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Common Loons,
Pesticides & Pollinators,
Bird Banding

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Photo by Bill Byrne/MassWildlife

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FEATURES

On the Cover: A Common Loon prepares to feed a young Smallmouth Bass to one of its chicks. Currently, there are about 40 pairs of breeding loons in the state with the core population found in north central Massachusetts, focused in and around the Quabbin and Wachusett Reservoir areas. Photo by Bill Byrne/MassWildlife

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Of Pollinators, Food and Poisons

Photo/honeybees © Sarah Rydgren

by Richard A. Callahan

In 1798, Thomas Malthus predicted the human population would shortly outgrow its food supply unless the population was controlled. At that time there were about 800 million people in the world; today there are 7.6 billion. What happened? Why aren't we all starving? The answer of course is that Malthus did not foresee the revolution in food production. Agricultural mechanization, intensive monoculture practices, hybrid plant development, synthetic fertilizers, and the development of pesticides dramatically increased crop yields.

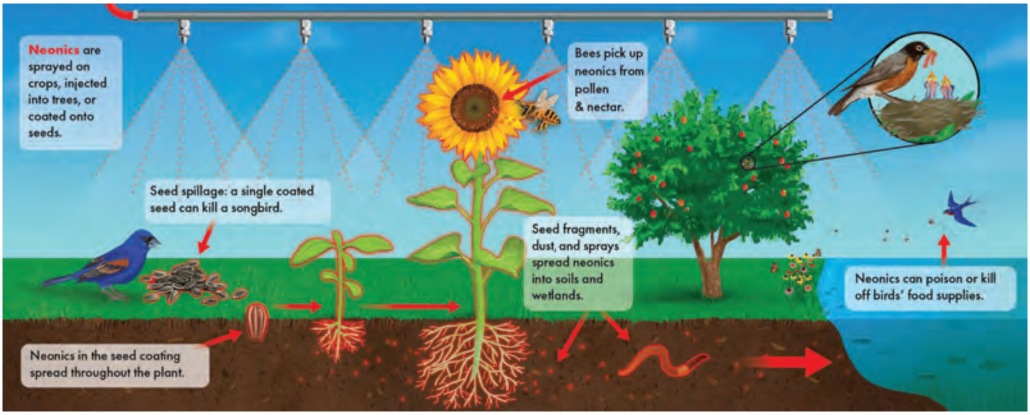
Although these changes allow the human population to increase and contribute to improved nutrition since Malthus' day, these developments are not without significant negative effects. The effects of altering plant genetics, synthetic chemical use, and mechanization are interrelated, impacting various environments and their species in unique and combined ways. Life is interrelated; life is complex.

Colony Collapse Concerns

Consider the following agricultural honeybee problem. Around 2006, beekeepers reported unusually high losses of 30–90 percent of their hives. The symptoms didn't match the usual beehive mortality factors. Worker bees were suddenly and inexplicably abandoning their hives, leaving

Examples of consumer products containing the insecticide Imidacloprid.

Neonic Insecticides and the Ecosystem



Graphic © American Bird Conservancy

Figure 1. The water-soluble nature of Neonicotinoid insecticides allows them to be taken up by the roots of plants, absorbed through leaves and stems, picked up by pollinators collecting nectar and pollen, and carried away from the application site by ground water where they can persistent and accumulate in the environment for months to years. Neonics can also poison or kill off avian food supplies and directly kill songbirds that ingest treated seeds.

their brood and queen behind. Without worker bees to bring food, guard the hive or clean it, the queen and larval bees left behind cannot sustain themselves and they die. This bee colony loss was named Colony Collapse Disorder (CCD). Because pollinating honeybees are a critical part of agricultural food production, the effort to discover the cause or causes of CCD went into high gear. There are many theories about the cause or causes of CCD. One includes effects of honeybee exposure to crops treated with pesticides.

About eight years ago Alex Lu, then at Harvard University, Ken Warchol and I embarked on measuring the effects of low levels of Imidacloprid (imi)—the most widely used neonicotinoid insecticide—on European honeybees (*Apis mellifera*). We wanted to determine if imi might be a cause of CCD.

Neonics Explained

Neonicotinoid insecticides, often referred to as neonics, are derived from nicotine, a natural antibiotic produced by the tobacco plant to defend itself from insects. (People using nicotine would do well to keep this fact in mind.) You may know that penicillin is a natural antibiotic product, derived from a mold that destroys competing bacteria. Just as penicillin was chemically altered into a family of powerful antibiotics; nicotine was altered into a series of insecticidal antibiotics and called Neonicotinoid insecticides. Penicillin and other antibiotics have side effects that are unrelated to their intended use. Similarly, neonics applied directly to the environment have side effects at low concentration levels that affect animals that come in contact with them. Neonics are the most widely used class of insecticide in the world. It is estimated that four million pounds of neonics were applied to 140–200 million acres in the lower 48 states in 2014; this is close to 10% of the entire country.

Unlike most other insecticides, neonics are water-soluble, which allows them to be taken up by the roots as well as absorbed through leaves and stems (Figure 1, pg. 19). Systemically, neonics are incorporated into all structures; roots, seeds, nuts, nectar, leaves, fruit and pollen. Once inside a plant, neonics are protected and can persist for years. Anything feeding on any part of a treated plant (including humans) ingests neonics.

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Neonics have been found in virtually every aquatic and terrestrial environment. A typical treated corn seed absorbs 5% of the neonic coating with 95% going into the soil and ground water. Dissolved in ground water neonics are transported away from the site of application; finding its way into trees, herbaceous plants, ditches, creeks, and rivers. Neonics persist in soils anywhere from months to years, causing the perennial vegetation surrounding treated fields and lawns to accumulate high concentrations after repeated treatments.

We designed an experiment to test the effects of long term exposure of honeybees to very small amounts of imi. The method involved exposing honeybees to imi in testing protocols called bioassays. Bioassays measure the response or reaction of animals to increasing concentration levels of a chemical. Bioassays using high dosages are used to determine the lethal or killing dosage of a chemical under differing conditions. Bioassays using lower dosages over prolonged periods of time are used to determine the presence of sub-lethal or damaging side effects, often called chronic toxicity. The advantage of bioassays is that they test the effects of the chemical simultaneously on all the complex and interacting systems of the living organism. When testing for sub-lethal toxicity levels it was vital to expose beehive populations to imi for at least an entire foraging season. It was also necessary to expose bees and measure their reaction to a range of imi dosages, from the highest concentration the organism could possibly encounter down to levels commonly found in the environment. The higher exposure levels help identify chronic symptoms, and if toxicity is not found, ensure safety at lower levels.

In our initial experiment we placed five hives in four testing locations. One hive at each location was fed one of five concentrated sugar solutions containing anywhere from zero (control/untreated hives) to high concentrations of imi (treated hives) over 13 weeks. The hives receiving the lowest concentrations received a total of 18/100,000 of an ounce per beehive over the entire summer foraging season. The highest dose hives received twenty times this amount.

Unexpected Results

Like butterflies and moths, bees transition from larval, pupal and then to adult life stages. Bees pupate for two weeks and in the summer live as adults for four to five weeks. Beehive reproduction is an important indicator of hive health. Honeybee hive populations normally peak in early summer (up to 50,000 bees) and then decline into fall (20,000 bees). By counting the pupae in all hives every two weeks over a three-month period we were able to accurately monitor the number of bees in each hive. We expected some toxic symptoms to occur among bees at least in our higher dose treatments, but after treating hives very aggressively for 13 weeks there appeared to be no differences between any of the hives. Our original hypothesis was that hives receiving the highest concentrations of imi would result in summer hive mortalities. This did not happen. Regardless of the insecticide dosage, all hives showed similar egg production, brood rearing success, foraging success and general hive vigor. We almost terminated the experiment at this point thinking there were no sub-lethal side effects to be found with imi. Luckily we decided to monitor the hives through the winter and following spring.

Fourteen weeks after we finished feeding imi, we observed treated hive populations starting to die. Hive mortality continued for nine weeks, an unanticipated occurrence (Figure 2, pg. 22). One hive treated at double the lowest dosage survived and one untreated hive died. These results indicated that even hives fed the lowest doses over an entire summer prevented bees from successfully surviving through winter.

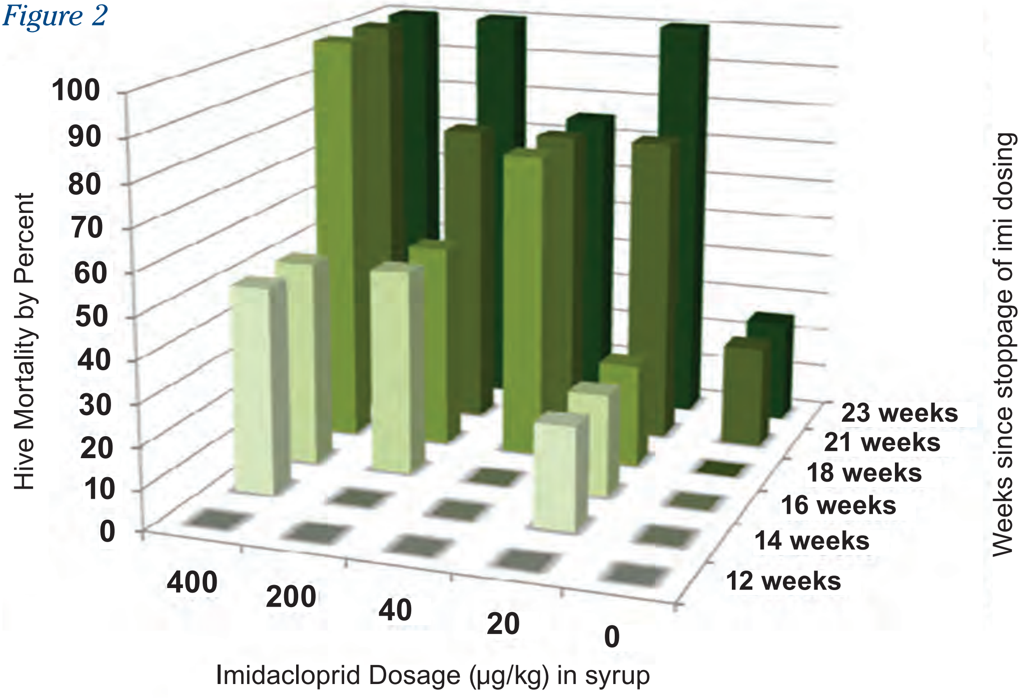
However in March, when we took the hives apart, we encountered a bigger surprise. Normally in New England dead bees accumulate over the winter in beehives because it is too cold for worker bees to remove them. As expected, in the untreated hives we saw thousands of dead bees stuck between the honeycombs with a large mat of corpses due to natural over-winter attrition at the bottom of those hives. What was unexpected was that in contrast, all of the imi-treated hives were almost empty. As we opened each dead treated hive there were almost no bees to be found. Several hives contained a remnant cluster of dead bees surrounding the dead Queen but tens of thousands of bees were gone. Instead of dying in the hive as normal bees do in New England winters, the bees treated with imi left the hive and most certainly had died. Our experiment showed that the imi treatment had caused a behavioral change (hive abandonment) in the bees that is associated with Colony Collapse Disorder.

Ours was the first study to treat hives of bees with an insecticide for an entire season and one of the first studies to show behavioral changes in bees associated with imi treatment. We repeated this experiment two years later with different sugar regimes and duplicated the data. Numerous other studies have subse-

Photo courtesy of Richard Callahan

A beehive frame containing many bee pupae and adult bees.

Figure 2



quently confirmed behavioral changes in honeybees and bumblebees exposed to neonics. Therefore it is reasonable to assume that neonics have a similar effect on the hundreds of species of native bees and other pollinators in Massachusetts. Much of our native flora depend on native pollinators for survival.

Bee Brains & Behavior

The question needed to be asked, "What is the mechanism causing these behavioral changes?" The physiological mechanisms that control animal behavior are not well understood in either insects or mammals. We do know that neonics are designed to kill insects by binding irreversibly to a key nerve receptor controlling the insect's motor reflexes. This causes the nerve to fire in an uncontrolled manner, destroying coordination and leading to death. A similar receptor in mammals differs slightly from that of insects. This subtle difference in structure prevents neonics from binding tightly to mammalian receptors, dramatically lowering the acute toxicity levels of neonics to mammals. In other words, it takes much higher concentrations of neonics to kill mammals, including humans.

The honeybee brain is a marvelous structure packed with sophisticated behaviors. It consists of more brain cells per unit area than any other animal studied thus far, including humans. Packed into the honeybee brain are all its instinctual behaviors to clean and feed the young, guard and protect the hive, and forage miles from the hive and return. It includes the dancing behaviors by which one forager bee tells other foragers where the nectar it just found is located and how to get there and the ability to locate and evaluate new nest sites, negotiate which is the best site with her sisters, and then direct 20,000 or so bees and the old Queen to their new home. These and many other complex behaviors are hardwired into the neural system. Honeybees are truly amazing animals.

During the pupal life stage, when bees' transition from a larval life stage to the adult bee, the bees' larval brain along with other organs are largely destroyed and transformed into the adult structures. We speculated that imi was producing behavioral changes either by altering the way the adult brain was formed during the pupal period or by altering the function of the normal adult brain after normal development. We designed a bioassay experiment to test whether the presence of imi during the formation of this complex organ caused behavioral changes or whether imi altered behavior by acting directly on the normal adult brain.

We tested these two possibilities in the following way. Six hives were located at three apiaries (18 hives). Three hives at each site (9 hives) were treated with the lowest concentration of imi in syrup as in our previous study. Then, in late fall, when all brood rearing had been completed and only adult bees remained in each hive, the bees were shaken from their hives and weighed. This allowed us to document the number of adult bees in each hive at the beginning of winter. Next we placed untreated bees back into their untreated hive (3 hives); placed treated bees back into their hive containing treated honey (3 hives); took bees from a treated hive and placed them in an untreated hive (6 hives); and took bees from an untreated hive and placed them into a treated hive (6 hives).

We designed the procedure to ensure we could observe the response of adult bees that were never treated with imi (control hives), bees treated with imi both as larvae and as adults, bees treated with imi as larvae and for a brief period as adults, and significantly, bees treated only as adults. Healthy, normal bees will return precisely to their hive location, so we also made certain that each beehive was relocated in the exact space in each apiary from which the bees originally came.

Our results showed that over 50% of bees from control hives (never exposed to imi) were accounted for in the spring. Meanwhile all hives with treated bees lost over 90% of their bees. Most notable was that the population in six hives of bees that were only treated as adults dropped the most, losing an average of 97% of their bees (Figure 3, pg. 24).

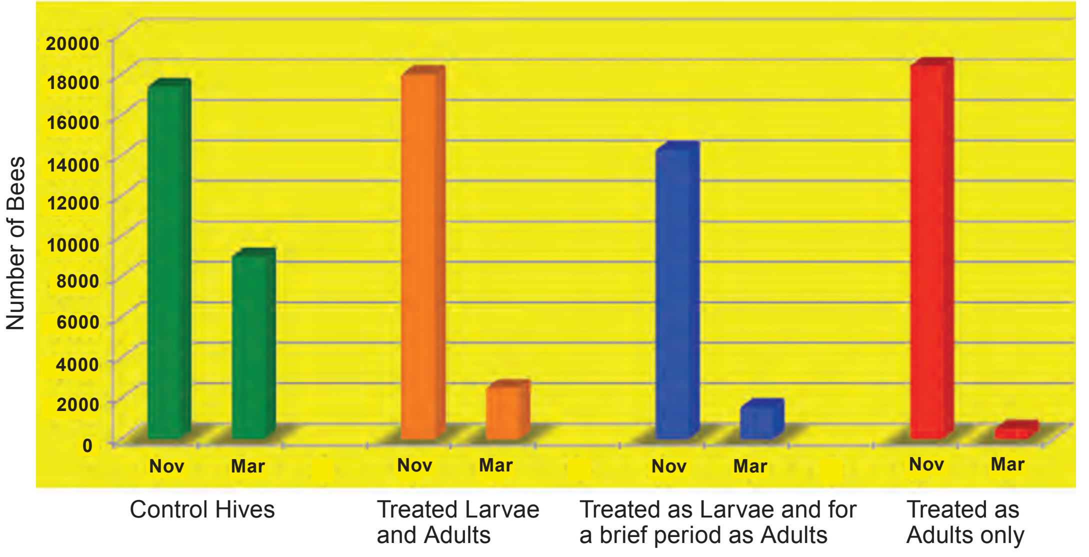
Our experiment demonstrated that imi acts directly upon the adult bee brain by causing abnormal behavior. Bees treated as larvae were also affected, possibly due to imi residues integrating into their adult bodies and thereby affecting their behavior. Behavioral effects seen in bees are undoubtedly occurring in other insects, other arthropods and perhaps in higher animals.

By now you can probably appreciate that measuring the toxicity of low levels of a single chemical on a single species housed in easily monitored, accessible hives is a complex process. A report on

Beehives at Apiary 1.

Figure 3 **Imidacloprid Hive Abandonment Results**

November (Live Bees) and March (Live + Dead Bees)



honeybee health released by the U.S. Department of Agriculture and the EPA in 2013 stated that the most pressing research questions relate to determining actual pesticide exposures bees receive in the field. Trying to observe and document the subtle effects of hundreds of pesticide compounds in combination on thousands of species in the open environment of course presents an overwhelming complex and impossible challenge.

In My Opinion

We are left with a dilemma: agricultural antibiotics are necessary to feed the current human population. Human exposure to neonics is universal and continuous throughout our food supply. It's quite possible mammals share the same physiological mechanisms driving behavioral changes observed in invertebrates. But how do we manage those products to protect the environment and the public?

I believe our repeating history of badly managing insecticides over the past century offers some important lessons and mitigating strategies worth considering.

First, persistent insecticides (except perhaps for limited use in structures) will cause environmental problems. A recently published study showed insect populations in a German Nature Preserve dropped almost 80% over 27 years. Ideally, half of an applied pesticide should naturally break down to nontoxic chemicals within 24 hours of application. These "soft" insecticides should be adequate to control pests, but also limit or minimize environmental contamination.

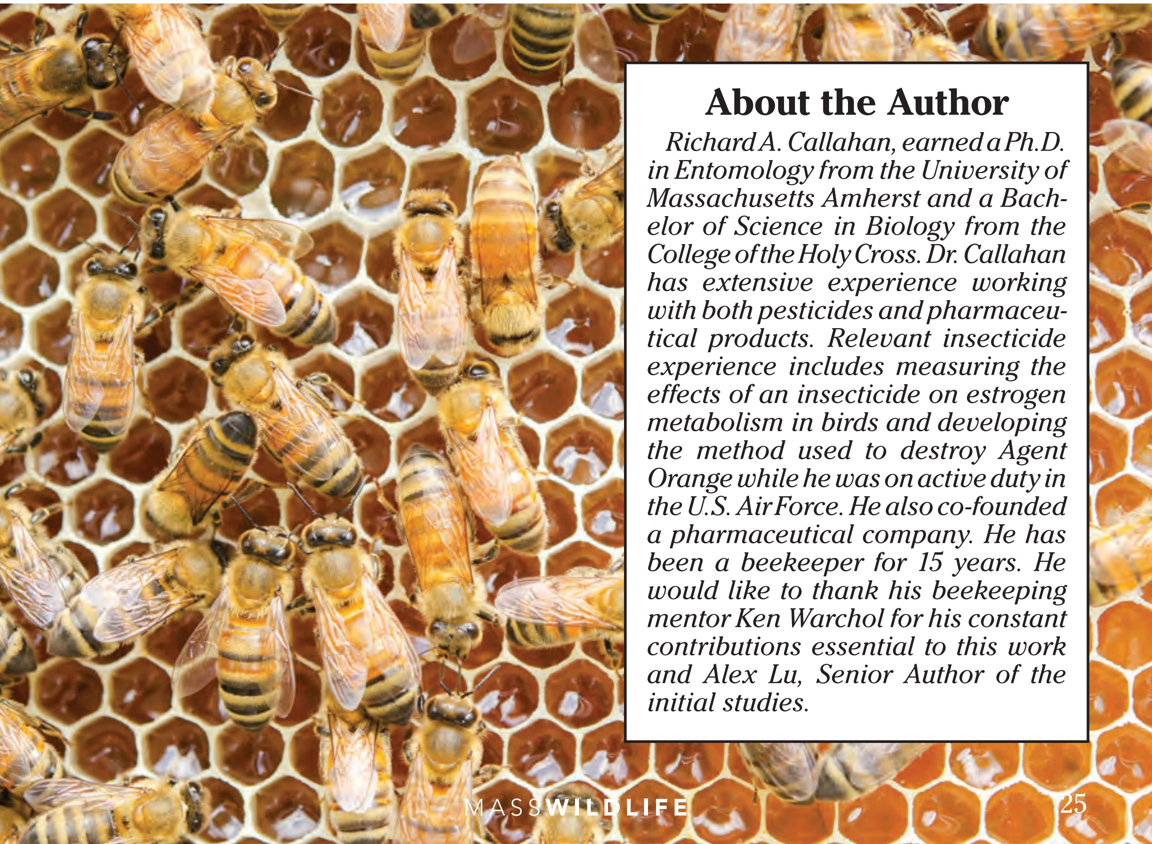
Second, use of systemic pesticides are problematic as they will be present in a wide segment of the human food web and may pose a hazard to people—particularly pregnant women and children. Broad application of systemic pesticides affects not just the target creature, but all species, including beneficial insects and pollinators. Perennial plants are likely to accumulate high concentrations. Water solubility results in environmental transport.

Finally, the claim that broad scale use of pesticides can be ecologically safe is mythical. Evidence continues to mount associating neonics and other pesticides with environmental calamity. Pesticides are designed to kill organisms and will always have side effects at levels well below their effective killing dose. This is the nature of every synthetic biologically active molecule ever tested whether as a drug for human use or an environmental poison. I suggest that pesticide applications need to be justified based upon absolute need. The province of Ontario has established a method whereby neonics can only be used after a third party verifies that such use is necessary. This method mirrors the prescription system used for pharmaceutical antibiotics. People obtain a prescription from a professional trained in the field before placing a few milligrams of an antibiotic into their body; it seems reasonable that a professional check that the application of many kilograms of an antibiotic insecticide is necessary before it is applied to the general environment we all share and into the food we all eat.

Recent actions include a European Union vote to ban all outdoor uses of neonics, including agricultural use, starting in 2020. The Massachusetts Medical Society passed a resolution regarding the potential harm neonics pose to people. Currently legislation has been filed in the Massachusetts House of Representatives with the intent of reducing residential use of neonics thereby limiting human exposure to concentrates and overuse in urban and suburban environments. One way you can help achieve that reduction is to consider refraining or seriously limiting your use of neonics and other synthetic, biologically active chemicals on your own property and in your neighborhood. A perfect, chemically-managed lawn is an ecological desert. Mix in clover, and avoid using insecticides and herbicides. Urge your legislators to pass legislation ensuring the sensible use of these antibiotics.

— Richard A. Callahan, Ph.D.

Photo © Sarah Rydgren



About the Author

Richard A. Callahan, earned a Ph.D. in Entomology from the University of Massachusetts Amherst and a Bachelor of Science in Biology from the College of the Holy Cross. Dr. Callahan has extensive experience working with both pesticides and pharmaceutical products. Relevant insecticide experience includes measuring the effects of an insecticide on estrogen metabolism in birds and developing the method used to destroy Agent Orange while he was on active duty in the U.S. Air Force. He also co-founded a pharmaceutical company. He has been a beekeeper for 15 years. He would like to thank his beekeeping mentor Ken Warchol for his constant contributions essential to this work and Alex Lu, Senior Author of the initial studies.

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