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Racing Towards Silent Spring

By William Quarles

In the last 40 years, the human population has nearly doubled—from 4.5 billion to 7.9 billion. We now have to feed nearly twice as many people as in 1980. Though organic agriculture could do the job with less of an environmental impact (Badgley et al. 2007; Rodale 2014), corporations have promoted GMOs and large fields of monocultures protected by pesticides and boosted by excessive applications of synthetic fertilizer (Quarles 2017a; Gomiero et al. 2011). Agricultural intensification of this kind has encroached upon wildlife areas and increased global warming and environmental pollution (Edenhofer et al. 2014; Dirzo et al. 2014).

While the human population has increased, most wildlife has seen severe decline. Though much attention has been given to loss of vertebrates, insects such as butterflies, bees, and beetles are also at risk (Sanchez-Bayo and Wyckhuys 2019). In the same 40-year time span, flying insects in some areas have decreased by more than 75%. Species that eat insects, such as frogs, birds, and bats have also been impacted (Lister and Garcia 2018; Hallmann et al. 2017; Dirzo et al. 2014). Major drivers of the invertebrate decline are habitat destruction, agricultural intensification, pesticide use, and climate change (Dirzo et al. 2014; Sanchez-Bayo and Wyckhuys 2019).

Many wild species are going extinct, and those that remain are showing reduced populations. We are racing toward Rachel Carson's *Silent Spring*—a world devoid of bird and insect sounds. Instead, there are electronic beeps, blaring horns, cell phone jabbering, sirens, and screams of urban crazies (Carson 1962, Dirzo et al. 2014, Barnosky et al. 2011).

This article briefly reviews the catastrophic collapse of insect populations, and proposes solutions to reverse it.

Photo courtesy of Kim Mitchell USFWS

Populations of the rusty-patched bumble bee, *Bombus affinis*, shown here, have dropped by 87% in the last 20 years, and it is considered an endangered species.

Vertebrates

Vertebrate decline first drew the eye of biologists, the amount of the loss depends on the populations surveyed (Diamond 1989; McCallum 2015). Clearly, human expansion can mean fewer tigers and elephants, but more mundane wildlife is also disappearing. The dramatic decline has been called by some biologists "the sixth mass extinction" (Barnosky et al. 2011: McCallum 2015). According to Dirzo et al. (2014), about 16-33% of wild vertebrate species assessed are threatened or endangered, and population numbers have been reduced by an average 28% over the past 40 years. Since 1500, 322 species have gone extinct.

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Update

Sanchez-Bayo and Wyckhuys (2019) report an average 22% of vertebrate species in decline and 18% threatened. The average reduction for amphibian species is 23%, land mammals 15%, bats 27%, and reptiles 19%.

A study of 3706 vertebrate species in 14,152 monitored populations mostly in Western Europe by the World Wildlife Fund (WWF 2016), showed an average 58% decline in wild vertebrate populations between 1970 and 2012. Terrestrial, marine and freshwater species were part of this number.

Terrestrial vertebrate species showed an average 38% decline. Marine mammal, bird, reptile and fish species had a 50% reduction. Most alarming, populations of freshwater vertebrates had dropped by 81% (WWF 2016).

Loss of Pollinators

Loss of pollinators first drew general attention to the disappearance of insects. A National Academy of Sciences study documented reduced populations of pollinators such as bees, butterflies, and bats (NAS 2007). Headlines about honey bee colony collapse disorder dramatized the situation (Schacker 2008; Quarles 2008ab).

About 75% of our crops are pollinated by insects, leading to about one-third of the food we eat, a service worth at least $14.6 billion due to honey bees, *Apis mellifera*, and $3.07 billion due to wild bees (NAS 2007; Losey and Vaughn 2006). In the U.S. much of the pollination is done by managed colonies of honey bees, but we cannot even control losses in managed colonies. Since 1947 we have lost 45% of our honey bee colonies. There are fewer beekeepers and less natural forage for bees due to loss of habitat. Each year, about 40-45% of existing colonies are destroyed by pesticides, bee mites and other causes. These losses have to be replaced by establishing new colonies each year (NAS 2007; Quarles 2008ab).

Pollinators such as moths and bees are decreasing both in diversity and abundance (Dirzo et al. 2014). Losses are being driven by habitat fragmentation and loss, "pesticide application and environmental pollution, decreased resource diversity, alien species, the spread of pathogens, and climate change" (Potts et al. 2010). See moths and bees below.

Photo courtesy of Kathy Keatley Garvey

Honey bee, *Apis mellifera*, pollinating an almond blossom.

Measuring Invertebrate Decline

But insect decline extends well beyond pollinators. Conservation biologists are alarmed at the dramatic collapse of many populations, including extinction of some species. Decline is documented by comparing current surveys with historical records. Most of the research covers insect populations in the U.S. and Europe, since historical records are more complete in these areas (Sanchez-Bayo and Wyckhuys 2019). Populations of individual species are counted, or just total insect biomass at a particular location (Dirzo et al. 2014; Hallmann et al. 2017).

A convenient technique is to map the geographical species range by presence-absence surveys on a 10 km (6 mi) grid. Numerical populations can then be estimated from a measurement of ranges. This technique shows that 50% of the bird species and 71% of the butterfly species surveyed in Britain have seen range reductions over about a 20-year period (1970-1995)(Thomas et al. 2004).

Another technique is direct counts at historical sites. Counts can be conducted by visual observations, traps, or sweep net sampling. Sweep nets or visual observations on flowers are often used for bee populations (Blaauw and Isaacs 2014; Cameron et al. 2011), and light traps for moth populations (Conrad et al. 2006). For general insect biomass, malaise traps (Hallmann et al. 2017) or suction traps (Shortall et al. 2009) are employed.

There is also qualitative information from citizen surveys using the "windshield" test. Drivers travel through a standard route and record the number of insects hitting a collection plate. This number is compared with a similar survey at a previous time (Jarvis 2018).

Photo courtesy of Gary McDonald

Wild bees like this mason bee, *Osmia sp.* provide much pollination, but they are disappearing.

Magnitude of the Effect

Individual species are endangered or becoming extinct, and reduced populations have been seen across several species. Severely reduced populations are the first step toward extinction. As mentioned above, reduced populations are often determined by visual counts at historical aggregation sites and by trapping. Changes are so dramatic that followup on baseline counts may have to be conducted in the middle of a new parking lot (Dirzo et al. 2014).

Photo courtesy of BioQuip

Netting of this malaise trap catches flying insects that then crawl into the collection cup at the top.

Each study gives slightly different numbers, but about 40% of invertebrate species that have been assessed are considered threatened, and "67% of monitored species show 45% mean abundance decline" (Dirzo et al. 2014). According to a review of 75 publications, an average 41% of the insect species studied are in decline, and 10% are showing extinction in local populations. Those most affected are aquatic insects such as Trichoptera (caddis flies, 68% decline), Lepidoptera (moths, butterflies, 53%), Hymenoptera (bees, 46%), Coleoptera (dung beetles and ground beetles, 49%) and Orthoptera (grasshoppers, 49%) (Sanchez-Bayo and Wyckhuys 2019). Surveys of local insect biomass are showing even greater reductions (see below)

Due to lack of research, the number of insect species that have gone extinct are likely underestimated. There are more than 3.4 million insect species. If extinction follows the same trend as mammals, 44,000 species have gone extinct in the last 600 years (Dunn 2005).

Some reduction results from habitat collapse of specialists such as prairie butterflies, but generalist insects as well as specialists are disappearing (Swengel et al. 2011).

A 76% Decline in Flying Insects

Insect biomass is showing an alarming drop, even in nature protected areas. Malaise trap data at 63 nature protected areas over a 27-year period (1989-2016) in Germany showed a 76% seasonal reduction in flying insect biomass. Though nutrient rich areas had more insects, insect decline did not vary with habitat. Traps were deployed within one meter (3.3 ft) of the ground, and about 94% of the sites were surrounded by agricultural fields. Hence, pesticides and agricultural intensification may explain the loss. Agricultural fields treated with pesticides could act as a sink for the insect populations (Hallmann et al. 2017).

The amount of reduction seen varies with the technology. Suction traps at 12.1 m (39.7 ft) above the ground showed losses in only one of four sites in Britain (Shortall et al. 2009). According to Hallmann et al. (2017), malaise traps near the ground are a better measurement of local insect populations.

Decline in Tropical Areas

Tropical areas are usually buzzing with insect life, but major losses have been seen even there. From 1976 to 2012 there was an 86% to 98% reduction in insect biomass in the Puerto Rican tropical rain forest. Sticky traps deployed at ground level showed a 98% reduction (470 to 8 mg/trap/day). Traps in the tree canopy showed an 86% reduction (37 to 5 mg/trap/day). Authors of the study believe that global warming may be the cause of the decline. During this time, mean maximum temperatures in the area increased by 2°C (3.6°F). Increasing temperature favors insects in temperate areas, but leads to decline in tropical regions (Lister and Garcia 2018).

Declining insect populations led to reductions in bird, frog, and lizard populations. For example, from 1990 to 2005, the number of captured birds in the monitored areas dropped 53%. Insectivorous birds showed a 90% decline (Lister and Garcia 2018).

Freshwater Species Collapse

The greatest reduction in both vertebrate and invertebrate populations is seen in freshwater environments. According to the World Wildlife Fund, decline of freshwater vertebrates such as frogs and fish is 81% (WWF 2016).

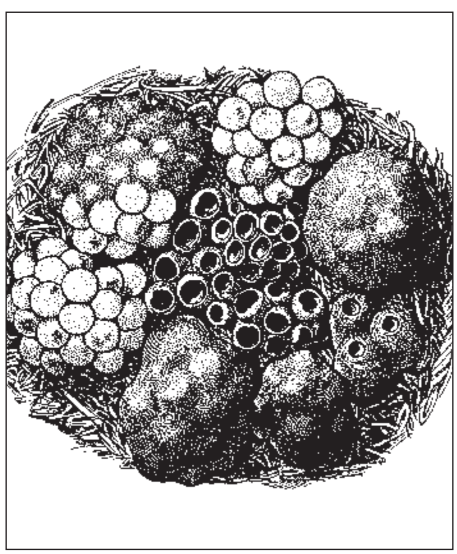
Collapse of freshwater vertebrates is partly due to the crash of the freshwater insects. Insects such as caddis flies (Trichoptera) that live near or in freshwater have declined by 68%. This includes both the larval aquatic form (44%) and the adult, moth-like terrestrial form (38%) (Sanchez-Bayo and Wyckhuys 2019). The most likely cause of freshwater species collapse is water pollution. Water in agricultural areas is extensively polluted with fertilizers and pesticides. For instance, in Iowa "approximately 75% of monitored rivers are designated as impaired or potentially impaired" (Olson et al. 2016).

Bee Decline

Much has been written about loss of honey bees, but in many areas of the U.S., bumble bee populations are crashing. Four species, *Bombus affinis*, *B. occidentalis*, *B. pensylvanicus*, and *B. terricola* have dropped by up to 96% and their ranges have contracted by 23-87%. *Bombus franklini* has gone extinct. Monocultures and subsequent loss of habitat is one cause of the decline. Pesticides, especially neonicotinoids, are another cause. Surviving bees also have high loads of pathogens such as *Nosema bombi* (Goulson and Nicholls 2016; Cameron et al. 2011).

Photo courtesy of Gary McDonald

Yellow-faced bumble bee, *Bombus vosnesenskii*, on a flower.



From Nixon 1954

Bumble bees nest in the ground. The spheres are cocoons. Open cocoons are being used for honey storage. Honey pots are at the right.

The most striking example is the once common rusty-patched bumble bee, *Bombus affinis*, which has declined by 87% over the past 20 years. It covers only 0.1% of its historic range, and it is now an endangered species. Habitat loss, intensive farming, pesticide use, and climate change are the causes of its decline (Colla and Packer 2008; USFWS 2017).

Bumble bees are especially susceptible to extinction because they reproduce at the end of a long colony cycle. Minor changes in food availability can have a big impact on reproductive success. They also need three different habitats for foraging, nesting, and hibernating in close proximity. Thus, they are very vulnerable to habitat destruction (Colla and Packer 2008).

In Great Britain honey bees do 34% of the work while wild pollinators do the rest. Populations of bumble bees have seen significant decline (Goulson and Nicholls 2016). Foraging bumble bees in Britain have been exposed to significant levels of agricultural pesticides (Botias et al. 2017).

Moths and Butterflies

In Britain, 66% of 337 moth species declined over a 35 year study period, and 21% of them dropped by more than 30% (Conrad et al. 2006). A study of 12 moth species showed ranges were shifting northward each year in concert with global warming. Some species were increasing in abundance, others, such as *Macaria wauaria*, were dropping by as much as 77% (Fox et al. 2011).

Butterflies in Great Britain are generally in decline, but some species are increasing in abundance (Isaac et al. 2011). Prairie butterflies in the Midwestern U.S. are disappearing, as prairies are being destroyed by development (Swengel et al. 2011). In the study areas of the World Wildlife Fund, grassland butterflies show a 33% decline over 22 years (WWF 2016). In the Netherlands 55% of butterfly species studied (11 of 20) show reduced populations, and cumulative butterfly abundance has dropped by about 30% (Van Dyck et al. 2009). More examples can be found in Sanchez-Bayo and Wyckhuys (2019).

Specialists at Greater Risk

Specialist butterflies that rely on specific plants are more endangered than generalist ones. Many species have become extinct. In Suffolk county England 42% of resident species have disappeared. In Bavaria 117 species have dropped to 71 since 1840 (Thomas 2016).

European grassland butterflies declined by 50% between 1990 and 2011 (Hallmann et al. 2014). A study of 673 Lepidopteran species in Great Britain showed 417 (62%) either declined or showed a tendency to decline over a 40 year period starting in 1970. Major drivers were habitat modification and climate change (Fox et al. 2014).

Monarch Populations

Specialists such as the monarch butterfly, *Danaus plexippus*, have been severely impacted. Overwintering populations have dropped 90% or more since the 1980s. The California population in the 1980s was estimated at 4.5 million (Schultz et al. 2017). Overwintering counts at 97 sites along the Pacific Coast in winter of 2018 revealed only about 20,000. This estimate is about 0.5% of the monarch population's historical size, and represents a catastrophic reduction of 86% from 2017. Possible factors are pesticides, drought, and forest fires that are encouraged by global warming (Pelton 2018).

But there is some good news. Monarch overwintering populations in Mexico showed a 144% increase in 2018 compared to 2017. There were 2.48 ha (6.1 acre) of overwintering monarchs in Mexico in 2017. This number increased to 6.05 ha (14.9 acre) in the winter of 2018.

Photo courtesy Jim Lovett, www.MonarchWatch.org

Populations of the monarch butterfly, *Danaus plexippus*, have seen catastrophic reductions. The California population has crashed from 4.5 million to 20,000.

This increase was probably due to favorable weather at the overwintering sites in Mexico. Populations are still well below historical levels (Ecowatch 2019).

Ecological Destruction

Removal of one species can have a cascade effect on other species. Loss of insects can lead to loss of birds, bats, and frogs that feed on insects. Loss of pollinators can also lead to loss of plants (Sanchez-Bayo and Wyckhuys 2019).

For instance, Trichoptera (aquatic insects) and Lepidoptera (moths) feed bats. Aquatic insects (caddis flies) are one-third the diet of the little brown bat, *Myotis lucifugus*. The 68% average decline of Trichoptera could severely reduce its food supply. Malnourished hibernating bats are more susceptible to the lethal white nose fungus, *Geomyces destructans*, that has killed about six million bats since 2006 (Quarles 2013; Sanchez-Bayo and Wyckhuys 2019).

Pesticides are likely a factor in insect food loss for bats. For instance, organic farms have more insects and more bats than conventional farms (Wickramasinghe et al. 2004).

Insectivorous birds are affected by the general insect decline (see below). Frogs are impacted by pesticides directly and also by loss of freshwater invertebrates such as Trichoptera. Malnutrition and pesticides could depress their immune systems and lead to increased infections with the chytrid fungus. U.S. surveys show an amphibian population decline of about 4% per year. Populations of the leopard frog, *Rana pipiens* have dropped about 50% (Quarles 2015; Mason et al. 2012).

Disappearing Birds

About 60% of birds rely on insects as a food source (Hallmann et al. 2017). About 42 common bird species in Canada, U.S. and Mexico have lost 50% of their populations in the last 40 years (Lister and Garcia 2018). According to one report, about 12% of the world's bird species are threatened with extinction, and 40% of 11,000 bird species are in decline. Bird populations in France have seen 33% reduction (Bird Life 2018).


Photo courtesy of Miguel Altieri

Flowers such as sweet alyssum, *Lobularia maritima*, can be planted in fields of monocultures to provide food for bees, butterflies and biocontrols.


Photo courtesy of Tony Morosco

Roadsides can be planted with floral resources such as the sunflower, *Helianthus sp.* shown here.


Photo courtesy USDA and NRCS

Cover crops can provide food for bees, butterflies, and biocontrols. They can be mechanically crimped down before planting.

Neonicotinoid insecticides, such as imidacloprid, have been linked to insect and bird loss in the Netherlands. Neonicotinoids are very persistent, and extremely soluble in water. They are applied each year to crops, so there is a flow from treated crops and seeds to soil, then to water. Concentration in water provides a sensitive assay for the amount present in the environment. Where the imidacloprid concentration in water exceeded 19.43 ng/liter, 14 out of the 15 insectivorous bird species studied showed reduced populations (Hallmann et al. 2014; Goulson 2014). [an ng, nanogram, is one-billionth of a gram]

The decline is likely due to fewer insects, and less food available. Van Dijk et al. (2013) had previously shown that insect populations in an area drop as water concentrations of imidacloprid increase.

In the U.S. 23-75% of water samples in corn and soybean regions are contaminated with neonicotinoids. Maximum amounts range from 42 to 356 ng/liter. These levels are greater than those associated with bird decline in the Netherlands (Hladik et al. 2014).

Neonicotinoids may also be impacting populations of seed eating birds. Populations of the bobwhite, *Colinus virginianus*, are lower in areas of Texas where crops are being raised with neonicotinoid treated seeds. As neonicotinoid use goes up, total bobwhite populations go down in all regions surveyed (Quarles 2014a; Erti et al. 2018).

Human Pests Thriving

Insects dependent on wild habitat are disappearing, but pests of humans and their food supply are thriving. Climate change is encouraging mosquitos, ticks, and human pathogens. Lyme disease has doubled in the U.S., and arthropod borne diseases are spiking (Quarles 2007; Quarles 2017a). Agricultural monocultures are encouraging specialist and generalist crop pests, leading to increased use of agricultural pesticides that kill beneficial insects and biocontrols (Gomiero et al. 2011). For instance, the number of U.S. soybean acres treated with insecticides increased by 20-fold between 1994 and 2015 (Quarles 2017b). Invasive species associated with increasing population and world trade such as the emerald ash borer, *Agrilus planipennis*, and the brown marmorated stink bug, *Halyomorpha halys*, are on the rise (Kenis et al. 2009; DeSantis et al. 2013; Quarles 2014b).

What to Do?

We need to reduce greenhouse gas emissions. We can do this through fuel efficient cars and renewable sources of power generation. We need to eat less meat and more vegetables. Less meat would mean fewer confined animal feeding operations (CAFOs) and less methane greenhouse gas emissions. When possible, we should buy organic food (Edenhofer et al. 2014; Smith et al. 2008).

We need to modify monocultures to reduce the impact of pesticides on beneficial insects and biocontrols. Regenerative agriculture techniques such as cover cropping, no-till production, in-field rows of floral resources, and vegetative barriers at the field edges to reduce water pollution are practical and possible. Microbial inoculants can be used to reduce pesticides and fertilizers (Rodale 2014; Quarles 2018ab).

In agricultural non-field areas, restorative techniques such as farmscaping should be employed. Areas around ditches, utility poles can be planted with floral resources for bees and butterflies. Insectary plants along field edges can increase biological controls (Quarles and Grossman 2002; Altieri 2004; Bugg et al. 1998; King and Olkowski 1991).

Photo courtesy Stephen Ausmus USDA

Adult western corn rootworm, *Diabrotica virgifera virgifera.*

IPM for Pests

We need to use fewer pesticides in crop production. IPM methods can be used to reduce insecticide applications. For example, monitoring, crop rotation, soil treatment with nematodes, and use of baits for the adult beetles can be used to control the western corn rootworm, *Diabrotica virgifera virgifera* (Quarles 2017c).

Roadside Restoration

Some studies suggest that populations of butterflies can be most effectively restored by establishing optimum stands of larval habitat (Thomas et al. 2011). In the case of the monarch butterfly, planting milkweed is an effective restoration action.

There are 10 million acres (4 million ha) of roadsides in the U.S. Establishing milkweed along roadsides can help preserve monarch butterflies. Establishing native plants in an IPM program for roadside weeds can provide nourishment for native bees and butterflies. For example, conversion of Iowa roadsides from herbicides to IPM management increased the number of roadside stands of milkweed by 64% (Harper Lore and Wilson 2000; Quarles 2003; Hopwood 2008).

Network of Garden Clubs

There are millions of backyard gardeners in the U.S. and 40 million acres (16.2 million ha) of lawns. Local action such as planting bee and butterfly gardens can have a national impact. Details of which plants to establish are in published articles (Quarles 2008a; 2016ab) on the birc website www.birc.org and elsewhere. A network of Garden Clubs with similar plans and policies could convert local conservation actions into a national program. There are also specialized conservation organizations such as the Sierra Club, Native Plant Societies, Xerces Society, Monarch Joint Venture, the North American Butterfly Association, Humane Society, Pollinator Partnership, National Wildlife Federation, American Bird Conservancy, and the Audubon Society.

Conclusion

Life on earth is being reconfigured from diverse populations in ecological balance to a simplified ecosystem of humans, human food, and human pests. In the last 40 years, human populations have nearly doubled, but many other living populations have dropped by 50% or more.

The degradation of wild populations was not necessary. We should try to mitigate some of this damage, or there will be consequences such as loss of pollinators, loss of ocean food, and a highly restricted food supply. We should increase regenerative and organic agriculture. IPM should be used to control pests. Backyard gardens and roadside plantings can compensate for some of the habitat loss.

Unless we reverse the wholesale destruction of wildlife, reduce pesticide applications, and mitigate global warming, we are headed toward the *Silent Spring* pictured by Rachel Carson.

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Rrom Nixon, 1954

Bumble bee, *Bombus sp.*

Conference Notes

ESA 2018 Meeting Highlights

By Joel Grossman

These Conference Highlights were selected from among 3,000 presentations at the Nov. 11-14, 2018 joint Annual Meeting of the Entomological Societies of America (ESA), Canada (ESC) and British Columbia (ESBC). The next ESA annual meeting is November 17-20, 2019 in St. Louis, Missouri. For more information contact the ESA (3 Park Place, Suite 307, Annapolis, MD 21401; 301/731-4535; http://www.entsoc.org).

Inner City Lady Beetles

Native lady beetles are declining in the U.S., and they are being displaced by exotic lady beetles. For instance, Cleveland, Ohio's 12 native lady beetles species compose only 28% of the city's lady beetle community, said Denisha Parker (Ohio State Univ, 2001 Fyffe Rd, Columbus, OH 43210; parker.1052@osu.edu). Cleveland's manufacturing jobs and many people have left, leaving 27,000 acres (11,000 ha) of vacant lots, a figure increasing by 4,000 acres (1,620 ha) annually. The vacant lots are being converted to rain gardens, urban gardens, and other green space uses. Green spaces can also be increased by planting patches of native wildflowers called "pocket prairies," an alternative that increases ecosystem services such as pollination and populations of native lady beetles such as *Brachiacantha ursina* and *Cycloneda munda.*

"Our goal was to examine if city-managed vacant lots, vacant lots receiving reduced management, or lots transformed to create low-diversity or high-diversity pocket prairies acted as a conservation resource for native lady beetles," said Parker. Lady beetles in general prefer similar habitats, so the pocket prairies did not increase native populations relative to exotics. High-diversity pocket prairies with 3 grasses and 16 native forbs had 28% native and 72% exotic lady beetles. Lady beetle populations in general, both native and exotic, increase when urban pocket prairies replace cement and other impervious surfaces.

Neonics in Aquatic Ecosystems

One-third of world insecticide use is neonicotinoids, and in the U.S., "an area at least the size of California" is annually planted with neonic-treated corn, soybean and cotton seed, said Sarah McTish (Penn State Univ, 101 Merkle Lab, University Park, PA 16802; stm5283@psu.edu). From 2014 to 2017, U.S. neonic use doubled: 79-100% of U.S. corn seed and 34-44% of soybean seed is treated with neonics. About 5% of neonic active ingredient passes from seeds to growing crops, with 1% becoming dust. Most neonic loss from treated seed is into groundwater. Early and late season rainfall washes neonics into surface water, where it can move up ecological food chains from aquatic life and insects to fish and birds.

Photo courtesy James Cane, USDA

A squash bee, *Peponapis pruinosa*, sips nectar.

In 2017, surface and subsurface water runoff from corn plots with thiamethoxam-treated seeds was analyzed "using HPLC/MS-Orbitrap for concentrations of thiamethoxam and its degradant clothianidin." Of the active ingredient applied to seeds, 94% was unaccounted for, and is presumably in the soil and subject to future leaching into water supplies. Given the large areas of the Midwest U.S. treated with neonics, progressively larger amounts of neonics from seeds, soils and dust could enter the environment in future years. "The slow release of neonicotinoids into waterways is likely chronically exposing aquatic organisms to neonicotinoids with unclear consequences," said McTish.

Neonic Wild Bee Threat

Solitary ground-nesting bees such as the hoary squash bee, *Peponapis pruinosa*, are "among the most important pollinators" of pumpkins, squash, gourds and other cucurbits. Populations in Ontario, Canada are at risk from residues from neonicotinoids such as imidacloprid, thiamethoxam and clothianidin, said Susan Chan (Univ Guelph, 50 Stone Rd E, Guelph, Ontario N1G 2W1, Canada; peponapis@yahoo.com). Bee neonic exposure from cucurbit farm soils during nest construction exceeded acceptable LC50 levels by over 35% in most soil samples from cucurbit farms.

"All ground-nesting bees that live on farms may be at risk of harm from exposure to soils of neonicotinoid-treated field crops such as corn, soybean, and wheat in Ontario, based on the hoary squash bee soil exposure," said Chan. "Recognition and mitigation of risks to ground-nesting bees from exposure to neonicotinoid residues in agricultural soil are needed to inform pesticide-use guidelines and protect crop pollinators."

Predatory Mites Protect Ornamentals

Amblyseius swirskii, a generalist predatory mite feeding on pollen, spider mites, broad mites, eriophyid mites, whiteflies and thrips on mock orange, citrus, maples and other plants, "does well in hot, humid climates found in the southeastern USA," said Karla Addesso (Tennessee State Univ, 472 Cadillac Lane, McMinnville, TN 37110; kaddesso@tnstate.edu). *A. swirskii* is available for purchase in slow release sachet/colonies, shaker bottles, strips, or bulk media for hand or mechanical dispersal. The predatory mites disperse well, and are consistently recovered from untreated control plots and ornamental pepper plants that act as banker plants or refuges.

In "container yard" nurseries with 3 gallon (11 liter) and 15 gallon (57 liter) potted maples, *A. swirskii* controlled-release sachets suppressed midsummer outbreaks of broad mites and spider mites. In greenhouses, pollen helped *A. swirskii* survive periods without prey. Releases of 5 *A. swirskii*/ft^2 (54/m^2) were sufficient for persistence on *Hydrangea* with dense leaf hairs. *A. swirskii* survives misting under plastics, but has difficulty establishing in propagation beds with discontinuous canopies.

Stink Bug Netting

In late-summer, North Central Washington apple orchards annually apply broad-spectrum insecticides to control stink bugs, which "has led to severe outbreaks of secondary pests such as spider mites and woolly apple aphids," said Adrian Marshall (Washington State Univ, 1100 N Western Ave, Wenatchee, WA 98801; atmarshall@wsu.edu). So, mechanical exclusion techniques used in organic orchards were tested: One, 5 kinds of 2×3 m (6.6×9.8 ft) sticky barriers; two, 3 types of 4×50 m (13×164 ft) shade net barriers, with and without deltamethrin; and three, no netting (the control).

Contrary to the traditional grower belief that there is one stink bug migration into apple orchards in August, "stink bugs move between the orchard and surrounding vegetation multiple times throughout the year starting as early as June," said Marshall. The best shade netting, bent to protect 10 apple trees behind a netting barrier, reduced stink bugs by 90%. Stink bug flight height, a factor in barrier selection, varies significantly; but most stink bugs fly about 1 m (3.3 ft) above the ground. In a year of low stink bug populations, a 39% reduction in orchard stink bug numbers was not statistically significant. But more organic apple farms are expected to use netting barriers.

Onion Thrips IPM

Onion thrips, *Thrips tabaci*, a key pest during the April to September onion season in New York and the Great Lakes region, went from easy to control with chemicals in the 1990s to pesticide resistant in the early 2000s to zero control with 30% yield losses by 2005, said Brian Nault (Cornell Univ, 630 W North St, Geneva, NY 14456; ban6@cornell.edu). With two weeks for a generation, onion thrips quickly builds up numbers on young, 3-4 leaf onion plants in April. Growers are now limited to two pesticide sprays per season, a week to 10 days apart.

By 2014, 80% of onion farmers scouted their fields. Action threshold use increased from 40% in 2014 to 57% in 2015, and 82% in 2017. In 2014, 52% rotated among four products from different chemical classes to counter insecticide resistance; by 2017, 100% rotated pesticide products among different chemical classes. Growers using action thresholds applied 2-4 fewer onion thrips pesticide sprays per year, saving $64/acre ($158/ha). Onion thrips chemical control costs dropped from $483/acre ($1,093/ha) in 2014 to $294/acre ($726/ha) in 2017, proving the economic value of IPM programs with scouting, action thresholds and resistance management.

Rove Beetles Versus Thrips

Western flower thrips (WFT), *Frankliniella occidentalis*, a worldwide pest resistant to many insecticides, can be controlled in chrysanthemum greenhouses using the fungus *Beauveria bassiana* GHA (Botanigard®) plus a soil-dwelling rove beetle, *Dalotia coriaria*, at 92% less cost (>$100) than spinosad (>$900), said Yinping Li (Kansas State Univ, Manhattan, KS 66506; yinpingli@ksu.edu). *D. coriaria*, a commercially available predator feeding on WFT pupae and prepupae in the soil, was evaluated in lab experiments.

A 1:15 predator:prey ratio (rove beetle:WFT) was more effective than either 1:5 or 1:10. Plant foliar quality (90% "great"), WFT levels (20 WFT/plant) and 8 weeks of yellow sticky card captures of WFT adults were similar when biocontrol was compared to treatment with the standard insecticides spinosad, pyridalyl, chlorfenapyr and abamectin.

Japanese Beetle Suppressive Soils

"Japanese beetle, *Popillia japonica*, the most important pest of golf courses in the Midwestern USA," and "a major pest of the nursery and fruit industries," is under federal quarantine limiting movement of infested agricultural products, said Michael Piombino IV (Michigan State Univ, East Lansing, MI 48824; mickpiombino@gmail.com). "Fairway turfgrass wilts and dies in patches after larvae consume most of the roots. Up until this time long-term biological control has largely been lacking."

However, *Ovavesicula popilliae*, a microsporidean pathogen discovered in Connecticut in 1988, reduces female egg laying 50%. Japanese beetle larvae survival was 78% in soils without *O. popillia*, versus 37.6% in soils with the pathogen. The pathogen, via direct mortality and reduced fecundity, is likely a reason southern Michigan soils have declining Japanese beetle populations. When *O. popillia* infections start in August to September, Japanese beetle mortality is 95-100% between October and May. Japanese beetle survival is higher when infections start after

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mid-October. "We were able to infect healthy larvae by putting them into soil from a site where *O. popillia* is active," said Piombino.

Asian Citrus Psyllid Biocontrol

Asian citrus psyllid (ACP), *Diaphorina citri*, vectors *Candidatus Liberibacter asiaticus*, the bacterium causing huanglongbing (HLB) (citrus greening), a lethal citrus tree disease. Classical biological control agents imported from Pakistan's Punjab region have reduced the pest psyllid by 70% on homeowner properties in southern California's Los Angeles County, said Mark Hoddle (Univ California, 900 University Ave, Riverside, CA 92521; mark.hoddle@ucr.edu). Of nine parasitoid species from Punjab, most were hyperparasitoids that did not attack ACP. However, *Tamarixia radiata*, which disperses up to 8 miles (13 km), and *Diaphorencyrtus aligarhensis* respond to ACP population increases.

Micro-video cameras recorded 19,200 hours with 647 ACP kills. About 60% of ACP mortality was due to syrphid flies; 29% was due to *T. radiata*; 12% of ACP were killed by lacewing larvae. Argentine ants, *Linepithema humile*, tend ACP for honeydew and block biocontrol by interfering with psyllid natural enemies. So, South America is being explored for classical biocontrol agents combating Argentine ants. Without ants, Asian citrus psyllid populations in commercial orchards drop 80% in four weeks when *T. radiata* is present.

Prototype infrared sensors, with videotape to check for accuracy, are being developed to transmit phone alerts to treat Argentine ant "hot spots" in citrus orchards. Sucrose baits with neonicotinoids such as thiamethoxam last for about a week before degrading, but can kill queen ants. Biodegradable hydrogel baits are effective, reducing ant observations to under 10 in a 2-minute count.

Drosophila Biocontrol

Adult spotted wing drosophila (SWD), *Drosophila suzukii*, on fall raspberries in Québec, Canada are effectively suppressed with synthetic insecticides, but pollinators can be harmed and SWD larvae inside fruit are unaffected, said Phanie Bonneau (Univ Laval, Phytologie, Québec City, Québec G1V 0A6 Canada; phanie.bonneau.1@ulaval.ca). Four commercially available predators were assayed for SWD biocontrol: spined soldier bug, *Podisus maculiventris*; the true bug (Miridae), *Dicyphus hesperus*; the green lacewing, *Chrysoperla carnea*; and the minute pirate bug, *Orius insidiosus*. These predators are also being tested in the U.S., and are likely already in use.

In no-choice, 24-hour trials with SWD on raspberry leaves, the predators easily found all SWD life stages, with least preference for pupae. In longer two week arena trials with organic raspberries and all SWD life stages, *Orius insidiosus* was the best forager, getting 50% of SWD, including eggs and larvae. The second best forager, *Chrysoperla carnea*, snagged 30% of SWD. In 2019, the four predators plus three parasitic wasp species will be tested in fruit fields.

Persistent Native Nematodes

"After multiple years of significant reductions to strawberry crop yields" at Rulfs Orchards in Clinton County, NY a single application of native New York entomopathogenic nematodes (EPNs) has provided five years of biological control of black vine weevil, *Otiorhynchus sulcatus*, in strawberry and blueberry fields, said Elson Shields (Cornell Univ, 4142 Comstock Hall, Ithaca, NY 14853; es28@cornell.edu). Root weevil infestations are very difficult to manage due to inconspicuous larval root feeding, and initial control of these invasive weevils with foliar and soil insecticides has been both costly and time-consuming.

Shields Lab reared multiple native New York nematode species in greater wax moth, *Galleria*

Calendar

February 22-23, 2019. 31st Annual CA Small Farm Conference. Davis, CA. Contact: Agricultural Sustainability Inst.; https://asi.ucdavis.edu

April 5-6, 2019. 37th National Pesticide Forum. New York City. Contact: Beyond Pesticides, 202-543-5450; www.beyond-pesticides.org

April 8-10, 2019. Board of Directors, Pest Control Operators CA, Sacramento, CA. Contact: PCOC, 3031, Beacon Blvd, W. Sacramento, CA 95691; www.pcoc.org

August 3-7, 2019. American Phytopathological Society Conference, Cleveland, OH. Contact: APS, 3340 Pilot Knob Road, St. Paul, MN 55121; 651-454-7250; aps@scisoc.org

August 11-16, 2019. 104th Annual Conference, Ecological Society of America, Louisville, KY. Contact: ESA, www.esa.org

October 15-18, 2019. NPMA Pest World, San Diego Conference Center, San Diego, CA. Contact: NPMA, www.npmapestworld.org

October 15-18, 2019. California Invasive Plant Council Symposium. Riverside, CA. Contact: California Invasive Plant Council, 1442 Walnut St., No. 462, Berkeley, CA 94709. www.cal-ipc.org

November 10-13, 2019. Annual Meeting, Crop Science Society of America. San Antonio, TX. Contact: https://www.crops.org

November 10-13, 2019. Annual Meeting, American Society of Agronomy. San Antonio, TX. https://www.acsmeetings.org

November 10-13, 2019. Annual Meeting, Soil Science Society of America. San Antonio, TX. Contact: www.soils.org

November 17-20, 2019. Annual Meeting, Entomological Society of America, St. Louis, MO. Contact: ESA, 9301 Annapolis Rd., Lanham, MD 20706; www.entsoc.org

November 20-22, 2019. Association of Applied Insect Ecologists. Visalia Convention Center, Visalia, CA. Contact: www.aaie.net

January 22-25, 2020. 40th Annual Eco-Farm Conference. Asilomar, Pacific Grove, CA. Contact: Ecological Farming Association, 831/763-2111; info@eco-farm.org

February 27-29, 2020. 31st Annual Moses Organic Farm Conference. La Crosse, WI. Contact: Moses, PO Box 339, Spring Valley, WI 54767; 715/778-5775; www.mosesorganic.org

March 2-5, 2020. Annual Meeting Weed Science Society of America. Maui, HI. Contact: www.wssa.net

March 15-18, 2021. 10th International IPM Symposium. Denver, CO. Contact: https://ipmsymposium.org *mellonella*, larvae and "then serially diluted" the nematodes in water for application. Multiple locally adapted nematode species were "integrated to deter host larvae populations in a combinatorial approach," said Shields. *Steinernema feltiae* 'NY 04' was chosen for its persistence in the top 7 cm (2.8 in) of soil. *Heterorhabditis bacteriophora* 'Oswego' was chosen for its persistence at a depth of 8-20 cm (3.1-7.9 in). "*S. carpocapsae* was originally paired with *S. feltiae*, but was found to be ineffective under plot conditions" in 2013.

After a single application (250 million of each species) combining *S. feltiae* 'NY 04' and *H. bacteriophora* 'Oswego' in August 2014, "black vine weevil was reduced to non-detectable by the end of June 2015" in a 4 ha (10 acre) strawberry field. An adjacent blueberry field, the weevil infestation source, was subsequently successfully treated with a single application of the native nematode combo.

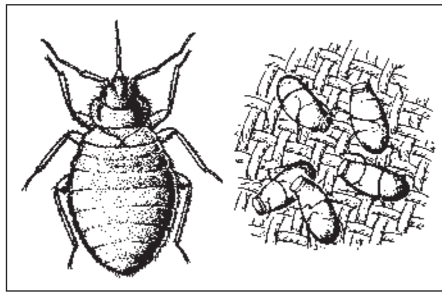
Steaming Bed Bugs

Professional and consumer-grade commercial steamers designed for cleaning homes are affordable and effective bed bug IPM tools, said Changlu Wang (Rutgers, 96 Lipman Dr, New Brunswick, NJ 08901; cwang@aesop.rutgers.edu). Representative steamers tested included: One, the inexpensive, portable HAAN HS-20R Handheld Steam Cleaner (HAAN Corp, Lancaster, PA), retailing for $60-75; two, the higher consumer-grade Steamfast SF-370WH Multi-Purpose Steam Cleaner (Steamfast, Andover, KS), retailing for $100-120; and three, the professional grade Amerivap Systems STM-BASIC Steamax Commercial Steam Cleaner (Amerivap Systems Inc, Dawsonville, GA), "commonly used by pest management professionals," priced in the $1200 range.

The boiling point of water at sea level is 100°C (212°F), and the minimum lethal temperature to kill bed bugs is 52°C (126°F). At 72-75°C (162-167°F), steamers can kill 100% of bed bug eggs and 91-95% of nymphs and adults on exposed surfaces, in box spring cracks and crevices, and the four corners of mattresses. However, that comes with a major caveat in the field, as bed bugs drop to the floor to avoid the lethal steam. So, areas under and around steamed surfaces must also be treated. But 100% bed bug mortality on mattresses and floors is possible; four seconds of steam is the minimum to treat bed bugs hiding in cracks.

With fabric covers, highest mortality is under thin sheets. Sofa leather lowers temperatures to under 45°C (113°F), resulting in low bed bug kill even with 15-30 seconds of steaming. Even with longer treatment times, steam may not pass through thick leathers. "Once water vapor had condensed over a fabric cover, it became less conducive to steam passing through," said Wang. "Moving the steamer attachment slowly across the surface of the cover is essential" to kill bed bugs hiding under fabric surface covers.

Bed bugs can hide under a great range of surface covers, carpets and fabric types, many untested, as well as paper, cardboard, and plastic. Important variables include "how fast steam is released and the attachment type being used." Larger brush attachments are generally selected over smaller tips to avoid steam being released so fast that bed bugs are blown to safety. But overall, "steamers at affordable prices achieved the same high control efficacy as the expensive steamer when properly used," said Wang.



Bed Bug, Cimex lectularius

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