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June 3, 2013

Don R. "Bud" Hover
Director, Washington Department of Agriculture

Cliff Weed
Compliance Manger, Pesticide Management Program

Washington Department of Agriculture
1111 Washington Street SE, 2nd Floor
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Sent via email

Re. Support for the Thurston County Board of Commissioners' petition to restrict use of neonicotinoid systemic insecticides in their county

Dear Mr. Hover and Mr. Weed,

The Xerces Society for Invertebrate Conservation and the Center for Food Safety applaud the efforts of the Thurston County Board of Commissioners to reduce unnecessary risks currently faced by honey bees and wild native bees due to homeowner use of systemic insecticides. The challenge today is that homeowners do not know that the products they buy from local garden and hardware stores contain toxins that are transported directly into the pollen and nectar collected by bees and other pollinators that visit the flowers that bloom on roses, rhododendrons, apples, and other treated plants. The Xerces Society and the Center for Food Safety support the petition submitted by the Thurston County Board of Commissioners to mandate that only certified applicators be allowed to apply products containing imidacloprid, clothianidin, and thiamethoxam.

In March 2012, following two years of background research and consultation with leading global bee toxicologists, the Xerces Society released *Are Neonicotinoids Killing Bees?* This 44-page report is the most comprehensive review of its kind and details the impacts of neonicotinoid insecticides on honey bees and other important agricultural pollinators.

Are Neonicotinoids Killing Bees? shows that these insecticides are very likely having a negative impact on not just honey bees but also on bumble bees and other agriculturally important pollinators. Key findings from the report include:

- Neonicotinoids are now one of the most widely used class of chemicals in this country.
- Neonicotinoid residues found in pollen and nectar are consumed by flower-visiting insects such as bees, and concentrations of these residues can reach lethal levels under some product uses, such as ornamental applications by homeowners.
- Neonicotinoids can persist in soil for months or years after a single application. Measurable amounts of residues were found in woody plants up to six years after a single application. Also, untreated plants may absorb chemical residues in the soil from the previous year.
- These products are also widely used around our homes and schools, and products approved for home and garden use may be applied to ornamental and landscape plants, as well as turf, at significantly higher rates (potentially 32 times higher) than those approved for agricultural crops.
- There is mounting evidence that the widespread use of neonicotinoid insecticides is harming bees.

The preponderance of studies published since this report was released further demonstrates that these products have a negative impact on both honey bees and wild bees.

Two studies of bumble bees exposed to varying levels of imidacloprid found that field realistic levels of this pesticide were capable of impairing foraging, increasing worker mortality, and reducing brood production by one-third (Gill et al. 2012; Laycock et al. 2012). Bumble bees exposed to low levels of imidacloprid (a level that might be found in pollen or nectar of a seed-treated plant) found an 85% reduction in the production of new queens and significantly reduced colony growth rates compared to control colonies (Whitehorn et al. 2012). Though these effects are sublethal, they can still have severe impacts. For example, decreased queen production can significantly reduce bumble bee populations.

Foraging honey bees exposed to a sublethal dose of thiamethoxam had reduced homing ability and survival (Henry et al. 2012). Though the study tested doses above what might be expected in seed-treated plants, the doses were realistic for treated ornamental plants or some crops treated via soil drench.

Recent research examining residue levels in pollen in nectar following soil treatment of an agricultural crop have found that levels exceed what has previously been reported for seed-treated crops (Dively and Kamel 2012; Stoner and Eitzer 2012). Additionally, observed residue levels were in a range known to cause harmful sublethal effects to bees. Rates applied to ornamental plants often exceed doses applied to agricultural crops. Correspondingly, residue levels in nectar or pollen of treated ornamental plants reported in peer-reviewed literature (Paine et al. 2011) or in industry reports (e.g., Maus et al. 2004) exceed levels reported in agricultural crops.

In the coming weeks we will also be releasing a follow up report that reviews the known science on how neonicotinoids are impacting additional beneficial, nontarget invertebrates.

While some research shows variability in how these chemicals impact nontarget invertebrates, the great majority of studies currently indicate that neonicotinoids are likely having a negative impact on biological control. This ecosystem service, provided by predator and parasitoid insects is conservatively valued at more than $4.5 billion annually (Losey and Vaughan 2006), providing pest control to farms, natural areas, and developed landscapes.

Key findings of the report (a PDF of the draft report is attached) include:

- Neonicotinoids are toxic to a wide variety or predators and parasitoids, though response can be variable.
- Predators and parasitoids are exposed to neonicotinoids directly during the application process, as well as beyond the time of application via consumption of contaminated plant materials or prey that have ingested the chemicals.
- The loss of predators and parasitoids due to neonicotinoid use can disrupt biological control and can foster secondary outbreaks.
- Prophylactic us of neonicotinoids is not compatible with IPM, and may contribute to the growing number of species that are resistant to neonicotinoids.
- Neonicotinoids are toxic to soil invertebrates that help maintain soil health and productivity, and widespread application may impact decomposition and soil quality.

After careful study and review of the research on the toxicity and exposure risks of neonicotinoid systemic insecticides, Xerces Society and Center for Food Safety scientists ask that the Washington Department of Agriculture mandate that all neonicotinoid products used by homeowner, commercial, and agricultural applicators include a clear and consistent warning on the label about the hazard to bees and other pollinators, including the unique exposure issues posed by contaminated pollen and nectar. This is particularly important for products marketed for garden and ornamental use.

Products marketed to homeowners for use on garden, lawn, or ornamental plants should all have a clear warning label that prominently states, “Use of this product may result in pollen and nectar that is toxic to pollinators.”

We also ask that Thurston County and/or the Washington Department of Agriculture consider banning the use of neonicotinoid insecticides for cosmetic purposes on ornamental and landscape plants, similar to a 2009 ban enacted by the provincial government of Ontario, Canada (http://www.ene.gov.on.ca/environment/en/category/pesticides/index.htm). Approved application rates for ornamental and landscape plants, as well as turf, are often much higher than for farm crops, and result in levels of neonicotinoids in pollen or nectar that can kill bees outright. Because of the lack of labeling on homeowner products, users of these products do not know that they may be directly poisoning bees and other pollinators. Furthermore, there is no significant economic reason or hardship imposed upon landowners by this action.

Thank you very much for your attention to these comments and additional materials submitted in support of this request by the Thurston County Board of Commissioners.

Sincerely,

Scott Hoffman Black
Executive Director
The Xerces Society

Andrew Kimbrell
Executive Director
Center for Food Safety

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BEYOND THE BIRDS AND THE BEES

Effects of neonicotinoid insecticides on non-target terrestrial invertebrates

By Jennifer Hopwood, Scott Hoffman Black, Mace Vaughan, and Eric Mader

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INTRODUCTION

The Xerces Society's 2012 report *Are Neonicotinoids Killing Bees?* summarized all available peer reviewed research on the impact of these pesticides on bees. Subsequently many new studies have been published that continue to provide evidence that these insecticides are having a negative impact on both honey bees and native pollinators. Additionally, a recent report by the American Bird Conservancy has detailed impacts to birds as well as to aquatic macroinvertebrates (Mineau and Palmer 2013).

The majority of media attention on neonicotinoid pesticides in recent years has focused largely on the known and perceived risks to bees. Although less charismatic than bees, invertebrates such as earthworms or predatory ground beetles play a critical role in ecosystem functioning, and may be impacted in detrimental ways. Now, compelling evidence is mounting that also points to detrimental impacts of neonicotinoids on these beneficial invertebrates.

Neonicotinoids are systemic insecticides, and may be applied to a plant as a foliar spray, as a seed coating, to soil as a drench or granule, or injected directly into the trunk of trees. The active ingredient permeates plant tissues and will travel within the plant by means of the plant's vascular system to leaves, stems, trunks, flowers, and fruits. Pest insects as well as non-pests that suck on plant fluids, chew leaves, or chew into wood will consume some amount of the active ingredient, as will insects that consume pollen or nectar.

Six neonicotinoids, imidacloprid, thiamethoxam, clothianidin, dinotefuran, thiacloprid, and acetamiprid, are approved for use on numerous crops. In the United States, over 3.5 million pounds of neonicotinoids were applied to nearly 127 million acres of agricultural crops annually from 2009-2011 (EPA 2012). In addition to uses in agriculture, imidacloprid, thiamethoxam, clothianidin, dinotefuran, and acetamiprid are approved for various uses on ornamental plants like turf grass and garden shrubs. Consequently, neonicotinoids can be applied in many diverse settings as well as farms, including gardens, schools, and cities. As neonicotinoid use becomes increasingly widespread, concerns are mounting about their impact on global ecosystem health.

This report reviews the known science on how neonicotinoids are impacting non-target invertebrates in three ways:

- *First, we examine how neonicotinoids are likely impacting beneficial predator and parasitoid insect populations.*

- *Second, we review research findings on the compatibility of neonicotinoids with Integrated Pest Management, and the development of pest resistance to neonicotinoids.*

- *Third, we summarize current findings on how neonicotinoids are impacting beneficial soil fauna, and the possible long-term effects of their use on soil health.*

While some research shows variability in how these chemicals impact non-target invertebrates, the great majority of studies currently indicate that neonicotinoids are likely having a negative impact on biological control. This ecosystem service, provided by predator and parasitoid insects is conservatively valued at more than $4.5 billion annually (Losey and Vaughan 2006), providing pest control to farms, natural areas, and developed landscapes.

Currently the recognized impacts of neonicotinoids on insects that provide biological control include death, sublethal effects (on reproduction, foraging, and longevity), and a loss of alternative prey/hosts. Predators and parasitoids may be exposed to neonicotinoids directly during the application process, as well as by eating contaminated plant materials or prey that have ingested the chemicals. Several studies show that the loss of predator and parasitoid insects from neonicotinoids may disrupt the process of biological control and foster secondary pest outbreaks.

Beyond impacts on biological control, neonicotinoids have been promoted as low-risk chemicals that fit well within the Integrated Pest Management (IPM) process (Elbert et al. 2008; Jeschke and Nauen 2008). Yet we believe the preemptive use of applications of neonicotinoids such as seed coatings represents a fundamental shift away from IPM, since chemicals are applied before pest damage has occurred. Use of neonicotinoid seed treatment on annual field crops has increased dramatically in the last decade (e.g. Stone 2013). In Iowa, for example, insecticide seed treatment of soybean was uncommon before 2000, but by 2009, at least 73% of soybean planted in Iowa was treated (Hodgson et al. 2012). However, preventative treatments like neonicotinoid seed coatings do not result in yield benefits in soybeans and are less cost effective than other control measures (e.g. Johnson et al. 2009). Additionally, recent field trials in field corn, conducted at several sites in Indiana, have not documented any pest management or yield benefit from low or high rates of neonicotinoid-treated seed compared with naked seed of the same hybrid. This suggests that the current approach of treating all corn seed with insecticides is unwarranted and unsupported by pest pressures or yield increases (Krupke, Pers. Comm. 2013).

Additionally, discussions around the role of neonicotinoids in IPM have promoted the ability to time applications for periods when beneficial insects are not present (Elbert et al. 2008). These claims however stand in stark contrast to the growing research demonstrating beneficial insect exposure and environmental persistence beyond the time of application.

Also related to IPM principles, neonicotinoid resistance has now been documented in a variety of pests. The environmental persistence of neonicotinoids such as imidacloprid and clothianidin, coupled with their widespread use, can facilitate pest resistance. For example, resistance to neonicotinoids has now been documented in a number of pests such as green peach aphid (*Myzus persicae*) (Jeschke and Nauen 2008) and Colorado potato beetle (*Leptinotarsa decemlineata*) (Olson et al. 2000).

Defining Integrated Pest Management (IPM)

Integrated Pest Management (IPM) is a decision-making framework that utilizes least hazardous pest management options only when there is a demonstrated need, and takes special precautions to reduce the hazards of pest management activities to living organisms and the environment.

IPM employs a four-phase strategy: (1) Reduce conditions that favor pest populations; (2) Establish an economic threshold of how much damage can be tolerated before pest control must occur; (3) Monitor pest populations; and (4) Control pests when the pre-established damage threshold is reached.

Finally, although there has been less research on the impact of neonicotinoids to soil organisms, the majority of studies to date have also found that neonicotinoids may have broadly negative effects on earthworms and other soil invertebrates. These organisms play multiple roles in maintaining soil health, such as enhancing decomposition, and influencing infiltration rates of water, nutrients, oxygen, carbon dioxide, salt, and pollutants within the soil (Anderson 1988; Setala et al. 1988; Stork and Eggleston 1992). Earthworms, for example, distribute organic matter during burrowing, thus influencing biological and chemical processes, and ultimately plant productivity. Earthworms and other soil invertebrates can be exposed to neonicotinoids when they are applied as soil drenches or granules, or as seed coating residues. Given the diversity of plants treated with neonicotinoids in this way, soil invertebrates face exposure in agricultural settings as well as in suburban and urban settings. This large-scale use of neonicotinoids across all landscapes raises concerns about the broad impact of these chemicals on soil health.

RECOMMENDATIONS

A growing body of research demonstrates risks from neonicotinoids to beneficial insects, particularly in agricultural systems but also in ornamental landscapes. Based on research findings, we make the following recommendations:

1) The US Environmental Protection Agency (EPA) should re-assess the ecological safety of currently approved neonicotinoids and immediately suspend all conditional registrations until we understand how to manage the risk to non-target species.

2) The EPA should significantly speed up the registration review process. The risk from exposure to neonicotinoid insecticides needs to be scientifically evaluated against the risk posed to beneficial species by alternative control measures.

3) The EPA should include additional non-target terrestrial insect species in the risk assessment process, such as a lady beetle species and a parasitoid wasp. The suite of non-target organisms used for risk assessment in Europe should be adopted here in the U.S.

4) Use of neonicotinoids should be immediately suspended for all cosmetic purposes (e.g. in parks, gardens) because of the risk they pose to non-target invertebrates.

5) There may be some pest risks that merit the use of neonicotinoids, such as in the control of invasive species that pose risk of plant species extirpation. Neonicotinoids should only be used when all other options are first exhausted. In such cases, application rates should be as low as possible, and applications should be timed to minimize impacts on beneficial species (e.g. applications should be made after flowering).

6) Until we understand if neonicotinoids can be used without causing undue harm to beneficial insects, prophylactic use of neonicotinoids on crops should be halted.

Neonicotinoids should only be used as part of an IPM plan with pest scouting or forecasts of pest pressure, and after considering alternative pest management strategies.

EFFCTS ON NON-TARGET BENEFICIAL INSECTS THAT PROVIDE BIOLOGICAL CONTROL OF PESTS

Billions of dollars are spent every year in the United States on measures to control agricultural pests, but these expenses would be exponentially larger without the free, and typically overlooked, pest control provided by beneficial predatory and parasitoid arthropods (a phenomenon known as "biological pest control"). The economic value of biological pest control in the United States provided by wild beneficial insects is conservatively estimated to be at least $4.5 billion annually (Losey and Vaughan 2006). Losses of these beneficial insects can lead to increased pest outbreaks (especially secondary pest outbreaks by species that were previously suppressed by beneficial insects), the greater need for pesticide use, and loss of crop yields.

Beneficial insects are common in crops but many also need non-crop habitat for shelter and alternative food sources (Landis et al. 2000). Parasitoid wasps, lady beetles, and lacewings prey upon other insects during part of their life cycle, and may feed on pollen or nectar during other parts of their life or when prey is scarce. For example, adult parasitoid wasps feed almost exclusively on nectar, and have a reduced ability to control pests without it (Lewis et al. 1998). When pollen or nectar sources are contaminated with neonicotinoid pesticides, the health of these beneficial insects may be compromised.

There is a growing body of evidence that beneficial insects are exposed to neonicotinoids through a number of pathways and that neonicotinoid exposure can cause harmful effects. These effects may include death, sublethal effects that reduce reproduction, foraging, and longevity, or indirect effects such as a loss of prey or hosts.

Below we provide a brief summary of studies related to neonicotinoids and beneficial insects that are known to provide biological control.

Neonicotinoid impacts on predator and parasitoid insects

Direct contact with neonicotinoids can occur when foliar sprays are applied and spray contacts the insect, or when the insect comes in contact with spray residues on the surface of vegetation.

- Dinotefuran sprays at label rates were highly toxic to a parasitoid wasp (*Leptomastix dactylopii*) and spray applications of acetamiprid, clothianidin, and dinotefuran were toxic to mealybug destroyer beetles (*Cryptolaemus montrouzieri*) (Cloyd and Dickenson 2006).

- Acetamiprid spray at the field rate was toxic to a predatory plant bug (*Deraeocoris brevis*) (Kim et al. 2006).

- Acetamiprid is toxic to a predatory thrip (*Scolothrips takahashi*) and a lady beetle (*Stethorus japonicus*) (Mori and Gotoh 2001, as cited in Narjano and Akey 2005).

- Imidacloprid spray at field rates caused significant mortality to nymph and adult predatory stink bugs (De Cock et al. 1996).

- Under lab conditions, acute contact applications of imidacloprid was found to be toxic to several species of predaceous true bugs, green lacewings, and lady beetles, although not to two species of predatory mites (Mizell and Sconyers 1992).

- Parasitoid wasps confined with citrus leaves that were treated with either imidacloprid or thiamethoxam had significantly higher mortality (Prabhaker et al. 2011).

- All life stages of a lady beetle used in biological control (*Harmonia axyridis*) were susceptible to topical treatment of a dose at label rates of acetamiprid, thiamethoxam, and imidacloprid (Youn et al. 2003).

Ground-dwelling beneficial insects such as rove beetles contact neonicotinoid residues present in soil.

- Applied to a growing medium at labeled rates, clothianidin, dinotefuran, and thiamethoxam were highly toxic to adults of a rove beetle (*Atheta coriaria*) (Cloyd et al. 2009).

- Imidacloprid, via applications to turf at label rates, significantly reduced the abundance of Hister beetles, and the larvae of predatory ground beetles and rove beetles (Kunkel 1999).

- Ground beetle and rove beetle abundance was significantly reduced by applications of imidacloprid granules at label rates (Peck 2009b). Ground beetle populations were reduced by up to 84% initially, and did not recover within a year (Peck 2009b). Ground and rove beetles are major predators of turf grass pests.

- Imidacloprid exposure does not always kill beneficial insects directly, but can make them more vulnerable to other threats. For example, ground beetles (*Harpalus pennsylvanicus*) exposed to imidacloprid in turf exhibited sublethal effects like temporary paralysis and impaired walking that made them more susceptible to predation (Kunkel et al. 2001).

- In the case of a parasitoid wasp, *Tiphia vernalis*, introduced to North America to control the Japanese beetle, exposure to imidacloprid (applied to the soil for Japanese beetle control) reduced their fecundity (and thus control of the beetle) (Rogers and Potter 2003).

- Granular applications of imidacloprid to turf did not affect ant populations or their predation on Japanese beetle grubs (Zenger and Gibbs 2001).

While most beneficial insects do not consume foliage, many feed on other plant parts such as nectar or pollen during at least one life stage. Beneficial insects can ingest neonicotinoid residues present in nectar or other plant parts of treated plants.

- Parasitoid wasps (*Microplitis croceipes*) experienced reduced foraging ability and shortened longevity after feeding on the extra-floral nectar of imidacloprid-treated plants in a lab experiment (Stapel et al. 2000).

- Pink lady beetles (*Coleomegilla maculata)* chronically exposed to imidacloprid residues in soil-treated sunflowers had reduced mobility and lower survivorship (Smith and Krischik 1999).

- Encyrtid parasitoid wasps (*Anagyrus pseudococci*) showed reduced mobility and lower survivorship after chronic exposure to flowers from plants treated with label rates of soil-applied imidacloprid (Krischik et al. 2007).

- Green lacewings (*Chrysoperla carnea*) exhibited significantly reduced survival after feeding on flowers treated with soil applications of imidacloprid (Rogers et al. 2007).

- Parasitoid wasps (*Avetianella longoi*) of pests of eucalyptus in California had reduced survival and reproduction after feeding on nectar from trees treated with imidacloprid at label rates five months before bloom (Paine et al. 2011).

- In addition to consuming pests like corn rootworms, adult ground beetles may also consume alternate foods such as pollen or occasionally seeds. In lab tests, ground beetle consumption of seeds treated with label rates of thiamethoxam, imidacloprid, or clothianidin caused nearly 100% mortality in the 18 species tested, though consumption of contaminated pollen caused no ill effects (Mullin et al. 2005).

- Lady beetles are common in agricultural crops, where they feed on aphids and other crop pests. *Harmonia axyridis*, a species introduced from Asia for biological control, will also feed directly on corn seedlings when prey is low. Larvae that briefly fed on seedlings grown from seeds treated with clothianidin or thiamethoxam experienced symptoms like trembling, paralysis, or loss of coordination, and significantly higher mortality (Moser and Obrycki 2009).

- Predaceous stink bug nymphs that consumed plant sap from thiamethoxam-treated cotton plants had reduced survival, and decreasing survival rates corresponded with increasing rate of application (Torres et al. 2003).

- In the absence of prey, minute pirate bugs had significantly higher mortality when confined with corn seedlings treated with imidacloprid seed treatments than with nontreated corn seedlings (Al-Deeb et al. 2001). Pirate bugs are known to feed on plant tissues when prey is scarce.

Beneficial insects may also consume prey insects that are contaminated with neonicotinoids.

- The lady beetle *Hippodamia undecimnotata* experienced reduced survival, longevity, and egg production following predation on aphids reared on bean plants treated with imidacloprid, applied to soil at a fraction of the label rate (Papachristos and Milonas 2008).

- After feeding on cottony cushion scales that had been raised on treated plants, adult vedalia beetles (*Rodolia cardinalis)* had lower survival and reduced fecundity, and larvae had high mortality rates (Grafton-Cardwell and Gu 2003). Vedalia beetles still provide the most effective control of cottony cushion scale, so insecticides must be used carefully to protect it.

- Ground beetles confined in a microcosm jar with soil, clothianidin treated corn seedlings, and corn rootworm prey had significantly higher rates of mortality, at least in part due to the ingestion of contaminated prey (Mullin et al. 2005).

- Minute pirate bug consumption of imidacloprid-contaminated corn rootworm eggs caused significantly increased rates of mortality (Elzen 2001). In contrast, big-eyed bugs suffered less mortality, but imidacloprid exposure did reduce big-eyed bug consumption of pest eggs (Elzen 2001).

Two unexplored routes of exposure to neonicotinoids for beneficial insects include the drinking or collecting of surface water contaminated with neonicotinoid residues, and the drinking of guttation fluids (xylem sap exuded by plants in the morning, appearing as droplets on leaf edges, or at the tip of the plant).

- Imidacloprid was found in 89% of surface waters sampled in agricultural regions in California, demonstrating that imidacloprid can move offsite from where it is applied and can contaminate water (Starner and Goh 2012). To our knowledge, no research has investigated the effects of neonicotinoids on beneficial insects that have been exposed to contaminated surface water. However, given that nearly 20% of the water samples exceeded the EPA benchmark for toxicity to aquatic invertebrates (Starner and Goh 2012), exposure of beneficial insects to neonicotinoids through surface water seems worthy of examination. Levels harmful to aquatic invertebrates are likely to be similarly harmful to terrestrial invertebrates as well.

- Guttation fluid of seed-treated corn can contain concentrations of imidacloprid, clothianidin, and thiamethoxam at levels that are toxic to beneficial insects (Girolami et al. 2009). Toxic levels of imidacloprid have also been reported in guttation of melons grown in imidacloprid-treated soil (Hoffman and Castle 2012). Guttation drops can serve as a water source for beneficial and pest insects, though the extent to which guttation fluid is consumed by beneficial insects in a field setting is unknown.

Not all groups of beneficial insects, even those that are closely related, respond similarly to neonicotinoid exposure.

- Field rates of imidacloprid applied to control aphids in stone fruits are toxic to some species of predatory mites, ground beetles, rove beetles, spiders, and predatory true bugs, but other species in these groups tolerated exposure (James and Vogele 2001 as cited by James and Price 2002).

- Imidacloprid is non-toxic to the predatory mite *Amblyseius victoriensis* (James 1997), but is highly toxic to another predatory mite *Neoseiulus fallacis* (Bostanian et al. 2010). Acetamiprid, thiamethoxam, imidacloprid are not toxic to a predatory mite (*Anystis baccarum)* found in apple orchards (Lauren and Bostanian 2007), but acetamiprid and imidacloprid are moderately toxic to another predatory mite (*Neoseiulus fallacis*) found in apples (Villanueva and Walgenbach 2005).

- Comparisons were made between predator species richness and abundance in fields planted with and without imidacloprid-treated corn seed. Populations of spiders, lady beetles and ground beetles in treated fields were not significantly different from untreated fields, while rove beetles and some predatory true bugs significantly declined in treated plots (Albajes et al. 2003).

The different types of neonicotinoids vary in their toxicity to beneficial insects. Some neonicotinoids are more toxic to beneficial insects than are other neonicotinoids.

- Imidacloprid and thiamethoxam are considered to be highly toxic to a predatory mite, while acetamiprid and thiacloprid are considered only mildly toxic (Bostanian et al. 2010).

- In cotton fields treated with either acetamiprid or imidacloprid foliar sprays, numbers of predatory big-eyed bugs were similar to control fields. However, big-eyed bug populations were significantly lower in fields treated with foliar applications of thiamethoxam (Kilpatrick et al. 2012).

- Spray of dinotefuran at a label rate was 120 times more toxic to a parasitoid wasp than acetamiprid or clothianidin (Cloyd and Dickenson 2006).

Much of the research investigating the effects of neonicotinoids on beneficial insects has involved imidacloprid; the effects of other neonicotinoids are less known. In particular, effects of dinotefuran, which is currently allowed for use in vegetables, leafy greens, some tree fruits, and some ornamental plants, is particularly understudied.

NEONICOTINOIDS AND INTEGRATED PEST MANAGEMENT

Given the important role that beneficial insects play in controlling crop pests, insecticide use should ideally balance the need to control pests with the maintenance of healthy populations of beneficial insects. Integrated Pest Management (IPM) provides a framework to reduce the effects of insecticides on non-target species. Following the basic tenets of IPM, control measures are instituted only after a regular surveillance program determines that pest levels have risen to an economically damaging level. When action is taken, the natural system is to be undisturbed as far as possible. An IPM program combines cultural, physical, biological, and least-toxic chemical control strategies.

Neonicotinoids have been promoted as low-risk for non-target organisms and the environment, and as compounds that are compatible with IPM (Elbert et al. 2008; Jeschke and Nauen 2008). Stated advantages for use of neonicotinoids in IPM include the ability to time applications for periods when beneficial insects are not present (Elbert et al. 2008). However, these claims stand in contrast to the growing research demonstrating beneficial insect exposure and environmental persistence beyond the time of application.

Neonicotinoids can disrupt biological control in some cropping systems by causing harm to beneficial insects.

- Researchers found that foliar imidacloprid did not control citrus pest species in California citrus orchards and it disrupted biological control. The suppression of parasitoid wasps by imidacloprid allowed pest populations to increase beyond those of untreated orchards (Grafton-Cardwell et al. 2008).

- In an experiment in Indiana, imidacloprid and thiamethoxam did not control euonymus scale (*Unaspis euonymi*), a pest common in ornamental plantings. However, the neonicotinoids did decrease parasitism of the scale by its natural enemy, a parasitoid wasp (*Encarsia citrina*), which led to increases in the scale pest (Rebek and Sadof 2003).

- Acetamiprid can contribute to control of a whitefly in cotton but is not a suitable substitute for insect growth regulators in an IPM program, because it reduces predators more than do the more targeted insect growth regulators (Naranjo and Akey 2005).

- Soybean fields can host a diverse community of beneficial insects, but imidacloprid or thiamethoxam seed treatment reduced predatory insects like damsel bugs and lacewings while pests such as soybean aphids, grasshoppers, and thrips were unaffected by neonicotinoid seed treatment (Seagraves and Lundgren 2012).

In some cropping systems, neonicotinoids have demonstrated little control of major pests or little or no improvement of yield.

- Imidacloprid or thiamethoxam treatments to soybean seeds did not result in yield benefits (Magalhaes et al. 2009; Schultz et al. 2011; Seagraves and Lundgren 2012).

- Soybean seed treatments (imidacloprid and thiamethoxam) had less impact on natural enemies but had limited, inconsistent yield protection compared to foliar insecticide applications made after aphid populations developed (Ohnesorg et al 2009).

- Preventative application of thiamethoxam applied to soybean seed did not significantly reduce soybean aphids or prevent yield loss compared with a well-timed insecticide application as part of an IPM program (Johnson et al. 2009).

- In a comparison between thiamethoxam seed treatment, IPM, and a preventative application of foliar insecticide, IPM treatments had the highest probability of recouping treatment cost, while seed treatment had the lowest probability of recouping cost (Johnson et al. 2009).

- Compared with imidacloprid seed-treated corn, untreated corn suffered more insect damage but yields between treated and untreated corn plots did not differ significantly (Pons and Albajes 2002).

- When pest activity is high, neonicotinoid seed treatment of corn can increase yields but when pest pressure is reduced, there are no consistent effects of seed treatment on yield (Wilde et al. 2007).

Neonicotinoids can be as toxic to non-target beneficial insects as older chemistries.

- In field studies of effects of insecticides used to control bollworm in cotton, mortality inflicted on predatory arthropods by thiamethoxam approached that exhibited by dicrotophos, an organophosphate (Kilpatrick et al. 2012).

- Ground beetle activity was significantly reduced in corn fields planted with clothianidin-treated seed, and was not statistically different from activity in fields treated with conventional pyrethroids (Leslie et al. 2010).

Pest resistance to neonicotinoids

Also related to IPM, neonicotinoid resistance has now been documented in a variety of pests. Although the introduction of neonicotinoids brought with it optimism that that this chemical class would be more resilient to pest resistance than past chemistries (Nauen and Denholm 2005), the environmental persistence of neonicotinoids such as imidacloprid and clothianidin, coupled with their widespread use, may have actually increased the likelihood of pest resistance.

A key strategy to reduce the selection of resistant pests is to use a product only when the need is demonstrated, such as when pest density exceeds an economic threshold. Extensive use of preemptive treatments like seed coatings may contribute to increased pest resistance.

To date, field resistance to neonicotinoids has been seen in a number of pests, including tobacco whitefly (*Bemisia tabaci*) (Horowitz et al. 2004), green peach aphid (*Myzus persicae*) (Jeschke and Nauen 2008), brown planthopper (*Nilaparvata lugens*) (Wen et al. 2009), Colorado potato beetle (*Leptinotarsa decemlineata*) (Olson et al. 2000), damson hop aphid (*Phorodon humuli*) (Jeschke and Nauen 2008), greenhouse whitefly (*Trialeurodes vaporariorum*) (Gorman et al. 2007), and cotton aphid (*Aphis gossypii*) (Wang et al. 2002).

Resistance to neonicotinoids can occur in pest species that have some existing degree of tolerance for nicotine (e.g. green peach aphid), in pest species that have built resistance after extensive exposure to many pesticides aside from neonicotinoids (e.g. Colorado potato beetle), and in pest species that have developed resistance through long-term selection after exposure to neonicotinoids (e.g. tobacco whitefly) (Tomizawa and Casida 2003).

There are six neonicotinoid compounds that are allowed for use on crops currently in the United States. The broad-scale use of these neonicotinoids will facilitate the development of pest resistance by enhancing conditions that favor resistant pests (Jeschke and Nauen 2008). Once resistance develops to one neonicotinoid compound, the pest shows some degree of resistance to the whole neonicotinoid class (Elbert et al. 2008). For example, in lab tests of all available neonicotinoids, researchers found that Colorado potato beetle had cross-resistance to all neonicotinoids tested, including some that had never been used in the field before (Mota-Sanchez et al. 2006).

Secondary pests

One unintended effect of insecticide use can occur when beneficial insects are accidentally killed, causing a sudden increase in pests that previously had been suppressed. Often those pests had not been recognized as a significant threat, and had not previously required pesticide control. The use of neonicotinoids to control one pest can cause harm to beneficial insects, and thus lead to the development of secondary pest outbreaks.

- Imidacloprid seed-treatment controlled some corn pests, but increased pests such as European corn borer (Pons and Albajes 2002).

- Hemlock trees treated with imidacloprid in order to control the hemlock woolly adelgid had larger populations of spider and rust mites (Raupp et al. 2004).

- Spider mite populations were higher, and damage to the plant was greater, on imidacloprid-treated ornamental plants, because the insecticide reduced a spider mite predator (Sclar et al. 1998).

- Neonicotinoid treatments to prevent glassy-winged sharpshooters, which oviposit on citrus, may contribute to outbreaks of cottony cushion scale because the treatment reduces survival of the predatory vedalia beetle (Grafton-Cardwell et al. 2008).

- After imidacloprid treatment to elm trees, insect predators decreased, and spider mite populations increased (Szczepaniec et al. 2011).

- High predator mortality due to applications of thiamethoxam in cotton resulted in a resurgence of bollworm larvae (Kilpatrick et al. 2012).

- Imidacloprid decreased plant defense capabilities in cotton, corn, and tomato against herbivores not susceptible to the treatment. The disruption of plant defense contributed to spider mite outbreaks in both greenhouse and field settings (Szczepaniec et al. 2013).

With only a few exceptions, the increasing prophylactic use of neonicotinoids represents a shift in pest management towards applying chemicals before pest damage has occurred and in some cases, before pests are even present. Preemptive treatments like seed coatings are contrary to the core principles of IPM because insecticides are used before their need is demonstrated. Due to the harm neonicotinoids cause beneficial insects and the subsequent disruption to biological control that can occur, it may be difficult to integrate these chemicals into IPM programs.

EFFECTS ON NON-TARGET INVERTEBRATES THAT LIVE IN LEAF-LITTER OR BELOWGROUND

Invertebrates such as earthworms, ants, and mound-building termites are considered to be "ecosystem engineers" for their ability to influence natural functions on a landscape level (Jones et al. 1994). Soil invertebrates enhance microbial activity, speed up decomposition, and influence movement of water, nutrients, oxygen, carbon dioxide, salt, and pollutants within the soil (Anderson 1988; Setala et al. 1988; Stork and Eggleston 1992). Earthworms, for example, through the movement of organic matter during burrowing, influence important biological and chemical processes in the soil, and can ultimately increase plant productivity.

Earthworms and other invertebrates that dwell in soil or leaf-litter can be exposed to neonicotinoids applied as soil drenches, granules, or coated seed. Given the diversity of plants treated with neonicotinoids in this way, soil invertebrates face exposure in agricultural settings as well as in suburban and urban settings. This large-scale use of neonicotinoids across all landscapes raises concerns about the broad impact of these chemicals on soil health, soil food webs, and soil invertebrate communities.

Earthworms, which are often used as a model test organism for ecotoxicology studies, are among the better studied soil invertebrates for non-target effects of neonicotinoids.

- Imidacloprid, clothianidin, thiacloprid and acetamiprid are more toxic to earthworms than other modern synthetic insecticides; of these four active ingredients thiacloprid is the least toxic to earthworms (Wang et al. 2012).

- Imidacloprid is toxic to earthworms at 2.30-3.48 ppm in dry soil (Zang et al. 2000; Wang et al. 2012).

- In spray applications made to turf grass at label rates, imidacloprid reduced earthworm populations by 40-50%, though populations recovered in about 40 days (Kunkel 1999).

- A range of sublethal effects have been observed in earthworms after exposure to environmentally relevant levels of imidacloprid (0.33-0.66 ppm), including sperm deformities, changes in burrowing behavior, reduced body mass, and reduced cast production (Luo et al. 1999; Lal et al. 2001; Mostert et al. 2002; Capowiez et al. 2003, 2010; Dittbrenner et al. 2010, 2011). Such sublethal effects may be impacting the activity of earthworms and thus their beneficial contributions to soil health.

- Capowiez et al. (2006) found that alterations to burrowing behavior of earthworms exposed to imidacloprid at field-realistic levels (0.1 and 0.5 ppm) altered gas diffusion in soil.

- Following soil-injection of imidacloprid to control emerald ash borer, soil concentrations reached a maximum of 200 ppm, and average concentrations in a small radius around the injection site were 12-25 ppm (Kreutzweiser et al. 2008). Earthworms foraging in that area would be exposed to highly toxic concentrations of imidacloprid, reported to be 2.30-3.48 ppm in dry soil (Zang et al. 2000; Wang et al. 2012).

The direct effects of neonicotinoids on soil invertebrates other than earthworms have not been well studied, though what studies do exist suggest negative impacts on some non-target invertebrates.

- Use of imidacloprid on turf at label rates for grub control for three growing consecutive seasons suppressed the abundance of collembola and adult beetles by 54-62%, though ants, fly larvae, beetle larvae, and soil mites were unaffected (Peck 2009a).

- Soil-dwelling insects may be more susceptible to parasitoid nematodes after exposure to neonicotinoids. Nematodes that infect insects and imidacloprid act synergistically on soil pests such as scarab beetle grubs (Koppenhofer et al. 2002) and termites (Ramakrishnan et al. 1999).

Both lethal and sublethal effects may be impacting the activity of earthworms and thus their beneficial contributions to soil health. Declines of non-target soil invertebrates can lead to impacts on decomposition and nutrient cycling.

- Earthworms had an aversion to leaves from ash trees treated with label doses of imidacloprid (leaf residues = 31 ppm), an aversion that can affect the decomposition of leaves (Kreutzweiser et al. 2009).

- Applied as a spray treatment to turf, clothianidin significantly reduced populations of earthworms, collembola, and oribatid mites, the predominant decomposers in cool season turf. Additionally, the decomposition of grass clippings was significantly delayed (Larson et al. 2012).

CONCLUSION

Neonicotinoids are now one of the most widely used class of pesticides in the United States, with over a hundred registered uses for various ornamental plants, crops, structural pests, veterinary purposes, and more. As a consequence, neonicotinoids are found across the county in every conceivable landscape: residential yards, gardens, schoolyards, and farms. In farmlands alone, millions of acres of neonicotinoid-treated seeds are planted every year, and countless other crops, including perennial fruit and nursery crops, are treated with foliar sprays or soil. In addition to being widely used, these chemicals are also persistent. Neonicotinoids are known to remain in the soil for months or years after a single application (EPA 2002) and measurable residue levels have been found in woody plants up to six years after a single application (Doering et al. 2004).

Because of this widespread use and environmental persistence, neonicotinoids are a threat to a wide range of beneficial wildlife. While earlier research demonstrates that neonicotinoids pose a risk to bees (for a summary, see the 2012 Xerces Society report, *Are Neonicotinoids Killing Bees?*), as this report now demonstrates, neonicotinoids also negatively impact other beneficial insects, including predatory and parasitoid species that provide biological control of crop pests, and soil invertebrates that are critical to soil health. Furthermore, beyond the scope of this report, additional research is now emerging that demonstrates harm from neonicotinoids to birds and aquatic invertebrates.

Collectively, all of this research points to a single conclusion: Despite pesticide industry claims to that neonicotinoids are a safer alternative to older insecticides, non-target animals still face a significant and growing threat from these chemicals.

Prophylactic neonicotinoid use is widespread. Virtually all non-organic corn seed planted is now treated with neonicotinoids (Krupke et al. 2011), and non-organic untreated seed is difficult to obtain. However, past and ongoing research demonstrates that preventative neonicotinoid seed treatments do not consistently result in management of key pests or yield benefits, which suggests that widespread use of treated seed is unwarranted. Though seed treatment is more convenient for farmers, its use is not always supported by pest pressures or yield increases, and it may not be as cost effective as measures taken as part of an IPM program.

The tradeoffs between pest control and impacts to non-target wildlife can be argued. In some cases, protection of human health may necessitate undesirable and harmful impacts on wildlife. What cannot be argued is the tradeoff between pest control and the protection of whole ecosystems and ecosystem services such as pollination, pest regulation, soil health, and clean water that sustain us. Pesticides such as neonicotinoids that threaten these ecosystem services are counter-productive, and pose an unacceptable risk to human health, food security, and biodiversity conservation.

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