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Environmental Risks to Arthropods from Imidacloprid Applications for Hemlock Conservation

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OVERVIEW:

Managing hemlock woolly adelgid (HWA) (*Adelges tsugae*) (Figure 1) can involve use of insecticides. When it does, the non-target impacts (negative effects to other organisms) need to be thoroughly considered and weighed against the environmental cost of inaction or alternative management approaches. Insecticides applied for HWA management are used for conservation purposes, which may seem counterintuitive. However, hemlocks are a key forest species, and so their loss can result in severe ecological consequences. To justify insecticide use against HWA, we have to ask: What are the possible negative consequences of using insecticides in the forest? We must consider these trade-offs in hemlock management. It is important to remember that there will be trade-offs in any kind of resource management discussion, even if it may not initially seem apparent. The negative environmental consequences of hemlock mortality must be weighed against the known consequences of insecticide use to preserve hemlocks.

Figure 1: ***Hemlock woolly adelgid.***
Elizabeth McCarty, University of Georgia

What insecticides are used for HWA suppression?

Imidacloprid, the insecticide most commonly used for HWA treatments, is a neonicotinoid insecticide. A single imidacloprid treatment can protect a hemlock tree for up to 7 years.[1] Dinotefuran, another neonicotinoid is also used, but much less often, because it only lasts up to two years[2] and is currently more expensive. Most research on non-target effects have focused on imidacloprid, since it is more commonly used in hemlock forests. Neonicotinoids are less toxic to vertebrates – humans and wildlife – than many of the older insecticides that are still currently being used, such as carbamates and organophosphates. Neonicotinoids were developed for this safer vertebrate environmental profile.

Neonicotinoids are sufficiently water soluble to allow their movement in sap within the vascular tissue of plants. A small amount can be applied to the soil around a tree or to the trunk of the tree, and the insecticide can move upward and throughout the canopy, suppressing HWA populations by exposing the insect from the interior of the tree. Compare this to entire canopy sprays using contact insecticides. Canopy sprays are generally impractical for forest settings, partly due to equipment access, but also because the spray easily deposits away from the tree. Spray not deposited on the foliage, branch, or trunk will end up in the surrounding environment, which could then affect surrounding species. However, since imidacloprid is somewhat water soluble, it can move away from the area where it is applied. It is essential to consider how far and at what concentrations does the insecticide move, and does it cause any biological problems? If there are problems, how does that factor into the trade-off between managing HWA and losing hemlocks?

How are insecticides applied to hemlocks?

Imidacloprid can be applied to trees by various methods: soil drench, soil injection, CoreTect® slow release pellets, trunk injection,[3,4] and basal bark spray. No matter the application method, the same amount of imidacloprid will be applied to a hemlock. All application methods provide HWA suppression in many forest locations. Soil and spray applications are not recommended within 10 feet of a stream channel, pond, wetland, etc., for the protection of aquatic organisms.

- Soil drench (Figure 2) involves pouring an imidacloprid suspension around the base of the tree within 6-24 inches of the trunk and requires no specialized equipment.
- Soil injection is the application of small volumes of imidacloprid slightly below the soil surface with a specialized soil injector.
- Basal bark sprays are performed by spraying imidacloprid on the bark of the hemlock. The insecticide moves through the bark to the vascular tissue in the tree. Basal bark sprays are often applied with a backpack sprayer.
- CoreTect® slow release pellets are applied by placing pellets in the soil around the base of a hemlock – about 2 inches below the soil surface.
- Trunk injections involve applying imidacloprid to the vascular tissue in the tree trunk. This method requires specialized training and equipment. However, this method is the only appropriate application method for trees that are within 10 feet of a stream channel. Trunk injections are more expensive and time consuming than the other application methods.

Figure 2: ***Imidacloprid soil drench application. Imidacloprid suspension is poured on the soil within 24 inches of the hemlock trunk.*** Elizabeth McCarty, University of Georgia

What are the environmental risks of imidacloprid use?

Anytime insecticide use is considered, an applicator must be mindful of possible environmental impacts. Vertebrate wildlife and human impacts are less of a concern than insects for imidacloprid impacts, due to the lower toxicity of neonicotinoids to vertebrates. However, the insecticides used in hemlock systems have the potential to negatively affect canopy arthropods, pollinators, soil arthropods, and stream macroinvertebrates (Figure 3). This risk would be a concern for any insecticide used in forest systems. Fortunately, non-target insecticide research has occurred and continues in hemlock forests. The realistic risk of non-target effects of imidacloprid is largely, while not completely, understood in the context of making wise management decisions.

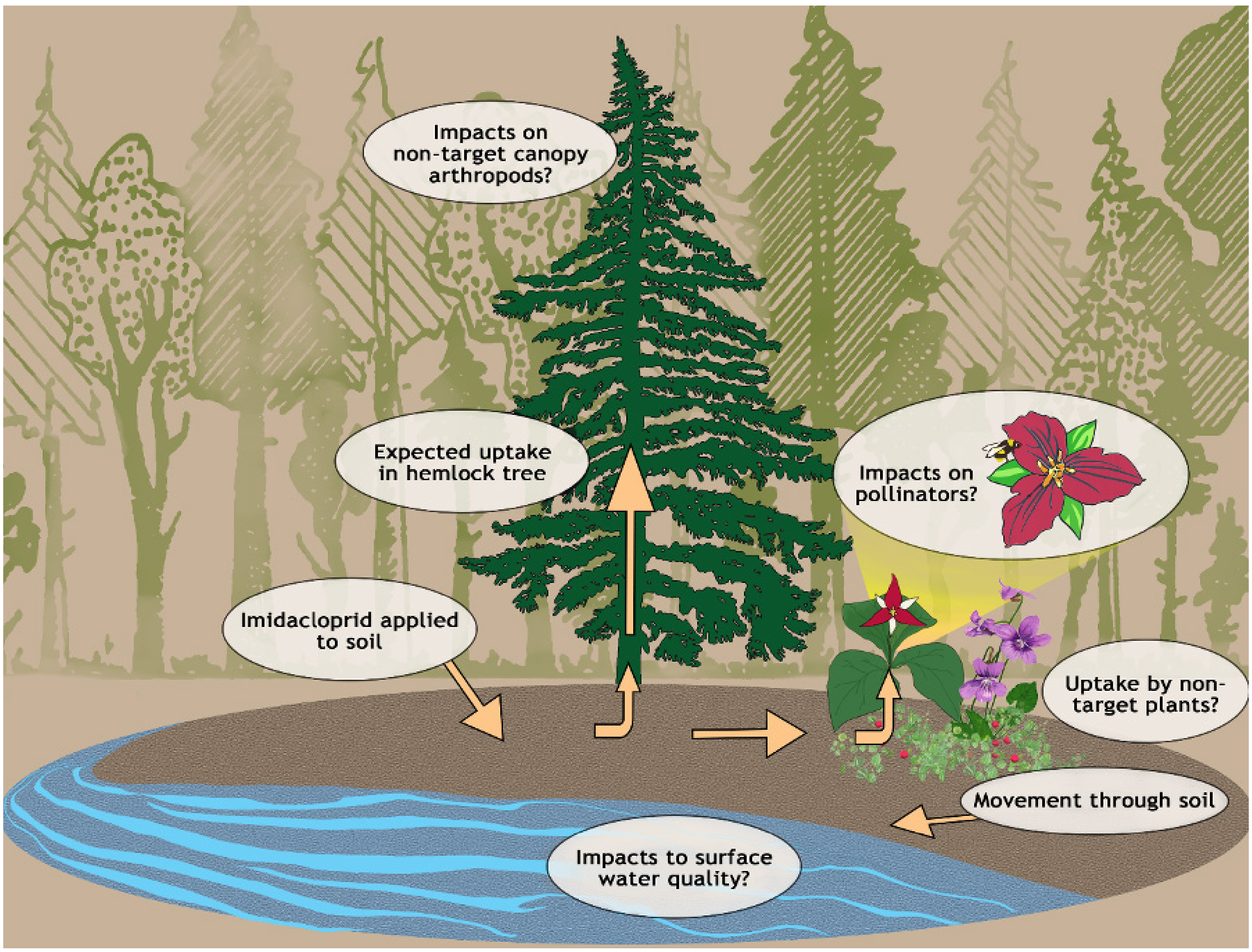

Figure 3: *Imidacloprid movement in the environmental and possible impacts to insects and other arthropods in forests. Imidacloprid concentrations decrease as it migrates away from the application site.*
Liz Moss, Center for Invasive Species and Ecosystem Health, University of Georgia, 2018

How long does imidacloprid move and persist in the ecosystem?

Imidacloprid can be persistent for numerous years in hemlock systems,[1,3,5] but when considering the presence of a compound in the environment we should ask more than "Is the chemical there?" Other questions to pose are, "How much of the chemical is present?" and "Is this amount harmful to other organisms?"

Imidacloprid begins to degrade once it is applied. The break down products, or metabolites, vary depending on where imidacloprid is in the system. For example, imidacloprid olefin (henceforth referred to as "olefin") is an insecticidal metabolite commonly found in plant tissues,[6] but it is not a prevalent breakdown product of imidacloprid in water.[7] So while olefin helps the HWA treatment last longer,[1] it is not as critical for affecting insects in aquatic environments compared to those feeding on plants.

Imidacloprid does move away from where it is applied, but it does so in small amounts as it degrades, or breaks down. It binds, or attaches, to clay and organic matter in soil, which helps hold it in place[8] and reduces the speed at which it moves in the environment. As insecticide residues move they are dissipating within larger volumes of soil, and they also are being degraded. Imidacloprid can move down the soil column[9] in lower concentrations than at the application site and leach into surface water.[10,11] Imidacloprid concentrations detected in streams in hemlock forests range from <20 – 800 parts per trillion.[10-12] A part per trillion is a way to measure the concentration of a substance. For example, 20 parts per trillion means that there is 20 parts of imidacloprid in every one trillion parts of water.

While imidacloprid moves in the environment in low concentrations, the next important question is, "Does imidacloprid cause biological problems in hemlock forests?" The focus will be on insects and other arthropods, as they have the highest risk of negative impacts from neonicotinoid insecticides. Risk is organized into four categories, starting at the top of the tree and working down to streams flowing through hemlock forests: canopy arthropods, pollinators, ground and soil-dwelling arthropods, and aquatic macroinvertebrates.

Does imidacloprid cause biological problems in hemlock forests?

Canopy arthropods

Canopy arthropods include all insects, spiders, and other arthropods living in tree canopies, including hemlock woolly adelgid. Insecticide applications are targeted to suppress a canopy arthropod, so some non-target impacts are reasonable to expect. Canopy arthropods show some negative, but not catastrophic, effects in the first two years after imidacloprid treatment. In a Tennessee study 33 of 293 arthropod species that were associated with eastern hemlock trees were affected by imidacloprid treatments. The species were either moths, which feed on plants, or psocopterans (bark lice), which feed on dead organic material.[13] All of the impacted moth species also pupate in the soil, often near the base of a tree, which means that they may have been impacted by insecticide residues in the soil rather than in the canopy. The overall arthropod abundance (number of individuals collected) in imidacloprid soil injection and trunk injection treatments was lower than untreated controls but higher than in soil drench treatments. Untreated trees, located in the more southern portion of hemlock's range, later died due to HWA feeding.[13] Thus, those canopy arthropod communities no longer had hemlock canopy habitat.

A second study from Great Smoky Mountains National Park assessed canopy arthropods as bird prey within two years of imidacloprid treatments. Richness (total number of types of insects collected) and abundance were the same in treated and untreated trees. However, plant-feeding hempiterans (insects like leafhoppers and stink bugs) and moths, while having similar abundance, made up a smaller percentage of the canopy insect communities in treated compared to untreated trees.[14]

A third study, which was conducted in Connecticut, compared canopy arthropod communities in treated and untreated hemlock trees three and nine years after imidacloprid treatment. Untreated hemlocks could be assessed nine years after treatment because the trees were still alive. Hemlocks in this more northern location tend to survive HWA infestations for longer time periods due to HWA mortality associated with lower winter temperatures.[15] There was no difference in arthropod abundance or richness in imidacloprid-treated trees three years after insecticide application compared to untreated hemlocks.[16] In other words, canopy arthropod numbers and the number of species present had recovered after three years. Nine years after treatments, canopy arthropod communities had similar abundance, but more species in treated compared to untreated trees.[16]

To put canopy arthropod risk in perspective, if the trees are not treated and die, which is common in the southern Appalachians, then canopy arthropods no longer have a habitat.[13] Thus, for management decisions, potential shorter-term canopy arthropod impacts of insecticide use must be weighed against the impacts of HWA-induced hemlock canopy loss or mortality. Insecticide use impacts cannot be realistically contrasted with an ideal healthy untreated hemlock, because these no longer occur after a HWA infestation.

Pollinators

Pollinators (Figure 4) include native bees, honeybees, butterflies, flies, wasps, and beetles. Effects of insecticide use on pollinators in hemlock systems is currently unknown, although research is underway. It is important to note that hemlocks are wind pollinated, and pollinators likely do not collect pollen from them. The most likely exposure route for pollinators would be uptake of imidacloprid by flowering plants growing adjacent to treated hemlock. Plants growing closer to the hemlock trunk would be at higher risk of accumulating higher concentrations of insecticide residues. Soil imidacloprid concentrations diminish as distance from application site increases. As soil concentrations decrease, there is less insecticide available for uptake into plants. Thus, insecticide accumulation is not a risk for all of the plants growing under the hemlock canopy. Risk to pollinators is expected to be low, especially on larger, stand-level or landscape scales. However, there are application tactics that can be implemented to reduce possible risks to pollinators. These include not applying insecticide solution where a flowering plant is growing, removing flowers of adjacent plants when making applications, and applying insecticide after bloom. Risks to pollinators are currently being assessed in small herbaceous plants growing adjacent to hemlocks treated either by bark spray, soil drench, or soil injection.[17] The goal of this study is to understand the highest likelihood for risk and how application methods may be more protective of pollinators.[17]

Figure 4: ***Mason bee,*** **Osmia ribiifloris**
Photo credit: Jim McCullouch

Ground and soil-dwelling arthropods

Soil arthropods are organisms like mites, springtails (Figure 5), ants, beetles, and many more that live in the soil, on the soil surface, or both. Springtails, for example, have been used as bioindicators, because they are abundant and are active in and on the soil. Soil arthropod populations using four different abundance metrics (total springtails, orbatid mites, mesostigmatid mites, total microarthropods) were similar in the soil around imidacloprid-treated hemlock trees compared to untreated trees.[18] These samples were collected at the application site, 1 meter away, 2 meters away, and at the hemlock drip line. Populations were assessed at 2 weeks, 6 months, and 12 months after imidacloprid treatments.[18] In addition, a study currently in progress is assessing ants living in the leaf litter where imidacloprid was applied to hemlocks by soil injection, soil drench, or bark spray treatments (McCarty, University of Georgia study). The leaf litter is sampled in one square meter starting at the hemlock trunk, where the imidacloprid application was made and extending downhill. Samples were collected before imidacloprid was applied and three weeks, four months, and 16 months after applications. Preliminary results from this ongoing study suggest that ant abundance and richness is similar when compared among all sampling times, among imidacloprid application methods, and when compared to untreated control areas.

Figure 5: ***Springtail***
Photo credit: Mardon Erbland, BugGuide.net

Aquatic macroinvertebrates

Aquatic macroinvertebrates (insects and other stream invertebrates) are very sensitive to imidacloprid – more sensitive than most terrestrial insects, including bees. The effects of hemlock imidacloprid use on stream aquatic macroinvertebrates have been assessed in two studies: one from near the north Georgia/North Carolina border[12] and another from Great Smoky Mountains National Park.[19] Both of these study areas are in the southern Appalachians.

Aquatic macroinvertebrates in four streams flowing through areas where imidacloprid soil injections were used were compared to a control stream, which flowed through forests where no imidacloprid had been used.[12] For simplicity, streams will be referred to as "treated" and "control", although the streams were not actually treated with insecticide. Hemlocks in the riparian areas were treated with imidacloprid soil injections. Comparisons were made before and for two years after imidacloprid application.

Three water quality metrics were used to assess aquatic macroinvertebrate communities. Mayflies (Ephemeroptera) (Figure 6), stoneflies (Plecoptera), and caddisflies (Trichoptera) are sensitive aquatic insects. The EPT metric is the total number of mayfly, stonefly, and caddisfly species at a site. Richness and the North Carolina Biotic Index (NCBI), along with the EPT metric, are all commonly used in water quality regulatory programs to assess stream health. Higher EPT, NCBI, and richness metrics indicate better water quality. While some variation is expected when comparing streams, commonly seeing lower metrics in treated streams could indicate ecological degradation in the streams.

Figure 6: ***Mayfly,*** **Caenis *sp.***
Photo credit: Elizabeth McCarty, University of Georgia

Each of the four treated streams was individually compared to the control stream before imidacloprid treatments were applied and seven additional times over the course of the study for a total of 31 comparisons (one comparison was removed due to drought conditions). Treated stream EPT metrics differed from the control in 6 of the 31 comparisons. In five of those six, a treated stream had a higher EPT metric than the control stream, and in one a lower EPT score was measured. In addition, EPT metrics remained unchanged in all four treated streams after the imidacloprid treatments, meaning that the imidacloprid treatments did not result in a decrease in sensitive aquatic insects over time.[12] On balance, the EPT ratings data do not indicate harm was caused to macroinvertebrate populations by having treated hemlocks neighboring these streams.

The richness and the NCBI measurements remained equivalent between treated and control streams throughout the two year study. If streams were impaired, then lower metrics would be expected in the treated streams throughout the comparisons. However, the aquatic macroinvertebrate communities, as assessed by three different community metrics, were not impaired.[12]

In Great Smoky Mountains National Park nine streams were assessed to examine whether imidacloprid treatments were harming aquatic macroinvertebrate communities.[19] Comparisons were made between macroinvertebrate communities downstream and upstream from hemlock soil drench treatment areas. All imidacloprid treatments followed product label maximum rate per acre limits, and a stream channel set back of ten feet was used. The downstream locations are considered "treated", while the upstream locations are controls (Figure 7). In addition, comparisons were made between species observed in downstream treated locations and species observed in those same locations previous to imidacloprid use in the Park (baseline data). Over 30 comparisons of EPT community metrics were made to assess whether imidacloprid treatments were negatively affecting aquatic macroinvertebrates.[19]

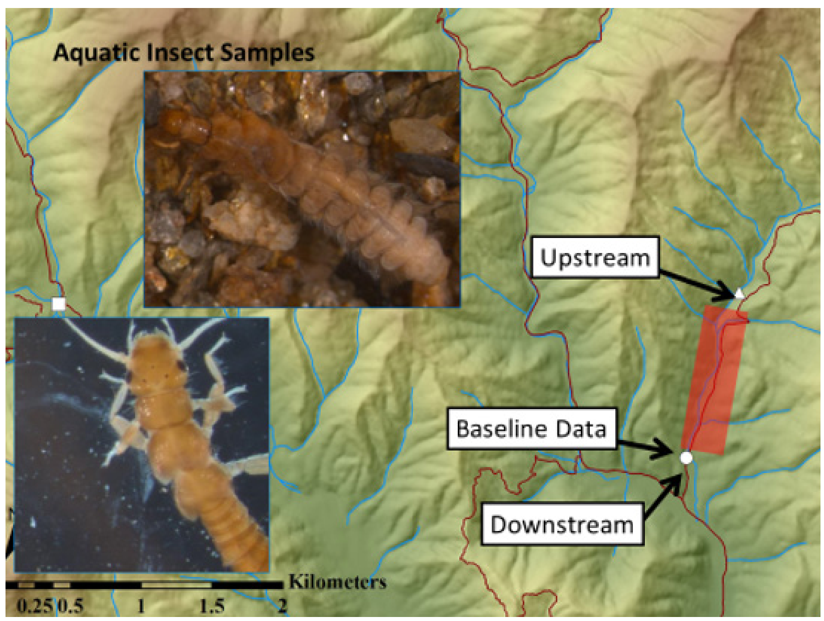

Figure 7: ***Great Smoky Mountains National Park stream sampling design. The red box indicates hemlock treatment areas where imidacloprid soil drenches were applied in riparian areas.***

Comparisons were made between all upstream and all downstream locations for richness, abundance, Shannon diversity, evenness, as well as comparisons of how aquatic macroinvertebrates feed (functional feeding groups) and behave (life habits). The study showed that EPT communities were not being impaired by imidacloprid treatments in the surrounding forest.[19]

In addition, diversity metrics were compared between upstream and downstream locations for each individual stream. While some expected natural variation occurred, common observation of lower metrics in treated streams did not occur. The Great Smoky Mountains National Park study showed that EPT communities in streams associated with hemlock imidacloprid treatment areas were healthy and included many organisms that are very sensitive to pollution.[19]

When making decisions on the risks and benefits of imidacloprid use for hemlock conservation, three things must be considered:

1. the benefits that hemlocks convey to forests in eastern North America
2. the cascading environmental effects of hemlock loss in eastern forests
3. the known environmental risks of judicious and responsible insecticide use

At this time research-based risk assessments document that:

a. canopy arthropod communities are initially impacted but recover within a few years
b. soil arthropod risks are low
c. aquatic macroinvertebrate communities are not impaired
d. pollinator risk assessments are underway

The use of insecticides to conserve hemlock forests can be an environmentally responsible management decision, when following label limits and aquatic resource setbacks. A hemlock can be preserved by applying imidacloprid that will provide five to seven years of HWA suppression.[1] This means numerous years of ecological benefit to the forest because hemlock trees are still present. At this time environmental risk assessments indicate that risks are low and when initially affected, invertebrate communities recover within the treatment timeframe. In addition, methods like optimized dosing[20,21] and integrating chemical and biological control[22] are moves toward more sustainable hemlock management.

Research on best management practices and environmental risks is ongoing. University researchers partner with federal and state natural resource agencies to continue to better understand effective hemlock conservation while protecting the natural resources of the entire forest system.

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