Nardone, E, PG Kevan, M Stasiak and M Dixon. 2012. Atmospheric pressure requirements of bumble bees *(Bombus impatiens)* as pollinators of Lunar or Martian greenhouse grown food. Gravitational and Space Biology 26: 13-21

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

PLANT REPRODUCTION

FOREWORD

TAXONOMY
- Know your Pollinators
- The "Other" Pollinators

BEE HEALTH
- New Treatment Helps Fight Virus
- Fungus Combats Deadly Parasite
- An Old Foe in New Form: *Nosema*
- Know your Enemy: the Small Hive Beetle
- Bees and Biomarkers
- Bees and Math

MANAGING POLLINATORS
- Brainy Bumble Bees
- Super Bees and Biovectoring
- Bees in Space

PLANT REPRODUCTION
- Playing Darwin
- Evolution of Selfing in Plants
- High Cost of Self-Pollination

WIND POLLINATION
- Blowing in the Wind
- Pollination in Ontario's "Green Arc"

ECOLOGY
- From Dump to Diversity
- Thieving Bees
- Measuring Pollination Services
- Managing Forests for Pollination
- Native Bee Diversity on Farms
- Lowbush Blueberry Pollination
- Highbush Blueberry Pollination
- Nocturnal Pollination
- Pollinators at the Top of the World
- Alien Invasion
- Through the Eyes of a Pollinator
- Pollination Networks I
- Pollination Networks II

GLOBAL CHANGE
- Secrets of the Museum
- Pathogen Spillover & Bumble Bee Decline
- Keeping up with Climate Change

ECOMONICS
- Bee-conomics

APPENDICES
- List of Projects
- Who's Who in CANPOLIN
- Partners
- Credits

PLAYING DARWIN

Exploring the evolutionary consequences of pollination between different species

In the wild, two different plant species may sometimes cross-pollinate to produce hybrid offspring. If the hybrid then backcrosses with one of the parent species, it allows genetic material from one species to enter the genome of another. This process, called introgression, often leads to offspring that is less robust and less likely to survive. But what if the hybrid offspring is able to succeed and adapt to new environmental conditions better than either of the parents? According to evolutionary biologists, this could be an important way in which wild plant populations adapt to new or changing habitats, or even evolve into new, distinct species altogether.

Loren Rieseberg, a working group 3 researcher at the University of British Columbia, is interested in how introgression might lead to so-called rapid adaptive evolution. "Introgression could provide a means for plants to adapt and evolve far more quickly than populations that depend only on random genetic mutations to develop new traits," he explains.

Rieseberg was especially interested in the case of sunflower plants in the genus *Helianthus*, which includes *H. annuus*, the wild parent of the modern cultivated sunflower. In Texas, *H. annuus* has hybridized with a local wild species, *H. debilis*. The resulting offspring (known as *H. annuus texanus*) has become a troublesome weed in Texas. It flourishes in habitats where *H.*

Researcher Loren Rieseberg with a cultivated *H. annuus* plant *(photo by B. Moyers)*

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

annuus typically can't survive, and produces more seeds than its parent species in the arid environment of central and southern Texas.

Working with Ken Whitney at the University of New Mexico, Rieseberg used sophisticated molecular techniques to determine if *H. annuus texanus* illustrates the potential of introgression as a route to rapid adaptive evolution. The researchers "recreated" contact between the two parent species at two controlled outdoor study sites, and monitored changes in the physical characteristics (phenotypes) and gene frequencies of the resulting offspring for over eight generations. This allowed them to determine if the environmental conditions in Texas would result in the same characteristics in the offspring under experimental conditions as it did in the wild.

"WE DID INDEED FIND THAT THE EXPERIMENTALLY PRODUCED HYBRID OFFSPRING DISPLAYED MANY CHARACTERISTICS SIMILAR TO WILD *H. A. TEXANUS*," SAYS RIESEBERG. "THIS SHIFT OF THE EXPERIMENTAL HYBRID TOWARDS THE PHYSICAL PHENOTYPE OF ITS NATURAL HYBRID COUNTERPART INDICATES THAT NATURAL SELECTION IN THE CHALLENGING TEXAS ENVIRONMENT FAVOURS THE EVOLUTION OF THIS PARTICULAR PHENOTYPE."

Native to Texas, *Helianthus debilis* is sometimes known as the beach sunflower *(photo by the US Geological Survey)*

The implications for sunflower adaptability to a changing environment do not end there. *Helianthus debilis* has evolved to contend with Texas heat and drought, but it is restricted to sandy soils, which are uncommon throughout its range. However, introgression of its genes may have allowed more widespread colonization by *H. annuus*. The latter grows well in the more common clay soils, but does not do well in the arid Texas climate. By capturing advantageous genetic material from the native *H. debilis*, *H. annuus* has evolved a new subspecies – and in doing so, it has expanded its range southward. Other adaptive traits transferred to *H. annuus* include resistance to two types of herbivore (seed-feeding midges and flower-feeding caterpillars), faster seed maturation, greater leaf area, and more flowers.

Of course, pollination plays a central role in this process, as insects are required to carry pollen between the species. The number of pollinator visits to a plant are closely correlated with the number of flowers. Plants in the experimental plots were monitored to see if there were differences in pollinator visits between parent and hybrid sunflowers. Pollinators (primarily Apidae, Halictidae, and Megachilidae) made significantly longer visits to hybrid plants. As expected, they tended to visit them more frequently as well. "Based on these findings, we can conclude

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

that first-generation hybrids do not suffer a reduction in reproductive fitness," notes Rieseberg.

With sunflowers now established as a highly effective model system for research on adaptation and speciation genomics, Rieseberg predicts that *Helianthus* will continue to generate valuable insights into the origin and evolution of weeds, crops, and species.

"The system is a window into the possible biological and genetic impacts of hybridization, which could be of particular interest in an era of rapid global change."

The wild sunflower hybrid *Helianthus annuus texanus* has become a troublesome weed *(photo by L. Rieseberg)*

LOOKING FOR MORE INFORMATION?

Scascitelli, M, KD Whitney, RA Randell, M King, CA Buerkle and LH Rieseberg. 2010. Genome scan of hybridizing sunflowers from Texas (*Helianthus annuus* and *H. debilis*) reveals asymmetric patterns of introgression and small islands of genomic differentiation. Molecular Ecology 19: 521-541

Whitney, KD, RA Randell and LH Rieseberg. 2010. Adaptive introgression of abiotic tolerance traits in the weedy sunflower *Helianthus annuus*. New Phytologist 187: 230–239

Renaut S., CJ Grassa, BT Moyers, NC Kane and LH Rieseberg. 2012. The population genomics of sunflowers and genomic determinants of protein evolution revealed by RNAseq. Biology 1: 575-596

Renaut, S, CJ Grassa, S Yeaman, BT Moyers, Z Lai, NC Kane, JE Bowers, JM Burke, and LH Rieseberg. 2013. Genomic islands of divergence are not affected by geography of speciation in sunflowers. Nature Communications 4, 1827

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

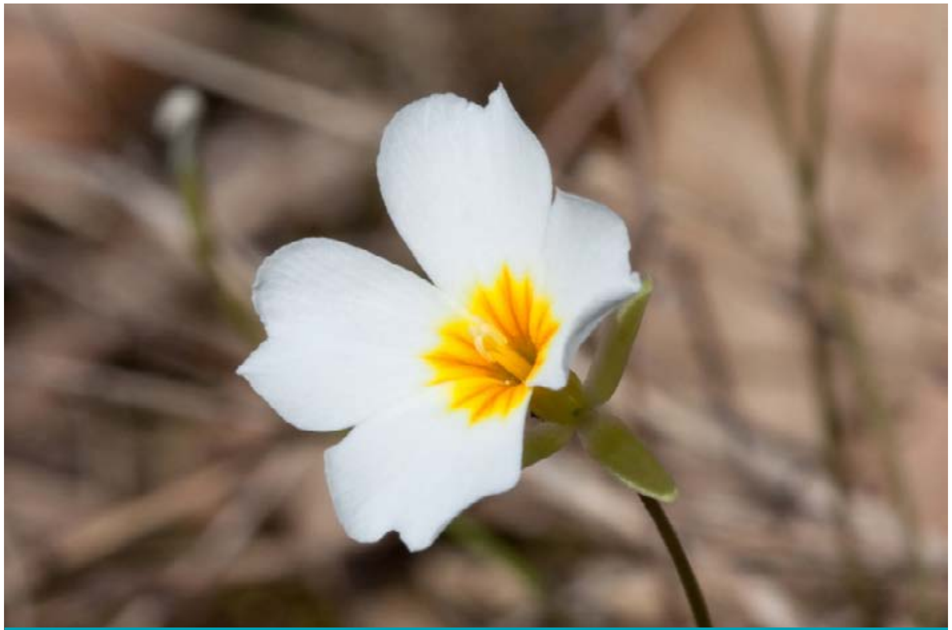
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

EVOLUTION OF SELFING IN PLANTS

What might happen to plants if pollinators are no longer present to provide pollination services?

The ability to recognize "self" is a fundamental ability of living things. Most people encounter the concept of self when their immune system battles infection or a body rejects a new organ. This incredibly complex biochemical system is built on a set of molecules (known as the Major Histocompatibility Complex) found on the surface of cells that allows the body to recognize other molecules as self or non-self. The latter can then be attacked and purged by the immune system.

In pollination, the recognition of self is based on a similar mechanism, but with the opposite goal: to *avoid* self. This helps prevent self-pollination and inbreeding, which leads to less fit offspring. While plants seem to be better than animals at coping with the challenges of inbreeding, most plants have evolved and maintained traits that prevent self-fertilization. Some produce male and female flowers on separate plants, or at different times. Others have genes that block fertilization by their own pollen, a system referred to as "self-incompatibility". This favours outcrossing, but it comes with a risk, because self-incompatible plants are vulnerable to reproductive failure if compatible mates are not available. Interestingly, approximately half of all plant species hedge their bets by allowing some self-pollination - perhaps as a reproductive "fail-safe" in the event that outcrossing does not occur.



The *Leavenworthia* genus offers many insights into the evolution of self-incompatibility in plants *(photo by Kildari, Wikicommons)*

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

One potential outcome from the global decline in pollinators is an increase in self-pollination and inbreeding in plant populations because pollinators are not available to transfer pollen. Because of this threat, one of the goals of working group 3 (Plant Pollination) was to gain a better understanding of the ecological and evolutionary mechanisms that can lead to a loss of self-incompatibility. "Self-incompatibility has actually been lost many times throughout the history of flowering plants," explains Dan Schoen, a plant geneticist at McGill University and leader of WG3. "It's an important first step in the evolution of selfing."

Schoen and his research team investigated the shift to self-compatibility in the genus *Leavenworthia*, a member of the mustard family. *Leavenworthia* are annual plants, confined to the southeastern United States in cedar glades underlain by limestone. The genus contains species that are either self-compatible or incompatible, and therefore serves as a useful model system for studies of the evolution of plant mating systems.

In most self-incompatible plants, recognition of self is controlled by a pair of tightly linked genes known as the "S-locus". According to Schoen, this common ancestral S-locus was lost in the *Leavenworthia* branch of the mustard family tree long ago.

He and his team found that modern *Leavenworthia* plants that exhibit self-incompatibility are the result of a novel set of genes that arose from precursors in a different location in the *Leavenworthia* genome.

"Self-incompatibility in *Leavenworthia* is especially effective at preventing self-pollination, and this new gene is an exciting discovery that could have practical applications for pollination control associated with the production of hybrid crops and cultivars," says Schoen (see box).

The team's detailed genetic analysis of *Leavenworthia* plants also led to some important ecological conclusions about how self-compatibility evolved in this

NEW GENE COULD LEAD TO NEW CROP

The novel gene complex for self-incompatibility discovered by Schoen and colleagues could be useful to the development of new crops and cultivars in the mustard family. In particular, discovery of the gene has opened up a new line of research focused on *Camelina sativa*, or false flax, a plant of growing interest to the lubricant and biofuel industry. By transforming false flax plants with the novel gene from *Leavenworthia* (easily done since both belong to the same family), breeders could acquire the ability to produce the self-sterile parent lines, essential for hybrid seed production. The work has led to U.S. and Canadian provisional patent applications.

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

genus. To start, Schoen and his team found that self-compatibility in *Leavenworthia* seems to have evolved independently at least five times, and that selection for selfing is unidirectional – in other words, it does not reverse itself. A severe population bottleneck is believed to be responsible for the breakdown of self-incompatibility in at least some populations of *Leavenworthia* that are able to self-pollinate. "Population bottlenecks occur when there is a drastic reduction in population size that also reduces the amount of genetic variability," explains Schoen. "For a plant that requires cross-pollination with an unrelated individual, this can lead to selection for the breakdown of self-incompatibility." The team also found that the "path of least resistance" towards self-fertility appears to be by independent mutations in the S-locus gene that codes for a pollen-recognition protein.

Disturbingly, the results from the study are consistent with a growing body of evidence that suggests the shift from an outcrossing to a selfing reproductive system leads to plant lineages that become evolutionary dead-ends, perhaps because of limited genetic diversity and hence, adaptability.

"ADOPTION OF SELFING APPEARS TO INCREASE THE LIKELIHOOD THAT A POPULATION WILL GO EXTINCT," SAYS SCHOEN.

"This could have serious consequences for plant populations. It could also, in turn, threaten some pollinator species, as secondary changes to the flower associated with the evolution of self-pollination include reduction in pollen and/or nectar, major food sources for some pollinators."

LOOKING FOR MORE INFORMATION?

Busch, JW, S Joly and DJ Schoen. 2011. Demographic signatures accompanying the evolution of selfing in *Leavenworthia alabamica*. Molecular Biology and Evolution 28: 1717–1729.

Joly, S and DJ Schoen. 2011. Migration rates, frequency-dependent selection and the self-incompatibility locus in *Leavenworthia* (Brassicaceae). Evolution 65: 2357–2369.

Herman, AC, Busch, JW and DJ Schoen. 2012. Phylogeny of *Leavenworthia* S-alleles suggests unidirectional mating system evolution and enhanced positive selection following an ancient population bottleneck. Evolution 66: 1849-1861.

Chantha S-C, AC Herman, AE Platts, X Vekemans and DJ 2013. Secondary evolution of a self-incompatibility locus in the Brassicaceae genus *Leavenworthia*. PLoS Biology 11: e1001560, doi:10.1371/journal.pbio.1001560

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

THE HIGH COST OF SELF-POLLINATION

Natural mutations in long-lived blueberry plants can lead to poor fruit set when flowers self-pollinate

Genetic mutations occur naturally in plant cells as they divide and grow into branches, stems, and leaves. Biologists call these "somatic" mutations, because they do not occur in the reproductive tissues of the plant. But vegetative growth eventually leads to the production of flowers, and the pollen and eggs produced by flowers may carry these somatic mutations. Biologists have long wondered about the role of somatic mutations in plant evolution. Until CANPOLIN, though, there were no empirical studies to measure the actual rate of somatic mutation in a plant, or its average effect on the fitness of its offspring.

WG3 researcher Dan Schoen at McGill University and graduate student Kyle Bobiwash changed all this with a groundbreaking study on lowbush blueberry.

McGill researcher Dan Schoen (left) and graduate student Kyle Bobiwash
(photos courtesy of D. Schoen)

Poor fruit set in blueberry
(photo by D. Schoen)

"A large, long-lived perennial plant like lowbush blueberry is likely to have more somatic mutations than an annual plant," explains Bobiwash, "But we don't know how frequently these mutations occur, or how they affect the size and number of fruit produced."

To find out, Bobiwash and Schoen conducted two types of controlled crosses on blueberry plants in a commercial field in Neguac, NB. In the first cross, flowers on one branch

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

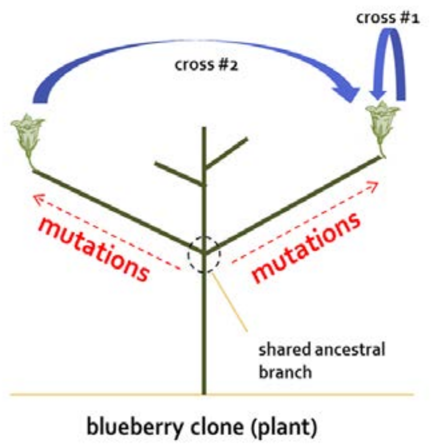
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits



Schematic of the two types of pollination crosses made by Schoen and Bobiwash

were self-pollinated (see diagram). In the second cross, flowers of one branch were pollinated with pollen from a different branch on the same plant. Because both branches shared a common ancestral growth point, the difference in fruit set between the two crosses provided an estimate of the rate of somatic mutation occurring in these branches.

"Fruit set should be the same in both cases if there is no significant mutation occurring along the branches," says Schoen. "But if there is (recessive or partially recessive) mutation occurring, it will be expressed in the self-pollinated fruit of the same branch because the seed can have two copies of the same deleterious somatic mutation, whereas seed from self-pollinated fruit on different branches cannot."

THE TEAM FOUND SIGNIFICANT INBREEDING DEPRESSION IN THE SELF-POLLINATED FLOWERS. MOREOVER, FRUIT SET RESULTING FROM WITHIN-BRANCH SELF-POLLINATION WAS SIGNIFICANTLY LOWER COMPARED TO BETWEEN-BRANCH CROSSES.

The team used a mathematical model to estimate that each branch contained an average of three deleterious somatic mutations - a "very high" mutation rate, says Bobiwash. "With that many mutations, a flower that undergoes within-branch self-pollination is expected to produce weak seeds and have low fruit set."

The findings have important implications for the role of insect pollinators in blueberry production. "We already know that insect pollinators are important for physically transporting pollen between flowers to make sure fertilization takes place, " says Schoen. " But they may be just as important as agents of 'pollen mixing' on a larger spatial scale. "

The study has been hailed not only as a step forward in the study of plant evolutionary genetics, but also as a important contribution to the management of a major agricultural crop.

LOOKING FOR MORE INFORMATION?

Bobiwash, K, ST Schultz and DJ Schoen. 2013. Somatic deleterious mutation rate in a woody plant: estimation from phenotypic data. Heredity 111: 338–344

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

WIND POLLINATION

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

BLOWING IN THE WIND

Researchers invent a new technique to tackle an old problem measuring pollen dispersal by wind

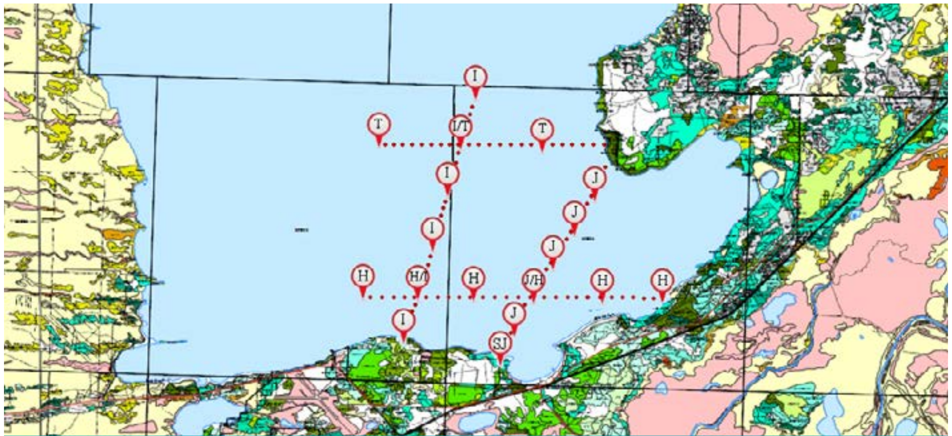
An understanding of pollination in Canadian ecosystems would be incomplete without some consideration of wind pollination. Many ecologically and economically important plants are pollinated by wind, including wheat, corn, barley and almost all other grasses, all conifer trees, and many hardwoods. Scientists have only a limited understanding of how pollen is released and carried on the wind – and yet this type of information is critical to answer questions around pollen forecasting for allergy sufferers, pollen contamination between GMO and non-GMO agricultural fields, and how quickly wind pollinated plants can migrate in an era of rapid climate change and habitat fragmentation. Illuminating the complex mechanics of wind pollination has been the purview of CANPOLIN's working group 4.

A question of particular interest to WG4 researchers is how far pollen can travel, and how pollen concentration changes with distance from the source plant. According to David Greene, leader of WG4 and professor at Concordia University, "There are pollen dispersal models available, but they tend to make very different predictions." Greene says that the problem lies in the lack of actual data to test which models are most accurate. "It is almost impossible to measure long distance pollen dispersal in the field, because there are usually multiple sources of pollen confounding the results."

To tackle the seemingly impossible, Greene and graduate student Gail MacInnis decided to try a novel approach: use floating pollen-capture devices to measure pollen dispersal distance across a large

Rotorod® pollen collecting device floating on Lake Clearwater *(photo by G. MacInnis)*

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits



Position of Rotorod® transects on Clearwater Lake *(figure by G. MacInnis)*

lake. As long as the lake had no islands, the team could be sure that any pollen collected on the lake came from known plant sources along the lake edge.

After much searching, they found a suitable site in north western Manitoba – Clearwater Lake. Approximately 16 km long by 16 km wide, the lake offered the perfect study location. MacInnis built 18 small rafts to carry automated pollen collecting machines called Rotorods® and distributed them throughout the lake at 1 – 2 km intervals across 4 transects. The arrangement allowed data to be collected for up to 10 km from the shoreline.

"The arrangement of the rotorods meant that we had transect lines running in different directions," explains Macinnis. "As long as the wind was blowing along one of the transect lines, we could collect data from that line."

MSc student Gail MacInnis assembles custom-made Rotorod® rafts for her experiment on Clearwater Lake *(photo courtesy of G. MacInnins)*

The team watched closely for the start and finish of pollen release from vegetation at the edge of the lake. Over a period of about a month, they were able to measure pollen dispersal distances for three species of conifer (black spruce, jack pine and balsam fir), and one deciduous shrub (speckled alder).

Although working on a lake offered up its own challenges (a number of Rotorods® were dislodged from their raft and sank during one particularly violent storm), Greene says that overall the experiment was a great success. "We now have the best long-distance set available for pollen dispersal."

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

ALL FOUR PLANT SPECIES SHOWED A SHARP DECLINE IN POLLEN CONCENTRATION OUT TO A DISTANCE OF ABOUT 2 KM, BUT BLACK SPRUCE AND JACK PINE POLLEN CONTINUED TO TRAVEL AT LEAST 10 KM. IT IS DATA THAT CAN BE OF IMMEDIATE USE TO PLANNING MINIMUM SEPARATION DISTANCES FOR GENETIC CONTAMINATION IN SEED ORCHARDS OR GMO FIELDS, SAY THE RESEARCHERS.

Perhaps even more importantly, though, the data shows that most of the existing models for pollen dispersal are poor predictors of what happens when pollen is shed in nature.

"This is a big concern," says Greene. "With a rapidly changing climate, we need to be able to predict how far and how fast at-risk plant species will migrate. And for that we need reliable models of long distance pollen dispersal.

As the scientific community works to develop these new models, the one-of-a-kind data set from Clearwater Lake will undoubtedly play a valuable role in testing them. Furthermore, because any model of pollen movement by wind applies to any sort of particle (not just pollen grains), the data set can also help validate models of spore or seed dispersal.

With wind pollinated plants in Canada facing their own environmental challenges in the 21st century, the Clearwater Lake study serves as an important first step in gaining some of the knowledge necessary to address these challenges.

LOOKING FOR MORE INFORMATION?

MacInnis, G. 2012. Measuring and modelling the dispersal of pollen and spores by wind. Concordia University MSc Thesis, 109 pp.

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

POLLINATION IN ONTARIO'S "GREEN ARC"

Massive field study yields valuable information about important changes to Ontario's flora

Plant ecologists have long noted the increase in the prevalence of wind pollinated plants with increasing latitude. The prevailing theory is that animal pollinators become more effective vectors of pollen for plant populations that exist at low densities - typical in tropical and sub-tropical areas with high biodiversity. In contrast, plant populations in temperate and boreal tend to be less diverse, and species exist in higher densities - making wind a good bet for transferring pollen between plants.

"There are many fundamental questions around the evolution of different pollination mechanisms in plants," explains Steve Murphy, a working group 4 researcher at the University of Waterloo. "One reason my lab is particularly interested in this question is because we suspect that climate change may help select plants that favour insect pollination over wind pollination, or a combination of the two."

Sampling transects across Southern Ontario used to assess wind pollination by Murphy lab members

Working with a team of several graduate students over the five year span of CANPOLIN, Murphy conducted a massive field study spanning what he has dubbed "the Green Arc" of Ontario. It includes the Greenbelt, mixed boreal, escarpment and Carolinian zones.

The team sampled at over 400 locations in meadows, shorelines and open woodlands, following transects approximately 50km apart. At each location, the team collected stigmas from several species known or believed to be wind pollinated. In the lab, the stigmas were examined under a microscope to determine how much pollen had been deposited, and whether it was from the right species. Seedheads were also collected from plants to determine overall reproductive success. In total, tens of thousands of samples have been collected from over 55 species of grasses, sedges, rushes, and forbs. In addition, the team made hundreds of hours of insect pollinator observations while in the field.

Sample processing and data analysis will be on-going for some time, but Murphy says that the study is already yielding some important insights.

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

"We have noted that in at least some species of maple, there appears to be a gradient of increasing ambophily (where plants are pollinated by a combination of wind and insects) from north to south in Ontario, matching the climate shifts that have been observed," says Murphy.

Thanks to the massive data set accumulated by his research group, Murphy will also now be able to compare pollen production in some of the same plant species from which he collected data over 20 years ago. It is a valuable opportunity to assess the impact of rapid environmental change on Ontario flora. So far, it appears that open pollinated crop species, and species that are the target of restoration activities, are doing well. But other at-risk species are in trouble, with pollen production down a mean of 40% from the early 1990s. It is not clear what exactly is driving the reduced pollen production, but it appears that climate change is playing a role, as well as soil alternations associated with changes in agricultural practices and land use.

Murphy's study further reveals that while many wind pollinated plants in southern Ontario are in decline, it is mainly a question of habitat. "Most wind pollinated plants exist in meadow habitats, a type of ecosystem that is under more threat than even the prairies," he notes.

"IT MEANS THAT THERE IS NO EASY FIX. CONSERVING AND RESTORING THESE SPECIES WILL REQUIRE BROAD-SCALE LAND MANAGEMENT AND POLICY CHANGES."

Meadow habitat is in decline in Ontario, which means many wind pollinated plants are also threatened *(photo by S. Leckie)*

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

ECOLOGY

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

FROM DUMP TO DIVERSITY

A study of bee succession in a unique ecological region in Canada

CANPOLIN researcher Miriam Richards *(photo courtesy of M. Richards)*

CANPOLIN researcher Miriam Richards' study of bee diversity in restored fragments of Carolinian landscapes is well known to residents of the Niagara region. That's because Richards' primary field site is the Glenridge Quarry Naturalization Site (GQNS), a groundbreaking rehabilitation project which has seen a former landfill transformed to a multipurpose urban nature reserve. After the landfill was closed and capped in 2001, the site was opened to the public in 2004 and now supports recreational activities, environmental education and research.

Richards began her study at GQNS in 2003 and, as a member of CANPOLIN, she has been able to continue the project for several additional years.

HER LAB NOW BOASTS WHAT IS BELIEVED TO BE THE LONGEST SERIES OF DEMOGRAPHIC DATA FOR ANY BEE COMMUNITY IN CANADA, AND LIKELY THE WORLD AS WELL.

CAROLINIAN **CANADA**

...is a unique ecological region in Canada, and an area of great biological diversity where southern species mix with more northerly species. In Canada, the Carolinian zone is found only in the extreme southwest corner of Ontario. It includes both forest and tall grass prairie, but due to intense urbanization and agriculture in the region, only a tiny fraction (~3%) of the original grassland or meadow now remains.

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

Examples of high disturbance (red arrow) and intermediate disturbance (blue arrow) sites that were part of Richard's study at the GQNS *(photo by M. Richards)*

By studying the site over such a long period, Richards is making important discoveries about how bee communities respond to land restoration activities, and how bee diversity and abundance can vary from year to year.

Richards' data indicates that, right from the start, a naturalization area can serve as a valuable refuge for bees, and it takes just 3-5 years for a fairly diverse bee community to re-establish itself.

Richards and her team collected 125 species from the GQNS area. Included in that number are a few species not previously recorded in Canada, such as *Osmia conjuncta*, a bee that nests in empty snail shells. Richards and her team also found that several invasive species were established in the area, and that their populations seem to be on the increase. "It is possible that some of these species may have been initially introduced to the area accidentally through material brought to the landfill," speculates Richards.

Not all areas within the site are created equal in the eyes of local bees. Richards' sampling sites encompass a range of disturbance levels, from undisturbed meadows to newly seeded ground, and there are significant differences in the bees found at each site. Cavity-nesting bees are less likely to be found in newly restored grasslands - probably due to the lack of woody plants that provide suitable cavities. In contrast, *Dialictus* bees (a sub-genus of *Lasioglossum*, which is notoriously difficult to identify) are particularly common in newly restored sites.

Year to year changes have also shown that there is considerable annual variation in bee abundance and species richness. According to Richards, the impact of severe weather is readily apparent in the data obtained from the site.

"VERY WET SPRING WEATHER

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

SEEMS TO CORRELATE WITH A DROP IN GROUND-NESTING BEES IN THE SAME YEAR, WHILE DROUGHT CONDITIONS LEAD TO A DECLINE IN OVERALL ABUNDANCE AND DIVERSITY THE FOLLOWING YEAR," SHE SAYS.

With support from CANPOLIN, Richards also expanded her sampling to include two other restored landfill sites in the region, which means her demographic studies can be replicated. Processing and identifying the many thousands of specimens collected each year at multiple sites is an ongoing task, but one thing is certain: they will continue to yield many insights into the succession of bee communities in restored habitats for some time to come.

TO SWEEP OR NOT TO SWEEP

As part of her bee diversity study, Richards also compared the effectiveness of different sampling methods: pan traps (pictured left), sweep netting on vegetation, and aerial netting on flowers. While some groups of bees were more likely to be caught by pan traps (e.g., Halicitidae) and others by sweep and aerial nets (e.g., Apidae), Richards found that bee abundance in pan traps and sweep nets were highly correlated. This suggests either method is a reliable way to measure bee abundance. In contrast, a study by fellow CANPOLIN researcher Chris Lortie at York University suggests that pan traps may be better for measuring bee *diversity*, at least in grasslands.

LOOKING FOR MORE INFORMATION?

Richards, MH, AC Rutgers-Kelly, J Gibbs, JL Vickruck, SM Rehan and C Sheffield. 2011. Bee diversity in naturalizing patches of Carolinian grasslands in southern Ontario. The Canadian Entomologist 143: 279-299

Rutgers-Kelly, AC and MH Richards. 2013. Effect of meadow regeneration on bee (Hymenoptera: Apoidea) abundance and diversity in southern Ontario, Canada. The Canadian Entomologist 145: 655-667

Onerfuko, T. 2013. Restoration and succession of a bee community in southern St. Catharines, Ontario, within a ten-year study period. Brock University MSc Thesis, 139 pp.

Spafford, R.D. and C.J. Lortie. 2013. Sweeping beauty: is grassland arthropod community composition effectively estimated by sweep netting? Methods in Ecology and Evolution 3: 3347–3358

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

THIEVING BEES
A WINDOW TO THE HEALTH OF BEE COMMUNITIES

Bees that hijack the nests of other bee species can indicate health of overall bee community

To assess biodiversity, ecologists traditionally rely on the number of species and abundance of individuals. But when it comes to bees, interpreting the results is not always simple. "This is because bees have such a wide range of lifestyles that numbers alone don't always tell the whole story," says Cory Sheffield, curator of invertebrate zoology at the Royal Saskatchewan Museum and former CANPOLIN research associate.

A female cuckoo bee in the genus *Nomada* searching for a host nest. Because they don't collect pollen, cuckoo bees are usually quite hairless compared to other bees *(photo by P. Coin)*

According to Sheffield, cleptoparasitic bees may offer a better way to assess bee diversity. Also known as "cuckoo bees", cleptoparasites are bees that don't collect pollen to feed their young like other bees. Instead, a female cuckoo bee lays her eggs in the nest of another bee species. The larvae hatch and consume the pollen provisions that were meant for the host species' offspring – and even consume the host larva itself. Different species of cuckoo bees target different groups of bee hosts.

"CLEPTOPARASITES ARE LIKE THE 'TOP PREDATORS' OF A COMMUNITY – THEY ARE COMPLETELY DEPENDENT ON THE PRESENCE OF THEIR HOST SPECIES. IF SOMETHING IS AFFECTING ONE OR MORE OF THE HOST SPECIES, THIS WILL QUICKLY BE REFLECTED IN THE COMPOSITION OF CUCKOO SPECIES," EXPLAINS SHEFFIELD.

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

To test their theory, Sheffield and colleagues from working group 1 re-examined data from a past study looking at bee diversity in agricultural fields in Nova Scotia. The fields had different levels of disturbance, ranging from intensely managed cropland and mowed pasture to woodland and meadow. The team found that when they focused only on the cleptoparasitic species, the relationship between bee diversity and habitat disturbance was much more consistent compared to using data for all bee species. In addition, using cleptoparasites as a proxy was particularly useful when it came to fields with intermediate levels of disturbance. Previous analyses for these sites gave inconsistent results.

Sheffield recommends that cuckoo bee diversity and relative abundance become a standard part of all assessments of bee community health. "We know that human activities are having a strong impact on biodiversity and ecological services such as pollination. Having accurate and consistent tools to measure diversity is essential to understanding changes in bee communities and developing effective conservation strategies."

Cory Sheffield with some of the insect cabinets at York University
(photo courtesy of C. Sheffield)

LOOKING FOR MORE INFORMATION?

Sheffield, CS, A Pindar, L Packer and PG Kevan. 2013. The potential of cleptoparasitic bees as indicator taxa for assessing bee communities. *Apidologie* DOI: 10.1007/s13592-013-0200-2

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

MEASURING POLLINATION SERVICES

Developing a tool to quantify a critical ecosystem service

Plants are the engine that converts sunlight and carbon dioxide into energy and food for all animals. Keeping this engine going is critical for humans and wildlife alike. That is why pollination is considered an "ecosystem service" - it maintains plant populations by helping them to reproduce. To fully understand and ultimately protect this essential service, we must first be able to measure it. At present, scientists lack the means to monitor and evaluate pollination quickly and cheaply over broad landscapes. The methods that do exist rely on pollinator surveys, which are labour intensive and require taxonomic expertise. Even when that expertise is available, the surveys still do not directly measure the actual service of pollination.

A native paper wasp visiting heath aster *(Symphyotrichum ericoides)*, one of the fall asters tested as a phytometer to measure pollination services *(photo by T. Woodcock)*.

A **PHYTOMETER** is any plant, whether it is wild, in a garden, or growing in a pot, that is used to measure something about the environment.

CANPOLIN research associate Tom Woodcock partnered with Environment Canada's Center for Environmental Sustainability Indicators (CESI) to take a different approach. Their goal was to determine if specially-raised plants could be used as a proxy to measure pollination services in a given ecosystem. To test this idea, they first had to identify a suitable plant. A suitable **PHYTOMETER** for measuring pollination service would have to meet several criteria. First, seed set in the plant must occur only through animal pollination. Second, the plant must not be able to self-pollinate, or to produce seeds with no pollination at all. Third, seed set must reflect levels of pollination limitation, rather than resource limitation. Finally, fertilized seeds must be easily distinguished from those that are unfertilized.

Woodcock knew that all of these requirements are satisfied by a genus of plants known as the fall asters *(Symphyotrichum)*. They are common and abundant

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

in southern Ontario, where the study took place. "Fall asters are an important late season resource for pollinators, especially those that overwinter as adults, like bumble bees," explains Woodcock. Six different *Symphyotrichum* species were grown from wild seed in pots at the University of Guelph, and fertilized regularly to ensure the plants had enough resources to set seed. When the plants began to bloom in early September, they were placed in one of 12 field sites to assess if they could be used to measure the level of pollination services.

Field sites were chosen to represent a wide range of pollination service, based on the history of the sites and information gleaned from previous pollinator sampling. Sites that were expected to have a low level of pollination service included a decommissioned landfill with low pollinator abundance and regenerating corn fields. In contrast, sites that had abundant wildflower and pollinator populations, and/or were part of active farmland pollinator conservation programs, were expected to have a high level of pollination service.

Woodcock placed a group of six plants at each field site. One branch on each plant was kept covered with cloth bags to keep pollinators out and to confirm that the plant would not set seed in the absence of pollinators. After one week in the field, the plants were transported back to the greenhouse. Once the plants had finished setting seed (which took about three weeks), Woodcock harvested the seeds for counting.

By comparing the seed set in the potted plants from different sites, Woodcock was able to assess the relative levels of pollination service. As expected, sites that were in early stages of regeneration or had few wildflowers present had the lowest seed set. In contrast, sites in later successional stages or that were planted specifically for pollinator conservation produced the most seed.

"I WAS PARTICULARLY ENCOURAGED BY THE SEED SET WE FOUND AT TWO POLLINATOR CONSERVATION PROJECTS IN NORFOLK COUNTY THROUGH THE ALTERNATIVE LAND USE SERVICES (ALUS) PROGRAM," SAYS WOODCOCK. "DESPITE THESE SITES BEING ONLY ABOUT FIVE YEARS INTO RESTORATION, THERE WERE DETECTABLE INCREASES IN

Potted purplestem asters *(Symphyotrichum puniceum)* at Eastview landfill in Guelph *(photo by T. Woodcock)*

Purplestem asters at Cruickston Creek Field near Cambridge. Note the greater abundance of wildflowers at Cruickston creek, a site with higher level of pollination service *(photo by T. Woodcock)*

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

Ripe fruits in a withered flower of purplestem aster *(Symphyotrichum puniceum)*, ready to be counted *(photo by T. Woodcock)*

THE POLLINATION SERVICE."

Woodcock says there were also a few surprises; phytometers placed at the apiary at the University of Guelph showed very low pollination service, despite being only a few meters from two dozen honey bee hives. "Apparently the honey bees did not forage on the asters in the phytometers."

All in all, the experiment suggests that this system has good potential for measuring pollination services. It can be readily expanded and adapted, using other plant species to measure pollination services at different times of the year. Plant species that are adapted to use a particular type of pollinator could also be used to measure services of a subset of pollinators, such as bumble bees or small-bodied flower visitors.

Whether in government, ecological research, or as an educational citizen science program (see box), it is possible that a system based on this method could one day provide a means of assessing and monitoring pollination service all across Canada.

Want to take part in this project?

Start your own pollination phytometer!

CANPOLIN's partner organization **Seeds of Diversity** has launched a citizen science program called the **Purplestem Aster Pollination Adventure**. Plant seeds in your garden and send in mature flower heads at the end of the year so that the seeds can be counted. The project provides information about pollination services in different urban and rural landscapes. Click here for more information.

LOOKING FOR MORE INFORMATION?

Woodcock, TS, LJ Pekkola, C Dawson, FL Gadallah and PG Kevan. 2014. Development of a pollination service measurement (PSM) method using potted plant phytometry. Environmental Monitoring and Assessment 186: 5041-5057

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

MANAGING FORESTS FOR POLLINATION

Forest gaps are critical to maintaining pollinator populations and the services they provide throughout the forest

Red raspberry and other sun-loving plants at Algonquin Park
(photo by T. Woodcock)

A natural forest is an ever-changing mosaic of habitats. Mature trees die and collapse, fires burn, insects defoliate and kill trees, and wind and ice storms break limbs and blow down swaths of forest. These disturbances open up gaps in the canopy that give young trees a chance to grow. They also allow other plants that can't tolerate shade to flourish in the sunlight. In this way, disturbances help build and maintain plant biodiversity in the forest. That is why harvesting practices are often designed to mimic natural disturbances, allowing trees to regenerate from wild seed sources and encouraging plant and animal biodiversity. Sustainability and responsible management go hand-in-hand, and pollinators are central to success.

The complex relationship between pollinators, plants and different logging practices is a question of interest to several CANPOLIN researchers. Four different research projects were conducted at Algonquin Park, the last provincial park in Ontario to allow logging (1-2% of the park is logged each year). The park provided an ideal location to evaluate the effects of different logging practices on plant and pollinator diversity in the forest.

Although each project focused on a different aspect of forest pollination ecology, the group shared one major finding in common: gaps are critical in maintaining pollinator populations and the services they provide to plants throughout the forest. One gap-loving plant species, red raspberry (*Rubus idaeus* var. *strigosus*), was found to be especially important; with its abundant flowers and production of sugary nectar, it is an excellent resource for pollinators (old stems can also provide

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

A miner bee *(Andrena erigeniae)* on a spring beauty flower. The bee is a specialist pollinator that completely depends on the pollen of this plant species. *(photo ©JohnAscher discoverlife.org)*

nesting sites for some species). By supporting bee populations, raspberry and other sun-loving gap plants indirectly help sustain pollination services to other forest plants.

THE FINDINGS MAY MEAN THAT A PLANT SOMETIMES CONSIDERED A FOREST "FOE" IS ACTUALLY A FRIEND. Raspberry is known to slow forest regeneration by up to 25 years (depending on the forest) by outcompeting young trees for space and light. However, CANPOLIN research clearly shows that the native plant is a positive influence on bee communities in the forest.

The studies carried out at Algonquin Park deliver a host of other interesting findings as well. Trent University researcher Erica Nol and graduate student Eleanor Proctor found that the group-selection logging, in which small groups of trees are removed rather than single trees, increased the abundance of pollinators and flowering stems, but only after the trees produced leaves in the forest canopy. However, reproductive success of spring beauty (*Claytonia caroliniana*), which flowers before the canopy appears, was higher in gaps than in the forest, suggesting that pollinators prefer foraging in gaps even when leaves are absent. In contrast, colleagues Marcel Dorken and Emony Nicholls, also of Trent University, found that pollination of wild sarsaparilla *(Aralia nudicaulis)*, which grows in shaded conditions in the mature forest, was not enhanced by gaps or light levels.

University of Guelph researchers Peter Kevan and Erika Nardone noted that bee community structure in the hardwood stands of Algonquin Park are fairly resilient to logging disturbances. However, different groups of bees tended to be associated with different successional stages, and both old and young habitat is necessary to have a high species richness. Gaps tend to support early season bees with short life cycles that are active during the bloom of spring ephemerals and raspberry, while bumble bees, which can travel longer distances to forage and are active all season, are more important in the surrounding forest. Graduate student Sarah Gunderson, who also worked with Dorken and Nol at Trent, found that bees are more diverse and abundant when logging practices most closely mimicked natural processes - namely, harvesting sporadic gaps together with the selective logging of individual trees elsewhere in the stand. In contrast, flower flies (Syrphidae), another major group of pollinating insects, are

Graduate student Sarah Gunderson putting out bee bowls for sampling bees; Sarah received a posthumous MSc from Trent University in recognition of her research contribution *(photo by M. Dorken)*

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

Two methods used to sample pollinators at Algonquin Park: trap nests (top), which are utilized by a variety of cavity-nesting bees, and a malaise trap (bottom), for flying insects *(photos by E. Nardone)*

more diverse and abundant under more intense logging regimes that consisted of frequent, regularly-spaced clearings and no single-tree selection.

Nol and Proctor's study suggests that the combination of increased light, warm, bare soils, and abundant nectar-rich raspberry flowers create ideal habitat for soil-nesting bees, factors that are largely missing from unharvested stands. This, in turn, may support higher populations of bees that forage in the shaded forest. Gunderson and Dorken further found that reproduction of the raspberry itself was affected by the density of the gaps and the pollinators present, and produced more flowers in intensively logged plots.

A mature forest tends to lose biodiversity when there is no disturbance, while a carefully managed harvesting program that considers the forest as an ecosystem may lead to development of sustainable harvesting practices and encourage pollinator conservation in the broader landscape. CANPOLIN research projects in Algonquin Park provide a good start in understanding how this might be accomplished.

LOOKING FOR MORE INFORMATION?

Nardone, E. 2013. The bees of Algonquin Park: a study of their distribution, community guild structure, and the use of various sampling techniques in logged and unlogged hardwood stands. University of Guelph MSc Thesis, 191 pp.

Nicholls, EIE and ME Dorken. 2012. Sex-ratio variation and the function of staminodes in *Aralia nudicaulis*. Botany 90: 575-585

Proctor, E, E Nol, D Burke and WJ Crins. 2012. Responses of insect pollinators and understory plants to silviculture in northern hardwood forests. Biodiversity and Conservation 21: 1703-1740

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

NATIVE BEE DIVERSITY IN CONVENTIONAL AND ORGANIC FARMS

A glimpse into the hedgerows of Eastern Ontario

Modern farming practices are widely believed to sacrifice biodiversity in order to maximize the amount of land that can be used to grow a small number of crops. This loss of biodiversity can lead to a loss of valuable ecosystem services, such as pollination by native bees.

"Although intensive farming may well be blamed for a loss of biodiversity on farms, its effects on native bees are not well understood," says WG5 researcher Pierre Mineau of Carleton University. He and graduate student Joanna James set out to study how farm management practices and the surrounding landscape affects bee diversity and abundance on farms.

"We wanted to know if there was greater native bee diversity on organic farms as opposed to conventional farms, and which farming practices are most detrimental to native bee diversity in eastern Ontario," explains Mineau.

Many factors may affect bee biodiversity on a farm, including whether or not insecticides or fungicides are used, and whether the farm is surrounded by natural land or is located in an intensively farmed landscape. The use of tillage can also impact bees, because ground nesting bees prefer undisturbed soils.

Graduate student Joanna James (right) and assistant Claire Yick (left) hunt for hedgerow bees with a sweep net *(photo by P. Mineau)*

While management practices may differ between conventional and organic farms, a common element shared by both types of farm is the presence of hedgerows alongside intensively cropped areas. Hedgerows provide both nesting and foraging habitat for native bees and can act as a bee reservoir. As such, they make a good place to evaluate bee biodiversity across different landscapes and farm management styles.

Mineau and James looked for hedgerows in "pairs" of organic and conventional soybean farms

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

in the same landscape that could be compared. They identified nine pairs of farms in eastern Ontario that were suitable for the study, and sampled native bees from hedgerows on each farm. A total of 3,472 native bees were collected over the season, most of which were ground nesting solitary bees. The specimens comprised 149 species of solitary bees and 13 species of bumble bees.

According to James, there was a surprising lack of difference between the two farm types. "Organic farms did not seem to have a greater abundance or diversity of native bees than conventional farms, and tillage and insecticide use on conventional farms did not appear to affect native bee diversity or abundance as compared to organic farms."

While the researchers note that tillage practices between the two farm types did not differ substantially, the findings suggest that overall, conventional soybean management practices employed in the Eastern Ontario cropping system do not have a detrimental impact on the native bee community at the local farm level.

"INSTEAD OF BEING VIEWED NEGATIVELY IN TERMS OF NATIVE BEE ABUNDANCE AND BIODIVERSITY, FARMS MAY ACTUALLY BE PROVIDING IMPORTANT HABITAT FOR THESE ORGANISMS," SAYS JAMES.

At the same time, however, the researchers also found that at the landscape level, bumble bees were more abundant in organic farms in intensively managed landscapes.

"The amount of semi-natural habitat in the larger landscape is actually the most important influence on bee populations. When there isn't enough natural habitat in the broader landscape, bumble bees are moving into organic hedgerows preferentially," explains Mineau.

Previous studies on the effect of organic farming on biodiversity have produced mixed results. Mineau and James' study adds to a growing body of literature that emphasizes the importance of taking the wider landscape into account when evaluating the effect of farm management on biodiversity. "To understand the true value of agricultural habitats for native bee biodiversity, it is critical that the broader landscape also be considered," says Mineau.

Hedgerows on a conventional (left) and organic farm (right) in Eastern Ontario *(photo by J. James)*

LOOKING FOR MORE INFORMATION?

James, J. 2011. Native bee diversity in conventional and organic hedgerows in Eastern Ontario. Carleton University MSc Thesis, 139 pp.

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

BLUEBERRY FIELDS FOREVER

CANPOLIN "hit-team" explores multi-faceted questions around pollination in lowbush blueberry

In the early days of the Network, lowbush blueberry was selected as a model crop for a large, multi-part study to examine pollination and fruit set. The choice was a logical one; blueberries have become a leading crop in Canada in terms of acreage and economic value, and they depend entirely on insects to set fruit. As well, lowbush blueberry is a relatively undomesticated crop, produced mainly from wild stands. That means that research insights gleaned from this crop have potential to be extended to other wild plants as well.

CANPOLIN researchers in Newfoundland, Nova Scotia, New Brunswick and Quebec joined forces in what came to be called the "blueberry hit-team". Their combined expertise in genetics, plant biology, entomology and ecology brought an innovative and integrative approach to the study of pollination in this important Canadian crop.

A lowbush blueberry field in New Brunswick *(photo by D. Schoen)*

Native to eastern North America, lowbush blueberry is a low, spreading shrub. As a long-lived "wild" plant, it presents some interesting production challenges that might otherwise be bred out of more domesticated crops. This includes a high degree of genetic variability between plants with respect to pest resistance and fruit production, a complete dependence on insect pollinators, and a growth habit that leads to the formation of large plants or "clones" that increase the likelihood a flower will receive related pollen and set little to no fruit (see "The High Cost of Self-Pollination" on pg. 42).

Working at field sites across eastern Canada, the hit-team's efforts have resulted in many new insights. One

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

important finding is that a goal of 100% fruit production (where every flower produces fruit) is likely not possible, no matter how much pollen blueberry flowers receive.

"In an insect-dependent crop like lowbush blueberry, yields that are less than what is theoretically possible are usually attributed to flowers not receiving enough pollen," explains Linley Jesson, a plant biologist at the University of New Brunswick.

CANPOLIN researcher Linley Jesson (*photo by R. Smith*)

Jesson and graduate student Melissa Fulton conducted a massive two-year field study that looked at the effect of adding extra pollen to flowers in 68 blueberry fields in two different regions of New Brunswick. Although adding pollen did indeed increase the percent of flowers that set fruit, the increase was consistently smaller than expected. "We found that most blueberry plants, regardless of year or location, can achieve a maximum fruit set of only about 60%," notes Jesson.

Rather than pollen limitation, Jesson says that the strongest "signal" in the data was related to the location of the field site.

"IN OTHER WORDS, FIELD SITE APPEARS TO BE THE BIGGEST DETERMINANT OF YIELD. PLANT GENETICS, SOIL QUALITY AND DISEASE LOAD CAN ALL IMPACT YIELD SIGNIFICANTLY, AND THESE FACTORS VARY A GREAT DEAL BETWEEN FIELDS," SHE SAYS.

On Prince Edward Island, Chris Cutler and graduate student Andony Melathopoulos from Dalhousie University looked at what happens to blueberry flowers *after* pollination has taken place. "Flowers can receive pollen and start to produce fruit, but many of these 'potential fruit' never make it to final fruit set," says Cutler. The large drops in yield that occur after pollen transfer appear to be related to lower amounts of genetic diversity in the field (which leads to higher levels of inbreeding), and to lower levels of soil calcium - a mineral that is required for pollen tube germination.

In all types of ecosystems, landscape factors can have a big impact on the local pollinator community. In agroecosystems, pollinator abundance typically declines with increasing distance from "natural" habitat at field edges. Valerie Fournier and MSc student Joseph Moison-DeSerres of Laval University found that pollinators are fairly evenly distributed in blueberry fields in the Lac-St-Jean region of Quebec and believe that this is likely due to the prevalance of windbreaks around fields. "Windbreaks are an integral part of the farmscape in this region, typically no more than 120 m apart," notes Fournier.

In New Brunswick, University of Ottawa researcher Risa Sargent and PhD student Irene McKechnie examined the influence of landscape on what matters most to a grower`s bottom line: crop yield. Plants in fields surrounded by large areas of blueberry acreage produced fewer fruit compared to plants located within a more diverse landscape. "Blueberries need pollinators, and large tracts of blueberry monocultures will have fewer floral

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

Bumble bee foraging on low bush blueberry flower (*photo by M. Wilkes)*

resources available to support a diverse and abundant pollinator community," says McKechnie.

These studies are just a sample of the work carried out by the blueberry hit-team. Members also looked at the effects of pesticides commonly used to control blueberry pests on bees, the connection between pest management, pollination and fruit set, and the contribution of nocturnal insects to crop pollination (see pg. 68).

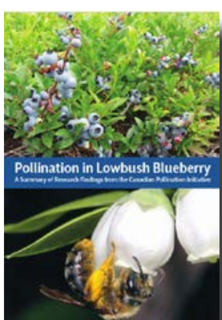
Yet more experiments have examined the effect of bee densities on yield, and the contribution of managed pollinators.

Dan Schoen from McGill University looked the effect of adding different combinations of managed pollinators (honey bees, bumble bees and leafcutter bees) to a field during bloom. ``We have evidence to suggest that adding managed pollinators may not always lead to a yield benefit,`` he says, pointing out that in those cases, native pollinators are doing an adequate job. ``But adding pollinators may still serve as an insurance policy when populations of native pollinators are low, or when the weather is poor."

ADDS JESSON, ``MUCH OF OUR ANALYSIS IS STILL ON-GOING, BUT IT IS QUITE CLEAR THAT NO SINGLE FACTOR ALONE LIMITS BLUEBERRY FRUIT PRODUCTION. THERE ARE MULTIPLE FACTORS AT PLAY.``

POLLINATION ON "THE ROCK"

Memorial University researcher Luise Hermanutz and MSc student Margie Wilkes have handy access to a rather unique location for pollination research. Because Newfoundland has very few introduced pollinators, it is one of the few places that studies of native pollinators and their impact on crop pollination can be made without the confounding effects of managed bees. "Honey bees were introduced from Europe in the 1600s and are now ubiquitous throughout most agricultural areas in North America. That makes it difficult to tease out the contribution of native species to crop pollination in most places,` says Hermanutz. She and Wilkes conducted a two year field study comparing native pollinator communities and fruit set in managed blueberry fields and wild patches near Grand Falls Windsor, Newfoundland.



LOOKING FOR MORE INFORMATION?

Jesson, L, D Schoen, GC Cutler and SL Bates. 2014. Pollination in lowbush blueberry: a summary of research findings from the Canadian Pollination Initiative. NSERC-CANPOLIN, 42 pp.

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

BLUEBERRY HIGH IN BRITISH COLUMBIA

West coast researchers study pollination in highbush blueberry

Lowbush and highbush blueberries may taste the same, but these two species and their production differ dramatically. Lowbush blueberries hail from largely wild stands growing in eastern North America, whereas highbush blueberry growers plant domesticated cultivars that produce bigger berries on plants that grow as much as ten times taller than their lowbush relative.

On the west coast of Canada, British Columbia has become a hot spot for highbush blueberry production. It is one of the top three blueberry producing regions in the world, and accounts for over half of all the blueberries produced in Canada.

Like its lowbush cousin, highbush blueberry relies on insect pollinators to set fruit, and there is keen interest in understanding the factors that affect pollination and hence yield in this high value crop. One question of interest to CANPOLIN researchers is how differences in flower morphology between different cultivars can influence pollination rates.


A highbush blueberry farm study site in British Columbia *(photo by E. Elle)*

"Highbush blueberry cultivars vary in flower size and shape. Because we approach the pollination problem from both the perspective of the plant and the perspective of the bee, we realized that floral differences were likely to affect the types of pollinator attracted, and how often they visit" explains Elizabeth Elle, a pollination ecologist at Simon Fraser University.

To determine how flower shape affects foraging behaviour, Elle and her team took detailed flower measurements and observed pollinators of four common highbush blueberry cultivars: Bluecrop, Draper, Duke and Liberty.

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

From Left: Flowers of the highbush blueberry cultivars Bluecrop, Draper, Duke and Liberty *(photo by E. Elle)*

THE RESULTS CONFIRMED THAT DIFFERENT TYPES OF POLLINATORS PREFERRED DIFFERENT CULTIVARS. HONEY BEES VISITED DUKE FLOWERS SIGNIFICANTLY MORE THAN DRAPER, BLUECROP AND LIBERTY FLOWERS. IN CONTRAST, NO BUMBLE BEES WERE OBSERVED VISITING DRAPER FLOWERS, BUT ALL REMAINING CULTIVARS WERE EQUALLY LIKELY TO BE VISITED BY A BUMBLE BEE.

Closer examination of bee visits to flowers revealed some interesting facts about pollinator behaviour on different cultivars. Almost 80% of honey bees that visited Duke flowers inserted their entire head into the flower, increasing the chance that pollen would be deposited on their faces and presumably then transferred to another flower.

This, says Elle, is what constitutes a "legitimate visit", because it is more likely to result in the transfer of pollen.

In contrast, Bluecrop flowers were most likely to be "robbed" by honey bees. These illegitimate visits consist of a honey bee chewing through the base of the flower to gain access to nectar, without depositing or removing pollen.

"Nectar robbing happens when bees cannot easily access the nectar reward through the mouth of the flower," says Elle, noting that Bluecrop flowers are narrower than those of the other varieties. "Honey bees have shorter tongues than bumble bees, and their heads are too wide to fit into the mouth of the Bluecrop flowers. We've even seen them get their heads stuck in the flower mouths when they attempt a legitimate visit! We figure this is why they are more likely to rob than bumble bees, who only made legitimate visits."

Of course, what matters most to growers at the end of the day is yield. Elle and her team also looked at the average fruit set in each of the cultivars. Duke was the clear winner, producing 20-50% more fruit than the other cultivars. It was also the cultivar with the highest visitation rate for both honey bees and bumble bees.

"Our study suggests flower morphology ought to be a consideration in future breeding programs for highbush blueberry," says Elle. "Cultivars that produce wider, shorter flowers can improve access to nectar rewards for honey bees, which were the predominant pollinators in our study sites—and this means greater yield for growers."

It turns out, though, that honey bees are not as effective as bumble bees at blueberry pollination. "Wild bumble bees can significantly enhance blueberry yield, on top of what honey bees would be able to do alone, meaning bumble bees increase grower profits" says Lindsey Button, an MSc student at Simon

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

Fraser who studied the contribution of wild and managed pollinators to blueberry yield. But, she adds, the presence of wild bees largely depends on the surrounding landscape.

"THERE ARE MORE BUMBLE BEES IN FIELDS SURROUNDED BY SEMI-NATURAL LAND LIKE PASTURES AND FALLOW FIELDS, AND FEWER BEES IN FIELDS SURROUNDED BY AGRICULTURE." THE STUDY PROVIDES ADDITIONAL EVIDENCE THAT MANAGING THE LANDSCAPE TO ENCOURAGE WILD POLLINATORS CAN HAVE A POSITIVE ECONOMIC BENEFIT FOR GROWERS.

DOES A FLOWER BY ANY OTHER NAME SMELL AS SWEET (TO A BEE)?

University of British Columbia researcher Kermit Ritland and graduate student Gwen Huber are examining another aspect of what draws pollinators to a flower: odour. Ritland and Huber have measured floral volatiles in ten different blueberry cultivars, finding variation in odour profiles both within and between cultivars. The duo are particularly interested in compounds which are present or absent in different cultivars, because these are the odour traits that would be most amenable to a breeding program.

UBC graduate student Gwen Huber collecting blueberry flower volatiles in the field *(photo courtesy of the UBC Farm Blog)*

LOOKING FOR MORE INFORMATION?

Courcelles, DMM, L Button and E Elle. 2013. Bee visit rates vary with floral morphology among highbush blueberry cultivars (*Vaccinium corymbosum* L.). Journal of Applied Entomology 137: 693-701

Button, L. 2014. Pollination in highbush blueberry (*Vaccinium corymbosum* L.) and the effects of surrounding landscape on wild bee abundance. Simon Fraser University MSc Thesis, 81 pp.

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

IN THE DARK OF THE NIGHT

Researchers studying nocturnal pollination of lowbush blueberry make a few surprise discoveries

Lowbush blueberry is Canada's most valuable horticultural crop, and insect pollinators are essential for fruit set. It has long been known that bees are responsible for most of the pollination that takes place, and growers will often augment wild bee populations with managed bees. But what happens at night, when bees are not active? It's a question that has been largely overlooked for most crop plants, and in particular *Vaccinium* and other berry crops.

Working group 5 researcher Chris Cutler and his research team at Dalhousie University have shed light on the role of nocturnal pollination in lowbush blueberry production. Using mesh cages to block pollinator access to flowers, the team crafted an experiment in which blueberry stems were exposed to insect pollinators during either the day or night. Other stems were exposed 24 hours a day, or covered with mesh 24 hours a day.

Blueberry flowers at dusk *(photo by C. Cutler)*

CANPOLIN researcher Chris Cutler *(photo courtesy of Dalhousie University)*

At harvest time, stems that were exposed only at night produced a surprising amount of fruit - about half as many ripe berries compared to stems that were pollinated only during the day. Interestingly, there was no difference in fruit quality/weight in berries that were day or night pollinated. Plants in control cages that excluded insects 24

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

hours a day produced essentially no fruit.

"OUR RESULTS SUGGEST THAT NOCTURNAL POLLINATORS MAKE A SIGNIFICANT CONTRIBUTION TO LOWBUSH BLUEBERRY POLLINATION," SAYS CUTLER.

In a follow up study, Cutler and his team used sweep nets and light traps to determine which insects were active in blueberry fields at night, and which of those species were physically transporting *Vaccinium* pollen.

Over a period of six nights, they captured 588 specimens representing 47 different families of insects. Some of the most commonly collected families that were also the most likely to be transporting blueberry pollen included weevils (Curculionidae), geometrid moths (Geometridae), owlet moths (Noctuidae) and tachinid flies (Tachinidae).

Capturing night-flying insects *(photo by C. Cutler)*

Because blueberry flowers require a special type of handling to remove pollen from the anther, Cutler speculates that nocturnal pollinators are likely moving pollen that has been dislodged by bees during the day.

Still, he says, nocturnal pollinators clearly can make a contribution to blueberry pollination and their potential importance should not be overlooked.

"WE ALREADY TRY TO MANAGE AGRICULTURAL HABITATS TO ENCOURAGE BEES AND OTHER BENEFICIAL INSECTS. IT MIGHT BE WORTHWHILE TO FIND WAYS TO ENHANCE THE ACTIVITY OF NOCTURNAL POLLINATORS AS WELL."

LOOKING FOR MORE INFORMATION?

Cutler, GC, KW Reeh, JM Sproule and K Ramanaidu. 2012. Berry unexpected: nocturnal pollination of lowbush blueberry. Canadian Journal of Plant Science 92: 707-71

Manning, P and GC Cutler. 2013. Potential nocturnal insect pollinators of lowbush blueberry. Journal of the Acadian Entomological Society 9: 1-3

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

POLLINATORS AT THE TOP OF THE WORLD

In a harsh alpine habitat, cushion plants and pollinators have a unique relationship

In many ecosystems, getting a foothold on life is difficult for both plants and animals. In particularly harsh habitats such as deserts, windswept mountaintops, and cold northern regions, only a few species are capable of surviving and reproducing. One such group of hardy organisms are cushion-forming plants, so named because their low, dense, dome shape resembles a pillow. Cushion plants are well adapted to extreme environments, in large part because they can moderate temperature and wind speed within the cushion while conserving scarce moisture and soil nutrients. Different cushion species are found in all major alpine and arctic environments around the world, and they are believed to play an important ecological role in supporting other plants and animals. Yet, despite their presumed ecological importance, only a few species have been studied closely.

An alpine meadow field site *(photo by A. Reid)*

WG5 researcher Chris Lortie from York University and graduate student Anya Reid were interested in the role of cushion plants in the structure and biodiversity of alpine ecosystems – including their impact on pollinator communities. Working high in the mountain ranges of BC, in an area covered with snow up to ten months of the year, Reid and Lortie focused on the cushion plant known as moss campion (*Silene acaulis*).

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

To understand how the plant influences other species in the alpine community, the team took a two-step approach. First, they compared the vegetation within each individual cushion plant and in a paired area outside of the cushion called non-cushions. "The plant communities on and away from cushions can differ," explains Reid.

Next, Reid and Lortie used Ipod nano® cameras to record insect visitors to cushion and non-cushion plants, and found that visitors were both more diverse and more abundant on the cushion plants.

"MOSS CAMPION PROVIDES NOT ONLY FLORAL RESOURCES FOR VISITORS, BUT A PHYSICAL REFUGE FROM A HARSH ENVIRONMENT AS WELL," NOTES REID.

Graduate student Anya Reid in the field *(photo courtesy of A. Reid)*

Although cushion plants are often called "nurse plants" because of their role in helping other plant seeds germinate and establish, Reid and Lortie found that the greatest positive effect exerted by moss campion was actually on floral visitors. "This means that cushion plants are doing more than just supporting plants – they are supporting species in other trophic levels as well," explains Reid.

The study also dispels a common assumption about alpine plants: that they are reproductively-limited because they do not get enough pollen transferred to their flowers (presumably because the environment is too cold to support many pollinators), and that high rates of self-pollination are common as a result. To assess if moss campion was pollen-limited, Lortie and Reid compared seed set in moss campion plants that were cross-pollinated naturally by insect visitors, plants supplemented with extra pollen by hand, and plants that self-pollinated.

Surprisingly, they found that outcrossing is the main method of reproduction in this population of moss campion. In fact, says Reid, plants that produce only female flowers and are completely dependent on insect pollinators make up more than half the moss campion population at the study site. "The rest of the plants are hermaphrodites. Their flowers have both male and female structures and they can self-pollinate if they need to."

Overall, these studies show that cushion plants play a role in alpine ecosystems that is even more important than previously assumed. Just as importantly, it also reveals that cushion plants

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

and pollinators rely heavily on each other for their long term survival.

"THE LOSS OR EVEN A REDUCTION OF EITHER CUSHIONS OR POLLINATORS CAN HAVE A MAJOR NEGATIVE IMPACT ON ALPINE COMMUNITIES," SAYS LORTIE. "GIVEN THE RATE OF ENVIRONMENTAL CHANGE OCCURRING IN NORTHERN AND ALPINE SYSTEMS, UNDERSTANDING THE ROLE OF KEY PLAYERS IN PLANT COMMUNITIES FOR POLLINATORS IS AN IMPORTANT STEP FORWARD".

Moss campion plays an important ecological role in alpine habitats *(photo by C. Lortie)*

LOOKING FOR MORE INFORMATION?

Reid, A and CJ Lortie. 2012. Cushion plants are foundation species with positive effects extending to higher trophic levels. Ecospheres 3: 96

Lortie, CJ and AM Reid. 2012. Reciprocal gender effects of a keystone alpine plant species on other plants, pollinators, and arthropods. Botany 90: 273-282

Lortie, CJ, AE Budden and AM Reid. 2011. From birds to bees: applying video observation techniques to invertebrate pollinators. Journal of Pollination Ecology 6: 125-128

Molenda, O, Reid, A and CJ Lortie. 2012. The alpine cushion plant *Silene acaulis* as foundation species: a bug's eye view to facilitation and microclimate. PloS ONE 7: e37223

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

ALIEN INVASION

Invasive plant have complex relationship with pollinators and the broader plant community

Exotic species of plants and animals are those that are not naturally found in a particular area, but have been introduced accidentally or intentionally by human activity.

Many exotics simply become part of the local flora and fauna and do not spread very far. Others, however, can spread rapidly and destroy or displace native organisms through direct predation, competition for space or nutrients, or other means. These harmful exotic species are what biologists call invasives, and they are one of the most serious and costly consequences of globalization.

The Garry Oak ecosystem on Vancouver Island is an example of a rare habitat threatened by invasive species *(photo by E. Elle)*

Biologists have been studying the ecological impacts of invasives for some time, but their relationship to the pollinator community - and the pollination services it provides - are not as well understood. Given the importance of pollinators to plant reproduction, it is critical to understand the potential domino effects of an invasive plant on flower visitors and pollination in the wider plant community.

Jana Vamosi, a plant ecologist at the University of Calgary, says those effects could be both negative and positive. "If pollinators prefer the invader, or if the bloom is large and showy and attracts more pollinators, it may reduce the amount of pollen

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

A Scotch Broom flower
(*photo by* H. Zell)

received by native species. In some cases, the invasive species' pollen may even block fertilization on a native plant, either physically or chemically," explains Vamosi. "On the other hand, a mass blooming invasive plant may also attract more pollinators to an area and increase the reproductive success of the natives."

Invasive species can cause particular problems in rare habitats, which often have many native species that have evolved under local conditions and do not occur elsewhere. That's why Vamosi and graduate student Jen Muir were particularly interested in the endangered Garry Oak savannah on Vancouver Island. Never large to begin with, this vulnerable ecosystem already suffers from fragmentation, urbanization, and the effects of fire suppression. It also has been invaded by the exotic plant Scotch Broom (*Cytisus scoparius*).

"Scotch Broom is a native European plant which has become a highly successful invader in dry shrublands and other open habits in North America, Australia, South America and Africa," says Muir. She explains that the plant forms dense stands and displaces native species by competing for space and resources, producing a toxic root exudate, and altering soil chemistry.

To understand how pollinators and an invader influence each other in a rare ecosystem like the Garry Oak savannah, Muir and Vamosi looked at flower visitors, pollen deposition, and fruit and seed set in Scotch

From Left: Native plants Blue-eyed Mary (*photo by W. Siegmund)* and Great Camas (*photo by G. George*) and the exotic Dovefoot Geranium (*photo by H. Zell*)

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

Broom and two native plants that flowered at the same time, Blue-eyed Mary (*Collinsia parviflora*) and Great Camas (*Camassia leichtlinii*). They also included another exotic, Dovefoot Geranium (*Geranium molle*), in their study.

Because all four study plants bloom at the same time, they were expected to be share the same suite of pollinators. But in reality, Muir and Vamosi found little overlap in the species that were visiting the different flowers. Only Great Camas shared a significant number of pollinators with other flowers.

In areas of the Garry Oak ecosystem that were invaded by Scotch Broom, Muir and Vamosi found that visitation rates to Great Camas were lower and significant quantities of Scotch Broom pollen were deposited on Great Camas flowers. At the same time, however, deposition of Great Camas pollen and fruit set actually increased.

Thus, while the mechanism is not entirely clear, **IT APPEARS THAT SCOTCH BROOM IS FACILITATING THE POLLINATION OF GREAT CAMAS.** In contrast, the invader had little detectable effect, positive or negative, on reproduction of either Blue-eyed Mary or Dovefoot Geranium.

"It appears that Scotch Broom is neither competing for pollination with native species nor facilitating the invasion of other exotics," sums up Vamosi. "While Scotch Broom management remains a priority for the conservation of the Garry Oak ecosystem, our study suggests that it is not having a harmful impact on pollination in the plant community."

Tales from an Invaded Grassland...

CANPOLIN researcher Chris Lortie and graduate student Ryan Spafford of York University examined the impact of the invasive plant spotted knapweed (*Centaurea stoebe*) on arthropod communities in grassland habitat in the western USA. They found that even very low levels of invasion led to measureable changes in the composition of the arthropod community. While the invader caused the abundance of some types of herbivores (such as predators and detritivores) to increase, generalist herbivores – including bees – were less abundant.

A *Lasioglossum* bee on spotted kapweed *(photo by R. Snyder)*

LOOKING FOR MORE INFORMATION?

Muir, J. 2013. Scotch broom (*Cytisus scoparius*, Fabaceae) and the pollination and reproductive success of three Garry oak-associated plant species. University of Calgary MSc Thesis, 161 pp.

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

THROUGH THE EYES OF A POLLINATOR

Floral patterns visible only to pollinators can have a big impact on foraging behaviour

Insect vision has long been a question of interest to entomologists. For insects that pollinate, visual cues help locate flowers and distinguish between different species of plants. But bee vision happens to be different than human vision, so what does a bee really see when it is foraging for floral resources?

"Unlike humans, bees can see ultraviolet light. Many flowers have UV absorbing pigments that create a floral pattern visible to bees," explains Jana Vamosi, a plant ecology researcher and member of CANPOLIN. "These patterns can be important in attracting pollinators and guiding them to the nectar source, and may influence other elements of pollinator behaviour as well."

Vamosi and U of Calgary honours student Jason Rae were interested in the impact of UV patterns on pollinators in one type of flower in particular - the yellow monkey flower, *Mimulus guttatus*. The plant is an important model species in studies of evolution and ecology.

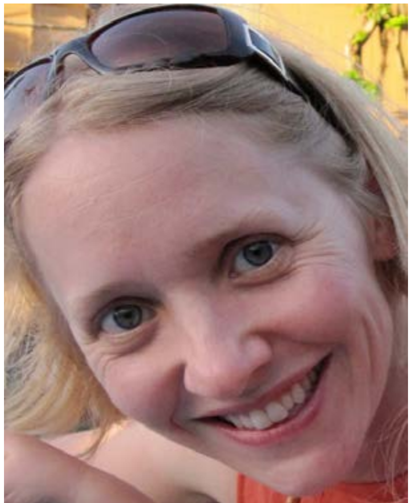
Using both regular and ultraviolet camera lens, Rae first photographed *M. guttatus* flowers in the field.

THE UV LENS REVEALED A MARKED CONTRAST BETWEEN THE LOWER PETAL, WHICH HAD LOW UV REFLECTANCE, AND THE SIDE AND TOP PETALS, WHICH HAD VERY HIGH UV REFLECTANCE. SURPRISINGLY, THE UV PATTERN DID NOT OVERLAP WITH OR COMPLEMENT THE FLOWER MARKINGS VISIBLE TO THE HUMAN EYE.

M. guttatus in the field (top) and as seen through a UV lens (bottom) *(photos by J. Vamosi)*

Rae then coated flowers with a light sunscreen spray to see how pollinators would respond if the UV pattern was disrupted. Control flowers received almost five times more visits from pollinators (which were mainly bumble bees in the study sites). The results, say Vamosi, suggest that the contrast provided by the UV pigments in *M. guttatus*

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits



CANPOLIN researcher Jana Vamosi studies plant evolution (photo courtesy of J. Vamosi)

helps pollinators locate the flowers against a sea of background vegetation.

Once a pollinator located a *M. guttatus* flower, UV reflectance continued to impact its behaviour. Bees visiting control flowers almost always oriented themselves correctly on a flower, landing on the lower petal with their heads pointed towards the source of nectar. In contrast, pollinators landing on treatment flowers oriented correctly only half of the time. The rest of the time they landed on the wrong petal or faced the wrong direction.

What happens next may be just as important, at least to *M. guttatus* flowers hoping to be cross-pollinated. Whether or not a bee oriented successfully on its first visit had a big impact on how many other monkey flowers it visited in the study area. Vamosi says that bees that stumbled in their first attempt to find nectar were 10 times more likely to leave the flower patch.

The results reveal the role of UV reflectance in the pollination ecology of *M. guttatus*. "Much progress is being made towards mapping the *M. guttatus* genome, and this could soon open the door to studies that examine how fast plant species can evolve to changing pollinator conditions. An important step can include estimating the number of genes involved in the development of floral traits such as UV reflectance," says Vamosi.

LOOKING FOR MORE INFORMATION?

Rae, JM and JC Vamosi. 2012. UV reflectance mediates pollinator visitation in *Mimulus guttatus*. Plant Species Biology, doi: 10.1111/j.1442-1984.2012.00375.x

DISCOVER THE HIDDEN WORLD OF FLORAL ADVERTISEMENTS

Curious about bee vision, CANPOLIN post-doctoral researcher Daniel Hanley created a fascinating database of floral images that demonstrate just how differently bees may see the world. To create the images, Hanley digitially transformed a collection of black and white floral photographs into normal full color images that depict how a flower is perceived by human vision, and how that same flower might be perceived by a pollinator that can see UV light. The colors and patterns on flower petals often appear far more contrasted to pollinators, illustrating how different types of flowers have evolved to get noticed by pollinators. The FLORAL IMAGE DATABASE is available online.

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

POLLINATION NETWORKS I

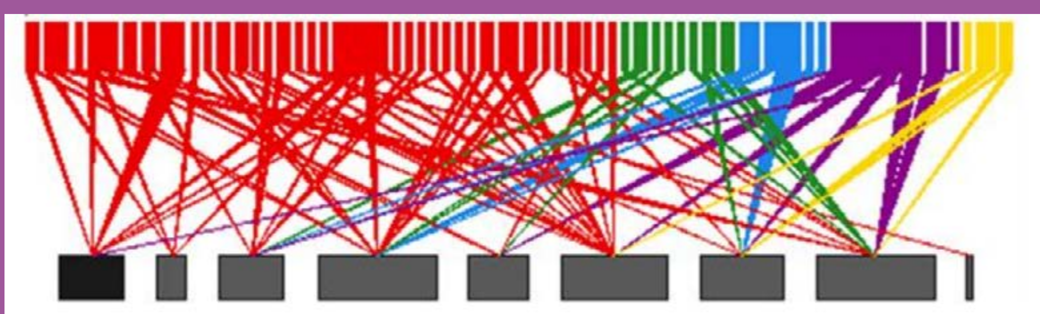
Networks as a tool for research and conservation

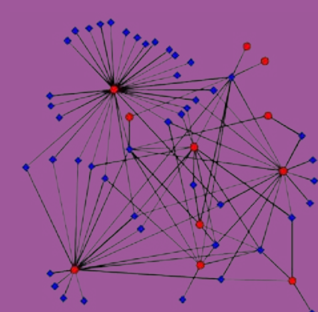
Making sense of ecosystems is a daunting task. Dozens, if not hundreds, of species are constantly engaged in a whirl of activity, and these activities affect one another in profound ways. Ecologists have come up with some creative ways to track and quantify the complex interactions among species. One such way is to construct "connectance networks" that visually depict the interactions between organisms. A familiar example is a food web, which illustrates the predator-prey relationships in a community and the flow of energy among organisms. Connectance networks provide a useful picture of a community and how it functions. Just as importantly, they can also show where there may be vulnerability to threats such as invasive species, climate change and habitat loss.

POLLINATION NETWORKS

In contrast to the more familiar food web, a pollination network has just two levels: plants and flower visitors. There is also a two way flow of benefits, with pollinators gaining nutrition and energy from plants in exchange for transporting pollen, which aids plant reproduction.

The diagrams below illustrate two different ways of depicting interactions between plants and insects in a pollination network.





FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

For pollination ecologists, networks are particularly useful for examining plant-pollinator communities. "Unlike biodiversity surveys, which only identify the plants and insects that are present, pollination networks let us assess the interactions that are actually taking place," explains Elizabeth Elle, leader of the ecosystems working group.

"WE CAN LEARN WHICH PLANTS DIFFERENT POLLINATORS ARE USING AS FOOD SOURCES, AND IF PARTICULAR PLANTS ARE RELIANT ON PARTICULAR POLLINATORS, INCLUDING THOSE AT RISK OF EXTINCTION. IN THIS WAY NETWORKS CAN TELL US IF A PARTICULAR PLANT-POLLINATOR COMMUNITY IS STABLE OR NOT."

Elle led a literature review[1] that determined which network measurements in particular are most useful for identifying vulnerable plant-pollinator communities. The first is **connectance**, the proportion of all possible interactions between species that are actually taking place. Highly connected networks tend to be more stable because there is more redundancy; in other words, if something happens to one plant or pollinator species, there is likely to be another species that can help perform the same function in the community. The second measurement is **interaction asymmetry**. The more "symmetrical" a network is, the more specialized interactions it has (e.g., pollinators that visit only a few types of plants, or plants that require a particular species of pollinator). These specialized interactions are more vulnerable to disruption compared to those involving generalists. Finally, **nestedness** is the extent to which interactions involving specialist bees or plants are "compartmentalized" within a wider array of interactions between generalists. The more nested a network is, the more likely it is that a change or disturbance will be confined to a single compartment, minimizing the effect on the rest of the network.


University of Manitoba graduate student Sarah Semmler in tall-grass prairie *(photo courtesy of S. Semmler)*

Several CANPOLIN researchers have used connectance networks to study the impacts of different types of disturbance on plant and pollinator communities across the country. In southern Ontario, for example, pollination networks were compared in former **agricultural fields** at different stages of succession According to Tom Woodcock at the University of Guelph, the average number of interactions per species in the network was greater in fields in a more advanced stage of succession, indicating that late succession pollination communities are more stable.

In Manitoba, pollination networks in **tall-grass prairie** were compared following another type of catastrophic disturbance: fire. The study, which was led by Anne Worley (University of Manitoba), Richard Westwood (University of Winnipeg) and graduate student Sarah Semmler, found that there was no difference in network

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

connectance or nestedness between sites that were burned 1, 5 or 10+ years ago, suggesting that pollination networks in tall-grass prairie are relatively resilient to fire.

In the **rough fescue grasslands** of southern Alberta, University of Calgary researcher graduate student Megan Evans, researcher Ralph Cartar, and Agriculture Canada ecologist Mark Wonneck investigated the effects of light and heavy livestock grazing on plant-pollinator communities in rough fescue prairie in landscapes of differing semi-natural amount. The study found that grazing had no effect on network connectedness or nestedness, although it could reduce the number of specialists – a finding that may have important implications for rare species at risk.

Megan Evans, a CANPOLIN graduate student at the University of Calgary, collects pollinators in the rough fescue grassland in Alberta *(photo by R. Cartar)*

Graduate student Sherri Elwell in shrubsteppe habitat in the BC interior *(photo by E. Elle)*

Further west yet, Elle and Simon Fraser University graduate student Sherri Elwell looked at the effect of grazing in endangered **shrubsteppe ecosystems** in British Columbia. While grazing did impact vegetation structure, they found that it had no significant impact on plant and pollinator diversity. Further analysis found that pollination networks in big sagebrush habitat were more resilient than networks in antelope-brush habitat, and that late-season networks were less vulnerable compared to other times during the season. "Knowing when and where grazing will have the least impact on pollinator communities is important knowledge for developing sustainable grazing regimes," notes Elle.

Finally, Elle and graduate student Grahame Gielens investigated network asymmetry in an endangered **oak-savannah** ecosystem in British Columbia. Larger networks in larger habitat fragments had more asymmetry,

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

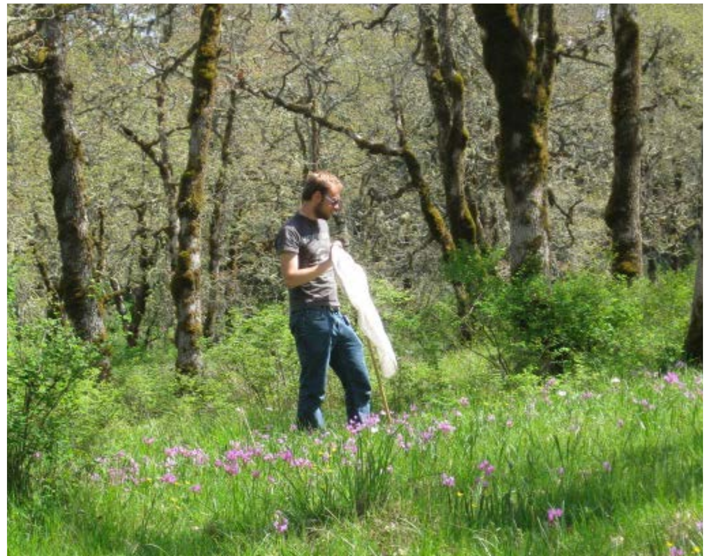
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

indicating they were more stable. These networks were also more likely to include both more specialized species, and super-generalist introduced plants and pollinators. Ironically, super-generalists are strong contributors to the asymmetry of large networks, and so invasive species removal plans may need to mitigate potential negative consequences for the interacting community.

These and other CANPOLIN studies (*see also p. 82*) are contributing to a rapidly growing body of literature on the use of pollination networks and increasing their value as a powerful tool for both research and conservation.



Graduate student Grahame Gielens in endangered oak-savannah ecosystem *(photo by E. Elle)*

[1] Part of special issue of the journal Botany (volume 90, issue 7) entitled "Pollination biology research in Canada: Perspectives on a mutualism at different scales" that features several articles from CANPOLIN researchers.

LOOKING FOR MORE INFORMATION?

Elle E, Elwell SL, Gielens GA. 2012. The use of pollination networks in conservation. Botany 90:525-534

Elwell SL. 2012. The effects of livestock grazing and habitat type on plant-pollinator communities of British Columbia's endangered shrubsteppe. MSc Thesis, Simon Fraser University, 120 pp.

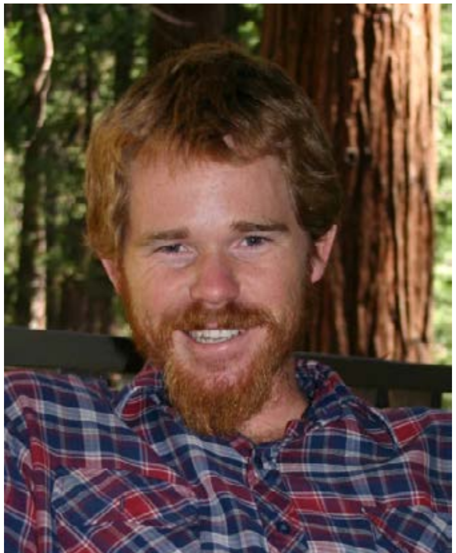
Evans MM. 2013. Influences of grazing and landscape on bee pollinators and their floral resources in rough fescue prairie. MSc Thesis, University of Calgary, 129 pp.

Gielens, GA. 2012. Pollen limitation and network asymmetry in an endangered oak-savannah ecosystem. MSc Thesis, Simon Fraser University, 101 pp.

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

POLLINATION NETWORKS II

Understanding what drives network structure



Post-doctoral fellow Scott Chamberlain examined the role of traits and phylogeny in the structure of pollination networks *(photo courtesy of S. Chamberlain)*

There is no question that pollination networks have become a practical tool for understanding plant-pollinator communities and how to protect them (see p. 80). But CANPOLIN researchers are also interested in understanding how the evolutionary history of plants and pollinators has shaped modern networks.

"Most pollination networks share certain structural similarities," explains CANPOLIN post-doctoral fellow Scott Chamberlain. "This suggests that there are common elements driving the arrangement of plant-pollinator interactions. It's likely that closely related species have evolved similar traits, and traits can exert a strong influence on network structure."

Traits affect networks because they determine which plants and animals

Tongue-length is an example of a bee trait that can influence plant-pollinator interactions and hence network structure *(photo courtesy of the USGS Bee Inventory and Monitoring Lab)*

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

can interact. For example, if an insect is not able to reach the nectar in a flower because its tongue is not long enough, that creates a barrier to their interaction. At the same time, some traits may be confined to a particular group of related species - thus linking evolutionary history to network structure. Evolutionary relationships between species are depicted through phylogenetic trees (see box), and the shape of the tree can provide information about the nature of those relationships.

CHAMBERLAIN WAS INTERESTED IN TWO QUESTIONS IN PARTICULAR: HOW DO PLANT AND POLLINATOR TRAITS AFFECT NETWORK STRUCTURE, AND DOES THE EVOLUTION OF PLANTS AND INSECT POLLINATORS LEAVE A SIGNATURE IN THE NETWORKS THAT CAN BE OBSERVED TODAY."

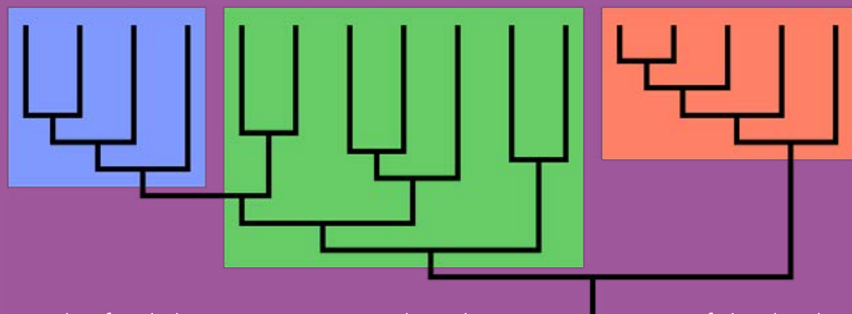
Working in collaboration with several CANPOLIN colleagues, Chamberlain analyzed dozens of networks from Canada and beyond. The group also ran simulations of pollination networks to explore artificially how altering certain phylogenetic variables affects network structure.

The study yielded some key pieces of information. The most important plant traits related to network structure are (a) mating system (i.e., if individual plants are male, female, or both), (b) growth form (woody or not), and (c) flower symmetry (bilaterally symmetrical flowers have hidden rewards and require specialized pollinators, while radially symmetrical flowers are more open and welcoming to all). In contrast, the most important pollinator traits were body size, with larger bees tending to be more specialized in their interactions with plants, and sociality. Social bees such as bumble bees interacted with more plant species overall compared to solitary species. Interestingly, pollinator traits were less important than plant traits in determining network structure.

Phylogenetic tree shape also influenced network structure. In general, species that were closely

THE TREE **OF LIFE**

Phylogenetic trees illustrate the evolutionary relationships between a group of species. The "trunk" of the tree represents a common ancestor in the deep evolutionary past, and each division of branches signifies a speciation event. The outermost tips of the branches denote species that exist in the present day. Trees may vary in shape depending on the rate of evolutionary change across the tree (e.g., balance), and variations in the timing of branching events.



Example of a phylogenetic tree. Large branches represent groups of closely related species, while those far apart on the trunk are more distantly related.

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

related phylogenetically tended to interact with similar sets of partners. Network connectance, which is related to the number of realized connections in a network (see pg. 78), was greater when plant phylogenies were more balanced (i.e., speciation events occurred relatively evenly throughout the tree, with different branches having a similar shape). In contrast, pollinator phylogenies did not significantly influence network connectance.

TAKEN TOGETHER, THE RESULTS SHOW THAT BOTH TRAITS AND PHYLOGENETIC HISTORY CONTRIBUTE TO INTERACTIONS WITHIN A NETWORK, ALTHOUGH THEY ARE LESS ABLE TO EXPLAIN VARIATION BETWEEN NETWORKS.

Chamberlain and colleagues also noted some mismatch between their computer simulations and network data from the field, indicating that future studies will require more complex approaches to fully explain network structure in nature.

"The more we can improve our understanding of the drivers of network structure, the more effective they will be as research tools," says Chamberlain.

LOOKING FOR MORE INFORMATION?

Chamberlain SA, Vasquez DP, Carvalheiro L, Elle E, and JC Vamosi . 2014. Phylogenetic tree shape and the structure of mutualistic networks. Journal of Ecology 102: 1234–1243.

Chamberlain SA, Cartar RV, Worley AC, Semmler SJ, Gielens G, Elwell S, Evans ME, Vamosi JC and E Elle. 2014. Traits and phylogenetic history contribute to network structure across Canadian plant-pollinator communities. Oecologia 176: 545-556.

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

GLOBAL CHANGE

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

SECRETS OF THE MUSEUM

Historical insect collections reveal several bee species in decline

Countless drawers containing hundreds of thousands of bee specimens lie in insect museums and private collections across North America, some dating back to the 1800's. These historical collections can be an invaluable source of information for researchers looking to see how bee populations have changed over time.

"IT IS REALLY DIFFICULT TO KNOW IF A SPECIES IS IN TROUBLE UNLESS YOU HAVE GOOD HISTORICAL DATA FOR COMPARISON," EXPLAINS SHEILA COLLA, A FORMER GRADUATE STUDENT AT YORK UNIVERSITY.

Historical bee collections are valuable tools to assess changes in species abundance and distribution *(photo courtesy of the Lyman Entomological Museum)*

Working with colleagues in the United States, Colla mined several insect collections in Canada and the United States looking for information on the distribution and abundance of 21 eastern species of bumble bees. In total, taxonomic and geographic data was collected from a total of 44,797 bee specimens collected between 1864 and 2009. The information was then used to measure the persistence and relative abundance of each species across the full range of their distribution.

The team found that 11 species in the *Bombus* genus are in decline. Of the 11 species found to be in decline, four are deemed "vulnerable", six are considered "endangered" and one is "critically endangered".

But the news was not all bad: the team also found that another eight species are stable or have even increased in abundance.

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

The bees most at risk tend to share similar characteristics. The most severely endangered species is a cuckoo bee, *Bombus variabilis*, which lays its eggs in the nests of other bumble bees to be raised by the host. Three other bee species in decline were also cuckoo bees. According to Colla, cuckoo species are sensitive to changes in the abundance of host bee species and are usually rarer than their hosts to begin with. (See p.52 for more information on how cuckoo bees can be used as indicators of bee community health.)

Other bee species most at risk tend to be long-tongued species with queens that emerge late in the season, such as the American bumble bee, B. *pensylvanicus*. Colla and colleagues also noted that species with smaller historical ranges were less likely to persist.

It is the first time data gathered from historical collections has been used to assess the current status of Nearctic bees across their entire native range. And while the need to better understand the causes of bee declines remains urgent, knowing which species are currently most at risk is an important step forward in protecting them.

The American bumble bee, *Bombus pensylvanicus*, one of the long-tongued species found to be in decline *(photo courtesy of the Packer Lab)*

LOOKING FOR MORE INFORMATION?

Colla, SR, F Gadallah, L Richardson, D Wagner and L Gall. 2012. Assessing declines in North American bumble bees (*Bombus spp.*) using museum specimens. Biodiversity and Conservation Biology DOI 10.1007/s10531-012-0383-2

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

BUMBLE BEE MYSTERY CONTINUES

Study finds that the primary suspect in bumble bee declines – pathogen spillover – is only part of the problem

Scientists and naturalists alike have noted a precipitous decline in several North American bumble bee species that began in the early 1990s. The population decreases appear to have begun shortly after the agricultural community started to use commercially-reared bumble bees to pollinate tomatoes and sweet peppers in greenhouses, leaving scientists to speculate that the two events may be linked.

"Artificially-reared bumble bees tend to carry higher levels of pathogens, and can easily escape from greenhouses through ventilation systems," explains CANPOLIN research Jeremy Kerr. "It is possible that commercial bees are contributing to the decline of wild bee populations by spreading disease outside of the greenhouse."

Commercial bumble bee hives in a greenhouse *(stock image)*

There is some circumstantial evidence to support this theory. For example, wild bumble bees near greenhouses tend to have higher pathogen loads. But scientists have not yet found a direct link between the advent of commercial greenhouse pollination and the observed population declines in native species.

To see if a connection could be more definitively established, Kerr and former graduate student Nora Szabo worked with colleagues

Bumble bees used in greenhouses can escape through vents and fans *(stock image)*

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

The yellowbanded bumble bee,
a species in decline now linked to
pathogen spillover from greenhouses
(photo by L. Richardson)

at York University, Yale University and the University of Connecticut. First, the group looked at more than 65,000 bumble bee records to compare changes in the ranges of three species: *Bombus terricola* (the yellowbanded bumble bee), *Bombus affinis* (the rusty-patched bumble bee) and *Bombus pensylvanicus* (the American bumble bee). They then examined agricultural census data from Canada and the US to determine if declines observed over the last three decades are linked to geographic areas with a high density of vegetable greenhouses.

The researchers found a connection between greenhouse density and population decline in two of the three bumble bee species: the yellowbanded bumble bee and the American bumble bee. However, there was no connection for the rusty-patched bumble bee, which has almost completely disappeared.

"THIS IS THE FIRST EVIDENCE LINKING DISEASE SPREAD FROM GREENHOUSES DIRECTLY TO THE DECLINES OF SOME BUMBLE BEE SPECIES," SAYS SZABO. "BUT IT ONLY PARTIALLY EXPLAINS THEIR PATTERNS OF DECLINE. THERE ARE STILL OTHER FACTORS AT PLAY."

To unravel what those other factors might be, the researchers also looked at two other common suspects of bee declines: pesticide use and habitat loss. Surprisingly, they found no significant relationship between areas with high levels of pesticide use or habitat loss and recent changes in bee distributions. "We know that habitat loss and pesticides have a negative impact on bumble bees. But when you consider their impact across the entire ranges of these three species, neither appears to be driving the current range shrinkage," says Szabo.

Kerr describes the results as a call to arms for more research. "We have seen major losses of some of our pollinator species and our study shows that those losses cannot be explained adequately," he says. "We can only speculate about why we're losing some of these species, but we can say with certainty that we need to solve the riddle of their declines quickly. Until we have a better understanding of the causes of decline, we cannot develop effective recovery strategies."

LOOKING FOR MORE INFORMATION?

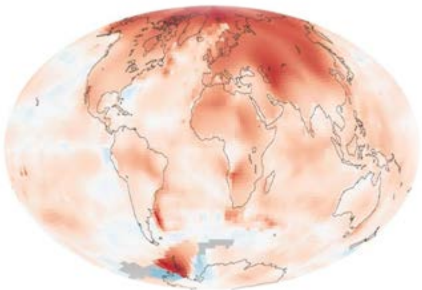
Szabo, ND, SR Colla, DL Wagner, LF Gall and JT Kerr. 2012. Do pathogen spillover, pesticide use, or habitat loss explain recent North American bumblebee declines? Conservation Letters 5: 232-239

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

KEEPING UP WITH CLIMATE CHANGE

Pollinator ranges are not shifting fast enough to keep pace with climate change

Global climate change has been called one of the greatest ecological challenges to ever face humanity. The sheer complexity and scale of the problem has made empirical studies almost impossibly difficult, but important progress is now being made. At the forefront of this research is Jeremy Kerr, a CANPOLIN researcher at the University of Ottawa and leader of the Prediction Working Group. Using vast amounts of information available in historical insect collection records, Kerr and his research team are developing innovative ways to analyze and predict the impacts of climate change on butterflies and bees.



Climate change will lead to significantly warmer temperatures in the 21st century *(image courtesty of NASA)*

Insect populations have always been largely at the mercy of the environment. Each species has a particular set of conditions – or "climate envelope" - in which it can survive. If a species can't shift its range or adapt fast enough to a changing environment, it is at risk of extinction. With the current climate change crisis, scientists expect temperatures at the southern boundary of a species' range to become too warm, causing the range to contract northwards. At the same time, temperatures at the northern boundary also warm, potentially extending the range to the north into new territory.

"That may sound encouraging, but colonization of new territory is fraught with difficulty," explains Kerr. "For a pollinator species to

Jeremy Kerr examining a butterfly specimen *(photo courtesy of the University of Ottawa)*

survive as it moves northward, it needs to have suitable food plants available as well. That means that success depends not only on the ability of a pollinator to disperse to new territory, but also on the ability of its host plant to colonize the new territory at the same time. "

Kerr and his team have developed a new type of model that sheds light on how of pollinator ranges

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

are shifting in response to climate change. The ground-breaking model incorporates not only environmental data, but also information about the biological processes that underpin range shifts as well, such as rates of pollinator reproduction and dispersal.

After applying the model to real-life data for 12 species of butterflies, the team was able to demonstrate how the model can be used to calculate the likelihood that a species will keep up with climate change by shifting its range.

"WE FOUND THAT THE CLIMATE ENVELOPES FOR THESE SPECIES ARE SHIFTING NORTHWARD AT AN AVERAGE RATE OF 3.25 KM PER YEAR AND THAT MANY OF THESE BUTTERFLIES, EVEN THOSE THAT ARE STRONG FLIERS, AREN'T KEEPING PACE WITH THE CHANGE. THE NET RESULT

The Eastern pine elfin is a butterfly species not expected to keep pace with climate change *(photo by M. Ostrowski)*

IS THAT THEIR RANGES ARE SHRINKING," SAYS KERR.

Kerr and colleagues are also looking at the impact of climate change on bumble bees. A study of hundreds of thousands of collection records from Europe and North America has revealed early evidence that climate change may have unexpected impacts on where bumblebee species are found on both sides of the Atlantic

"Just like butterflies, the ranges of many bumble bees have been affected by rapidly changing climates," notes Alana Taylor-Pindar, a post-doctoral researcher working with Kerr.

The models developed in Kerr's lab are being expanded to include such factors as land use change and other biologically relevant data, such as the time of spring emergence and breadth of diet.

"THE MORE WE CAN INTEGRATE BIOLOGICAL DATA WITH THEORY IN THESE MODELS, THE MORE POWERFUL THEY WILL BE AS PREDICTIVE TOOLS," SAYS KERR.

"Ultimately, they may serve as catalysts for the development of more effective conservation strategies to help save pollinators and the vital services they provide."

LOOKING FOR MORE INFORMATION?

Bedford, FE, RJ Whittaker and JT Kerr. 2012. Systemic range shifts lag among a pollinator species assemblage following rapid climate change. Botany 90: 587-597

Leroux, S, M Larrivee, V Boucher-Lalonde, A Hurford, J Zuloaga, JT Kerr, and F Lutscher. 2013. Mechanistic models for the spatial spread of species under climate change. Ecological Applications 23: 815-828

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

ECONOMICS

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

BEE-CONOMICS

An economic analysis ohighlights both challenges and opportunities faced by today's beekeepers

In dollar terms, apiculture makes a small dent in Canadian agribusiness, but the crucial role bee pollination plays in agriculture goes far beyond products of the hive. CANPOLIN researchers in working group 8 (Economics) led the first economic analysis of the Canadian beekeeping industry to better identify the challenges and opportunities faced by the industry.

According to WG8 leader Alfons Weersink, an economist at the University of Guelph, the study found that BEEKEEPING OPERATIONS IN CANADA ARE BECOMING FEWER, LARGER, AND BUSIER. Over the last 20 years, the number of beekeepers in Canada has fallen from 14,276 beekeepers in 1990 to 7,284 in 2010 – a decline of almost half. "It's a big drop that illustrates a major industry trend toward consolidation and the loss of hobby and small-scale beekeepers," says Weersink.

MORE THAN JUST HONEY...

Beekeeping is a multi-product industry. Bee colonies generate a number of saleable products, most notably honey, but also beeswax and specialty products such as royal jelly, propolis (resinous water-proofing material), bee pollen and even venom for medical use. Some products require extra effort and specialized equipment to gather. Beekeepers may also sell workers bees that are used to start other colonies, individual queens, or nucs (small colonies that include a queen and some related workers).

Many beekeepers also rent their hives to farmers who produce insect-pollinated crops. These "pollination services" are estimated to be worth up to $1.7 billion annually in Canada.

Although the number of hives is up in recent years (from 531,955 in 1990 to 617,264 in 2010), honey production has been in noticeable decline since the 1990's with the introduction of *Varroa* mites. Winter mortality has been unusually and devastatingly high in recent years – with as many as 35% of colonies perishing over winter. More and more, beekeepers are relying on the purchase of additional queen and worker bees to ameliorate winter losses and mortality caused by disease.

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

Still, Canada is a net exporter of honey, and average honey production in Canada is about 60 kg per hive, which is more than twice the world average. With a total of 34,000 tonnes of honey produced per year, Canada is the world's twelfth-largest producer of honey.

But honey production is just a drop in the bucket compared to the crucial role honey bees play in pollinating crops. The Canadian Honey Council estimates that the value of pollination services provided by honey bees is $1.3–$1.7 billion annually, nearly 20 times that of honey. Every year, 300,000 honeybee colonies, almost half of the total national stock, are used to pollinate canola fields alone. Weersink notes that the acreage of crops that depend on pollinators is growing steadily in Canada, creating an opportunity to grow the market for pollination services and expand the production and use of other managed bees, such as alfalfa leafcutter bees, bumble bees and blue orchard bees.

IN A SEPARATE STUDY, GRADUATE STUDENT LINA URBISCI FOUND THAT SIZE DOES MAKE A DIFFERENCE WHEN IT COMES TO THE PROFITABILITY OF APIARY OPERATIONS. SMALLER OPERATIONS (50 HIVES OR LESS) ARE MORE PROFITABLE PER COLONY. HOWEVER, THEY ALSO HAVE MORE VARIABLE PROFITS, WHILE LARGER OPERATIONS STABILIZE AROUND $200 PER COLONY. BEEKEEPERS WHO OFFERED TWO OR MORE GOODS OR SERVICES EARNED MORE ON A PER-COLONY BASIS.

Both studies are an important step in understanding the shifts in beekeeping and their implications for trade, agriculture, the environment, and the beekeeping industry itself.

The number of beekeepers in Canada has fallen by half over the last 20 years *(stock photo)*

NEED MORE INFORMATION?

Daly, Z, Melhim, A and A Weersink. 2012. Characteristics of honey bee and non-*Apis* bee (Hymenoptera) farms in Canada. Journal of Economic Entomology 105: 1130-1133

Urbisci, L. 2011. The economic effects of size and diversity on apiary profits in Canada. University of Guelph MSc Thesis, 87 pp.

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

APPENDICES

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

PROJECT INVENTORY

TAXONOMY

Key to the species of *Megachile* of Canada (Packer, York)

Key to the species of *Dufourea* of Canada (Packer, York)

Key to the species of *Ceratina* of eastern NA and description of a new species (Packer, York)

Key to Anthophorine bees (Packer, York)

Key to Melectine bees (Packer, York)

Revision of *Dialictus* in Canada (Packer, York)

Revision of the *Coelioxys* (Megachilidae) of Canada (Packer, York)

Revision of the Osmiini of Canada except for Osmia (Megachilidae) (Packer, York)

Revisions of Canadian Halictine bees (Packer, York)

Sampling and databasing of Canadian bees (Packer, York, with several others)

A catalogue and image-bank of the bees of Canada (Packer, York)

Barcoding the bees of Canada (Packer, York)

Trap-nesting bee biology (Packer, York)

Development of a user-friendly, web-based guide to flower flies (Marshall, U Guelph; Skevington, AAFC)

Development of a user-friendly, web-based guide to blow flies (Marshall, U Guelph)

Development of a web-based identification guide to cluster flies (Marshall, U Guelph)

A review of the flower fly genus *Ocyptamus* (Marshall, U Guelph; Skevington, AAFC)

A review of the flower fly genus *Platycheirus* (Marshall, U Guelph; Skevington, AAFC)

Revision of *Dasysyrphus* (Syrphidae) (Marshall, U Guelph; Skevington, AAFC)

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

Revision of *Chrysotoxum* (Syrphidae) (Skevington, AAFC)

Revision of *Sericomyia* (Syrphidae) (Skevington, AAFC)

Syrphidae specimen databasing (Marshall, U Guelph; Skevington, AAFC)

Flower fly "status of species" assessment (Marshall, U Guelph; Skevington, AAFC)

Reassessment of *Volucella bombylans* taxonomy (Syrphidae) (Skevington, AAFC)

Development of DNA barcode database for world Syrphidae (Marshall, U Guelph; Skevington, AAFC)

Revision of Conopidae (Skevington, AAFC)

Taxonomy and evolutionary biology of pollinating Lepidoptera (Sperling, U of Alberta)

Long term variation in bee abundance and diversity in Southern Ontario (Richards, Brock U)

Range mapping and prediction of *Xylocopa virginica* (Richards, Brock)

BEE HEALTH

Development of a network with diagnostics capacity for economically important pests and diseases of honey bees (Guzman, U Guelph, Pernal, AAFC, Currie, U Manitoba)

Analysis of colony losses in Canada (Currie, U Manitoba, Guzman, U Guelph, Pernal, AAFC)

Impacts of pathogens on honey bees (Currie, U Manitoba)

Control of Deformed Wing Virus by RNA Interference (Currie, U Manitoba)

Pathogen spillover in native pollinators (Currie, U Manitoba)

Impact and control of viruses on comb on honey bees (Currie, U Manitoba)

Impacts of pollen feeding on tolerance to poor quality carbohydrate stores and tolerance to pathogens (Currie, U Manitoba)

Assessment of new acaricides for control of *Varroa* mites (Currie, U Manitoba)

Assessment of new acaricides for control of *Varroa* mites (Pernal, AAFC; Guzman, U Guelph)

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

Pathogenic effects of *Nosema ceranae* and *N. apis* and induction of immune resistance in honey bees (Guzman, U Guelph)

Biocontrol of *Varroa destructor* with entomopathogenic fungi (Guzman, U Guelph)

Response of the small hive beetle to soil humidity and temperature conditions and methods of pest control (Fournier, Laval)

Integrated management of *Nosema* & detection of antibiotic residues (Pernal, AAFC)

Assessment freeze-dried garlic powder to promote honey bee health (Kevan, U Guelph)

Design and development of aerodynamic bottom-board to reduce thermal and respiratory distress and as possible dispenser for biocontrol agents (Kevan, U Guelph)

Epidemiology of *Varroa* mite infestations and colony collapse (Kevan and Eberl, U Guelph)

Impacts of new reduced-risk insecticides on bumble bees and leafcutting bees (Cutler, Dalhousie; Scott-Dupree, U Guelph)

Semi-field experiment assessing effects of acetamiprid and spinosad foliar sprays to lowbush blueberry on *Bombus impatiens* (Cutler, Dalhousie)

Field experiment assessing effects of exposure to neonicotinoid seed-treated corn on *Bombus impatiens* (Cutler, Dalhousie)

Pesticides in honey bee hives in the Maritimes: residue levels and interactions with *Varroa* and *Nosema* in colony stress (Cutler, Dalhousie)

Effect of Amitraz on Honey Bee Learning and Memory (Cutler, Dalhousie)

Development of a biomonitoring tool using biomarkers to detect intoxication of honey bees by pesticides (Chagnon, UQAM)

Development of methodology to determine the levels of dichlorvos insecticide in leafcutter bee incubators (Kevan and Purdy, U Guelph)

MANAGING POLLINATORS

Bumble bee biovectoring in greenhouse crops (Shipp, AAFC; Kevan, U Guelph)

Field crop evaluation of bee-vectoring technology of beneficial inoculants to enhance seed and fruit health, yield and quality (Kevan, U Guelph)

Bumble bees as biocontrol vectors for *Botrytis* control in blueberries (Cutler, Dalhousie)

Honey bee biovectoring: development of effective tracking dispensers (Kevan, U Guelph)

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

Floral scent and pollination of greenhouse tomatoes (Shipp, AAFC; Kevan, U Guelph)

***Bombus impatiens* behaviour on tomato flowers and its consequences for pollination** (Shipp, AAFC)

Imbibition rates of artificial nectars by honey bees and bumble bees (Kevan, U Guelph)

Learning and cognition in *Bombus impatiens* (Kevan, U Guelph)

Insect pollination in low atmospheric pressure environments (Kevan, U Guelph)

PLANT REPRODUCTION

Assessment of the fitness consequences of inbreeding in commercial lowbush blueberry stands (Schoen, McGill)

Factors influencing fruit yield in lowbush blueberry (Jesson, UNB; Schoen, McGill)

Establishment of a database to collect multi-year/multi-field information from blueberry growers (Jesson, UNB)

Mating system, clonal structure and pollination in BC blueberry species (Ritland, UBC)

Inheritance pattern and inbreeding in highbush blueberry (Vaccinium corymbosum) (Ritland, UBC)

Reproductive potential, success and pattern of paternity in a highbush blueberry research plot (Ritland, UBC)

Cultivar specific differences among highbush blueberry floral characteristics (Ritland, UBC)

Influences of neighbouring landscape type on pollinator community and pollen limitation of Vaccinium angustifolium (Sargent, U Ottawa)

The relationship between mycorrhizal and pollination of V. angustifolium (Sargent, U Ottawa)

Meta-analysis of the influences of habitat disturbance on plant reproductive success (Sargent, U Ottawa)

Long-term Natural Selection and Adaptive Evolution in Weedy Sunflowers (Reiseberg, UBC)

The self-incompatibility (SI) system of Leavenworthia alabamica (Schoen, McGill)

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

WIND POLLINATION

Interspecific pollen transfer and pollination effectiveness in southern Ontario meadows, shorelines, and open woodlands with an emphasis on wind pollinated species (Murphy, U Waterloo)

Pollen clumping and release mechanisms in anemophilic plants (Greene, Concordia; Ackerman, U Guelph)

Anemophilous pollen flux, deposition and fertilization (Greene, Concordia)

Predicting the date of anthesis onset in silver maple (Greene, Concordia)

Long distance pollen dispersal (Greene, Concordia)

Particle capture on a 2D cylinder subject to flow-induced oscillation in a cross flow: implications for wind pollination (Ackerman, U Guelph)

Including ecology in particle capture mechanisms: the effects of oscillation on particle capture in wind pollinated plants (Ackerman, U Guelph)

Morphometrics of anemophilous pollen and flowers/ receptive surfaces (Ackerman, U Guelph)

Establishment of LTER network for anemophilious pollination (Greene, Concordia)

ECOLOGY
AGROECOSYSTEMS

Pollination in lowbush blueberry under different pesticide inputs (Cutler, Dalhousie)

Inter- and intra-species and clonal pollen compatibility in lowbush blueberry inputs (Cutler, Dalhousie)

Interactions between plant limitations, pollinator diversity and yield in lowbush blueberries (Cutler, Dalhousie)

Nocturnal pollinators of wild blueberry (Cutler, Dalhousie)

Bee diversity and pollination of managed and non-managed blueberry on the island of Newfoundland (Hermanutz, Memorial; Cutler, Dalhousie)

The effects of landscape and agricultural practices on pollination, bee diversity, and yield in highbush blueberry (Elle, SFU)

Diversity and abundance of pollinators in lowbush blueberries in QC: effect of border distance and wind break (Fournier, Laval)

Effects of landscape and managed pollinators on wild bee communities and canola pollen deposition (Cartar, U Calgary)

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

Effects of farm type on the ecology of pollinators in Eastern Ontario (Mineau, Carleton)

Landscape structure, crop diversity and pollination (Mineau, Carleton)

ECOLOGY *FORESTS*

Assessing the effect of forest loss on habitat heterogeneity and insect pollinator communities in Algonquin Provincial Park, Ontario (Kevan, U Guelph)

The effects of pollinators and sex ratios on the evolution of life-history traits in *Aralia nudicaulis* (Dorken, Trent)

Rubus pollination in forested landscapes: landscape drivers of pollinator diversity and consequences for raspberry pollination and fruit production (Dorken, Trent)

Patterns of pollinator diversity and seed set in forest silviculture gaps (Nol, Trent)

Phylogenetic relatedness and plant invader success in Garry Oak meadows (Vamosi, U Calgary)

How does diversity affect pollen limitation and plant-pollinator interaction networks in the Garry Oak Ecosystem? (Elle, SFU)

Pollinator guild use of natural versus man-made landscapes surrounding Garry Oak Ecosystem fragments on Vancouver Island BC (Elle, SFU)

Landscape and habitat impacts of logging on the reproductive performance of understory plants pollinated by bumble bees in foothills forest (Cartar, U Calgary)

ECOLOGY *GRASSLANDS*

Influences of landscape and grazing regime on bee pollinators and their floral resources in rough fescue prairie (Cartar, U Calgary)

The effects of grazing intensity on plant and pollinator community interactions and diversity in Antelope-brush shrubsteppe of the South Okanagan (Elle, SFU)

Assessment of pollinator services in tall grass prairie (Worley, U Manitoba; Westwood, U Winnipeg)

Plant-pollinator interactions and pollinator services to flowering plants in tall grass prairie (Worley, U Manitoba; Westwood, U Winnipeg)

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

ECOLOGY
ARCTIC, BOREAL AND ALPINE

Pollinator and insect biodiversity in arctic and boreal forest ecosystems (Kevan, U Guelph)

Spatial dynamics of pollination in dioecious *Shepherdia canadensis* **(Elaeagnaceae) in Yukon, Canada** (Nol, Trent)

Cushion plants in the alpine of BC: systemic review, trophic facilitation and pollen limitation (Lortie, York)

Phylobetadiversity within subalpine communities (Vamosi, U of Calgary)

The effects of turnover in plant-pollinator interactions on diversity of Scrophulariaceae in alpine meadow communities (Vamosi, U of Calgary)

The role of pollination in influencing the altitudinal range limits of plants (Eckert, Queen's U)

ECOLOGY
URBAN AND DEGRADED HABITATS

Diversity and abundance of urban pollinators (Kevan, U Guelph)

Pollinator monitoring in degraded ecosystems (Kevan, U Guelph)

Development of pollination connectance webs along a successional gradient in former agroecosystem (Kevan, U Guelph)

ECOLOGY
POLLINATION OF SPECIES OF INTEREST

Pollination ecology and the floral rewards of *Vaccinium myrtilloides* **and** *V. vitis-idaea* **(Ericaceae) in Saskatchewan** (Davis, U Saskatchewan)

Pollination ecology of Queen Anne's lace (Hunter, Brock)

Flower visitors to a species of concern in Ontario – *Ptelea trifoliata* (Kevan, U Guelph)

ECOLOGY
ECOSYSTEM FUNCTIONING

Species and phylogenetic heterogeneity in pollinator visitation affects selfing and seed production in an island system (Vamosi, U Calgary)

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

Ecosystem function provided by pollinator diversity (Vamosi, U Calgary; Elle, SFU)

Pollination networks and population genetics in fragmented habitats (Kevan, U Guelph)

Effect of microclimate on pollinators and ornamental plants (Kevan, U Guelph)

An evaluation of latent Dirichlet allocation in the context of plant-pollinator Networks (Ali, U Guelph)

Dirichlet multinomial regression in the context of modeling pollination networks (Ali, U Guelph)

Monte Carlo methods for studying network metrics (Ali, U Guelph)

Incorporating sampling weights into models for pollination networks (Ali, U Guelph)

Comparing counts of coevolutionary events between two groups of host-symbiont cophylogenies (Ali, U Guelph)

Cross-network analysis of pollinator diversity (Elle, SFU; Vamosi, U Calgary)

Pollinator monitoring – Eastview Landfill and Waynco aggregate pit (Kevan, U Guelph)

Pollinating insects at Norfolk Alternative Land Use Services (ALUS) restoration projects (Kevan, U Guelph)

Pollinator-plant interactions and community dynamics (Lortie, York)

Bee recolonization of a newly restored landfill sites in Niagara (Richards, Brock U)

The effect of *Cytisus scoparius* on pollen limitation within Garry Oak Communities (Vamosi, U of Calgary)

GLOBAL CHANGE

Land use change - climate change interactions on butterfly range shifts (Kerr, U Ottawa)

Bumblebee phenological shifts across North America due to climate change and land use change (Kerr, U Ottawa)

Cross-continental range margin shifts in bumble bees along species niche and range limits (Kerr, U Ottawa)

Phenological shifts in butterflies across Canada in the past century (Kerr, U Ottawa)

Mechanistic dispersal models for butterflies during climate change (Kerr, U Ottawa)

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

ECONOMICS

Economic analysis of bee farms in Canada (Weersink, U Guelph)

Impacts different pest management practices on beekeepers' productivity (supply of pollination) (Weersink and Hailu, U Guelph)

Valuation of pollination services: a proposed framework for future analysis (Weersink, U Guelph)

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

WHO'S WHO IN CANPOLIN

Researchers *(in alphabetical order)*

Ackerman, Joe (U Guelph)
Ali, Ayesha (U Guelph)
Cartar, Ralph (U Calgary)
Chagnon, Madeleine (UQAM)
Currie, Rob (U Manitoba)
Cutler, Chris (Dalhousie U)
Davis, Art (U Saskatchewan)
Dorken, Marcel (Trent U)
Eberl, Hermann (U Guelph)
Eckert, Chris (Queen's U)
Elle, Elizabeth (Simon Fraser University)
Fournier, Valerie (Laval U)
Greene, David (Concordia U)
Guzman, Ernesto (U Guelph)
Hailu, Geta (U Guelph)
Hermanutz, Luise (Memorial U)
Hunter, Fiona (Brock U)
Jesson, Linley (U New Brunswick)
Kerr, Jeremy (U Ottawa)
Kevan, Peter (U Guelph)
Marshall, Stephen (U Guelph)
McNeil, Jeremy (U Western Ontario)
Mineau, Pierre (Environment Canada)
Murphy, Stephen (U Waterloo)
Nol, Erica (Trent U)
Packer, Laurence (York U)
Pernal, Stephen (AAFC)
Richards, Miriam (Brock U)
Rieseberg, Loren (U British Columbia)
Ritland, Kermit (U British Columbia)
Sargent, Risa (U Ottawa)
Scott-Dupree, Cynthia (U Guelph)
Schoen, Daniel (McGill U)
Shipp, Les (AAFC)
Skevington, Jeff (AAFC)
Sperling, Felix (U Alberta)
Thomas, Vernon (U Guelph)
Thomson, James (U Toronto)
Vamosi, Jana, (U Calgary)
Weersink, Alfons (U Guelph)
Westwood, Richard (U Winnipeg)
Worley, Anne (U Manitoba)

Research Associates

Sheffield, Cory (York U)
Woodcock, Thomas (U Guelph)

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

Graduate Students, Post-Docs and Technicians

Adderley, Lorraine
Albert, Jen
Andrachuk, Heather
Andrews, Krysta
Aras, Philippe
Bahreini, Rasoul
Baldwin, Sarah
Balsdon, Jennifer
Beaunoyer, Geneviève
Bennett, Nicholas
Bernier, Martine
Bobiwash, Kyle
Borges, Daniel
Button, Lindsey
Callaghan, Liam
Chamberlain, Scott
Chantha, Sier-Ching
Cheryomina, Mariya
Colla, Sheila
Craig, Pam
Crea, Cathy
Daly, Zach
Davila, Yvonne
De Silva, Nick
Desai, Suresh
Dombroskie, Jason
Drummond, Emily
Dufour Tremblay, Geneviève
Dumesh, Sheila
Ellis, Deanna
Elwell, Sherri
Evans, Megan
Fulton, Melissa
Gadallah, ZuZu
Gavreau, Sophie,
Gervaise, Amelie
Gibson, Joel
Gielens, Grahame
Girard, Melissa
Govers, Gwyn
Gradish, Angela
Gunderson, Sarah
Haapalainen, Tiia
Hajdur, Katherine
Hanley, Daniel
Hamiduzzaman, Mollah
Hargreaves, Anna
Herman, Adam
Horn, Marianna
Hotte, Thomas
Huber, Gwen
Hubner, Sariel
Ibrahim, Abdullah
James, Joanna
Jewess-Gaines, Adam
Johnson, Sarah
Joly, Simon
Kane, Nola
Kastner, Martin
Kelly, Paul
Koleoglu, Gun
Krick, Julian
Kutby, Rola
Larose, Marc-André
Larrivee, Max
Leon Cordero, Rodrigo
Leroux, Shawn
Lin, Peter
Lin, Yu
Locke, Michelle
MacInnis, Courtney
MacInnis, Gail
MacIvor, Scott
Malik, Pankhuri
Mancuso, Kristen
Manning, Paul
Matheson, Sarah
McConnell, James
McGowan, Janine
McGrath, Darby
McGraw-Alcock, Andrea
McKechnie, Irene
McLeod, Kylie
McTavish, Mike
Melathopoulos, Andony
Melhim, Almuhanad
Merilo, Mark
Miranda, Gil
Mirwan, Hamida
Mitra, Ombor
Mohan, Murali
Moisan De Serres, Joseph
Moore, Charlotte
Morse, Andrew
Muir, Jennifer
Mustafa, Ghulam
Nardone, Erika
Naroditsky, Liora
Neame, Lisa

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

Nicholls, Emony
Normandin, Etienne
O'Neail, Dan
Ogutcen, Ezgi
Onerfuko, Tom
Ostevik, Kate
Parsons, Graham
Poon, Kenneth
Proctor, Eleanor
Proshek, Ben
Ramanaidu, Krilen
Ratti, Vardayani
Ratti, Vardayani
Rattie, Claudie
Rayome, Donnie
Reeh, Kevin
Reeh, Kevin
Reid, Anya
Rigney, Christa
Robson-Hyska, Cole
Rousseau, Andrée
Roussy, Anne-Marie
Rowe, Genevieve
Salehi, Bahrain
Scascitelli, Moira
Semmler, Sarah
Siegwart-Collier, Laura
Sinia, Alice
Sloan, Heather
Spafford, Ryan
Sproule, Jason
Stephens, Danielle
Straka, Jason

Sudarsan, Ranga
Szabo, Nora
Taylor-Pindar, Alana
Thompson, Cody
Timerman, David
Trant, Andrew
Turner, Kathryn
Urbisci, Lina
Valizadeh, Pegah
Van den Heever, Johan
Villa, Sandra
Villalobos, Soraya
Villier, Arnaud
Walker, Jessica
Wilkes, Margie
Woodcock, Thomas
Wray, Julie
Yeuh, Hesther
Young, Andrew
Zink, Lindsay

Plus a small army of undergraduate summer assistants...

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

GOVERNANCE

Board of Directors

Kraft Sloan, Karen (Chair), Econexus
Kevan, Peter, University of Guelph
Livernois, John, AVPR, University of Guelph
Breau, Anne, Canadian Museum of Nature
Borden, John, Contech Inc.
Saindon, Gilles, Agriculture and Agri-Food Canada
Vaissière, Bernard, National Institute for Agricultural Research
Davies Adams, Laurie, Pollinator Partnership
Lafrenière, Rhéal, Manitoba Agriculture, Food & Rural Development
Packer, Laurence, York University
Janidlo, Alison, NSERC *(non-voting)*
Bates, Sarah, CANPOLIN *(non-voting)*

Scientific Advisory Committee

Kevan, Peter (Chair), Scientific Director
Packer, Laurence, York University
Schoen, Dan, McGill University
Elle, Elizabeth, Simon Fraser University
Weersink, Alfons, University of Guelph
Kerr, Jeremy, University of Ottawa
Potts, Simon, University of Reading
Buchmann, Steve, Consultant
Drexler, David, Bayer CropScience
Richards, Ken, Agriculture and Agri-Food Canada
Janidlo, Alison, NSERC *(non-voting)*
Bates, Sarah, CANPOLIN *(non-voting)*

Board of Directors meeting at the University of Guelph in May 2011 *(photo by A. Janidlo)*

Working Group Leaders*

Packer, Laurence - Working Group 1
Currie, Rob - Working Group 2
Schoen, Dan - Working Group 3
Greene, David - Working Group 4
Elizabeth Elle - Working Group 5
Kerr, Jeremy - Working Group 7
Weersink, Alfons - Working Group 8

**Working Group 6 was eliminated prior to the launch of the Network.*

Network Secretariat

Kevan, Peter, Scientific Director
Bates, Sarah, Network Manager
Charles, John, Network Assistant (2014)
Dawson, Cara, Network Assistant (2012)
McGraw-Alcock, Andrea, Network Assistant (2009-2011)

FOREWORD

TAXONOMY
Know your Pollinators
The “Other” Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario’s “Green Arc”

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who’s Who in CANPOLIN
Partners
Credits

PARTNERS

Abacus Consulting
Aboriginal Affairs and Northern Development Canada
Agriculture and Agrifood Canada
Alberta Beekeepers Commission
Alberta Conservation Association
Alberta Crop Industry Development Fund
Arctic Net/CiCAAT
Atlantic Organic Berry Network
Bayer CropScience
Bee Maid Honey
Bee Vectoring Technology
Biobest Canada
Bleuets NB Blueberry
Bragg Lumber Co
British Columbia Blueberry Council
Brock University
Canadian Bee Research Fund
Canadian Centre for DNA Barcoding
Canadian Foundation for Innovation
Canadian Honey Council
Carleton University
Centre de recherche en sciences animales de Deschambault
College of the North Atlantic
Concordia University
Conservation Council of British Columbia
CropLife
Dalhousie University
Dow Agrosciences
DuPont
Entomogen

ABOUT OUR PARTNERS

NSERC-CANPOLIN was funded primarily by the Natural Sciences Engineering and Research Council. Most Network projects were also supported by other agencies and/or private sector partners with cash and/or in-kind support, while numerous individual growers and beekeepers across the country generously provided access to field sites, bee hives and other resources. Partner universities also made significant contributions to CANPOLIN through graduate student support, infrastructure and additional operating funds. NSERC-CANPOLIN thanks all of its partners and supporters for helping to make this extraordinary network possible.

Environment Canada
Genome Canada
Government of Brazil
Government of Canada
Government of Korea
Government of Manitoba
Government of Ontario
Government of Saudi Arabia
Government of the Northwest Territories
Greenway Blooming Centre
Helen Peacock Foundation
International Polar Year

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

International Society of Aboriculture
Jasper Wyman and Sons
Koppert Biological Systems
Manitoba Beekeepers
Manitoba Conservation Grant
Manitoba Hydro
Manitoba Sustainable Development Fund
McGill University
Medivet Pharmaceuticals
Memorial University
Meridian Credit Union
Monsanto
National Research Council
National Sciences Foundation (US)
Nature Conservancy of Canada
Nelson Aggregate
New Brunswick Beekeepers Association
New Brunswick Department of Agriculture and Aquaculture
Newfoundland and Labrador Department of Environment & Conservation
Newfoundland and Labrador Department of Natural Resources
Norfolk Alternative Land Use System
North American Pollinator Protection Campaign
Northeast Seed Management Association
Nova Scotia Beekeepers Association
Nova Scotia Department Agriculture
OmniTRAX
Ontario Centres of Excellence
Ontario Ministry Natural Resources
Ontario Ministry of Agriculture, Food and Rural Affairs
Ontario Beekeeper's Association
Ontario Fruit and Vegetable Growers Association
Parks Canada
Prince Edward Island Wild Blueberry Growers' Association
Quebec Beekeepers Federation
Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec
Queens University
rare Charitable Research Reserve
Regulus Investments
Royal Saskatchewan Museum
Saskatchewan Alfalfa Seed Producers Association
Saskatchewan Beekeepers Association
Seeds of Diversity
Simon Fraser University
Syngenta Crop Protection Inc.
TD Friends of the Environment
Trent University
United States Department of Agriculture
United States Department ofof Defence
Université Laval
University of Alberta
University of British Columbia
University of Calgary
University of Guelph
University of Manitoba
University of New Brunswick
University of Ottawa
University of Saskatchewan
University of Toronto
University of Waterloo
University of Western Ontario
University of Winnipeg
Western Garfield Foundation
Wild Blueberry Producers Assoc. of Nova Scotia

FOREWORD
TAXONOMY
Know your Pollinators
The "Other" Pollinators
BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math
MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space
PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination
WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"
ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II
GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change
ECOMONICS
Bee-conomics
APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits

POLLINATION NATION

Credits

Editor: Sarah Bates
Contributors: Sarah Bates, Thomas Woodcock
Design: Red Pencil Design

ISBN 978-0-9940532-0-6

Funding for this digest was provided by the Strategic Network Enhancement Initiative (NSERC).

For more information about NSERC-CANPOLIN, visit: www.uoguelph.ca/canpolin

FOREWORD

TAXONOMY
Know your Pollinators
The "Other" Pollinators

BEE HEALTH
New Treatment Helps Fight Virus
Fungus Combats Deadly Parasite
An Old Foe in New Form: *Nosema*
Know your Enemy: the Small Hive Beetle
Bees and Biomarkers
Bees and Math

MANAGING POLLINATORS
Brainy Bumble Bees
Super Bees and Biovectoring
Bees in Space

PLANT REPRODUCTION
Playing Darwin
Evolution of Selfing in Plants
High Cost of Self-Pollination

WIND POLLINATION
Blowing in the Wind
Pollination in Ontario's "Green Arc"

ECOLOGY
From Dump to Diversity
Thieving Bees
Measuring Pollination Services
Managing Forests for Pollination
Native Bee Diversity on Farms
Lowbush Blueberry Pollination
Highbush Blueberry Pollination
Nocturnal Pollination
Pollinators at the Top of the World
Alien Invasion
Through the Eyes of a Pollinator
Pollination Networks I
Pollination Networks II

GLOBAL CHANGE
Secrets of the Museum
Pathogen Spillover & Bumble Bee Decline
Keeping up with Climate Change

ECOMONICS
Bee-conomics

APPENDICES
List of Projects
Who's Who in CANPOLIN
Partners
Credits