Emamectin Benzoate (TREE-äge®)

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Discovery and Derivation from Abamectin/Avermectin

Emamectin benzoate is the 4”-deoxy-4”-methylamino semi-synthetic derivative of abamectin, a 16-membered macrycyclic lactone produced by the fermentation of the soil actinomycete *Streptomyces avermitilis*. Emamectin benzoate (EB) derived from avermectin B1, a mixture of the natural avermectin B1a and B1b in a 5-stage process discovered in 1984. Prepared as the salt with benzoic acid, emamectin benzoate, which is a white or faintly yellow powder. Emamectin, belongs to the avermectin family of compounds all of which exhibit toxicity to nematodes, arthropods, and several other pests. EB is a neural toxin, which acts as a chloride channel agonist (causing the release of chloride ions and), preventing insect muscular contraction. Emamectin benzoate is particularly toxic to Lepidopteran defoliators (Jansson et al. 1996, 1997) The benzoate salt of emamectin in particular has found widespread use as an insecticide and is approved by the EPA for use in prevention and control of emerald ash borer in ash tree. Emamectin has also shown promising applications in the eradication of fish lice and in fish farming.

Jansson et al. 1996. Emamectin benzoate (MK-0244) is a novel semi-synthetic derivative of the natural product abamectin in the avermectin family of 16-membered macrocylic lactones. This epi-methyl amino derivative has unprecedented potency against a broad spectrum of lepidopterous pests with LC_{90} values ranging between 0.001–0.02 µg/ml in ingestion-based foliar spray assays. Emamectin benzoate is ca. 1,500-fold more potent against certain armyworm species, and 2- to 5-fold more potent against diamondback moth, *Plutella xylostella* (L.), than abamectin. It is 18- to 80,400-fold more potent against *P. xylostella*, cabbage looper, *Trichoplusia ni* (Hubner), and beet armyworm, *Spodoptera exigua* (Hubner), than other new insecticides, such as fipronil, chlorfenapyr, and tebufenozide. In the field, the compound is very effective at controlling all lepidopterous pests of cole crops at low use rates (8.4 g ai/ha). The mode of action is similar to abamectin (GABA - and glutamate-gated chloride channel agonist) and is not cross resistant with any other compound currently used commercially. The first registrations for the compound on cole crops in the U.S. and Japan are anticipated for 1997. An overview of its potential for control of lepidopterous pests in cole crops is provided.

Registration and Basic Uses

Emamectin is widely used in the US and Canada as an insecticide because of its chloride channel activation properties. It is primarily used in controlling lepidopterous pests (order of insects that as larvae are caterpillars and as adults have four broad wings including butterflies, moths, and skippers) in agricultural products in the US, Japan, Canada, and recently Taiwan. The low-application rate of the active ingredient needed (~6 g/acre) and broad-spectrum applicability as an insecticide has gained emamectin significant popularity among farmers.

Emamectin has also been successfully employed by fish farmers in the control of sea lice in Atlantic salmon. The United Kingdom, Chile, Ireland, Iceland, Finland, the Faroe Islands, Spain, and Norway are currently registered to use emamectin in their fish feed. Removal of the afflicting sea louse represents an increase in the integrity of their salmonid product due to the subsequent reduction of bacterial and viral pathogens possibly carried by the sea lice (Stone et al. 1999). Emamectin has shown efficacy against all life-cycle stages of *Lepeophtheirus salmonis* (Salmon louse) and *Caligus elongatus* (Sea louse), preventing maturation to the reproductive stage.

A water-soluble preparation of emamectin in polysorbate, acetone, and methanol was shown to prevent the wilting of Japanese black pine trees inoculated with pine-wood nematodes (*Bursaphelenchus xylophilus*) (Takai et al. 2000, 2001, 2003a, 2003b). Previous treatment of *B. xylophilus* infections involved eradicating the local population of Japanese pine sawyers (*Monochamus alternatus* Hope (Coleoptera: Cerambycidae) associated with the spread of the nematode.

Emamectin has been shown to possess a greater ability to reduce the colonization success of engraver beetles and associated wood borers in loblolly pines (*Pinus taeda* L). A 2004 study tested trunk injections of four types of systemic pesticides and found emamectin (Denim Insecticide, 2.15% emamectin benzoate, Syngenta Crop Science, Greensboro, NC) to be the greatest reducer against these insect species with respect to the amount of larval feeding, length, and number of egg galleries (Grosman and Upton 2006). These initial studies confirmed the efficacy of the active ingredient and its mobility within the sapwood tissues when injected directly into the stem. However, subsequent tree autopsies discovered the formation of long vertical lesions in the phloem and xylem from the injection points indicating phytotoxicity of the Denim (EC) formulation. In 2005, Arborjet, Inc. (Woburn, MA) developed a novel 4% tree injectable formulation, which yielded a micro-emulsion concentrate (MEC). In 2006, the formulation was further modified and optimized by Arborjet to the current formulation (TREE-äge®, 4% emamectin benzoate, MEC) to increase formulation stability and to reduce phytotoxicity in plants. EPA approved the registration of TREE-äge in 2010. A new formulation, also 4%, was registered as TREE-age G4 in 2016 as a General Use Product. Other formulations are also available including Abormectin, Boxer Insecticide-Miticide, Mectinite, TreeMec,and TREE-age R10.

TREE-äge – registration

Current uses

According to the EPA label "TREE-äge is for control of mature and immature arthropod pests of deciduous, coniferous, and palm trees including, but not limited to, those growing in residential and commercial landscapes, parks, plantations, seed orchards, and forested sites (in private, municipal, state, tribal and national areas). TREE-age contains the active ingredient emamectin benzoate and is formulated to translocate in the tree's vascular system when injected. This product must be placed into active sapwood and will actively control pest for up to two years."

TREE-äge can be used to control /suppress populations of the following insect/mite groups and/or species:

- Pine Coneworm (*Dioryctria* spp), Pine Cone Seed Bug (suppression of *Leptoglossus* and *Tetyra* spp in the year of treatment).
- Bagworm, Fall Webworm, Gypsy Moth, Mimosa Webworm, Oak Worm, Tussock Moth, Leafminers (including, Lepidoptera, Coleoptera, Hymenoptera), Honeylocust Plant Bug, Pine Needle Scale, Red Palm Mite, Sawfly, (including Elm, Pine)

- Tent Caterpillars (including Eastern, Forest, Pacific, and Western), Western Spruce Budworm, Winter Moth
- Flatheaded borers (including adult and larvae of Emerald Ash Borer, Bronze Birch Borer, Two-lined Chestnut Borer),
- Clearwing borers (including Ash and Sequoia Pine Pitch Tube Moth)
- Roundheaded borers excluding (Asian longhorn borer)
- Scolytids (bark beetles) *Ips* Engraver Beetles, Mountain Pine Beetle, Southern Pine Beetle, Spruce Beetle, Western Pine Beetle
- Pinewood Nematode

2(ee) Additional Pests (2014)

- Cankerworms, Casebearer, Eastern oak looper, Elm spanworm, Leafrollers,, Linden looper, Pine needle miner, Pine tip moth, Poplar tentmaker, Variable oakleaf caterpillar, Yellownecked caterpillar.
- Conifer mites
- Ambrosia beetles (such as Polyphagous shot hole borer)
- Black turpentine beetle, Walnut twig beetle
- Banyan stem gall wasp, Black oak gall wasp
- Carpenterworm
- Cottonwood twig borer
- White pine weevil
- Zimmerman moth

Nematode

Jansson and Rabatin. 1998. Studies were conducted to determine the potential of two avermectin compounds, abamectin and emamectin benzoate, for controlling plant-parasitic nematodes when applied by three methods: foliar spray, root dip, and pseudostem injection. Experiments were conducted against *Meloidogyne incognita* on tomato, *M. javanica* on banana, and *Radopholus similis* on banana. Foliar applications of both avermectins to banana and tomato were not effective for controlling any of the nematodes evaluated. Root dips of banana and tomato were moderately effective for controlling M. incognita on tomato and R. similis on banana. Injections (1 ml) of avermecfins into banana pseudostems were effective for controlling M. javanica and R similis, and were comparable to control achieved with a conventional chemical nematicide, fenamiphos. Injections of 125 to 2,000 lag/plant effectively controlled one or both nematodes on banana; abamectin was more effective than emamectin benzoate for controlling nematodes.

Pinewood Nematode

Takai et al. 2000. In order to develop an effective trunk-injection agent against pine wood nematode, *Bursaphelenchus xylophilus*, an in vitro assay was used to examine the antinematodal activity of 58 commercially available compounds with known modes of action. Among compounds tested, the GABA receptor agonists had better anti-nematodal activity than compounds influencing glutamate, Nmethyl-D-aspartate, b-adrenergic, dopamine, muscarinic acetylcholine and nicotinic acetylcholine receptors, as well as those inhibiting acetylcholinesterase, monoamine oxidase, 5-hydroxytryptamine uptake and Ca2., K, Na, and Cl channels. Avermectins and milbemycins strongly inhibited propagation of the nematode. Emamectin benzoate proved to be the most active (IC95 0.050mM) being over 140 times more active than the active ingredient of conventional trunk-injection agents. It is concluded that emamectin benzoate is a strong candidate for an anti-nematodal trunk injection agent.

Takai et al. 2001. Water-soluble preparations have been investigated to develop a trunk injection agent based on the poorly water-soluble anti-nematode emamectin benzoate. Following tests on the phytotoxicity of some solvents and solubilizers and demonstration of the ability of some solubilizers to dissolve emamectin benzoate in water, acetone + methanol was selected as the solvent and Polysorbate 80 as the solubilizer. This water-soluble preparation of emamectin benzoate prevented the wilting of pot-grown 4-year-old trees of the Japanese black pine, *Pinus thunbergii*, artificially inoculated with the pine wood nematode, *Bursaphelenchus xylophilus,* at a dose of 20 g emamectin benzoate per cubic metre of pine tree.

Takai et al. 2003. Injection of the poorly water-soluble emamectin benzoate (EB) into pine trunks required the development of an efficient liquid formulation. For injection into big trees in forests a good rate of injection and a high active content were required. Tests on the viscosity and EB-solubilizing ability of 14 various solubilizers in diethylene glycol monobutyl ether (DGMBE) led to the selection of Sorpol SM-100PM as the solubilizer of the formulation. Relationships between the solubilizing ability and amounts of Sorpol SM-100PM and DGMBE relative to that of EB, and between the concentration of the latter and the viscosity or the injection rate of the formulation led to a novel 40g litre_1 emamectin benzoate formulation (Shot Wan Liquid Formulation), which was composed of EB (40), Sorpol SM- 100PM (120), DGMBE (160) and distilled water (50g litre_1) in methanol. Injection of this formulation at a dose of 10g EB per unit volume of pine tree prevented over 90% of the trees fromwilting caused by pine wood nematode, and this preventative effect continued for 3 years. Neither discolouration of the leaves nor injury around the injection hole on the trees was observed after injection of the formulation.

Takai et al. 2004 In an earlier paper the authors reported the creation of a novel emamectin benzoate 40 g litre(-1) liquid formulation (Shot Wan Liquid Formulation). The injection of this formulation exerted a preventative effect against the pine wilt disease caused by the pine wood nematode, *Bursaphelenchus xylophilus* (Steiner & Buhrer) Nickle, and this effect lasted for at least 3 years. The present study was carried out to show experimentally that the marked effect of this formulation was due to the presence and persistence in pine tissues of sufficient amounts of emamectin benzoate to inhibit nematode propagation. A cleanup procedure prior to quantitative analysis of emamectin benzoate by fluorescence HPLC was devised. The presence of the compound in concentrations sufficient to inhibit nematode propagation in the shoots of current growth and its persistence for 3 years explained the marked preventative effect. Non-distribution of emamectin benzoate in some parts of the lower trunk suggested that the formulation should be injected at several points for large trees in order to distribute the compound uniformly to lower branches.

Chen et al. 2009. The toxicity of eight single chemicals on Bursaphelenchus xylophilus were tested by the methods of immersion in laboratory. The result showed that abamectin, emamectin benzoate and copper sulfate ($CuSO_4 \cdot 5H_2O$) at low concentration had stronger nematicidal activity against the Bu.xylophilus. The median lethal concentrations (LC50) of these three chemicals were 0.1346 mg/mL,0.2965 mg/mL and 0.3179 mg/mL, respectively. And dichlorophos, mesulphen and dimethoate had weaker nematicidal activity than that of abamectin, emamectin benzoate and copper sulfate, the nematicidal activity of imidacloprid and matrine were weakest between them. The results show that the enhanced toxicity on Bu.xylophilus was observed in infected-poison determination of combined application of pesticides. The field test results of trunk injection showed that two pharmaceutical combination of which 0.1%emamectin benzoate + 0.4% imidacloprid and 1%Abamectin+ 1% matrine had a preventative and treatmentive effect against the Bu.xylophilus, and this effect can lasted for 2 years.

Lee et al. 2009. This study was carried out to select effective preventive pesticides against pine wilt disease caused by pinewood nematode (PWN), Bursaphelenchus xylophilus on trunk injection. 1,000 fold aquatic solution of abamectin 1.8% EC and emamectin benzoate 2.15% EC were lower mortality (7.3% and 8.3% respectively) against PWN on 1 day after treatment. However effects of abamectin 1.8% EC, emamectin benzoate 2.15% EC, fosthiazate 30% SL and fenitrothion 30% SL were inhibited the reproduction of PWN over 99.6% in Botrytis cineria media. Effect of trunk injection of abamectin 1.8% EC and emamectin benzoate 2.15% EC at the rate of 10 ㎖ per 10 cm in diameter of breast height (DBH) on mortality of Japanese black pine, Pinus thungergii by inoculated PWN was 0% and 3.3%, respectively at the applied year however when injection of fosthiazate 30% SL were treated with the rate of 5 ㎖ per 10 cm tree DBH, mortality of tree was 63.3%. Abamectin 1.8% EC and emamectin benzoate 2.15% EC was showed high preventive efficacy representing >90% against PWN at the following year. PWN preventing efficacy of trunk injection was lower in naturally occurred area (mortality of pine tree in control was 11.7% at the first year) of PWN than artificially infected site (mortality of pine tree in control was >76.7% at the first year), PWN preventing efficacy of trunk injection of abamectin 1.8% EC and emamectin benzoate 2.15% EC at the rate of 10 ㎖ per 10 cm in DBH was 91.5% and 82.9%, respectively, at the applied year and 89.5% and 82.6% respectively at the following year in PWN naturally occurred site. Control efficacy by trunk injection of abamectin 1.8% EC and emamectin benzoate 2.15% EC was more higher in 10 fold dilution with 10 fold high amount of aquatic solution than no dilution with 10 fold less amount of aquatic solution. The preventive effect of trunk injection of abamectin 1.8% EC and emamectin benzoate 2.15% EC at the rate of 5 ㎖ per 10 cm in DBH was showed 100% at the applied year in PWN inoculated tree.

Sousa et al. 2013 The pine wood nematode *Bursaphelenchus xylophilus* (Steiner et Buhrer) Nickle is the causal agent of pine wilt disease. We evaluated the efficacy of emamectin benzoate (EB) for preventing wilt disease in the field and its effect on the vector *Monochamus galloprovincialis* (Olivier) (Coleoptera: Cerambycidae). Four experimental plots were delimited in a maritime pine (*Pinus pinaster* Aiton) forest in Portugal. Trunk-injection trials with EB included three dose-rates: 0.032 g a.i. cm^{-1} diameter at breast height—DBH, $n = 75$ trees; 0.064 g a.i. cm^{-1} DBH, $n = 75$ trees; and 0.128 g a.i. cm^{-1} DBH, $n = 50$ trees; along with an untreated control plot ($n = 75$ trees). EB was successfully injected and translocated in pines at an effective concentration. None of the treated trees died after a period of 26 months, contrasting with a 33% mortality of non-treated pines. Analysis of residues successfully detected EB in branches of treated pines, with the quantity increasing relative to the injection dose rate, and was found to have a clear effect on the longevity and feeding activity of adult *M. galloprovincialis* feeding on branches. EB was efficient in preventing wilt disease and bark beetle attacks in the terrain, and its application by trunk injection is a new option for wilt disease management programs in Portugal and in Europe.

Bi et al. 2015. To understand the efficacy of emamectin benzoate, avermectin, milbemectin, and thiacloprid on the reproduction and development of *Bursaphelenchus xylophilus*, seven parameters, namely population growth, fecundity, egg hatchability, larval lethality, percent larval development, body size, and sexual ratio, were investigated using sublethal (LC_{20}) doses of these compounds in the laboratory. Emamectin benzoate treatment led to a significant suppression in population size, brood size, and percent larval development with 411, 3.50, and 49.63%, respectively, compared to 20850, 24.33, and 61.43% for the negative control. The embryonic and larval lethality increased obviously from 12.47% and 13.70% to 51.37% and 75.30%, respectively. In addition, the body length was also significantly reduced for both males and females in the emamectin benzoate treatment. Avermectin and milbemectin were also effective in suppressing population growth by increasing larval lethality and reducing larval development, although they did not affect either brood size or embryonic lethality. Body length for both male and female worms was increased by avermectin. Thiacloprid caused no adverse reproductive effects, although it suppressed larval development. Sexual ratio was not affected by any of these four nematicides. Our results indicate that emamectin benzoate, milbemectin, and avermectin are effective against the reproduction of *B. xylophilus*. We think these three nematicides can be useful for the control of pine wilt disease.

Shin et al. 2015. Pine wood nematode (PWN), Bursaphelenchus xylophilus is one of the most serious pests of pine tree. Trunk injection of some nematicides in tree is well known as an effective control method. However there are some limitating factors which hindering the efficacy of trunk injection in field or potted tree. In this study we suggested easy and useful alternative screening methods of nematicides against PWN. Reproduction of PWN was influenced by tree twig moisture (high reproduction in high moisture trig) and paraffin coating was 78.6% reduced moisture loss in tested twig. There were no reproduction different in up and down site from infection site of twig at 1 month after inoculation of PWN and also distance (5 and 10 cm) from inoculation site of PWN did not influence the reproduction of PWN. Numbers of reproduced PWN were higher with decreasing diameter of twig. Numbers of reproduced PWN were similar to P. thunbergii and P. densiflora. However reproduction was increased depending on high inoculation density and longer propagation period. When inoculation of PWN on cut twig injected with emamectin benzoate 2.15% EC and morantel tartrate 8% SL in trunk of Pinus thunbergii in the field, PWN number were significantly reduced than untreated control. We suggest this screening method for PWN control agents.

Li et al. 2016. Forest efficacy of six liquid-formulated trunk-injected pesticides (avermectin, emamectin benzoate, matrine and acetamiprid) were studied using auto flow trunk injection. After 15 months residues from liquid-formulated trunk-injections in pine were recovered and detected using high-performance liquid chromatography (HPLC). Also, positive and quantitative detection of Bursaphelenchus xylophilus (BX) in dead pine trees was studied with a BX Isothermal Amplification Diagnostic Kit. Results showed that the prevention effect from the six liquid-formulated trunk injection pesticides was significant (P<0.05) with one injection controlling pine death rate between 0.4%-4.4% for two consecutive years. Avermectin, emamectin benzoate, and aloperine with trunk-injection slowed the spread of pine wilt disease with a field efficacy above 80%. All liquid-formulated residue concentrations in the trunk xylem were reached except dead pine trees one year after injection the maximum residue concentration was found with emamectin benzoate [having at least (0.15±0.11) mg.kg-1]. Also, after injection all pine trees died due to BX nematodes with an average BX nematode content of at least 897.34 g-1 in the trunk xylem. Thus, because of its favorable effect and long duration of efficacy, this liquid-formulated pesticide injection could be popularized and used in practical control.

Lai 2017. This study was aimed to review the controlling experience of pine wilt disease in the past 25 years, explore the theories and methods of controlling pine wilt disease, and improve the scientific level of controlling techniques and the protection capacity of healthy pine trees. [Method] Eleven items of effects were used to refine the theory of clearing dead pine trees affected by pine wilt disease, namely, "1 priority", "2 objections", "3 principles", "4 measures", and "5 managements". On the basis of comprehensive control and complete removal of the infected pine trees, a variety of comprehensive and efficient controlling methods were developed to carry out targeted chemical ecology trapping, bionic pesticide killing and releasing natural enemies of Sclerodermus guani, Dastarcus helophoroides. High efficient emamectin benzoate immune injection was developed to inject the healthy pine trees for prevention, so as to extinguish the pine wilt disease. [Result] The pine wilt disease dropped from the peak of 3.5 million dead trees with an infecting area of 28 273 hectares in 1999 to 0.068 million with an area of 4 333 hectares in 2012 gradually, reducing by 98.06% in number and 84.84% in area, respectively. On the basis of removal, Dastarcus helophoroides was also released, which could make the number of dead pines decrease more significantly than the control, and after releasing for 5 consecutive years, the dead pine trees dropped to 0.511 plant/hm2 in 2012, with a mortality rate of 0.022 7%, which achieved the control effect, reaching extremely significant level. "Forest land removal+infected trees isolation+natural enemy release" could extinguish the pine wilt disease. The test of isolating 24 heaps of infected pine trees showed that there were 9 heaps of pine trees extinguished the pine wilt disease, which controlled the occurrence of pine wilt disease for 100%, accounting for 37.5% of the total, in which the number of those isolated using iron netting and nylon net were 4 for each, accounting for 88.9%, and there was one heap using polypropylene net, accounting for 11.1%. The invention of emamectin benzoate immune injection laid the foundation for extinguishing pine wilt disease. The follow checking of the effects of emamectin benzoate immune injection on pine wilt disease found that the number of dead trees caused by pine wilt disease decreased significantly after injecting, and became very small in October of the next year, and the disease was completely extinguished in the third year. [Conclusion] Pine wilt disease could be controlled and extinguished with positive control by using "comprehensive cleaning+industrialized removal", "comprehensive cleaning+ natural enemy release", "comprehensive cleaning+infected trees isolation+natural enemy release" and "comprehensive cleaning+emamectin benzoate immune".

Lee et al. 2020. In this study, we investigated the preventive effects of emamectin benzoate 9.7% SL, which was newly developed to reduce the injection volume and number of injection holes required to protect against pine wood nematode. None of the *Pinus thunbergii* trees injected with emamectin benzoate 9.7% SL at 0.3 mL/cm diameter at breast height (DBH) died within 2 years of inoculation with pine wood nematodes. Emamectin benzoate 9.7% SL injected at 0.6 mL/cm DBH resulted in no tree mortality for 3 years. Mean residue of emamectin benzoate 9.7% SL in pine twigs injected with 0.3 mL/cm DBH was 0.490 µg/g at 1 year after injection and 0.303 µg/g after 2 years. These residues values are greater than 0.031 µg/g, previously determined IC95 value for emamectin benzoate against the pine wood nematode. Our field experiment and residue analysis showed that emamectin benzoate 9.7% SL could be a substitute agent for emamectin benzoate 2.15% EC, which is widely used to prevent pine wood nematode in the field and that injection volume and number of injection holes can be greatly reduced using this new formulation, which will reduce injury to the cambium, interruption of water movement, and infection of inoculation wounds by wood-decay or blue stain fungi.

Zhang et al. 2019. In order to prevent and control pine wilt disease, 10% emamectin benzoate soluble granule was prepared for trunk injection. Its control efficacy against pine wood nematode disease was evaluated after trunk injection. Sodium benzoate, lactose monohydrate, soluble starch and CMC were tested as the water-soluble carrier. The formulation of the water-soluble carrier was optimized using the uniform design of experiments with mixtures and partial least squares regression. The emamectin benzoate (oil phase) was dissolved in n-butanol and emulsifier OP-10, and mixed with water-soluble carrier with different mixing time. And then the optimal formulation and mixing time was obtained by tracking and detecting of the indicators. The optimum formulation of emamectin benzoate 10% soluble granule was composed of emamectin benzoate 14.3% (pure 10.0%), OP-10 5.7%, n-butanol 12%, sodium benzoate 39.0%, lactose monohydrate 20.5%, water-solubility starch 3.0% and CMC 4.5%. After 10 min mechanical kneading, the appearance of the granule was the cylinder in milk white. And all the indicators were up to the standard. The field experiments showed that the granule could completely dissolve in water and effectively conduct in P . massoniana after the trunk injection. In the pine wood nematode disease area in Donghu Village, 110 pines were injected. The mortality of P. massoniana was 0 after 1 year. And the mortality of P. massoniana in the control group was 6.1%. In the Xian' gong Mountain, 230 pines were injected. The mortality of P. massoniana was 1.7%, and the mortality of P. massoniana in the control group was 10.8%. The soluble granule can be used during the whole pine resin secretion period. And it features simple and safe production procedure, no packaging pollution and significant control effect.

Lu et al. 2020.
Background: Emamectin benzoate (EB) has recently been successfully applied as a trunk injection for preventative control of the pine wilt disease (PWD) caused by Bursaphelenchus xylophilus (Steiner & Buhrer) Nickle. Here, a whole-organism transcriptomic analysis provides comprehensive insights into the adverse effects of EB on B. xylophilus.
Results: A large set of differentially expressed genes (DEGs) were found, demonstrating the antagonistic effects of EB on B. xylophilus embryonic and larval development, reproduction, nervous and motor systems, and pathogenesis. In toxicity assays with EB, the number of eggs laid, hatching rate, thrashing frequency, and developmental rate of B. xylophilus were significantly suppressed at low concentrations (0.1 μg mL−1). Moreover, the transcriptional changes validated by real-time quantitative PCR showed downregulated transcript levels of the genes encoding pectate lyases, β-1,4-endoglucanases, and upregulated the genes encoding glutamate-gated chloride channel, γ-aminobutyric acid type β receptor, uridine 5′-diphospho-glucuronosyl transferase, ATP-binding cassette transporter. The potential responses of B. xylophilus to EB included the upregulation of several genes putatively contributing to oocyte protection, stem cell renewal, and xenobiotic degradation, implying the potential for drug resistance to develop.
Conclusions: Our findings further our understanding of the effects of EB for managing the PWD and may help to improve the pesticide-use strategies for controlling B. xylophilus.

Pine seed orchards

Grosman et al. 2002 Three systemic insecticide treatments, emamectin benzoate alone, imidacloprid alone, and a combination of emamectin benzoate and thiamethoxam, were injected one or two times into loblolly pine, *Pinus taeda* L., during a 2 yr period in a seed orchard in east Texas. Single injections of treatments containing emamectin benzoate reduced coneworm (*Dioryctria* spp.) damage by 94–97% during the study period. A second injection after 1 yr did not improve protection. Imidacloprid also significantly reduced coneworm damage in 1999, but not in 2000. Significant reductions in damage from pine seed bugs (*Tetyra bipunctata* Say and *Leptoglossus corculus* Herrich-Schaffer) and an increase in the number of full seeds per cone resulted from imidacloprid and thiamethoxam treatments and to a lesser extent from emamectin benzoate. Yearly injections of imidacloprid or thiamethoxam were required to maintain protection against seed bugs. The best overall treatment, two injections of emamectin benzoate plus thiamethoxam, reduced cone and seed losses from insects by 86%.

Grosman et al. 2007. The efficacies of systemic insecticides emamectin benzoate and fipronil were evaluated in four southeastern pine seed orchards for preventing damage and mortality to cones by cone and seed insects. Single injections of emamectin benzoate consistently reduced cone damage and mortality (70 – 95%) by coneworms in slash pine and loblolly pine orchards for two years compared to untreated checks. Fipronil performed nearly as well on most sites reducing coneworm damage by 66 – 92%. Both chemicals were moderately effective against pine seed bugs during the first year after injection; reducing damage by 3 – 37% compared to checks. No significant treatment effect was observed against seed bugs during the second year. Emamectin benzoate demonstrated some activity against slash pine flower thrips in Alabama.

Emerald ash borer, Soapberry borer, Gold spotted oak borer

Smitley et al. 2010. Green ash (*Fraxinus pennsylvanica* Marsh.) street trees ranging in size from 25 to 45 cm dbh were trunk injected with emamectin benzoate at rates of 0.10–0.60 g ai/2.54 cm dbh at three Michigan, U.S., locations in 2005 or 2006. Tree health was monitored by annual canopy thinning and dieback ratings for up to four years after a single treatment. Branch samples were collected in the autumn and the bark removed to count emerald ash borer larvae for most treatments over the same period of time. A single trunk injection treatment of emamectin benzoate at the 0.1, 0.2, or 0.4 g ai rate gave 100% control of emerald ash borer larvae in 98 of 99 treated trees for 2–3 years. Canopy ratings for treated trees remained similar for 2–4 years following trunk injection, while >50% of the control trees died during the same period of time. Ash trees that received a combination of an imidacloprid trunk injection and an imidacloprid basal drench or an annual imidacloprid basal drench had similar canopy ratings, but more larvae were found in branches from trees receiving the annual basal drench.

Herms 2010. Research and experience has shown that insecticides provide a viable option for protecting high value ash trees (Herms et al. 2009). However, questions remain regarding their optimal use. In 2006, we initiated three studies in Toledo, Ohio to evaluate the effectiveness of systemic insecticides for protecting large caliper ash street trees from emerald ash borer in the face of extremely high pest pressure. Specific objectives were to: (1) evaluate efficacy of different rates of imidacloprid (Merit and Xytect) soil drenches made annually in spring or fall, (2) determine the number of years of control provided by different rates of a single emamectin benzoate (Tree-äge) trunk-injection, and (3) compare multi-year efficacy of emamectin benzoate (Tree-äge) and imidacloprid (Ima-jet) trunk injections applied once, consecutively, or in alternate years.

McCullough et al. 2011a. Our ability to use systemic insecticides to protect ash (Fraxinus sp.) trees from emerald ash borer (EAB), Agrilus planipennis Fairmaire, has advanced considerably, representing one of the few bright spots in the EAB saga in North America. Systemic insecticides, applied to the soil or directly into the tree, are preferred to cover sprays for protecting trees in landscapes because there are no problems with drift. In addition, systemic insecticides are associated with minimal applicator exposure and nontarget concerns, and provide a greater chance of controlling insects in the upper canopy of large trees. The three insecticides most commonly used for EAB control contain imidacloprid, dinotefuran or emamectin benzoate. Several products with imidacloprid, a neonicotinoid insecticide, are available and are applied either as a soil drench around the trunk of the tree or via injection into the base of the tree trunk. Imidacloprid is not highly soluble in water and moves into and through trees relatively slowly. Eff ectiveness of imidacloprid products varies with tree size; results are less consistent for large trees (e.g. > 30 cm DBH) than for small trees. This likely reflects the exponential relationship between the area of trees that must be protected by the insecticide and tree diameter (McCullough and Siegert 2007), which determines the application rate of systemic insecticides. A relatively new product used for soil application (Xytect®), is labeled for higher application rates than other imidacloprid products registered for soil drenches. Studies by other scientists indicate the high rate is likely to be more eff ective than the lower rates for medium and large trees. Cost of treatment, however, also increases with application rates, and treatment costs for large trees may become prohibitive. Imidacloprid can also be applied as a trunk injection. Many products and application devices are marketed by various companies, but efficacy of these products varies considerably. Dinotefuran, a new generation neonicotinoid, is sold as Safari®. It is registered for soil applications and can also be applied to ash trees as a basal trunk spray. This insecticide is 80 times more soluble in water than imidacloprid and moves through trees more rapidly than imidacloprid. The basal trunk spray is becoming popular among arborists because it is effi cient, requires only a garden sprayer, and does not require wounding the tree or introducing insecticide into the soil. Bark on the trunk of the tree is sprayed from the base up to approximately 1.5 m high, using low pressure to avoid any backsplash, until the appropriate rate has been delivered. Data from our studies has shown the insecticide moves through the bark and is readily translocated to branches and foliage in the canopy. Emamectin benzoate is an avermectin insecticide that attained full EPA registration for EAB control on ash trees in 2010. It is sold as TREE-äge® and is applied as a trunk injection. We completed a study in 2009 that was designed to compare EAB control provided by emamectin benzoate, dinotefuran, and imidacloprid products. Results showed that density of EAB larvae on trees treated with the emamectin benzoate was >99 percent lower than larval density on control trees, even 2 years after treatment. Untreated control trees in this study were heavily infested, and canopy decline was apparent in the second year. The neonicotinoid products reduced larval density by 30-70 percent, but only if trees were treated annually. A more recent study was designed to evaluate EAB control on trees that were treated with a low rate of emamectin benzoate, a higher rate of emamectin benzoate, the dinotefuron basal trunk spray, or imidacloprid injected with Mauget capsules. Preliminary results indicate that both rates of emamectin benzoate provided nearly 100 percent control of EAB, even 3 years post treatment. Other studies in Michigan and Ohio have similarly documented 3 years of highly effective EAB control with emamectin benzoate. The multiyear control provided by emamectin benzoate reduces logistical issues and costs associated with treating large numbers of trees. Emamectin benzoate is currently being used to slow EAB population growth and delay ash mortality in the SLAM Pilot Project currently underway in selected EAB outlier sites in Upper Michigan (EABSLAM.info). Goals of the SLAM project, which stands for SLow Ash Mortality, are to reduce the onset and progression of ash mortality in localized, recently established EAB outliers. Results from simulation models have shown that using emamectin benzoate is substantially more effective at slowing EAB population growth and spread than using girdled ash trees as population sinks ,or felling ash trees to reduce phloem availability (Mercader et al., in press a, in press b). Ideally, however, emamectin benzoate, girdled trees, and ash removal are employed in an integrated strategy such that the management options act in a synergistic manner. Girdling trees in the center of a newly established outlier site, for example, should act to attract and retain ovipositing female EAB beetles. Ash trees within and surrounding the girdled trees can be treated with emamectin benzoate to control beetles that would otherwise disperse or colonize nontreated trees. Lethal trap trees provide another option for reducing EAB population growth. In major studies conducted in 2009 and 2010, we compared EAB larval densities on ash trees that were untreated, girdled, injected with emamectin benzoate, or injected with emamectin benzoate then girdled 3 weeks later. We hypothesized that the girdling would attract adult EAB, but the trees treated with emamectin benzoate then girdled would kill adult beetles that fed on foliage and control larvae if beetles laid eggs on the trees. Results in both years confirmed our hypothesis. Girdled trees were heavily infested and control trees were also colonized. In contrast, there were almost no live larvae on trees treated with emamectin benzoate, even the lethal trap trees that were girdled 3 weeks after injection. Lethal trap trees, therefore, represent another option for slowing EAB population growth and spread, particularly in outlier sites. Currently, we are applying simulation models of EAB population growth, dispersal and ash mortality to evaluate optimal allocation of resources in urban settings. The high efficacy and multiyear control provided by emamectin benzoate makes it economical to treat ash trees in municipalities and residential areas, rather than removing and replacing those trees. We created an artificial environment to represent a subdivision where up to 50 percent of the trees growing along boulevards could be ash trees. We assumed EAB was introduced by a specific homeowner, then we allowed beetles to disperse and reproduce over a 10- year period. We compared ash tree survival under different management scenarios to assess effects of: (1) treating 10 percent versus 20 percent of the ash trees annually; (2) beginning treatment 1 year versus 3 years after the EAB introduction; and (3) targeting trees near the introduction area for treatment versus treating the same number of randomly selected trees. Preliminary results suggest randomly selecting trees for treatment protected more trees than targeting a specific area for control. Treating 20 percent of trees protected substantially more trees over the 10-year period than treating only 10 percent of trees. Results also demonstrated the need to begin treating trees as soon as possible after EAB is detected. We are planning to expand on this work and consider larger and more realistic scenarios for our simulations.

Results should be useful to city foresters and municipal arborists in the eastern United States where EAB populations threaten high value, abundant landscape ash trees.

McCullough et al. 2011b. Effective methods are needed to protect ash trees (Fraxinus spp.) from emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), an invasive buprestid that has killed millions of North American ash (Fraxinus spp.) trees. We randomly assigned 175 ash trees (11.5-48.1 cm in diameter) in 25 blocks located in three study sites in Michigan to one of seven insecticide treatments in May 2007. Treatments included 1) trunk-injected emamectin benzoate; 2) trunk-injected imidacloprid; 3) basal trunk spray of dinotefuran with or 4) without Pentra-Bark, an agricultural surfactant; 5) basal trunk spray of imidacloprid with or 6) without Pentra-Bark; or (7) control. Foliar insecticide residues (enzyme-linked immunosorbent assay) and toxicity of leaves to adult A. planipennis (4-d bioassays) were quantified at 3-4-wk intervals posttreatment. Seven blocks of trees were felled and sampled in fall 2007 to quantify *A. planipennis* larval density. Half of the remaining blocks were retreated in spring 2008. Bioassays and residue analyses were repeated in summer 2008, and then all trees were sampled to assess larval density in winter. Foliage from emamectin benzoate-treated trees was highly toxic to adult *A. planipennis*, and larval density was < 1% of that in comparable control trees, even two seasons posttreatment. Larval densities in trees treated with trunk-injected imidacloprid in 2007 + 2008 were similar to control trees. Dinotefuran and imidacloprid were effectively translocated within trees treated with the noninvasive basal trunk sprays; the surfactant did not appreciably enhance *A. planipennis* control. In 2008, larval densities were 57-68% lower in trees treated with dinotefuran or imidacloprid trunk sprays in 2007 + 2008 than on controls, but densities in trees treated only in 2007 were similar to controls. Highly effective control provided by emamectin benzoate for > or = 2 yr may reduce costs or logistical issues associated with treatment.

Doccola et al. 2011. Trunk injection of systemic insecticides or fungicides is an effective way to manage destructive insects or diseases of trees, but many arborists are still reluctant to inject trees because of the potential for infection by pathogens, structural damage, or adverse effects on tree health. The authors of the following study examined wound responses of green ash (*Fraxinus pennsylvanica* Marsh.) for two years following trunk injection, by sectioning tree trunks to look for evidence of infection associated with injection sites, and by collecting data on annual radial growth and rate of closure around injection sites. All healthy trees successfully compartmentalized injection wounds without any signs of infection, decay, or structural damage. Wound closure was positively correlated with the tree health as measured by annual radial growth.

McCullough and Mercader 2012. Emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), an invasive pest native to Asia, has killed millions of ash (Fraxinus spp.) trees in North America since it was first discovered there in 2002. As of autumn 2011, *A. planipennis* has been detected in 15 US states and two Canadian provinces. A pilot project to slow the onset and progression of ash mortality, termed SLAM (SLow Ash Mortality), has been implemented in localized *A. planipennis* populations. Here we use spatially explicit simulations to evaluate the potential of a recently developed systemic insecticide to protect the ash resource in urban forests as a component of the SLAM approach. Over a 10- year horizon, simulations showed ash survival varied depending on: (i) how soon insecticide treatment began after the *A. planipennis* introduction; (ii) the proportion of trees treated; and (iii) the distribution of treated trees relative to the *A. planipennis* introduction point. Annual treatment of 20% of ash trees annually protected 99% of trees after 10 years, and the cumulative costs of treatment were substantially lower than costs of removing dead or severely declining ash trees.

Vannatta et al. 2012. Emerald ash borer, *Agrilus planipennis* (Fairmaire) (Coleoptera: Buprestidae), plays a significant role in the health and extent of management of native North American ash species in urban forests. An economic analysis of management options was performed to aid decision makers in preparing for likely future infestations. Separate ash tree population valuations were derived from the i-Tree Streets program and the Council of Tree and Landscape Appraisers (CTLA) methodology. A relative economic analysis was used to compare a control option (do-nothing approach, only removing ash trees as they die) to three distinct management options: 1) preemptive removal of all ash trees over a 5 yr period, 2) preemptive removal of all ash trees and replacement with comparable nonash trees, or 3) treating the entire population of ash trees with insecticides to minimize mortality. For each valuation and management option, an annual analysis was performed for both the remaining ash tree population and those lost to emerald ash borer. Retention of ash trees using insecticide treatments typically retained greater urban forest value, followed by doing nothing (control), which was better than preemptive removal and replacement. Preemptive removal without tree replacement, which was the least expensive management option, also provided the lowest net urban forest value over the 20-yr simulation. A “no emerald ash borer” scenario was modeled to further serve as a benchmark for each management option and provide a level of economic justification for regulatory programs aimed at slowing the movement of emerald ash borer.

Good 2013. Invasive species have the capability to alter landscapes and change the composition of a forest in a very short time. The recent invasive pest, Agrilus planipennis, emerald ash borer, was unintentionally introduced to the United States via ship route to Michigan. The pest attacks and kills all five native ash species in Ohio. This study focused on an area in west central Ohio not yet affected by the borer. Ash centered plots were used to record all species and sizes (diameter at breast height) within a 5m radius of a central ash tree. Plots ranged in topography and all five ash species were sampled. Moisture contents were calculated for each plot based on topographical variables in ArcGIS. My objectives were to answer the following questions: What species will replace ash and how do replacement species vary among different ashes and with topography? Also, how does the understory composition vary among ash species as related to topography? Results suggest that sugar maple will be the likely successor of ash species. Sugar maple was the most important species in all plots and under all ash species except for the black and pumpkin ash which were associated with hydric species. American elm was highly associated with both white and blue ash. A moisture index (IMI) showed a significant separation of black and pumpkin ash, found in swampy regions, from the other three ashes. Black and pumpkin ashes were found in the wettest sites followed by blue, green, and white ash. Detrended correspondence analysis found the five ash species to segregate in a two-dimensional space based on a moisture gradient. Significant correlations were found between the ordination scores and both the size of the central tree and the nearest neighbor indicating a possible succession gradient as well. Post emerald ash borer trends appear to be toward a forest dominated by maples and possibly elms.

Tanis 2013. Agrilus planipennis Fairmaire (Coleoptera: Buprestidae), a secondary pest of stressed or declining ash (Fraxinus) trees in its native Asia, is the most destructive forest insect to ever invade North America. To date, tens of millions of ash trees have been killed in 19 states and two Canadian provinces. North American ash species are generally less resistant to A. planipennis than Asian species. Fraxinus quadrangulata Michx. and Fraxinus americana L. were originally abundant in two woodlots in southeast Michigan, but survival rates of the two species following A. planipennis invasion differed profoundly. Overall, 63% and 71% of F. quadrangulata trees were alive at the sites. In contrast, only 16% (all <11 cm diameter) of the F. americana trees survived at one site and all were dead at the second site.
Urban trees are often planted in confined spaces and may experience varying degrees of environmental stress. Fertilizer and paclobutrazol (PB), a gibberellin inhibitor, may be applied to enhance tree vigor. Effects of fertilizer and PB were assessed on the physiology and growth of North American (F. americana and F. quadrangulata) and Asian (Fraxinus mandshurica Rupr.) ash trees in a plantation established in 2006. Fraxinus quadrangulata had 33% less radial growth, 13% more root biomass and 25% lower foliar nitrogen than F. americana or F. mandshurica. Ratios of pre: post treatment radial growth in control and fertilized trees were 33 and 43% higher, respectively, than PB trees. Aboveground growth of F. quadrangulata and F. mandshurica were reduced by PB treatment while F. americana was unaffected. Fertilized F. quadrangulata trees had higher relative chlorophyll content and nitrogen concentrations than control or PB trees, but other species did not respond to fertilizer. Suitability of the ash species for adult A. planipennis feeding and survival and larval density was also determined. Survival of adult A. planipennis caged on F. quadrangulata was lower and beetles consumed less leaf area than beetles caged on other species. North American Fraxinus nigra Marsh. and Fraxinus pennsylvanica Marsh. trees were heavily colonized by A. planipennis larvae. In contrast, F. quadrangulata and F. mandshurica were rarely colonized, while F. americana were moderately colonized. Results confirm North American F. quadrangulata has resistance to A. planipennis similar to F. mandshurica. Systemic trunk injected insecticides are often used to protect ash trees from A. planipennis, but wounds and injury are a concern. We examined basal trunk sections from 22 F. pennsylvanica and 24 F. americana trees macro-injected

with a low or medium rate of emamectin benzoate in 2008 only or 2008+2009. Only 12 of the 233 injection sites had evidence of injury and there was no sign of pathogen infection. Confocal laser scanning microscopy (CLSM) examination showed xylem discoloration was not indicative of tissue damage. Crosssectional area of earlywood lumen was 55% larger in F. quadrangulata than in F. pennsylvanica trees. Interspecific differences in xylem anatomy likely influence efficiency of trunk injections. Phenolic compounds and reactive oxygen species (ROS) are produced by plants in response to injury, stress or insect damage. Autofluorescence indicative of phenolics was detected in F. quadrangulata and F. mandshurica phloem, but not in F. pennsylvanica phloem. Fluorescence of ROS was detected in all the phloem of all three ash species, but F. mandshurica produced three times more than the other species. A continuous layer of sclerenchymatous cells was observed in F. quadrangulata and F. mandshurica and may affect A. planipennis larvae.

Bicks and Bernick 2014. Currently, the most effective insecticide tool for control of invasive species Emerald Ash Borer (EAB), Agrilus planipennis, on ash trees is emamectin benzoate. Arborists, applicators and scientists noted, when working with formerly the only available 4% emamectin benzoate formulation for tree injection, Arborjet's TREE-age®, that they were challenged by its restricted use label and the high variability and amount of time for insecticide uptake. The purpose of developing a novel formulation, ArborMectin™, was to create a 4% emamectin benzoate General Use pesticide with a consistent uptake speed that is effective for Emerald Ash Borer control. The research objectives were to 1) determine the efficacy of ArborMectin™ on EAB and 2) to evaluate the speed and variability of product uptake for ArborMectin™.

It was hypothesized that there is no significant difference between ArborMectin™ and Tree-age® for EAB control. To evaluate, the Canopy Thinning and Dieback Rating Scale, developed by Dr. David Smitely at Michigan State University (http://www.emeraldashborer.info/treatment.cfm#sthash.53HPxX9i.dpbs) was utilized across all studies. All applications were completed through Arborjet's TREE I.V. MICRO INFUSION® equipment. Four efficacy studies were conducted to evaluate ArborMectin™ across multiple tree size classes and insect pressures.

Rainbow Scientific contracted Ohio State University entomologist Dr. Dan Herms to evaluate ArborMectin™, TREE-age® and Xytect™ (imidacloprid) insecticide treatments on small (6" DBH) green ash trees (Fraxinus pennsylvanica) for Emerald Ash Borer control. Treatments were applied once in the spring of 2012 and evaluations consisting of canopy ratings yearly, exit hole counts yearly and bark pealing and counting EAB larval galleries in August 2014. Exit hole counts were unreliable due to visual difficulty and canopy ratings were indistinguishable due to initial low insect pressure. Untreated control trees averaged 55 larval galleries per tree, and Xytect™ treatments averaged higher than control trees and ArborMectin™ and TREE-Age® averaged 3.5 galleries per tree, statistically equivalent.

Rainbow Scientific partnered with the Village of Mt Prospect, IL and The Morton Arboretum to evaluate ArborMectin™, Transtect™ (dinotefuran) and Xytect™ (imidacloprid) insecticide treatments on large (>15" DBH) green ash trees for emerald ash borer pressure utilizing the Smitley Canopy Thinning and Dieback rating scale. Treatment applications occurred in 2012 and in 2014, with evaluations conducted annually in early spring and summer. Untreated control trees averaged 72% dieback, Transtect™ averaged 52% dieback, Xytect™ averaged 22% dieback, and ArborMectin™ averaged 14% canopy dieback in 2014.

Rainbow Scientific partnered with Bartlett Tree Experts to evaluate ArborMectin™ and TREE-age® insecticide treatments on large (22" DBH) green ash trees for emerald ash borer pressure utilizing Smitley Canopy Thinning and Dieback rating scale. Treatment applications occurred in 2011 and in 2014 and visual evaluations were conducted annually, early spring and summer. The Untreated control trees averaged 64.4% dieback while TREE-Age® and ArborMectin™ performing equivalently, averaging 12.0% canopy dieback.

Rainbow Scientific contracted Purdue University entomologist Dr. Cliff Sadof to evaluate ArborMectin™ and TREE-age® insecticide treatments on large (30" DBH) green ash trees for emerald ash borer pressure by utilizing Smitley Canopy Thinning and Dieback rating scale. Treatments were applied once in 2013 and visual evaluations are conducted annually in fall and spring. Preliminary results from Site 1 show untreated control trees averaged 27.7% canopy thinning in 2014, TREE-age® trees averaged 8.57% thinning and ArborMectin™ trees averaged 2.5% thinning with 5 replicates. At Site 2, untreated control trees averaged 21.0% canopy thinning in 2014, TREE-age® trees averaged 9.0% thinning and ArborMectin™ trees averaged 7.0% thinning with 12 replicates. Evaluations will continue over the next 2 years as untreated trees reach mortality.

It was hypothesized that there is no significant difference between ArborMectin™ and TREE-age® in insecticide uptake speed and variability. This hypothesis was tested on two sets of equipment, Arborjet's TREE I.V. MICRO INFUSION® system and Rainbow Treecare Scientific Advancements' Q-Connect plug-less injection system. Three studies were set up in July 2014 to evaluate insecticide uptake and variability. Each utilized 10 replications per treatment in a Randomized Block design. To determine uptake speed, a stop watch was started when the valve allowing insecticide flow was opened and the watch was stopped when the product completely cleared the lines.

In Kansas City, MO Rainbow Scientific collaborated with Davey Tree to determine uptake speed on 9" DBH white ash trees (Fraxinus americana). This study utilized the Q-Connect injection system with ArborMectin™ and TREE-age®. ArborMectin™ was found to have 28% faster uptake than TREE-age® with one fourth the variability in uptake speed. In Plymouth, MN the experiment was repeated on green ash trees averaging 19.5" in diameter. The TREE I.V. MICRO INFUSION® system was used in addition to the Q-Connect. In large trees, the ArborMectin™ was found to have 62% and 58% faster uptake than TREEage® on systems respectively with one third the variability in uptake speed. Statistically significant differences were found between formulations across all treatments.

Additionally, in Plymouth, MN an experimental design was implemented where two Q-Connect systems were attached to a single large (19.5" in diameter) green ash tree. This was repeated for 10 trees. The total number of injection ports recommended per tree (DBH / 2) was maintained by taking the total number of recommended ports divided by two on each system. Each system alternated port location and half the dose of emamectin benzoate were placed within each system. This experimental design addresses potential variability in prior studies caused by the individual tree. To determine uptake speed, a stop watch was started when the two valves allowing insecticide flows were opened simultaneously, time was noted when product completely cleared the first system's lines and the watch was stopped when the product completely cleared the second system's lines. ArborMectin™ was found to have 68% faster uptake than TREE-age® on each tree with one fourth the variability in uptake speed.

The successful development of ArborMectin™ has major implications for applicators and municipalities. ArborMectin™ was found to be statistically equivalent to TREE-age® in terms of efficacy for emerald ash borer control. ArborMectin™'s CAUTION EPA signal word and general use label does not negatively impact insect control. Additionally, in most states, applicators do not need to hold a pesticide applicators license to apply ArborMectin™ for personal use. The 28% to 62% increase in product uptake speed will allow applicators to treat and protect ash trees more efficiently. This efficiency leads to more cost effective applications allowing more ash trees to be protected from Emerald Ash Borer.

Billings et al. 2014. *Sapindus saponaria* var*. drummondii* (Western Soapberry) is a small- to medium-sized tree native to the western Gulf Region and southwestern US and is valued in urban and rural landscapes. Recently in the United States, it has become host to an invasive insect introduced from Mexico. *Agrilus prionurus* (Coleoptera: Buprestidae) (Soapberry Borer) was first reported in Travis County, TX, in 2003 and has been detected in 51 additional counties as of December 2013. As its populations expand rapidly in Texas, this invasive pest is killing Soapberry trees >6 cm in diameter. Additionally, it may eventually threaten Western Soapberry populations throughout the tree's range. Infestations of Soapberry Borer are similar to those of *A. planipennis* (Emerald Ash Borer), a destructive invasive pest of *Fraxinus* spp. (ash) but not yet found in Texas. Signs of Soapberry Borer infestation include large bark flakes that accumulate at the base of infested trees, galleries between the bark and sapwood, trees that die back from the top, and excessive epicormic sprouts on the lower trunk. Western Soapberry appears to be the Soapberry Borer's sole host in Texas, and trees of this species exhibit little resistance to this introduced pest. Preliminary studies indicate that Soapberry Borer adults emerge and fly from late May to August and that this species has no more than one generation per year in Texas.

Preventative and therapeutic treatments with the systemic insecticide emamectin benzoate are showing promise as a means to protect valuable Soapberry trees in rural and urban landscapes.

O'Brien and Herms 2014. Wide-scale mortality of ash trees caused by emerald ash borer (Agrilus planipennis, EAB) threatens Fraxinus spp. with regional extirpation, creating the need for strategies to conserve the ash gene pool. In such an attempt, the Five River MetroParks (FRMP) in Dayton, OH initiated an ongoing program in 2011 to protect 600 mature (reproductive) ash trees with insecticide. The goal of our study is to evaluate the efficacy of this management strategy on maintaining ash regeneration and a stable age structure throughout the course of the EAB invasion. We set up 24-one hectare stands within six metroparks across a treatment density gradient (high, medium, low, and untreated control) to quantify the effect of insecticide treatment on ash demography (seed, seedling, sapling, and tree densities) and ash health (canopy decline rating). Baseline densities (mean stems per hectare) of ash indicate a stable age structure with 20,950 ± 3021 seedlings, 130.2 ± 30.9 saplings, 41.1 ± 10.1 immature trees (< 10 cm dbh), and 91.7 ± 7.7 mature trees (≥ 10 cm dbh). We found significant differences in seedling densities (p=0.001) and proportions of healthy (p=0.01) and dead ash trees (p=0.02) between study sites (metroparks), indicating variation of EAB impact across Dayton, OH. However, no relationship was found between treated tree densities and abundance of new ash regeneration. We anticipate that as ash mortality increases and treated trees become an increasingly larger proportion of the surviving ash population, the spatial relationship between treated trees and density of ash seedlings will strengthen.

Flower et al. 2015. Emerald ash borer (EAB), a non-native invasive tree-boring beetle, is the primary agent behind the widespread mortality of ash trees (*Fraxinus* spp.) in both natural forests and urban areas of North America. While a variety of insecticide options have been adopted for protection against EAB attacks, little has been reported on the success of insecticide treatments on EAB-infested trees. This is particularly important because EAB is difficult to detect in early stages of its infestation and protective treatment may be undertaken on trees already in decline. Here, we investigated the effectiveness over a four-year period of biennial emamectin benzoate injections in trees exhibiting different initial EAB infestation levels (estimated using visual ash canopy condition metrics) in an ash forest in central Ohio. Results indicate that emamectin benzoate treated trees exhibited less canopy decline relative to non-treated control trees over the course of the experiment. In fact, all untreated trees died over the course of the four-year experiment, while on average treated trees did not exhibit a significant decline. Furthermore, initially healthy and moderately EAB impacted trees treated with insecticide either maintained or improved their canopy condition, while initially heavily EAB impacted trees stabilized, declined slightly, or died. Our results suggest that by using trunk injections of emamectin benzoate, private and public landowners may effectively be able to preserve lightly or moderately EAB infested trees or delay the replacement of ash trees at varying levels of EAB infestation.

McCullough et al. 2015. BACKGROUND: Economic and ecological impacts of ash (*Fraxinus* spp.) mortality resulting from emerald ash borer (EAB) (*Agrilus planipennis* Fairmaire) invasion are severe in forested, residential and urban areas. Management options include girdling ash trees to attract ovipositing adult beetles and then destroying infested trees before larvae develop or protecting ash with a highly effective, systemic emamectin benzoate insecticide. Injecting this insecticide and then girdling injected trees a few weeks later could effectively create lethal trap trees, similar to a bait-and-kill tactic, if girdling does not interfere with insecticide translocation. We compared EAB larval densities on girdled trees, trees injected with the emamectin benzoate insecticide, trees injected with the insecticide and then girdled 18–21 days later and untreated controls at multiple sites. RESULTS: Pretreatment larval densities did not differ among treatments. Current-year larval densities were higher on girdled and control trees than on any trees treated with insecticide at all sites. Foliar residue analysis and adult EAB bioassays showed that girdling trees after insecticide injections did not reduce insecticide translocation. CONCLUSIONS: Girdling ash trees to attract adult EAB did not reduce efficacy of emamectin benzoate trunk injections applied ≥18 days earlier and could potentially be used in integrated management programs to slow EAB population growth.

Lewis and Turcotte 2015. The destruction of the ash (Fraxinus) resource in North America by the emerald ash borer has progressed rapidly since it was first identified in 2002 in and around Detroit, Michigan. A 2004 survey estimated that 15 million ash trees had been severely impacted or killed by this pest insect and by late 2005 infested ash trees were detected in Indiana and Ohio. The emerald ash borer infestation has continued to expand, currently encompassing 24 states and various locations in southern Ontario and Québec, Canada. The first emerald ash borer population in West Virginia was discovered in 2007 in the southern part of the state. A management area with a radius of 800 meters was established and a tree inventory and biological assessment identified a light infestation among 309 ash trees. A host reduction and chemical protection effort was then initiated in 2008 whereby infested ash (25 trees) were felled and most ash saplings were removed. The remaining ash (163 trees) were treated once with TREE-age® (emamectin benzoate) at three rates based on tree stem diameter and subsequently monitored. Four years following treatment, a dozen of the treated trees and four control trees were cut down to assess treatment impact and status of the borer infestation. Insect trap catches, tree health assessments and tree mortality confirm that the beetle is present in and around the management area, while treated trees remain healthy with few signs of colonization. This study integrates area-wide ash removal and chemical protection of remaining ash trees as a management tool. This, along with standard forestry practices of thinning, timber stand improvement and crop tree techniques provide options for land managers faced with an emerald ash borer infestation. Removal and retention of trees will help control the rapid mortality trajectory caused by emerald ash borer, manage canopy disturbance and tree fall.

McCullough et al. 2015. Practical and effective strategies to manage emerald ash borer (EAB) (*Agrilus planipennis* Fairmaire; Coleoptera: Buprestidae) are increasingly important given economic and ecological impacts of this invader. While EAB detection remains challenging, tactics are available to protect individual ash (*Fraxinus* Linnaeus; Oleaceae) trees and slow EAB population growth, thereby delaying ash mortality. Simulations with a coupled map lattice model, parameterised with data from numerous field studies, showed treating trees with a highly effective systemic insecticide (TREE-äge™; emamectin benzoate), would be more effective in slowing EAB population growth than girdling trees to attract ovipositing females then destroying trees before larvae develop, while harvesting ash to reduce available phloem would have the least effect. From 2008 to 2012, cooperators participated in a pilot project to implement an integrated strategy for an EAB infestation in Upper Michigan, United States of America. Ash was inventoried and EAB density monitored using girdled ash detection trees supplemented with baited artificial traps across the >750 km2 project area. While only a tiny fraction of ash trees in the project area were girdled (444–855 trees annually) or injected with TREE-äge™ (<360 roadside trees annually), and treatment distribution was restricted, both treatments slowed EAB population growth. Coupling TREE-äge™ injections with other tactics will likely yield additive or synergistic outcomes.

Mercader et al. 2015. Emerald ash borer, *Agrilus planipennis* Fairmaire*,* has become the most destructive forest insect to invade North America. Unfortunately, tactics to manage *A. planipennis* are limited and difficult to evaluate, primarily because of the difficulty of detecting and delineating new infestations. Here we use data from a unique resource, the SL.ow A.sh M.ortality (SLAM) pilot project, to assess whether treating a small proportion of trees with a highly effective systemic insecticide or girdling ash (*Fraxinus* spp.) trees to serve as *A. planipennis*population sinks can result in discernable effects on *A. planipennis* population growth or ash mortality. Components of the SLAM pilot project included an extensive inventory of ash abundance across a heterogenous area encompassing >390 km^2, treatment of 587 ash trees with a highly effective systemic insecticide, and girdling 2658 ash trees from 2009 to 2012. Fixed radius plots were established to monitor the condition of >1000 untreated ash trees throughout the area from 2010 to 2012. While only a very small proportion of ash trees in the project area were either treated with insecticide or girdled, both tactics led to detectable reductions of *A. planipennis* densities and protected ash trees in areas surrounding the treatments. The number of trees treated with the systemic insecticide reduced larval abundance in subsequent years. In contrast, the area of phloem in the insecticide-treated trees had no discernable effect on *A. planipennis* population growth, indicating that the number of treated trees was more important than the size of treated trees. Significant interactions among girdled trees, larval density, and the local abundance of ash phloem indicate girdling trees has a positive, but complex potential as a management tactic.

Doccola et al. 2016. Two studies were presented as conceptual bases to model urban tree protection from emerald ash borer (Agrilus planipennis) (EAB). The two studies were located in Metro Parks, Louisville, KY and in St. John's, Michigan. The results of a 5-year study in Metro Parks demonstrated that canopy decline in large trees from EAB was managed by tree injection of TREE-äge® (4% wt. /wt. Emamectin benzoate MEC, Syngenta Crop Protection, Greensboro, NC). In St. John's MI, EAB infested ash (Fraxinus pennsylvanica Marshall) were treated (A) to investigate adult EAB mortality by injection of systemic insecticides and (B) to investigate the effects of tree injection in ash vascular tissues. The "A" trees were treated at a higher density and frequency than the "B" trees. Differential canopy health in these, and in an adjacent plot, "C" of untreated trees outside of our study area was observed. The three plots were not replicated, so our observations are anecdotal. Nevertheless, observations of these three plots suggest an "island effect" where untreated trees in proximity to treated trees could be "protected". We believe this effect is likely related to the (1) proximity to insecticidal treatment (i.e., reduction of EAB adults), (2) density and the spatial distribution of treated trees, and (3) the level of EAB infestation. Together, these two studies suggest a program for effective EAB management in urban trees.

Flower et al. 2016. These results support the notion that insecticide application of ash trees with healthy canopies (AC1 or AC2) can maintain the health of ash trees even despite continued EAB pressure. In fact, biennial emamectin benzoate injections improved the health of trees exhibiting light EAB-induced canopy decline (AC2) over the 4-year experiment. Although most trees initially rated AC3 and AC4 declined over the experiment, several trees in these groups did exhibit stabilized or improved canopy condition, highlighting the potential use of emamectin benzoate for preventing EAB-induced mortality of high value urban trees

Tanis and McCullough 2016. Emerald ash borer (EAB) (Agrilus planipennis), first identified near Detroit, Michigan, U.S., in 2002, has killed millions of ash trees (Fraxinus spp.) in 28 states and two Canadian provinces to date. Trunk injections of insecticide products containing emamectin benzoate (EB) (e.g., TREE-äge®) are often used to protect ash trees in landscapes from EAB, but wounds and potential injury resulting from injections are a concern. Researchers examined 507 injection sites on 61 trees and recorded evidence of secondary wounding (e.g., external bark cracks, internal xylem necrosis and pathogen infection). Researchers assessed 233 injection sites on 22 green ash and 24 white ash trees macro-injected with a low or a medium-high rate of EB in 2008 only, or in both 2008 and 2009. Only 12 of 233 injection sites (5%) were associated with external bark cracks and there was no evidence of pathogen infection. On 39 of the 46 trees (85%), new xylem was growing over injection sites. Researchers assessed 274 injection sites on 15 green ash trees injected annually with EB from 2008 to 2013 or injected in 2008 and again in 2011. Bark cracks were associated with four injection sites on three trees, but no evidence of injury was found on the other 12 trees. All 15 trees had new xylem laid over injection sites. Confocal laser scanning and polarizing digital microscopy were used to assess the integrity of discolored xylem tissue removed from the immediate area surrounding 140 injection sites on 61 trees. Researchers found no evidence of decay associated with discoloration.

Poland et al. 2016. Emerald ash borer (*Agrilus planipennis* Fairmaire) (Coleoptera: Buprestidae), an invasive phloem-feeding insect native to Asia, threatens at least 16 North American ash (*Fraxinus*) species and has killed hundreds of millions of ash trees in landscapes and forests. We conducted laboratory bioassays to assess the relative efficacy of systemic insecticides to control emerald ash borer larvae in winter 2009 and 2010. Second- and third-instar larvae were reared on artificial diet treated with varying doses of emamectin benzoate (TREE-äge, Arborjet, Inc., Woburn, MA), imidacloprid (Imicide, J. J Mauget Co., Arcadia, CA), dinotefuran (Safari, Valent Professional Products, Walnut Creek, CA), and azadirachtin (TreeAzin, BioForest Technologies, Inc., Sault Ste. Marie, Ontario, and Azasol, Arborjet, Inc., Woburn, MA). All of the insecticides were toxic to emerald ash borer larvae, but lethal concentrations needed to kill 50% of the larvae (LC_{50}), standardized by larval weight, varied with insecticide and time. On the earliest date with a significant fit of the probit model, LC_{50} values were 0.024 ppm/g at day 29 for TREE-äge, 0.015 ppm/g at day 63 for Imicide, 0.030 ppm/g at day 46 for Safari, 0.025 ppm/g at day 24 for TreeAzin, and 0.027 ppm/g at day 27 for Azasol. The median lethal time to kill 50% (LT_{50}) of the tested larvae also varied with insecticide product and dose, and was longer for Imicide and Safari than for TREE-äge or the azadirachtin products. Insecticide efficacy in the field will depend on adult and larval mortality as well as leaf and phloem insecticide residues.

Mercader et al. 2016. Information on the pattern and rate of spread for invasive wood- and phloem-feeding insects, including the emerald ash borer (EAB) (*Agrilus planipennis* Fairmaire), is relatively limited, largely because of the difficulty of detecting subcortical insects at low densities. From 2008 to 2011, grids of girdled and subsequently debarked ash (*Fraxinus* spp.) detection trees were established across a >390 km^2 area encompassing two recently established EAB infestations in Michigan as part of the SLow Ash Mortality (SLAM) Pilot Project. Ash distribution and abundance were inventoried across the project area which included public and private forestland, a state park, and street trees in a small municipality. Spread rates of EAB from 2008 to 2011, based on larval presence in girdled detection trees, were estimated to be 1.2–1.7 km yr^{-1} in the larger, presumably older, infestation and 0.4–0.7 km yr^{-1} in the smaller infestation; suggesting a slower spread rate during the initial stages of population establishment. From 2009 to 2011, a total of 587 ash trees in the project area were trunk-injected with a highly effective, systemic emamectin benzoate insecticide. Potential effects of girdled ash trees and the systemic insecticide treatment on EAB spread were evaluated using a simulation model and a simple descriptive model of observed spread. Not surprisingly, density of trees treated with the insecticide was too low to exert a detectable effect on EAB spread. However, while the density of girdled trees was also relatively low, model results indicated a reduced spread of EAB out of areas containing girdled trees.

O'Brien 2017. Emerald ash borer (EAB) has killed millions of trees since its accidental introduction to southeastern Michigan more than 20 years ago. Near the invasion epicenter, nearly all mature ashes have died, reproduction has ceased, and the seed bank depleted, leaving an "orphaned" cohort of established seedlings and saplings. Because of high seedling mortality, it is possible that seedlings that established recently may have lower genetic variation than those that established before the EAB invasion. Insecticides can successfully protect ash trees from EAB and clusters of treated ash trees may slow ash mortality by reducing EAB densities. Therefore, insecticides, in high enough densities, may protect ash trees in order to maintain reproduction, regeneration, and genetic variation. I tested these questions at Five Rivers Metroparks in southwestern Ohio and the Upper Huron River Watershed in southeastern Michigan. From 2014 – 2016, green and white ash mortality differed between parks, with survival higher at Sugarcreek, Englewood, and Germantown Metroparks (low EAB impact) than at Cox Arboretum, Taylorsville, and Twin Creek (high EAB impact). I found that survival of untreated green-white ashes increased with percentage of ash phloem area treated, but only in parks with low EAB impact. Additionally, survival of untreated trees was higher when the nearest treated ash was within 100 m, percentage of ash phloem treated was high, and EAB impact was low. However, this pattern was not observed in parks with high EAB impact. These results suggest that treating ash trees with insecticide may slow the progression of ash mortality if the program is initiated when ash mortality is still low. There were more flowering green and white ash trees (treated and untreated) in plots with higher percentage ash phloem treated. In parks with high EAB impact, seedling density was low and was not affected by insecticide treatment. In parks with low EAB impact, seedling densities increased with percentage of ash phloem treated. Density of seedlings increased with density of flowering ash trees and decreased with height of herbaceous understory vegetation, which may suppress seedling population through competition for resources. Overall, these results show that protecting trees with insecticide can maintains ash reproduction. Patterns of genetic variation of seedling and sapling populations differed in Michigan and Ohio. In Michigan, established seedlings and saplings had similar allelic richness, but there was also less genotypic variation in the larger seedlings and saplings than in smaller seedlings. In Ohio, newly germinated and small established seedlings had higher allelic richness than larger established seedlings, but each population had similar number of effective alleles (high frequency alleles). Larger seedlings had the least genotypic variation and newly established seedlings had the most. Collectively, these results are consistent with a loss of genetic variation in Michigan, but no loss of genetic variation in Ohio. EAB-induced ash mortality and density of treated ash trees also had no effect on genetic variation in populations of ash seedlings, but the impact of the EAB invasion and the conservation benefits of insecticide treated trees may intensify as ash mortality increases over time.

Bick et al. 2017. We evaluated the efficacy of two formulations of emamectin benzoate applied as trunk injections, and imidacloprid applied as a soil drench for control of emerald ash borer (EAB) (*Agrilus planipennis* Fairmaire) for 3 years following application. A 0.2-ha plantation of ash (*Fraxinus*) species was established in May 2003 at the Michigan State University's Tollgate Education Center in Novi, MI. On 15

May 2012, green ash (*Fraxinus pennsylvanica*) with trunk diameters averaging 15.2 cm at breast height were treated with 4% emamectin benzoate (TREE-age®; Arborjet, Woburn, MA), a novel formulation of 4% emamectin benzoate (ARBORMECTIN™; Rotam Agrochem International Co. Ltd., Hong Kong, China), or imidacloprid (Xytect® 75 WSP; Rainbow Treecare Scientific Advancements, Minnetonka, MN). Emamectin benzoate formulations were applied as trunk injections at a rate of 10 ml/in. trunk diameter using the Arborjet Tree I.V system with #4 Arborplugs® (Arborjet, Woburn, MA). Imidacloprid was applied as a soil drench (Table 1) at a rate of 1.4 g active ingredient per inch trunk diameter. The experiment was designed as a randomized block with five replicate trees per insecticide treatment and six replicates for the untreated control.

Flower et al. 2017. The emerald ash borer (EAB, Agrilus planipennis) is a non-native forest pest that has been sweeping across North America causing widespread mortality of trees in the genus Fraxinus, which includes the economically valuable white ash (F. americana). The rapid spread and lethality of EAB, paired with low levels of natural resistance in ash trees, has left forest managers with few management options to slow EAB or to conserve ash trees. Here we present the initial findings of a collaborative project to pursue regional genetic conservation of white ash trees across the Allegheny National Forest. The network of white ash conservation plots consists of 29, 3.24 ha (8 ac) plots distributed across the forest, each containing a subset of 20 ash trees that received insecticidal treatment with emamectin benzoate trunk injections. This design will allow us to test for associational protection of non-insecticide treated trees with treatment levels varying from 10 to 91 percent (i.e., proportion of protected ash trees in a stand). In conjunction with the ash conservation project, we monitored ash tree canopy health from 2010 (prior to the arrival of EAB) to 2015 across 193 permanent plots in the Allegheny National Forest. Following the arrival of EAB to the Allegheny National Forest in 2013, we conducted a follow up survey of ash canopy health in 2015 and discovered further canopy decline in both upper and lower slope positions, likely caused by EAB. Furthermore, canopy traps revealed that EAB, which was first discovered in the southern region of the forest in 2013, had now spread to the northern region.

Coleman et al. 2017. From 2009 to 2013, we tested four systemic insecticide formulations and five application methods against the invasive goldspotted oak borer, *Agrilus auroguttatus* Schaeffer (Coleoptera: Buprestidae), in California. The insecticides were evaluated in three experiments: 1) 2009 remedial applications of emamectin benzoate (stem-injection) and imidacloprid (stem-injection and soil-injection); 2) 2009–2012 emamectin benzoate and imidacloprid initially applied at different times during the dormant season with varying injection technologies; and 3) 2013 dinotefuran applied to several tree diameter size classes. Adult leaf-feeding bioassays were used to assess the impact of systemic treatments against *A*. *auroguttatus*, whereas enzyme-linked immunosorbent assays determined the quantity of the active ingredient of insecticide residues in foliage. Imidacloprid (experiment 1) persisted at elevated levels in foliage of coast live oak, *Quercus agrifolia* Née, for 1.5 yr following stem injections. Stem injections of emamectin benzoate (experiment 2) sometimes significantly decreased survival in adults fed foliage from treated *Q*. *agrifolia*, and both the emamectin benzoate and imidacloprid treatments reduced adult feeding in some trials. Imidacloprid residues in *Q. agrifolia* and California black oak, *Quercus kelloggii* Newb., foliage remained at elevated levels (>10 μg/g) ∼2 yr postapplication. In 2013 (experiment 3), dinotefuran residues were highest in foliage collections 2 wk postapplication and greatest in smaller diameter oaks, but insecticide treatment had no effect on survival or frass production by adults fed foliage from treated trees. Systemic injections of emamectin benzoate and imidacloprid applied during the dormant season to uninfested or lightly infested oaks can reduce adult *A*. *auroguttatus* survival and maturation feeding.

Chen et al. 2017 BACKGROUND:The invasive goldspotted oak borer, *Agrilus auroguttatus*, is threatening the health and survival of oak trees in San Diego County, California. From two sites in the core area of the infestation, we report a 2.5 year investigation of the impact of *A. auroguttatus* on coast live oak, Quercus agrifolia, before and after treatment with two systemic insecticides, emamectin benzoate (EB) and imidacloprid (IC). RESULTS: None of the 446 survey trees died during the study. The crown dieback rating of most trees at both study sites remained unchanged, regardless of insecticide treatment. A higher cumulative increase in the number of *A. auroguttatus* emergence holes was observed on trees that were previously infested and on trees with larger diameters. Over the 2.5 year period, the new infestation rates of initially uninfested trees across the untreated and treated groups were 50% (EB) and 32% (IC), and neither EB nor IC treatment affected cumulative increases in the number of emergence holes. EB-injected trees did not have significant annual increases in the number of A. auroguttatus emergence holes at either 1.5 or 2.5 years compared with that at 0.5 years, whereas untreated trees had significant annual increases. Although IC-injected trees had a significantly greater annual increment in the number of emergence holes than untreated trees during the last year of the study, treated trees had significant reductions in annual increases in emergence holes at both 1.5 and 2.5 years compared with that at 0.5 years. Untreated trees had no significant reduction in the annual increase in emergence holes at 1.5 and 2.5 years. CONCLUSIONS: *A. auroguttatus* preferentially attacked previously infested and larger (diameter at breast height > 15-30 cm) oak trees, but the attacks led to very gradual changes in the health of the trees. Both EB and IC provided minor suppressive effects on A. auroguttatus emergence.

Sadof et al. 2017. Advances in control can help municipal foresters save ash trees from emerald ash borer (EAB) [Agrilus planipennis (Fairmaire)] in urban forests. Although ash trees of any size can be protected from this pest, cities often do not implement programs because they fail to recognize and act on incipient populations of EAB. In this study, researchers develop a model for predicting ash mortality over an eight-year period, and validated with data from the removal of >14,000 ash trees killed by EAB in Fort Wayne, Indiana, U.S. researchers then developed a sampling scheme to help foresters map their ash trees along the expected progression of ash decline. This model was then used to modify a web-based EAB cost calculator that compares discounted annual and cumulative costs of implementing a variety of management strategies. It was determined that strategies that most heavily relied on saving ash trees were less expensive and produced a larger forest than those strategies that mostly removed and replaced ash trees. Ratios of total discounted costs to discounted cumulative benefits of strategies that saved most ash trees were over two-thirds lower than strategies of proactive tree removal and replacement. Delaying implementation of an ash management program until damage would be visible and more obvious to the community (Year 5 of the model) decreased the cost–benefit ratio by <5%. Thus, delays that rely on the abundance of locally damaged trees to bolster community support do not necessarily diminish the utility of implementing a control strategy.

Bick et al. 2018. Emerald ash borer (EAB), *Agrilus planipennis (*Fairmaire; Coleoptera: Buprestidae), is decimating ash trees (Fraxinus spp.) in North America. Combatting EAB includes the use of insecticides; however, reported insecticide efficacy varies among published studies. This study assessed the effects of season of application, insecticide active ingredient, and insecticide application rate on green ash (*Fraxinus pennsylvanica* Marsh.) (Lamiales: Oleaceae) canopy decline caused by EAB over a 5- to 7-yr interval. Data suggested that spring treatments were generally more effective in reducing canopy decline than fall treatments, but this difference was not statistically significant. Lowest rates of decline (<5% over 5 yr) were observed in trees treated with imidacloprid injected annually in the soil during spring (at the higher of two tested application rates; 1.12 g/cm diameter at 1.3 m height) and emamectin benzoate injected biennially into the stem. All tested insecticides (dinotefuran, emamectin benzoate, and imidacloprid) under all tested conditions significantly reduced the rate of increase of dieback.

Liu 2018. A conceptual framework designed to protect and preserve ash trees (Fraxinus spp.) from the emerald ash borer, *Agrilus planipennis* Fairemaire (Coleoptera: Buprestidae), at the community level was created in Pennsylvania in 2012. Advancements in the most recent Fraxinus systematics, taxonomy, distribution, and biogeography were reviewed. Description, biology, hosts, damage, invasion, spread, and potential impacts of *A. planipennis* were summarized. Ash resources at risk were identified, and pest status of *A. planipennis* was evaluated. Current management strategies for *A. planipennis* (containment and eradication, host resistance, silviculture, chemical control, biological control, and slow ash mortality) were incorporated into the model plan. A template with step-by-step instructions was made available for communities to develop their own management plans by selecting from four management options (no action, selective management, preemptive management, and aggressive management) to fit their needs. Follow-up training and promotion of the model plan, coupled with technical support and financial assistance to participating communities resulted in 12 finished plans across the state, with more than 7,000 hazard trees removed, 5,000 trees treated, and 3,000 non-host trees planted. Case studies for three communities with implemented plans provided details to the plan development and execution process. The future of ash species and the direction of *A. planipennis* and ash management in North America are discussed.

Olsen 2018. Emerald ash borer (EAB), Agrilus planipennis (Coleoptera: Buprestidae), is an aggressive invader from Asia that has killed millions of trees in North America. Recently EAB has been documented developing in a novel host, white fringetree, Chionanthus virginicus. I evaluated larval performance in two common ash species and white fringetree by infesting excised bolts with emerald ash borer eggs. In addition I evaluated several plant characteristics to determine which most influence larval development. I also conducted choice and no choice assays using the classical biological control agent, Tetrastichus planipennisi (Hymenoptera: Eulophidae), to assess its ability to locate larval EAB in the different host plants. I found significantly lower survival rates of EAB larvae in white fringetree compared to white ash, F. americana. Larval phloem consumption and larval growth were lower in fringetree than in both ash tested. In choice and no choice assays T. planipennisi failed to parasitize larvae in fringetree. Failure of T. planipennisi to parasitize larvae within fringetree has implications for the efficacy of this classical biological control agent. Coupled with the use of white fringetree as a reservoir host, the enemy free space provided to EAB through use of this alternate host may have repercussions for EAB invasion dynamics.

McCullough et al. 2019. We assessed density of emerald ash borer (*Agrilus planipennis* Fairmaire) (Coleoptera: Buprestidae) larvae over a 6-yr period by felling and sampling a total of 315 green ash (*Fraxinus pennsylvanica* Marsh.) trees that were left untreated or treated with imidacloprid, dinotefuran, or emamectin benzoate products at 1-yr, 2-yr, or 3-yr intervals. Our study, conducted across a 32-ha forested area, began soon after emerald ash borer became established and continued through the peak and eventual decline of the emerald ash borer population. Less than half of the 96 trees in the pretreatment sample were infested and larval densities were very low. Densities of emerald ash borer remained low for 3 yr, then increased exponentially, eventually resulting in mortality of most untreated overstory ash. Trees treated with either low or moderate rates of emamectin benzoate applied via trunk injection had few or no emerald ash borer galleries, even 3 yr post-treatment. Basal trunk sprays of dinotefuran applied annually were also effective at preventing larval densities from reaching damaging levels. Average larval densities on trees treated with a trunk injection of imidacloprid were lower but did not differ from untreated trees, regardless of treatment frequency. Larval parasitism was rare, while woodpecker predation was common and accounted for nearly all natural larval mortality, even on trees with very low densities of larvae.

Hanavan and Heuss. 2019. Street- and park-planted ash (Fraxinus spp.) trees infested with emerald ash borer (Agrilus planipennis Fairmaire) ranging in size from 30 to 55 cm (11.8 to 21.7 in) dbh and 10 to 20 m (32.8 to 65.6 feet) in height were measured over two sites. The first group was treated with an emamectin benzoate stem injection at 10 ml/2.54 cm dbh (0.4 g ai) in June 2014, and the second group was left as an untreated control. Chlorophyll concentration and fluorescence was measured to assess plant fitness and vitality over three summers. Trees treated with emamectin benzoate showed improvements in chlorophyll concentration and plant fitness and vitality over the course of the study with peak improvement occurring in the second year. The untreated control trees showed continued signs of decline in each year of the study. This work demonstrates the utility of chlorophyll fluorescence for detecting plant stress related to forest health threats and could potentially inform managers on both short term and long-term management options.

Greene 2019. Ash (Fraxinus spp) trees on the Michigan State University's campus have been injected with insecticides since 2005 to protect against the emerald ash borer Agrilus planipennis Fairmaire (Coleoptera: Buprestidae). Annual applications of imidacloprid and bi- to tri-annual applications of emamectin benzoate have been the primary chemicals used by the university, with emamectin benzoate becoming the primary chemical used in 2013. Imidacloprid was the cheapest chemical to apply but must be applied annually and efficacy can vary. Emamectin benzoate was the most expensive chemical to apply, but the costs were annualized across two to three years, reducing the initial cost. The condition of the ash population improved as trees were protected from year to year with the ash population having an overall low percentage of canopy dieback and transparency. Ecosystem services were quantified via i-Tree Eco, which valued the ash population at nearly 10 times the total cost of treating the ash trees. Alternate management strategies were simulated: 1) remove and replace all ash; 2) treat trees ≥ 20 cm, remove and replace trees < 20 cm; and 3) treat all trees with emamectin benzoate on a four-year rotation. When compared to the current management strategy, the cheapest option was to treat all ash trees on a four-year rotation of emamectin benzoate and the most expensive option was the removal and replacement of all ash trees.

Aubihl 2019. The study of the rapid decline of ash trees caused by the emerald ash borer beetle (EAB) has been well documented, but little is known about the decline of ash stands when a subset of trees is treated with insecticide. The treatment of a subset of ash trees in areas may provide protection to those ash trees that are untreated, resulting in the associational protection of untreated ash trees provided by treated ash trees. Two objectives of this study were to test whether such associational protection can occur, and the threshold, if any, at which associational protection occurs. The third objective was to test whether any ensuing mortality depended on the density of ash trees. This study was conducted in the Allegheny National Forest, located in Northwestern Pennsylvania and is part of a larger study by the U.S. Forest Service focused on preserving the genetic diversity of ash trees in the Allegheny National Forest. My analyses indicate no protection from insecticide and no associational protection. Further, I found that low ash density forest stands display faster rates of decline caused by EAB than high ash density forest stands. These findings are from the analyses of datasets from the first two years of a ten-year study and although they are from the early stages of a long-term study, the management implications are valuable.

Sadof et al. 2020. Managing exotic invasive pests like emerald ash borer can strain budgets and the capacity of cities to protect their urban forest. Area-wide management approaches, like SLAM (SL.ow A.sh M.ortality), can potentially protect trees at a greatly reduced cost. We tested this strategy in three urban forests in Indiana by treating 40 % of the ash trees with insecticides. While the urban SLAM approach reduced overall mortality of untreated ash trees, survivorship varied considerably between sites. SLAM was most successful (54 % survival) where initially < 10 % of the ash trees were moribund (canopy thinning > 30 %) and 40 % of all trees were treated with emamectin benzoate every two years. The approach was less successful (38 % survival) in a site with similar initial ash morbidity but where 15 % of trees were treated with emamectin benzoate and 25 % with annual applications of imidacloprid. In the third site, where 51 % of ash forest were initially moribund and 40 % of the ash trees were treated, only 23 % survived. Overall survival of treated ash trees declined by 18–22 %, and trees that were not moribund were most likely to survive. Although many treated trees that were initially moribund regained their health by the end of the project, this was not the case for untreated ash trees. Where SLAM was most successful, both untreated and treated white ash were more likely to survive than green ash trees. Untreated ash trees at all three sites were more likely to survive when closer to trees treated with emamectin benzoate, but not to those treated with imidacloprid. Our findings suggest that the SLAM approach can protect urban ash trees, but its success is strongly influenced by initial tree condition, species composition and proximity to treated ash trees.

McCullough 2020. Emerald ash borer (EAB) (Agrilus planipennis Fairmaire), discovered in southeastern Michigan, USA in 2002, has become the most destructive and costly invasive forest insect in North America. This phloem-boring beetle has also invaded Moscow, Russia and continued spread of EAB potentially threatens European ash (Fraxinus spp.) species. This review summarizes EAB life history, including interspecific variation in host preference, invasion impacts and challenges of detecting new infestations and provides an overview of available management tactics. Advances in systemic insecticides, particularly emamectin benzoate products applied via trunk injection, have yielded effective and practical options both to protect individual trees and to slow EAB population growth and ash decline on an area-wide basis without disrupting natural enemies. Economic costs of treating ash are substantially lower than removal costs, retain ecosystem services provided by the trees, reduce sociocultural impacts and conserve genetic diversity in areas invaded by EAB. Girdled ash trees are highly attractive to EAB adults in low-density populations and debarking small girdled trees to locate larval galleries is the most effective EAB detection method. An array of woodpeckers, native larval parasitoids and introduced parasitoids attack EAB life stages but mortality is highly variable. Area-wide management strategies that integrate insecticide-treated trees, girdled ash trap trees and biological control can be adapted for local conditions to slow and reduce EAB impacts.

Evans et al. 2020. The threats posed by the buprestid beetles emerald ash borer (Agrilus planipennis Fairmaire) and bronze birch borer (Agrilus anxius Gory) have been the subject of considerable research, primarily to develop methods for detection and management of the pests. PREPSYS, a Euphresco project, has worked with collaborators globally to assess the 'state of the art' for the two insect pests and to identify those measures that would best prepare Europe for potential invasion by the pests, especially emerald ash borer which is now in the western part of Russia and in eastern Ukraine. Building on an excellent exchange of knowledge and discussion at the OECD sponsored international conference held in Vienna in October 2018, the concept of a European Toolbox to increase preparedness for dealing with the pests has been developed. This includes key components including surveillance, direct intervention, use of natural enemies and increased awareness of the problems associated with the pests. Collaboration is essential in delivering and refining the European Toolbox.

De Andrade et al. 2021.
Background: The emerald ash borer (EAB) (Agrilus planipennis Fairmaire) (Coleoptera: Buprestidae) is now the most destructive invasive species in North America. While biocontrol using parasitoids shows promising results in natural forests, strategies are needed to protect high-value trees against invasive EAB populations. Emamectin benzoate is a commonly used systemic insecticide for the protection of valuable trees. Methods that optimize its use allow for reduced quantities of insecticide to be released in the environment and save time and money in efforts to protect ash trees from EAB. We hypothesize that a treated tree can also offer a protective neighboring effect to nearby untreated ash trees, allowing for an optimized spatial planning of insecticide applications.

Results: We sampled 896 untreated ash trees, in the vicinity of treated trees, in Maryland and Washington DC. We recorded signs of EAB infestation (canopy condition, exit holes, wood pecks, epicormic growth, and bark splits). Two subsequent yearly samplings were made of 198 and 216 trees, respectively. We also present a novel proximity index for this particular application. Results show consistent decrease in EAB infestation signs in untreated trees as proximity to treated trees increases.

Conclusion: Results support that a neighboring effect occurs. However, proximity to treated trees must be high for a tree to be safely left untreated. This proximity seems rare in forests, but can happen in urban/planted landscapes. Future studies should test and validate these findings, and could lead to a more precise recommended safe index tailored across multiple ash species and geographic regions.

Pine bark beetles, Pine sawyer

Grosman and Upton 2006. We evaluated the efficacy of the systemic insecticides dinotefuran, emamectin benzoate, fipronil, and imidacloprid for preventing attacks and brood production of southern pine engraver beetles (Coleoptera: Curculionidae: Scolytinae) and wood borers (Coleoptera: Cerambycidae) on standing, stressed trees and bolt sections of loblolly pine, *Pinus taeda* L., in eastern Texas. Emamectin benzoate signiÞcantly reduced the colonization success of engraver beetles and associated wood borers in both stressed trees and pine bolt sections. Fipronil was nearly as effective as emamectin benzoate in reducing insect colonization of bolts 3 and 5 mo after injection but only moderately effective 1 mo after injection. Fipronil also significantly reduced bark beetle-caused mortality of stressed trees. Imidacloprid and dinotefuran were ineffective in preventing bark beetle and wood.borer colonization of bolts or standing, stressed trees. The injected formulation of emamectin benzoate was found to cause long vertical lesions in the sapwood-phloem interface at each injection point.

Grosman et al. 2009. We evaluated the efficacy of systemic insecticides emamectin benzoate and fipronil for preventing mortality of individual loblolly pines, *Pinus taeda* L., as a result of attacks by southern pine bark beetles (Coleoptera: Curculionidae, Scolytinae) for two consecutive years in Mississippi (2005 - 2006) and Alabama (2006- 2007). Trees were injected once in the spring of 2005 (Mississippi) or 2006 (Alabama) and then were baited with species-specific bark beetle lures several weeks later. The southern pine beetle, *Dendroctonus frontalis* Zimmermann, was the target species but was changed to *Ips* spp. in Mississippi (but not Alabama) the second year because of few southern pine beetle attacks on baited trees. Single injections of emamectin benzoate were effective in reducing tree mortality caused by bark beetles compared with untreated checks. Although less effective overall, fipronil also significantly reduced tree mortality from southern pine beetle compared with the checks during the second year in Alabama. Tree mortality continued well after the lures had been removed. Evaluations of bolts taken from experimental trees killed in 2006 indicated that emamectin benzoate effectively prevented parent bark beetle gallery construction and that fipronil significantly reduced lengths of galleries constructed by adult beetles, brood development, and emergence, compared with checks. In contrast, neither insecticide treatment prevented the bark beetles from inoculating blue stain fungi, *Ophiostoma* spp., into treated trees.

Grosman et at. 2010. Bark beetles (Coleoptera: Curculionidae, Scolytinae) are important tree mortality agents in western coniferous forests. Protection of individual trees from bark beetle attack has historically involved applications of liquid formulations of contact insecticides to the tree bole using hydraulic sprayers. More recently, researchers looking for more portable and environmentally safe alternatives have examined the effectiveness of injecting small quantities of systemic insecticides directly into trees. In this study, we evaluated trunk injections of experimental formulations of emamectin benzoate and fipronil for preventing tree mortality due to attack by western pine beetle (*Dendroctonus brevicomis* LeConte) on ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) in California, mountain pine beetle (*Dendroctonus ponderosae* Hopkins) on lodgepole pine (*Pinus contorta* Dougl. ex Loud.) in Idaho, and spruce beetle (*D. rufipennis* [Kirby]) on Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) in Utah. Fipronil appeared ineffective for protecting *P. ponderosa* from mortality due to *D. brevicomis* over the 3 years in California because of insufficient mortality of untreated, baited control trees the first 2 years and high mortality of the fipronil-treated trees in the third year. Emamectin benzoate was effective in providing protection of *P. ponderosa* from *D. brevicomis* during the third year following a single application. To our knowledge, this is the first demonstration of the successful application of a systemic insecticide for protecting individual conifers from mortality due to bark beetle attack in the western United States. Estimates of efficacy could not be made during both field seasons in *P. contorta* because of insufficient mortality in control trees. Both emamectin benzoate and fipronil were ineffective for protecting *P. engelmannii* from *D. rufipennis*. Lower ambient and soil temperatures and soil moisture may have limited chemical movement and thus efficacy at the Idaho and Utah sites.

Kim et al. 2011. Trunk injection of nematicides was applied to prevent pine wilt disease (PWD). Although the trunk injection of nematicides was effective to PWD prevention, it was not effective to a vector, Monochamus alternatus. Thus, This study was investigated for the insecticidal activity and the effect of oviposition deterrence by injecting to pine trees with systemic insecticides such as Acetamiprid SC 10%, Imidacloprid DC (20%), and Thiamethoxam DC (15%). As a results, mortality of M. alternatus adults was 100% at 56 days after trunk injection. Percentage of M. alternatus adults moved to a young black pine tree by trunk injection of Imidacloprid DC (20%) and Thiamethoxam DC (15%) in screen cage (4.0×2.0×2.5m) was 76.7% and 70.0%, respectively. But the mortality of M. alternatus adults showed 100%. Percentage of M. alternatus adults moved to the treated and untreated young black pine trees by trunk injection of Acetamiprid SC (10%) in screen cage (4.0×2.0×2.5m) were 25.9% and 49.5% at 1st day and 3rd day after treatment, respectively. Percentage of M. alternatus adults oviposited to treated pine logs at 3month after trunk injection of liquid mixture of Acetamiprid SC (10%) and Emamectin benzoate EC (2.15%) in screen cage (72×72×100㎝) was 25%. But, untreated pine logs was 100%

Fettig et al. 2013. The results of the many studies presented in this chapter indicate that preventative applications of insecticides are a viable option for protecting individual trees from mortality due to bark beetle attack. Bole sprays of bifenthrin, carbaryl and permethrin are most commonly used. Several formulations are available and effective if properly applied. Residual activity varies with active ingredient, bark beetle species, tree species and associated climatic conditions, but generally one to three years of protection can be expected with a single application. Recent advances in methods and formulations for individual tree injection are promising, and further research and development is ongoing. We expect the use of tree injections to increase in the future. In general, preventative applications of insecticides pose little threat to adjacent environments, and few negative impacts have been observed. We hope that forest health professionals and other resource managers use this publication and other reports to make informed, judicious decisions concerning the appropriate use of preventative treatments to protect trees from mortality due to bark beetle attack. Additional technical assistance in the U.S. can be obtained from Forest Health Protection (USDA Forest Service) entomologists (www.fs.fed.us/foresthealth/), state forest entomologists, and county extension agents (www.csrees.usda.gov/Extension/). We encourage use of these resources before applying any insecticides to protect trees from bark beetle attack.

Fettig et al. 2014. BACKGROUND: Protection of conifers from bark beetle colonization typically involves applications of liquid formulations of contact insecticides to the tree bole. An evaluation was made of the efficacy of bole injections of emamectin benzoate alone and combined with the fungicide propiconazole for protecting individual lodgepole pine, *Pinus contorta* Dougl. ex Loud., from mortality attributed to colonization by mountain pine beetle, *Dendroctonus ponderosae* Hopkins, and progression of associated blue stain fungi. RESULTS: Injections of emamectin benzoate applied in mid-June did not provide adequate levels of tree protection; however, injections of emamectin benzoate + propiconazole applied at the same time were effective for two field seasons. Injections of emamectin benzoate and emamectin benzoate + propiconazole in mid-September provided tree protection the following field season, but unfortunately efficacy could not be determined during a second field season owing to insufficient levels of tree mortality observed in the untreated control, indicative of low D. ponderosae populations. CONCLUSION: Previous evaluations of emamectin benzoate for protecting *P. contorta* from mortality attributed to *D. ponderosae* have failed to demonstrate efficacy, which was later attributed to inadequate distribution of emamectin benzoate following injections applied several weeks before *D. ponderosae* colonization. The present data indicate that injections of emamectin benzoate applied in late summer or early fall will provide adequate levels of tree protection the following summer, and that, when emamectin benzoate is combined with propiconazole, tree protection is afforded the year that injections are implemented.

Fettig et al. 2017. Several tactics are available to manage bark beetle infestations and to reduce associated levels of tree mortality. Direct control involves short-term tactics designed to address current infestations by manipulating beetle populations, and typically includes the use of insecticides, semiochemicals, sanitation harvests, trap trees, or a combination of these treatments. Indirect control is a preventative tactic designed to reduce the probability and severity of future infestations within treated areas by manipulating stand, forest, and/or landscape conditions by reducing the number of susceptible hosts through thinning, prescribed burning, and/or altering age classes and species composition
Our results indicate narrowly spaced (7.6-cm) injections of TREE-äge are effective for protecting Pi. engelmannii when applied about 1 yr prior to treatments being challenged by D. rufipennis. Two years of efficacy can be expected. Bole sprays of carbaryl are typically used for protecting high-value Pi. engelmannii from mortality attributed to D. rufipennis (e.g., in USDA Forest Service campgrounds) but require transporting sprayers and other large equipment into remote areas, which can be problematic. Additionally, many sites where bole sprays are frequently applied occur near water sources (e.g., streams and lakes), limiting applications due to restrictions concerning the use of no-spray buffers to protect nontarget aquatic organisms, thus leaving some hosts untreated and susceptible to colonization by D. rufipennis. For these and other reasons, injections of TREE-äge may represent a desirable option for reducing levels of tree mortality attributed to D. rufipennis.

Grosman and Cox 2018. The present invention provides a method for the prevention / treatment of bark beetle and / or wood borer infestation of trees comprising treatment of the tree with a composition comprising a macroyclic lactone .

Fettig et al. 2020. Bark beetles are important disturbance agents in coniferous forests, and spruce beetle, Dendroctonus rufipennis (Kirby) (Coleoptera: Curculionidae), is one of the more notable species causing landscape-level tree mortality in western North America. We evaluated the efficacy of bole injections of emamectin benzoate (TREE-äge®; Arborjet Inc., Woburn, MA) alone and combined with propiconazole (Alamo®; Syngenta Crop Protection Inc., Wilmington, DE) for protecting Engelmann spruce, Picea engelmannii Parry ex Engelmann (Pinales: Pinaceae), from mortality attributed to colonization by D. rufipennis. Two injection periods in 2013 (the spring and fall of the year prior to trees first being challenged by D. rufipennis in 2014) and distributions of injection points (7.6- and 15.2-cm spacings) were evaluated. Tree mortality was monitored over a 3-yr period (2014–2017). Emamectin benzoate injected in spring at a narrow spacing (7.6 cm) was the only effective treatment. Two (but not three) field seasons of protection can be expected with a single injection of this treatment. We discuss the implications of these and other results regarding the use of emamectin benzoate and propiconazole for protecting western conifers from mortality attributed to bark beetles, and provide suggestions for future research. A table summarizing the appropriate timing of treatments in different bark beetle/host systems is provided.

Doccola et al. 2020. The protection of high-value trees against bark beetles and the development of alternatives to bole sprays is a priority for the tree manager. The objective of this study was to evaluate stem-injected TREE-äge® (emamectin benzoate [EB]) as a protective treatment for western white pines (Pinus monticola Dougl. ex D. Don) against mountain pine beetle (MPB, Dendroctonus ponderosae Hopkins). Treatment efficacy was based solely on tree mortality as per Shea protocols (i.e., ≥ 60% check vs. ≤ 20% treated tree mortality). Our first experiment was installed in 2007 and included trees stem-injected with TREE-äge and untreated controls. Bole application of S-(-)-verbenone and green leaf volatile (GLV) blend was included for observational comparison. Pressure from MPB was heavy, as indicated by the number and timing of control tree mortality (90%). Strip attacks by MPB in TREE-äge trees indicated that the impacts of EB, and by inference its distribution, were inconsistent. In 2009, the injection protocol was revised to improve EB distribution in the phloem via closer injection points. In the 2009 TREE-äge-treated trees, adult beetle mining stopped when they contacted phloem and was insufficient to cause tree death by girdling. Blue-stain fungi colonized the sapwood of trees in both studies. Isolates from autopsied trees treated with TREE-äge alone were subsequently identified as Grosmannia clavigera and Leptographium longiclavatum (Ophiostomatales: Ascomycota), species that can incite tree mortality. In 2013, we revised our protocol to include GLV plus verbenone or propiconazole with TREE-äge, wherein these treatments proved effective in protecting trees against MPB and their associated pathogenic fungi.

Lee et al. 2020. Pine wilt disease (PWD) caused by pine wood nematode (PWN), Bursaphelenchus xylophilus, which is transmitted by Monochamus alternatus and M. saltuarius, is a serious threat to coniferous forests in the Northern Hemisphere, including Korea. The efficacy of abamectin and emamectin benzoate for preventing the PWD in the field and its effect on the vectors Monochamus alternatus and M. saltuarius (Coleoptera: Cerambycidae) were evaluated. An experimental plot was delimited, of which consists of Japanese red pine (Pinus densiflora) forest in South Korea, and trunk injection trials were made with abamectin and emamectin benzoate. Branches of each tree were collected, and are subsequently subjected to the analysis of residues for both nematicides. Results obtained in this study showed that abamectin and emamectin benzoate showed over 90% mortality at the recommended concentration after 6 days and 8 days, respectively. Consequently, it was found that both insecticides have a higher effect on the susceptibility and persistence of two vectors of PWD, M. alternatus and M. saltuarius feeding on branches of the trees, and its application by trunk injection is confirmed as an option for pine wilt disease management programs in Korea.

Asian Longhorn Beetle

Poland et al. 2006. Anoplophora glabripennis (Motschulsky) (Coleoptera: Cerambycidae), a pest native to China and Korea, was discovered in North America in 1996. Currently, the only reliable strategy available for eradication and control is to cut and chip all infested trees. We evaluated various doses of the systemic insecticides azadirachtin, emamectin benzoate, imidacloprid, and thiacloprid for control of A. glabripennis in naturally infested elms (Ulmus spp.), poplars (Populus spp.), and willows (Salix spp.) in China between 2000 and 2002. Significantly more dead A. glabripennis adults were found beneath elm and poplar trees treated with imidacloprid (in 2000 and 2001) or thiacloprid (in 2001) and beneath willow trees injected with imidacloprid or thiacloprid (in 2002) compared with control trees. In 2000, 4 mo after injection, the density of live A. Glabripennis was significantly reduced in poplar trees treated with imidacloprid (90%) and in willow trees treated with imidacloprid (83%) or emamectin benzoate (71%) compared with controls. In 2001, 9 mo after injection, the density of live A. glabripennis was significantly reduced in poplar (76%) and willow (45%) trees treated with imidacloprid compared with control trees. Similarly, percentage mortality of all life stages of A. glabripennis feeding within trees was signiÞcantly higher on poplar trees 4 mo after injection with imidacloprid (64%) in 2000 and on elms (55%) and poplars (63%) 9 mo after injection with imidacloprid in 2001 compared with control trees. Imidacloprid residue levels in leaves and twigs collected at various times from 1 d to 9 mo after injection ranged from 0.27 to 0.46 ppm. Injecting A. glabripennis-infested trees with imidacloprid can result in significant mortality of adults during maturation feeding on leaves and twigs and of all life stages feeding within infested trees. Imidacloprid is translocated rapidly in infested trees and is persistent at lethal levels for several months. Although, injection with imidacloprid does not provide complete control of A. glabripennis, systemic insecticides may prove useful as part of an integrated eradication or management program.

Wang et al. 2020. The efficacy of tree injected with emamectin benzoate (EB) against the Asian long-horned beetle (ALB) was tested in a heavily infested willow forest in Beijing, China. In a 1.7-ha plot, 240 out of 310 trees were treated with two EB formulations at various rates. After fall application, the larval population decreased by 89% in the following spring and by >99% during the second year detected by monitoring new frass emission from marked holes. Consequently, the number of exit holes of emerging adults decreased to 0 in the second year. Re-infestation occurred in the third year after application. This high efficacy and lasting activity might be contributed to: a) a favorable translocation of EB in trees when injected into the sapwood; b) the high intrinsic activity against ALB larvae with LC50 of 20–30 ppb; and c) a reduced lifespan of ALB adults by over 60% when feeding on twigs of EB-treated trees. On untreated control trees, the larval population decreased during the first winter. In the second year after application, the larval population was wiped out during winter and a re-infestation started from border trees by adults flying in from outside the trial plot. This pattern indicates an eradication of the ALB population in the 1.7-ha plot can be expected 2 yr after EB treatment. The benefit of treating with EB on the surrounding population was observed in both the untreated trees and imidacloprid-treated trees, suggesting that treatment of EB benefits both the treated trees and the surrounding trees in the area.

Ambrosia Beetles

Eatough-Jones et al. 2017. A recently discovered ambrosia beetle with the proposed common name of polyphagous shot hole borer (Euwallacea sp., Coleoptera: Curculionidae: Scolytinae), is reported to attack >200 host tree species in southern California, including many important native and urban landscape trees. This invasive beetle, along with its associated fungi, causes branch dieback and tree mortality in a large variety of tree species including sycamore (Platanus racemosa Nutt.). Due to the severity of the impact of this Euwallacea sp., short-term management tools must include chemical control options for the arboriculture industry and private landowners to protect trees. We examined the effectiveness of insecticides, fungicides, and insecticide–fungicide combinations for controlling continued Euwallacea sp. attacks on previously infested sycamore trees which were monitored for 6 mo after treatment. Pesticide combinations were generally more effective than single pesticide treatments. The combination of a systemic insecticide (emamectin benzoate), a contact insecticide (bifenthrin), and a fungicide (metconazole) provided some level of control when applied on moderate and heavily infested trees. The biological fungicide Bacillus subtilis provided short-term control. There was no difference in the performance of the three triazole fungicides (propiconazole, tebuconazole, and metconazole) included in this study. Although no pesticide combination provided substantial control over time, pesticide treatments may be more effective when trees are treated during early stages of attack by this ambrosia beetle.

Mayorquin et al. 2018. Fusarium Dieback (FD) is a new vascular disease of hardwood trees caused by *Fusarium*spp. and other associated fungal species which are vectored by two recently introduced and highly invasive species of ambrosia beetle (*Euwallacea* spp. *nr. fornicatus*). One of these ambrosia beetles is known as the Polyphagous Shot Hole Borer (PSHB), the other as the Kuroshio Shot Hole Borer (KSHB). Together with the fungi that they vector, this pest disease complex is known as the Shot Hole Borer-Fusarium Dieback (SHB-FD) complex. Mitigation of this pest-disease complex currently relies on tree removal; however, this practice is expensive and impractical given the wide host range and rapid advancement of the beetles throughout hardwoods in southern California. This study reports on the assessment of various pesticides for use in the management of SHB-FD. *In vitro* screening of 13 fungicides revealed that pyraclostrobin, trifloxystrobin, and azoxystrobin to generally have lower

EC_{50} values across all fungal symbionts of PSHB and KSHB; metconazole was found to have lower EC_{50} values for *Fusarium* spp. and *Paracremonium pembeum*. Triadimefon and fluxapyroxad were not capable of inhibiting any fungal symbiont at the concentrations tested. A one-year field study showed that two insecticides, emamectin benzoate alone and in combination with propiconazole, and bifenthrin could significantly reduce SHB attacks. Two injected fungicides (metconazole and a combination of carbendazim and debacarb) and one spray fungicide (tebuconazole) could also significantly reduce SHB attacks. Bioassays designed to assess fungicide retention one year post application revealed six out of the seven fungicides exhibited some level of inhibition *in vitro* and all thiabendazole-treated trees sampled exhibiting inhibition. This study has identified several pesticides which can be implemented as part of an IPM strategy to reduce SHB infestation in low- to moderately- infested landscape California sycamore trees and potentially other landscape trees currently affected by SHB-FD.

Grosman et al. 2019.
The polyphagous shot hole borer (*Euwallacea* nr. *fornicatus*, Coleoptera: Curculionidae: Scolytinae), an exotic and invasive ambrosia beetle, was recently found attacking a number of tree species in Los Angeles, Orange, Riverside, and San Diego Counties in southern California. Their colonization and subsequent inoculation of a suite of symbiotic fungi that cause Fusarium Dieback, has resulted in extensive mortality of some tree species, including, California sycamore (*Platanus racemose* Nutt.). There are no sustainable control options for polyphagous shot hole borer other than maintaining tree vigor and removal of severely infested host material. The effectiveness of therapeutic treatments of an injected systemic insecticide containing emamectin benzoate (EB) alone and in combination with a systemic fungicide, propiconazole (P), was evaluated over a 4-yr period for maintaining the health of individual sycamore trees infested by polyphagous shot hole borer. All treatments containing EB reduced levels of polyphagous shot hole borer colonization and associated sap flow at attack sites compared to untreated controls. A second trial evaluated preventative treatments of EB and P alone or combined to protect individual sycamore from colonization by polyphagous shot hole borer. After 45 mo posttreatment, all treatments significantly reduced polyphagous shot hole borer attack levels and successful attacks compared to untreated controls (EB + P > EB alone > P alone). We concluded that EB alone or combined with P are acceptable therapeutic and preventative treatments for management of polyphagous shot hole borer in California sycamore in southern California.

Byrne et al. 2020. The polyphagous shot hole borer (PSHB) and the Kuroshio shot hole borer (KSHB) are newly invasive ambrosia beetles in California. They are vectors of the plant pathogen Fusarium euwallaceae (S. Freeman, Z. Mendel, T. Aoki, K. O’ Donnell), the causal agent of Fusarium dieback in a broad host range that includes commercial avocados, landscape trees, and native tree species in urban and wildland environments. Management of these beetles using contact insecticides is challenging because the beetles spend little time outside their hosts. Trunk injection of systemic insecticides has been proposed as an alternative to contact treatments because insecticides can more effectively target the vascular tissues where the beetles establish their colonies. In this study, several field trials were conducted to evaluate the efficacy of trunk injections of the systemic insecticide emamectin benzoate in avocado trees. The uptake and persistence of emamectin benzoate were determined by quantifying residues in wood cores sampled at various heights within the trees where beetles would likely target. In conjunction with the field trials, a series of bioassays was conducted with a KSHB colony using an avocado-based artificial diet infused with the insecticide. The bioassays showed a dose-dependent effect of emamectin benzoate on the survival and development of the beetle in diet. We derived a tentative working threshold of 300 ng/g insecticide from the bioassay data that we subsequently used as a guide in evaluating the efficacy of the trunk injections. Emamectin benzoate established quickly within trees at the threshold concentration in the areas most vulnerable to attack and colonization by KSHB. Injection of the insecticide in a more dilute form promoted both faster uptake and more rapid establishment of effective concentrations than the undiluted form, thereby providing potential options in how the material is injected based on the levels of infestation of groves.

Wheeler 2020. Chapter 3 Abstract. The black stem borer (BSB), (Coleoptera: Curculionidae: Scolytinae) Xylosandrus germanus (Blandford), is an ambrosia beetle that has recently been found attacking seemingly healthy orchard trees in the United States. BSB are attracted to ethanol produced by stressed trees, which can be the case when topworking (grafting a new cultivar onto established trees). The objective of this study is to evaluate the efficacy of two insecticides, emamectin benzoate and azadirachtin, and injection timing fall and spring, on their ability to control BSB in apple trees with simulated topworking and ethanol injection as an attractant. To induce BSB colonization, trees were injected with ethanol using a previously reported method (Reding et. al. 2013). Our study shows evidence that both emamectin benzoate and azadirachtin injections can reduce BSB infestations. Timing of the injection influences the outcome in terms of protecting apple trees from BSB, with spring injected azadirachtin being more effective than fall injections. Emamectin benzoate likely affects BSB adults directly by reducing successful attacks/entries, while and azadirachtin appears to reduce BSB attacks and limits gallery success.

Red Palm Weevil

Habib et al. 2017. The red palm weevil (RPW), Rhynchophorus ferrugineus Oliv, (RPW) (Curculionidae: Coleoptera), is an economically important, tissue - chewing pest of date palm in many parts of the world. The invasion of Red palm weevil (Rhynchophorus ferrugineus) to Tunisian ornamental palms was detected in 2011. It has begun a real threat to date palms Phoenix dactylifera. Chemical control becomes an essential mean to recover infested palm trees. In this study, we evaluated several chemical products: Spinetoram + sulfoxaflor, Imidacloprid, Thiametoxam, XDE-607 and Emamectin benzoate against RPW at different localities in Tunis. Palms were selected randomly based on visual symptoms. Three methods of chemical delivery were used: powdering, irrigation and injection. This study revealed that the use of Imidacloprid 5% (Suxon mini) by irrigation with the dose of 500 g/Palm give better results in protecting the palm. Emamectine benzoate shows significant efficacy using the product: Pro-act while applying a dose of 100 ml/palm.

Ali-Bob. 2019. Adhering to sustainable date farming practices in Al-Mohamadia farm in Al-Kharj region of Saudi Arabia has resulted in increased date fruits production by 2 fold in a 3 year time span from mature date palm trees grown on sandy soils and employing modern irrigation systems. The quality of date fruits has improved dramatically. The irrigation regime adopted resulted in enhanced water use efficiency and had a positive impact on date yield and fruit quality improvement. Among 20 date palm cultivars grown in Al- Mohamadia farm, 'Sagae' cultivar and male trees from different age groups were found to be more susceptible to RPW infestations. On-farm management practices of date palm pests particularly the notorious red palm weevil Rhynchophorus ferrugineus (Olivier) is presented. Control efforts against the RPW focused on the use of a blend of tactics including visual inspection and pheromone trapping, prevention and suppression through field sanitation, cultural practices, mechanical methods, eradication of severely infested palm trees, and chemical injection of Emamectin benzoate insecticide, which has shown good and long lasting effect. Steinernema carpocapsae (Weiser) nematodes alone or in combination with a local strain of Beauveria bassiana Bals. using trunk injections to control RPW showed mixed results. Some of red palm weevil management challenges, from a farmer's perspective were discussed.

Ferry et al. 2019. To control successfully the RPW, it is essential to implement a programme conceived and applied to obtain the pest decline as fast as possible. Such objective is easy to reach when RPW is not yet too widespread and abundant. Unfortunately, in most of the infested countries, it is not at all the case anymore. The challenge now is to propose strategies and technical solutions sociologically, economically and environmentally sustainable. In a territory of five grouped municipalities in the French Riviera, has been applied since 2016 a strategy elaborated by the Phoenix Research Station (PRS) and implemented under the supervision of the inter-municipality authority in charge of this territory (CAVEM). Although the area is heavily infested by the RPW, the objective is to demonstrate that it is possible in few years to stop the palms hecatomb and to obtain a rapid decline of the RPW ("palms" refer generally in this paper to Phoenix canariensis that is by far the main target and main incubator of the RPW). The main challenge, here like everywhere in the infested countries, is to get the palm owners acceptation to the proposed strategy and their collaboration. One essential point that has contributed greatly to face this challenge has been the existence of a very active association of private palms owners (Propalmes 83). To obtain the public and private palms owners collaboration it was fundamental that the proposed strategy be conceived taking into consideration the capacities and economic means of these actors.

Therefore, the PRS proposed that CAVEM organize the activities to facilitate as much as possible their grouping to reduce the costs to a minimum. Among the different activities, the PRS proposed that preventive treatment based on an injection technique, because of its much lower cost and its great safety compared with other techniques, be the core of the action plan. This proposal is based on the results of a theoretical analysis presented here on the evolution of the number of new yearly infested palms. This analysis allowed establishing, with a probability of 95% for the confidence intervals, the number of new yearly infested palms based on the percentage of treated palms. The field results available for the CAVEM territory for 2016 and partially for 2017, confirm the validity of this analysis. These results showed that, if as planned, the objective of 75% of injected palms on the total number of palms is reached, the number of infested palms will decrease very quickly in 3-4 years, leading to a considerable decline of the native population of RPW and of the number and size of the infested spots, that in addition will be perfectly located. Once this result will be reached, it will become quite feasible to treat all the palms, even with biological agents, in the infested spots and so finally to eradicate the RPW. Of course, the same strategy has to be followed rapidly by the surrounding territories, otherwise such result would be vain as re-infestation will occur.

Mashal and Obiedat. 2019. Red palm weevil is the most injurious pest on dates globally. The purpose of this field trial was to evaluate the preventative & curative effect of the micro emulsifier insecticide Emamectin Benzoate in two formulations: Revive®4 % and ReviveII®9.5 % against the red palm weevil for one year. A completely randomized block design was applied on 36 mid to high infested trees with 4%,9.5% and the control. One single direct micro-injection was applied at the base of the trunk using Syngenta TMI 4.1 device, under low pressure of 2 bar. Biweekly monitoring for Red palm weevil external symptoms of treated trees. Treated Trees were cut and dissected after: 3, 6,&12 months from injection date collecting all RPW individuals from the outside and the inside of the tree trunk, it was found that RPW mean mortality% cause by Revive was 88.1 and 98.8for Revi-veII®9.5%. descriptive symptom data and RPW mortality% inside the trunks showed that trees injected byRevive®4% and ReviveII®9.5% were cured 100% from RPW for one year by killing renewable infestation. LOQ of Emamectin benzoate were quantified in fruit and compared with MRL level after 60 and 100 days. Results indicated that no residues of ReviveII® in fruit samples after 60days.

Chihaoui-Meridja et al. 2020. The control of the invasive red palm weevil (RPW) Rhynchophorus ferrugineus (Olivier, 1790) is a challenge. This pest has a cryptic behavior, as it achieves most of its life cycle within host tissues, where larval instars are endophytic and are out of reach from insecticides applied as cover sprays. In order to increase the efficacy of chemical control, stem injection technique, known also as endotherapy, has been implemented and recommended as an alternative approach, which requires the use of highly systemic and persistent insecticides. In this paper, we report the results of endotherapy essays carried out on ornamental palm trees, Phoenix canariensis Chabaud in Carthage, Tunis (Tunisia) and Catania, Sicily (Italy), between 2015 and 2018, using thiamethoxam, emamectin benzoate and imidacloprid. The mobility, persistence and efficacy of these insecticides were evaluated. We found that emamectin benzoate is more systemic and persistent (up to 5 months) in palm tissues than thiamethoxam and imidacloprid. Maximum residues of emamectin benzoate (1.87 mg\kg) were detected in leaf base samples, 10 days after its injection. Residues of imidacloprid were detected 10 days after application (0.194 mg\kg), with a maximum (0.277 mg\kg) registered 2 months after its injection with a persistence period up to 3 months. Residues of thiamethoxam were detected (0.123 mg\kg) only once, 10 days after application. Then values were below the limit of detection (0.1 mg\kg). Field essays with selected insecticides applied as preventive and curative endotherapy treatments showed that emamectin benzoate is able to protect palm trees from RPW infestation up to 9 months.

Yellow Spotted Pine Weevil

Hong et al. 2016. In order to investigate effective prevention and control methods against Pissodes nitidus, seven bioinsecticides, including the 3% high penetrable fenoxycarb EC,0.5% emamectin benzoate EC,0.5% imidacloprid EC,4.5% beta-cypermethrin EC,2% abamectin EC,2% acetamiprid EC and 0.3% soluble matrine, were tested both in the lab using the hydroponic the tips of red pine Pinus koraiensis and in the field control bioassays via red pine trunk injections. The high penetrable fenoxycarb at 3 500×, emamectin benzoate at 3 500× or imidacloprid at 4 000× resulted in a corrected mortality rate of the pine weevils being above 70%, showing no significant dosage effects (p 0.05) In the field bioassays with one-time of trunk injection, fenoxycarb (at three concentrations,5×,10× and 15×) emamectin benzoate (at 5×) and imidacloprid (at 5×) all achieved 80% corrected pine weevil mortality rates. The beta-cypermethrin, abamectin and acetamiprid were field tested in a two-year control trial (applied once a year) against P.nitidus. All the treatments except beta-cypermethrin at 15× showed 60% corrected mortality rates, which were significantly different from the control group (p 0.01); whereas abamectin and acetamiprid at 5× and 10× had 80% corrected mortality rates in the first year. The control efficacy was even higher in the second year with 90% pine weevil corrected mortality rates. The trunk injection applications of these insecticides in the two consecutive years resulted in a 4% infestation rate by the pine weevils on the Pinus koraiensis trees, and 84.9%-88.9% reductions in the damage rates. Therefore, high penetrable fenoxycarb at 5×,10 ×, and 15 ×, emamectin benzoate at 5×, imidacloprid at 5×, abamectin and acetamiprid at 5× and 10× can be used to effectively control P. nitidus in pine forests with trunk injections.

Gall wasp

Doccola et al. 2009. The erythrina gall wasp (EGW), believed native to Africa, is a recently described species and now serious invasive pest of *Erythrina* (coral trees) in tropical and subtropical locales. *Erythrina* are favored ornamental and landscape trees, as well as native members of threatened ecosystems. The EGW is a tiny, highly mobile, highly invasive wasp that deforms (galls) host trees causing severe defoliation and tree death. The first detection of EGW in the United States was in O´ahu, Hawai´i in April 2005. It quickly spread through the Hawai`ian island chain (U.S.) killing ornamental and native *Erythrina* in as little as two years. At risk are endemic populations of *Erythrina* as well as ornamental landscape species in the same genus, the latter of which have already been killed and removed from O´ahu at a cost of more than USD $1 million. Because EGW are so small and spread so quickly, host injury is usually detected before adult wasps are observed, making prophylactic treatments less likely than therapeutic ones. This study evaluates two stem-injected insecticides, imidacloprid (IMA-jet®) and emamectin benzoate, delivered through Arborjet Tree I.V.® equipment, for their ability to affect *E. sandwicensis* (*wiliwili*) canopy demise under severe EGW exposure. IMA-jet, applied at a rate of 0.16 g AI/cm basal diameter (0.4 g AI/in. dia.), was the only effective treatment for maintaining canopy condition of *wiliwili* trees. Emamectin benzoate, applied at a rate of ~0.1 g AI/cm basal diameter (~0.25 g AI/in. dia.), was not effective in this application, although it was intermediate in effect between IMA-jet and untreated trees. The relatively high concentrations of imidacloprid in leaves, and its durability for at least 13 months in native *wiliwili* growing on a natural, dryland site, suggest that treatment applications against EGW can impact canopy recovery even under suboptimal site and tree conditions.

Bhandari and Cheng 2016. Chinese banyan, *Ficus microcarpa* L. f. (Rosales: Moraceae), is a popular landscape tree in many tropical regions of the world. In Hawaii, these trees are severely infested by 2 host-specific insect species in the family Agaonidae (Hymenoptera: Chalcidoidea): the Chinese banyan leaf gall wasp, *Josephiella microcarpae* Beardsley & Rasplus, and the stem gall wasp *Josephiella* sp. (currently being described). Infestations by these insects result in gall formation on young leaves and shoots, premature leaf drop, new shoot death, poor tree health, and eventually death of the tree. We evaluated the efficacy and persistence of 2 systemic insecticides, imidacloprid and emamectin benzoate, with or without phosphorous acid amendment, delivered through trunk injection to control these 2 wasp species in Honolulu, Hawaii. Although both systemic insecticides had some effect against leaf gall wasps for up to 18 mo post treatment, only emamectin benzoate persisted against stem gall wasps for up to 14 mo post treatment. Phosphorous acid amendment did not provide any benefits for Chinese banyans to mitigate wasp infestations. In conclusion, trunk injection of emamectin benzoate could be a feasible management strategy to control stem and leaf gall wasps on Chinese banyans in Hawaii.

Davis and Elkinton 2018. Black oak, *Quercus velutina* Lamarck, is the dominant deciduous tree on Cape Cod, Nantucket, and Martha's Vineyard, Massachusetts, and in recent years it has experienced widespread mortality and severe canopy loss due to infestations of a stem gall wasp, *Zapatella davisae* Buffington and Melika (Hymenoptera: Cynipidae). A single application of systemic insecticides emamectin benzoate and imidacloprid was found to reduce or prevent further accumulation of *Z. davisae* damage on infested black oak during a 1-yr trial.

Kellar 2018. Landscape plants provide beneficial effects such as increasing air quality, promoting mental health, and improving aesthetics. The need to have effective control methods for pests is important to maintain these benefits. This study investigated manamgent tactics for Oryctes rhinoceros, Josephiella spp., and Paratachardina pseudolobata, pests that attack important landscape plants in Hawaiʻi including coconut palm, Chinese banyan and weeping banyan. Various systemic insecticides were tested on O. rhinoceros in the laboratory. The highest percent of affected beetles were observed in acepahte and imidacloprid treatments. Irrigation did not impose negative impacts on insecticide efficacy and followed similar trends to insecticide treatmetns alone against banyan pests. A comparative study on different systemic application methods on controlling P. pseudolobata found that both injection and soil drench were effective at suppressing P. paratachardina.

Lobbate 2020. This thesis, presented in three chapters, focused on evaluating the phenology, density, distribution and parasitism of Asian chestnut gall wasp (ACGW) (Dryocosmus kuriphilus Yasumatsu), as well as the level and persistence of two systemic insecticides in chestnut orchards in southwest Michigan. In chapter one, phenology, density and parasitism of ACGW were monitored in up to nine Michigan chestnut orchards from 2017 to 2019. Phenology was related to cumulative degrees days which provided precise timing recommendations for scouting activities or applying cover spray insecticide applications that target the adult wasp. After cold winter temperatures in 2019, the ACGW population was significantly reduced at all monitored locations. The parasitoid of ACGW is established in Michigan and naturally spreading with ACGW.

In chapter two, spread and distribution of ACGW was monitored at both the local and regional scale. Diffusion of ACGW through individual orchards progressed quickly and annual spread across Michigan showed large jump distances. Cold winter temperatures in 2019 halted ACGW spread across the state, suggesting ACGW may face a climatic barrier.

In chapter three, imidacloprid and emamectin benzoate residues were assessed in chestnut foliage, catkins and nuts. Both insecticides were occasionally found in catkin samples and rarely found in nut samples. Imidacloprid foliage residues were generally high, but variable. Emamectin benzoate foliage residues varied considerably between two treatment years.

Birch Leafminer

Fettig et al. 2011. Extensive defoliation of ornamental birch by the Ambermarked birch leafminer, *Profenusa thomsoni* (Konow) (Hymenoptera: Tenthredinidae) in Alaska requires that suitable control measures be evaluated and developed. A study was conducted in Fairbanks, AK (64.85 °N, 147.73 °W, 92.5 m elevation) in 2010 in cooperation with the City of Fairbanks, AK. Two treatments were applied:(1) emamectin benzoate (TREE-age®) injected undiluted at 1.97 ml/cm in diameter at breast height (dbh, 1.37 min height) into the tree bole with the QUIK-jet Microinjection system (Arborjet Inc., Woburn, MA), and (2) an untreated control. Each treatment was randomly assigned to 15 paper birch, *Betula papyrifera* Marsh., trees (n = 30). All experimental trees (treated and untreated) were evaluated for levels of leaf mining (whole canopy) on 29 July 2010. Visual estimates of the amount of leaf mining were conducted by 3 independent, experienced observers without knowledge of treatment. Individual estimates of the percent leaf mining that occurred on each tree ranged from 0% (19 of 87 estimates by all three observers; TREE-ii.ge®-treated trees only) to 40% (2 of 87 estimates; untreated control only). Estimates provided for each tree by the 3 observers were within five percentage points 75.9% of the time (22 of 29 trees). TREE-age® significantly reduced crown damage (percent leaf mining) compared with the untreated control ($t = 7.366$, $df = 27$, $P < 0.001$).

Fettig et al. 2013. Ambermarked birch leafminer, Profenusa thomsoni (Konow) (Hymenoptera: Tenthredinidae), is an exotic, invasive pest of urban and wildland birch, Betula spp., first reported in the eastern United States in the early 1900s. It has since spread throughout the northern United States and Canada. Profenusa thomsoni was detected in Alaska near Anchorage in the mid to late 1990s. By 2003, > 12,800 ha of birch were defoliated in the Anchorage Bowl. Aerial detection surveys of the Anchorage Bowl and surrounding areas in 2004 reported the outbreak had expanded to >55,000 ha. Since then, an extensive survey conducted by the USDA Forest Service to determine the extent of exotic leaf mining sawflies in Alaska reported P. thomsoni to be present in >20% of the area surveyed, with the largest populations in South-central Alaska and portions of Interior Alaska. Severe infestations of P. thomsoni result in extensive chlorosis of foliage and premature leaf fall, but generally do not result in tree mortality. Repeated infestations can weaken trees, perhaps increasing their susceptibility to other forest pests. In 2010, we initiated a study in Fairbanks, AK (64.85 °N, 147.73 ow, 92.5 m elevation) to determine the efficacy of emamectin benzoate (TREE-age®) for reducing mining by P. thomsoni on paper birch, Betula papyrifera Marsh. Fettig et al. (2011 , J. Entomol. Sci. 46: 339 - 341) provide a complete description of methods. In brief, TREE-age® was injected undiluted at 1.97 ml/cm in diameter at breast height (dbh, 1.37 m in height) into the tree bole on 7 May 2010 (14°C, sunny) with the QUIK-jet Microinjection system (Arborjet Inc.). Trees (arcsine square root [% leaf mining]) transformations were used when data deviated significantly from a normal distribution. t-Tests were performed on the percent leaf mining that occurred using alpha= 0.05. We observed no external symptoms of phytotoxicity associated with TREE-age®. However, bleeding occurred around some injection ports (Fig. 1), which might be considered unsightly and therefore undesirable in some environments. This was not observed in 2010. Estimates of the percent leaf mining that occurred on each tree ranged from 0% (11 of 15 TREE-age®-treated trees) to 12% (untreated control). Whereas populations of P. thomsoni declined in 2011 compared with 2010 within the study area, TREE-age®-treated trees had significantly less crown damage (percent leaf mining) compared with the untreated control ($t = 8.649$, $df= 27$, $P < 0.001$; mean ± SEM = 0.3 ± 0.1 and 4.9 ± 0.8%, respectively) in 2011 . Based on these results, we conclude that a single injection of TREE-age® provides two field seasons of protection, and holds promise for control of P. thomsoni on individual birch trees in Interior Alaska.

Diamondback moth

Leibee et al. 1995. Emamectin benzoate (MK-244; Merck & Co., Rahway, NJ), used alone and alternated with *Bacillus thuringiensis* (Berliner) ssp. aizawai (Bta), Bta alone, and *B. thuringiensis* ssp. kurstaki (Btk) alone, were evaluated for control of diamondback moth, *Plutella xylostella* (L.), in head cabbage at three locations in Florida. Additional treatments unique to each location were also evaluated. Emamectin benzoate alone, Bta alone, emamectin benzoate alternated with Bta, and mevinphos were shown to be effective. Btk was less efficacious than Bta at two locations.

Eastern Tent Caterpillar

Potter et al. 2005. An equine disease now known as mare reproductive loss syndrome (MRLS) struck the Ohio Valley in 2001-2002 causing thousands of foal abortions and enormous economic loss. Evidence that pregnant mares' exposure to Eastern tent caterpillars *Malacosoma americanum* (F) induces MRLS created an urgent call for control measures suitable for use on horse farms. We surveyed egg mass distribution and monitored emergence in wild cherry trees, and evaluated reduced-risk treatment strategies including foliage sprays, trunk injections, winter egg mass treatments and barrier sprays to intercept larvae entering pastures. Egg masses were concentrated in the lower canopy, on exposed sides of trees. Larval emergence began in mid-March. Emergence was prolonged (3-4 weeks) in 2002, a typically cool spring, but more synchronized in warmer 2003. Winter treatment of egg masses with bifenthrin or permethrin in a penetrating solvent prevented emergence, but 3% horticultural oil was ineffective for that purpose. Insecticidal soap or oil sprayed directly on neonates gave relatively poor control. Bifenthrin and spinosad were effective as foliage sprays against all instars, their field-weathered residues active for at least 7 days. *Bacillus thuringiensis* Berliner var *kurstaki* controlled neonates within 3 days but was less active against late instars, with shorter residual action than bifenthrin or spinosad. Larvae did not avoid insecticide-treated leaves. Trunk microinjection of cherry trees with dicrotophos was effective against all instars, whereas microinjection with milbemectin or abamectin gave poor or inconsistent control. Trunk injection with emamectin benzoate also was effective. Dry permethrin residues controlled late instars crawling in pasture grass for at least 7 days. Factors complicating *M americanum* management on horse farms are discussed.

Western spruce budworm

Fidgen et al. 2013. Stem injections of insecticides are generally regarded as a safer and a more environmentally friendly option (compared to foliar sprays) for protecting high-value trees against insects in sensitive areas or near homes. We carried out athree year study to determine the efficacy of trunk injections of emamectin benzoate for protection of foliage of three common host species attacked by the western spruce budworm, *Choristoneura occidentolis* Freeman (Lepidoptera: Tortricidae). Defoliation by *C. occidentolis* was significantly reduced by nearly half over a3-year period on treated compared to control grand fir, Douglas-fir, and alpine fir. Reduction of defoliation was comparable to standards used for aerial spraying (e.g., 50%) of conifer feeding budworms in Canada.

Ponderosa pine cone beetle

Cook et al. 2013. Conifer seed orchards are used to produce high-quality seed from selected genotypes of important tree species. Two of the primary insect pests in pine seed orchards in Idaho are the ponderosa pine cone beetle, *Conophthorus ponderosae* Hopkins (Coleoptera: Curculionidae: Scolytinae), and coneworms in the genus *Dioryctria* (Lepidoptera: Pyralidae). We evaluated the use of two bole-injected systemic insecticides (emamectin benzoate applied at a rate of 0.07 ml active ingredient [AI]/cm dbh and imidacloprid applied at a rate of 0.1 ml AI/cm dbh) applied at two different times of the year (fall versus spring) for management of the insects in a ponderosa pine, *Pinus ponderosa* (Laws), orchard in northern Idaho. Bole injection of emamectin benzoate significantly reduced the percentage of cones on trees that were killed by the beetle or infested with coneworm. Both fall and spring injection periods were equally effective. There was also a lower percentage of the emamectin benzoate-treated trees that produced brood beetles. There were no differences among treatments in the percentage of brood from successfully attacked cones that survived a 7-month cold period (3-4° C) or that survived for 10 days after removal from cones after the cold period. Therefore, although trees treated with a bole injection of emamectin benzoate produced a significantly higher percentage of healthy cones and fewer brood beetles, brood survival in emamectin benzoate-treated cones that were successfully attacked did not differ from brood survival in cones from trees that were not treated. Further, in a laboratory test, there was no discrimination among treatments in their acceptability to attacking beetles the spring after the fall treatment period.

Douglas-fir tussock moth and Fir coneworm

Cook et al. 2013. One management technique that has been receiving attention for use against various forest insects are applications of bole-injected systemic insecticides. We evaluated the use of two such insecticides (emamectin benzoate applied at a rate of 0.07 ml AI/cm dbh and imidacloprid applied at a rate of 0.1 ml active ingredient (AI)/cm dbh) applied at two different times of the year (fall versus spring) for management of Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough) (Lepidoptera: Lymantriidae) and the fir coneworm, *Dyorictria abietivorella* (Grote) (Lepidoptera: Pyralidae), insects that cause damage to Douglas-fir foliage and cones, respectively. Spring and fall bole injection of emamectin benzoate significantly reduced survival of Douglas-fir tussock moth caterpillars fed foliage from treated trees and reduced fir coneworm infestations on treated trees compared with untreated controls. Both fall and spring injection periods were equally effective. Douglas-fir tussock moth caterpillar survival was also significantly lowered when they fed on foliage from trees that had received spring injections of imidacloprid. At the dose tested, the fall treatment of imidacloprid did not reduce Douglas-fir tussock moth survival and neither fall or spring treatments significantly reduced infestation levels of fir coneworm. The results suggest that bole-injection treatments of emamectin benzoate can be effective in minimizing insect damage when applied the year prior to foliar feeding or harvest of the cone crop. Imidacloprid appears to be effective only for foliage protection and only when applied during the spring of the year that protection is needed.

Nettle Caterpillar

Huang et al. 2016. The screening of suitable insecticides is a key factor in successfully applying trunk injection technology to ornamental plants. In this study, six chemical pesticides were selected and injected into the trunks of Osmanthus fragrans to control the nettle caterpillar, Latoia lepida (Lepidoptera: Limacodidae), using a no-pressure injection system. The absorption rate of the insecticides, the leaf loss due to insect damage, and the mortality and frass amount of L. lepida larvae were evaluated after 77 and 429 days. The results showed that 4% imidacloprid + carbosulfan and 21% abamectin + imidacloprid + omethoate had the fastest conductivity and were completely absorbed into the trunkswithin14 days; however, the efficiencies of these insecticides in controlling L. lepidawere extremely low. Additionally, the treatment 10% emamectin benzoate + clothianidin and 2.5% emamectin benzoate was almost completely absorbed within 30 days and exhibited a longer duration of insecticide efficiency (>80% mortality) in the upper and lower leaves of the canopy. Treatment with these insecticides also resulted in significantly lower leaf loss and frass amounts. We conclude that emamectin benzoate and emamectin benzoate + clothianidin have a rapid uptake into O. fragrans, and are effective as insecticides over long durations. Hence, they may be a suitable control option for L. lepida in O. fragrans plants.

Box Tree Moth

Bras et al. 2017. Revive®, an emamectine benzoate formulation, is used as tree micro injection into the trunk of trees to limit, over several years, the damage associated with multiple pests. Since the invasion of the box tree moth in Europe, treatment of ornamental box trees using current methods (*i.e.*, *Btk*) must be repeated several times a year to effectively reduce defoliations and prevent tree mortality. To assess the relevance of Revive® injections in ornamental box trees, three distinct volumes of the product have been injected in trees of 3±1 cm diameter, and their survival was then compared with control trees with either no injection or water injection. The effectiveness of Revive® against the pest was tested by checking mortality of young neonate larvae after *ca.* eight days feeding on branches from each condition. Mortality reached 46.1% to 62.5% depending on the injected volume of Revive®, *versus* less than 10% in control conditions. However, these positive results are still preliminary and do not allow determining the minimal effective dose yet. This dose must be determined depending on the size of target trees, the cinetics of the insecticide's effect on larvae, and its remanence in injected trees.

Lin et al. 2018. Spodoptera litura is a widespread polyphagous insect pest that can develop resistance and cross-resistance to insecticides, making it difficult to control. Insecticide exposure has previously been linked with induction of specific olfactory-related proteins, including some chemosensory proteins (CSPs) and odorant-binding proteins (OPBs), which may disrupt detection of environmental factors and reduce fitness. However, functional evidence supporting insecticide and OBPs/CSPs mediation remains unknown. Here we fed male S. litura moths with sucrose water containing one of three insecticides, chlorpyrifos, emamectin benzoate or fipronil, and used real-time quantitative polymerase chain reaction and RNAi to investigate OBPs and CSPs expression and their correlations with survival. Chlorpyrifos and emamectin benzoate increased expression of 78% of OBPs, plus 63 and 56% of CSP genes, respectively, indicating a major impact on these gene families. RNAi knockdown of SlituCSP18, followed by feeding with chlorpyrifos or fipronil, decreased survival rates of male moths significantly compared with controls. Survival rate also decreased significantly with the downregulation of SlituOBP9 followed by feeding with chlorpyrifos. Thus, although these three insecticides had different effects on OBP and CSP gene expression, we hypothesize that SlituOBPs and SlituCSPs might mediate their effects by increasing their expression levels to improve survival. Moreover, the differential response of S. litura male moths to the three insecticides indicated the potential specificity of chlorpyrifos affect SlituCSP18 and SlituOBP9 expression.

Leaf rollers, Oriental fruit moth, leafhoppers

Van Woerkom et al. 2014. Field studies, laboratory bioassays, and residue profile analysis were used to determine the seasonal effectiveness of trunk injected pesticides against key apple disease and insect pests. Insecticides formulated for trunk injection, imidacloprid (Ima-jet™), rynaxypyr (XCL-r8™), and emamectin benzoate (TREE-age™) were injected into semi-dwarf Empire apple trees Malus domestica (Borkhausen) and evaluated for a wide range of insect pests. The fungicide compounds, propiconazole (Alamo®), phosphites (Phospho-jet), and penthiopyrad (Fontelis™), were injected into semi-dwarf MacIntosh (RedMax) apple trees M.domestica (Borkhausen) for control of apple scab fungus, Venturia inaequalis (Cooke). After the original single injection, imidacloprid was highly effective in controlling piercing and sucking pests such as the potato leafhopper, Empoasca fabae (Harris), and aphids (Aphididae), and emamectin benzoate was highly effective in controlling the oblique banded leaf roller, Choristoneura rosaceana (Harris), and potato leafhopper, E. fabae (Harris), and rynaxypyr was highly effective in controlling Oriental fruit moth, Grapholita molesta (Busck), and leafrollers all for two growing seasons. The residue profiles for insecticides showed that vascular delivery was predominantly to foliage, with fruit residues far below the EPA maximum residue limits (MRLs), and low to no residues detected in apple flower parts. Phosphites provided significant levels of apple scab control over two seasons for the single injection after the foliage recovered from the phytotoxicity damage in the first season. Propiconazole and penthiopyrad showed limited effectiveness for the control of apple scab. The residue profiles for fungicides showed phosphites to be delivered primarily to foliage, but inconsistent foliar residue levels for the other two compounds suggests possible incompatibilities may be responsible for poor product performance. These incompatibilities may include molecular or chemical properties. For example, on the molecular level such as the molecular size too large to fit through vascular tissue and chemical properties such as the viscosity of the compound resulting in poor translocation or pH.

Wise et al. 2014. Trunk injection technology represents an alternative delivery system to provide crop protection for horticultural crops of commercial and smallholder farmers in the developed and developing world. Field studies, laboratory bioassays, and residue profile analysis were used to determine the seasonal effectiveness of trunk injected insecticides against key apple insect pests. Insecticides formulated for trunk injection, imidacloprid, rynaxypyr, and emamectin benzoate were injected into semi dwarf Empire apple trees and evaluated for a wide range of insect pests. Imidacloprid controlled piercing and sucking pests, and emamectin benzoate controlled leaf rollers, Oriental fruit moth, and leafhoppers. The residue profiles for insecticides showed that vascular delivery was predominantly to foliage, with fruit residues far below the EPA maximum residue limits. These results suggest that trunk injection is a promising delivering system for plant protection materials for control of foliar pests, while minimizing impacts on natural enemies, eliminating spray drift, and reducing the pesticide load in the agro-ecosystem. For smallholder farmers this low-capital investment technology has the potential to significantly reduce the human health risks associated with pesticide use, while protecting high value horticultural crops from pests.

Coslor 2017. In conventional apple orchards, insect pests are managed with insecticides delivered to the canopy using airblast sprayers, which provide good canopy coverage. However, spraying results in significant product loss: as little as 26% is estimated to reach the tree canopy due to spray drift and less than 0.1% of insecticide ends up reaching the target pest. The remainder is lost to the environment with potential to harm people or non-target organisms. Trunk injection is a discriminating pesticide delivery system which reduces insecticide inputs and environmental exposure by delivering chemicals directly to the vascular system. It is commonly used to deliver pesticides in ornamental and shade trees. Recent work with trunk injection in apple orchards has shown promise, but more research must be done to determine efficacy and safety in tree fruit crops. In the following studies, we injected emamectin benzoate, imidacloprid, dinotefuran, spinosad, chlorantraniliprole, and abamectin into apple trees to expand the list of insecticides compatible with trunk injection. Nectar and pollen were sampled from trees to compare the effects of injection timing on insecticide concentration in floral resources. In addition, two fundamental injection tool types were compared: drill-based and needle-based. To test compatibility of combined insect and disease management, an insecticide and a fungicide were injected simultaneously. Finally, low-volume injections were performed on nursery apple trees, which normally require high pesticide inputs and do not produce fruit for several years. Emamectin benzoate, chlorantraniliprole and abamectin resulted in moderate to high mortality and reduced feeding in Choristoneura rosaceana bioassays using leaves sampled from trunk injected apple trees. Neonicotinoids reduced Empoasca fabae density in field evaluations, and also showed activity on C. rosaceana at higher concentrations. Spinosad was not welltransported within the apple tree vascular system. Numbers of E. fabae nymphs were lower on trees injected with imidacloprid using a drill-based tool compared with untreated trees in all years, despite a trend of initially higher foliar concentrations with the needle-based tool. This demonstrated that delivery method is an important factor in effective trunk injection based apple management. We found that when an insecticide and a fungicide are injected, they can interact dynamically within the vascular system of a tree. Injections of emamectin benzoate followed by phosphorous acid into the same set of injection ports resulted in higher mortality of C. rosaceana larvae and lower incidence of apple scab compared with untreated trees. This has important implications for expanding the utility of trunk injection for fruit tree management. Nursery tree injections were most effective when emamectin benzoate was injected into the trunk versus the taproot. A rate equivalent to 1/8 the rate used for mature tree injection reduced insect pests more than a 1/80 rate. The higher rate of emamectin benzoate was also persistent in the following year. Imidacloprid and emamectin benzoate were injected in the spring and fall, and nectar and pollen were sampled the following spring. Imidacloprid was not detected in nectar or pollen when injected in the previous spring. Conversely, emamectin benzoate was detected when injected in the previous spring, but was not detected in nectar or pollen when injected in the fall. This study expanded the list of insecticides compatible with trunk injection, demonstrated novel uses of trunk injection to reduce insect pests in apple trees, and introduced possible ways to mitigate accumulation of insecticides in nectar and pollen.

Coslor et al. 2019. Trunk injections reduce pesticide inputs and environmental contamination, and recent work has addressed apple production systems. Insecticides and fungicides have been demonstrated for apple tree injection, however combinations of the two have not yet been tested. Trunk injections of the systemic insecticide emamectin benzoate and systemic acquired resistance (SAR) fungicide phosphorous acid were performed on mature apple trees to combine management strategies for foliar insect pests and apple scab (Venturia inaequalis). Injections of emamectin benzoate followed by phosphorous acid into the same set of injection ports resulted in higher mortality of Choristoneura rosaceana larvae and lower incidence of apple scab compared to the control. Scab incidence on trees in which phosphorous acid was injected into the same set of ports before emamectin benzoate were not different from control trees early in the growing season. Injections of emamectin benzoate and phosphorous acid into the same holes in either order showed higher mortality and reduced larval feeding in C. rosaceana bioassays compared with products injected into separate holes. This study demonstrates that two pesticides can interact dynamically within the vascular system of a tree, which has important implications for expanding the utility of trunk injection for fruit tree management.

Coslor et al. 2019a. We evaluated the potential for using preplant trunk injections of emamectin benzoate in nonbearing apple trees. Trees were evaluated for pest injury and emamectin residues throughout the planting season and into the following year. Injections into the trunk best delivered emamectin benzoate to the canopy compared with injections into the taproot, and the higher rate reduced insect pests more than the lower rate. In the following year, differences in insect control between trunk and root injections were less pronounced, but the higher rate of emamectin benzoate persisted longer and better reduced pests relative to the other treatments.

Coslor et al. 2019b. Background: Trunk injection is an established method for delivering pesticides in ornamental and shade trees, but further research is needed to determine efficacy and pollinator safety in tree fruit crops. Apple trees were injected in 2013 and 2014 with the insecticides emamectin benzoate, imidacloprid, dinotefuran, spinosad, chlorantraniliprole, or abamectin. Additional emamectin benzoate and imidacloprid injections were performed in the spring and fall of 2015. Nectar and pollen were sampled in the following spring to compare the effects of application timings on insecticide loading into flowers.

Results: Neonicotinoids reduced Empoasca fabae density in the field. Emamectin benzoate, chlorantraniliprole, and abamectin resulted in moderate to high mortality and reduced Choristoneura rosaceana feeding in bioassays. Imidacloprid was not detected in nectar or pollen when injected in the spring, and was detected at 0.39 ng g-1 in pollen when injected the previous fall. Emamectin benzoate was not detected in nectar or pollen when injected the previous fall, and was detected at 7.36 ng g-1 (nectar) and 1.15 ng g-1 (pollen) when injected in the spring.

Conclusions: This study identified a broader list of possible trunk-injectable pesticides for apple trees. This study also shows that managing the seasonal timing of injection can reduce the risk of insecticide exposure to pollinators.

Coconut Black Head Caterpillar

Kamadal et al. 2018. The study was aimed at identifying alternative to monocrotophos, the only chemical recommended for root feeding against which the Opisina arenosella has shown resistance. This experiment was carried out in laboratory as well as in field conditions. In laboratory condition, among the tested chemicals viz., monocrotophos 36% SL, neemazal 1% and emamectin benzoate 5% SG gave one hundred per cent reduction followed by bifenthrin 10% EC (98.35%) and imidocloprid 17.8% SL (98.35%) as compared to untreated control. Field evaluation of selected chemicals indicated that monocrotophos 36% SL and neemazal 1%, gave one hundred per cent reduction followed by emamectin benzoate 5% SG (97.83%) and imidocloprid 17.8% SL (97.04%) as compared to untreated control. Thus besides monocrotophos other chemicals such as neemazal, emamectin benzoate, bifenthrin and imidacloprid also recorded significant mortality of coconut black headed caterpillar. The coconut palm successfully absorbed all these chemicals and can be used for root feeding.

Chaowattanawong et al. 2020. The aims of this research were to study on the efficacy and residue of trunk injection application for controlling coconut black-headed caterpillar in Young Nam-Hom coconut. The experiments were conducted on the Young Nam-Hom coconut orchard at Banpaw district, Samut Sakorn province at the height of 4-6 m. and 6-10 m. at Muang district, Lopburi province during July 2017 – September 2019. The application of abamectin 1.8% EC and emamectin benzoate 1.92%EC at various rates per coconut tree by trunk injection were applied. The result indicated that the application of abamectin 1.8% EC at 15 millilitres per coconut tree and emamectin benzoate 1.92%EC at 5 millilitres per coconut tree were effective to control coconut black-headed caterpillar at least 90 days after injection and no residue of these insecticides were detected from the coconut water. No sign of phytotoxicity was found in the experiments.

Japanese Pine Bast Scale

Fang et al. 2009. The control effects of Matsucoccus matsumurae in the forest with eleven different insecticides (Emamectin Benzoate-chlorfenapyr, Imidacloprid, Omethoate, Imidacloprid+Abamectin, DDVP+Omethoate) were studied by the method of trunk injection. The results showed that the control effect of all the insecticides was good, and which was related with the insecticide kinds, the doses and the applying time. Imidacloprid, Emamectin Benzoate+Omethoate (2%+20%) and Imidacloprid+Abamectin (4%+0.15%) had better control effects. The control effects reached 88.73%, 86.98% and 93.03% within 19 days after a trunk injection (2 mL/cm, respectively). The experiment showed that both the insecticides could be used in the control of Matsucoccus matsumurae.

Lobate Lac Scale

Bhandari and Cheng 2018. The lobate lac scale, Paratachardina pseudolobata Kondo & Gullan, is a recent insect invader to Hawaii that was first found in October 2012 on Oahu, Hawaii. It infests young branches of woody plants (usually less than 2 cm in diameter), forming a mass that appears as a dark crust, resulting in an unhealthy appearance, defoliation of leaves, and death of some plant species. This insect has infested many native and non-native plant species on Oahu, and the number of infested plant species is increasing. Our recent survey results, reported in this article, revealed 28 new host plant species in addition to 83 host species that we had reported previously, making 111 host plant species in Oahu's urban landscape. Efficacy and longevity of preventive treatment using the systemic insecticides imidacloprid and emamectin benzoate, delivered through trunk injection, against lobate lac scale on Chinese banyan, Ficus microcarpa, and curative treatment using imidacloprid on weeping banyan, Ficus benjamina, were evaluated. Forty-five Chinese banyans and 10 weeping banyans were included in this study. Our findings suggest that imidacloprid delivered via trunk injection is effective in preventing lobate lac scale infestation for at least 22 months post-treatment, and also in reducing lobate lac scale infestation curatively for at least 20 months post-treatment. This study provides an update on lobate lac scale's host species in Hawaii's urban landscape, and an effective preventive and curative management strategy against this pest.

Walnut Husk Fly

Kiss et al. 2020. The walnut husk fy (Rhagoletis completa) is one of the main pests affecting common walnut in both Europe and America. This work examines the effects of abamectin on the development of walnut husk fly larvae by injecting the product Vertimec 1.8 EC (Syngenta) into the trunks of walnut trees in Hungary. In the case of properly injected trees, the infection rate was negligible and the abamectin content in the husk samples ranged between 1.54 and 3.00 ng/g; controls show a very high (>90%) infestation rate and an abamectin content under the detection limit. Abamectin residue measured in walnut kernel did not exceed the maximum residue limit; moreover, the active ingredient content was below the detection limit (0.0003 mg/kg) in all the collected kernel samples. Our results confrm that trunk injection is a viable method for walnut pest control.

Red Palm Mite

Rodrigues and Pena 2012. The red palm mite (RPM), Raoiella indica Hirst, is a predominant pest of coconuts, date palms and other palm species, as well as a major pest of bananas (Musa spp.) in different parts of the world. Recently, RPM dispersed throughout the Caribbean islands and has reached both the North and South American continents. The RPM introductions have caused severe damage to palm species, and bananas and plantains in the Caribbean region. The work presented herein is the result of several acaricide trials conducted in Puerto Rico and Florida on palms and bananas in order to provide chemical control alternatives to minimize the impact of this pest. Spiromesifen, dicofol and acequinocyl were effective in reducing the population of R. indica in coconut in Puerto Rico. Spray treatments with etoxanole, abamectin, pyridaben, milbemectin and sulfur showed mite control in Florida. In addition, the acaricides acequinocyl and spiromesifen were able to reduce the population of R. indica in banana trials.

Blue Stain Fungi

Wyka et al. 2016. Bark beetles carry a number of associated organisms that are transferred to the host tree upon attack that are thought to play a role in tree decline. To assess the pathogenicity to western white pine (WWP; Pinus monticola) of fungi carried by the mountain pine beetle (MPB; Dendroctonus ponderosae), and to evaluate the potential for systemic prophylactic treatments for reducing fungal impacts, experiments were conducted with WWP seedlings to meet three objectives: 1) evaluate pathogenicity of two MPB-associated blue-stain fungi; 2) evaluate phytotoxicity of tree injection products; 3) evaluate the anti-fungal activity of tree injection products, in vitro and in vivo, toward the associated blue-staining fungi. To evaluate pathogenicity, seedlings were inoculated with Grosmannia clavigera or Leptographium longiclavatum, common fungal associates of MPB. Seedling mortality at four months after inoculation was 50% with L. longiclavatum and 90% with G. clavigera, both significantly higher than controls and thereby demonstrating pathogenicity. Phytotoxic effects of TREE-äge®, Alamo®, and Arbotect® were evaluated by stem injection; no phytotoxic effects were observed. Anti-fungal properties of the same three products were evaluated in vitro against G. clavigera, where Alamo was most active. Co-inoculation of G. clavigera and L. longiclavatum into seedlings after a stem injection of Alamo showed significantly less mortality and lesion formation than either species alone. Results support the hypothesis that MPB blue-stain associates, particularly G. clavigera, promote death of WWP when attacked by MPB. These findings suggest that the administration of a fungicide with insecticide for tree protection against bark beetles may be advantageous.

Tree Injection

Doccola and Wild 2012. Today, tree injection is an alternative method of chemical application with definite advantages: (1) efficient use of chemicals, (2) reduced potential environmental exposure, and (3) useful when soil and foliar applications are either ineffective or difficult to apply (Stipes, 1988; Sanchez-Zamora and Fernandez-Escobar, 2004). Tree injection is used when trees are at risk from attack from destructive or persistent pests. It may be put to good use in tall trees. They are administered in trees growing in environmentally sensitive locations (e.g., near water, in sandy soils). Tree injection does create wounds, however the benefit of the introduced chemistry to protect trees often outweigh the drilling wound. The new paradigm weighs the potential of off target consequences of application to the consequences of the drilled wound made by tree injection. Unintended off target exposures include toxicity to earthworms, fish, aquatic arthropods, pollinators and applicator. Insecticides are by design, toxic, albeit useful, substances. Tree injection is a method to deliver specific toxicants to the injurious pest and to minimize non-intended exposures. In this chapter, three specific insecticides used in tree injection were considered, each with unique attributes for specific applications in trees. Tree injection is an alternative methodology to apply systemic insecticides for tree protection.

Zhang et al. 2018. The effects of tree species, crown size and insecticides on the absorption and conduction of insecticide applied by trunk injection has been investigated. The 2.8% emamectin benzoate + 0.3% carbosulfan (hereafter 3.1% EB), 6% emamectin benzoate + 4% imidacloprid (10% EB), and 2% emamectin benzoate + 0.5% abamectin (2.5% EB) was made from a mixture of emamectin benzoate with carbosulfan, imidacloprid and abamectin, respectively. The influences of tree species and insecticides (3.1% EB and 10% EB), and crown diameter (2.5% EB) on the absorption conduction of those insecticides in Citrus grandis were studied by flowing trunk injection, meanwhile the residual period of 2.5% EB was investigated by the high performance liquid chromatography (HPLC-UVD) method. The results showed that the absorption rate of insecticides was significantly affected by tree species: Salix babylonica > C. grandis > Koelreuteria paniculata. Moreover, the insecticides were completely absorbed into the trunk within 5 days in S. babylonica. However, the remaining 3.1% EB and 10% EB in K. paniculata were up to 66.6% and 48.6%, respectively. Although the absorption rate of 10% EB (12.6% remaining) in C. grandis was faster than that of 3.1% EB (29.3% remaining) within 5 days, there was no significant difference between these two insecticides in other treatments. The absorption of 2.5% EB was positively related to the crown diameter of C. grandis. On the 113rd day after injection, abamectin and emamectin benzoate were still observed in the branches and leaves. The overall analysis suggested that the best absorption of 3.1% EB or 10% EB was observed in the case with S. babylonica. And there was no significant difference between the absorption of 3.1% EB and that of 10% EB among three tested trees. In addition, the absorption of 2.5% EB was positively related to the crown diameter of C. grandis, and the residual period of 2.5% EB in C. grandis was up to 90-120 days.

Acimovic et al. 2016. Excessive tree wounding is a common concern regarding the use of trunk injection technology for tree protection purposes in landscapes and urban greening. We investigated the rate of healing of injection ports (points) in apple trees by monitoring parameters such as port diameters, the size of bark cracking, and port depths. We compared drilled injection ports from 4.4 and 9.5 mm drill bits, with latter being sealed with plastic-silicone plug (Arborplug®) or not, and the lenticular port from a double-edged blade. Depending on port size and type, port closure ranged from one to more than two years. Bark cracking around injection ports was more pronounced longitudinally. On the sealed 9.5 mm port, bark cracking was largely similar to all drilled ports. The depth of port wounds decreased faster on the port from the 4.4 mm drill bit and on lenticular injection port versus the unsealed port from the 9.5 mm drill bit. Plastic-silicone plugs, which simulate removed bark, slowed the healing of 9.5 mm drill port with callus and increased the port depths over time due to callus formation over the top of the plug. From fastest-healing to slowest-healing, on average the injection ports were: lenticular port from blade (70.8%), the unsealed 9.5 mm drill port (44.4%), 4.4 mm drill port (43.9%), and 9.5 mm drill port sealed with plastic-silicone plug (20.4%).

Berger and Laurent. 2019. An alternative to the conventional delivery methods of pesticides is needed to limit risks for consumers, users and the environment. Managing pests and diseases in orchards, forests and urban environment using trunk injection of plant protection products is a promising strategy to reduce the risks associated with spraying. This environmentally friendly method was developed in the years following the emergence of phytosanitary problems and new scientific knowledge in the field. Recently, renewed interest in the trunk injection method has emerged following the apparition of new biological control agents and technologies which are more tree-friendly. Here we compare existing injection devices and their impact on trunk injection. We focus on the advantages and drawbacks of endotherapy with respect to environmental concerns and the risks for tree and human health. We also discuss the factors that influence the effectiveness of the trunk injection including the characteristics of the agrochemicals and biological control agents, tree anatomy and physiology. The match between pest or disease occurrence and the timing of the injections also has an influence on the success of this alternative treatment method.

Feltmeyer 2020. Oak wilt, caused by Bretziella fagacearum, is one of the most destructive diseases affecting urban and rural oak trees in the Midwest USA. The disease is difficult to control due to the systemic movement of the pathogen through the vascular system of oak trees. Primary approaches used to control oak wilt include disrupting underground spread through root cutting and the prevention of wounding during the high-risk period that the insect vectors of the oak wilt fungus are active. Preventative or therapeutic treatment of oaks using systemic injection techniques are a more recently developed control approach used by arborists and urban foresters. Systemic injection into xylem vascular elements of woody plants, however, involves physical wounding to the lower stem or root crown. The ability of a tree to compartmentalize such damage may affect tree vigor or even a tree's ability to survive after repeated treatments. This thesis summarizes results of research on compartmentalization of damage associated with systemic injection of propiconazole fungicides in northern pin oak in Anoka County, Minnesota.

Su et al. 2020. Background: Trunk-boring pests (TBPs) are an important type of forest pest, TBPs not only feed on the branches and trunks of trees, but also spread quarantine diseases in forests. However, because the larvae of TBPs live inside the trunk and are well concealed, prevention and control are difficult. The lack of effective control methods leads to the death of many trees in forests. In this study, a novel nanopesticide featuring high bioactivity and slow-release properties was developed to control TBPs. Thiacloprid (THI), which is commonly used to control Coleoptera species, was used as a model pesticide.

Results: The oleophobic properties of bovine serum albumin (BSA) were exploited to encapsulate the hydrophobic pesticide THI by self-assembly, and the size of the obtained nanoparticles, THI@BSA·NPs, was approximately 23 nm. The loading efficiency reached 70.4%, and THI@BSA·NPs could be released continuously for over 15 days, with the cumulative release reaching 93.5%. The fluorescein isothiocyanate (FITC)-labeled nanoparticles were evenly distributed in the digestive tract and body surface of a typical TBPs, M. alternatus, and the stomach and contact toxicities increased by 33.7% and 25.9%, respectively, compared with those of free THI. Furthermore, the results showed that the transport efficiency of THI@BSA·NPs was highest at a concentration of 50 μg/mL, and the THI@BSA·NPs content in the trunk, from to lower to higher layers, was 8.8, 8.2, 7.6, and 5.8 μg/g. At the same time, THI@BSA·NPs also exhibited high transport efficiency in dead trees.

Conclusion: The transport efficiency and toxicity of the active ingredients are the key factors for the control of TBPs. This work provided idea for the application of biological delivery system encapsulated hydrophobic pesticides. The novel self-assembled THI@BSA·NPs have promising potential for sustainable control of TBPs.

Human Health and Ecological Risk Assessment

"EXECUTIVE SUMMARY"

October 28, 2010

General Considerations

Emamectin benzoate is used for control of the emerald ash borer (*Agrilus planipennis* Fairmaire, commonly abbreviated as EAB), an insect pest of ash trees (*Fraxinus spp.*). This document provides human health and ecological risk assessments to support an assessment of the environmental consequences of using this pesticide in Forest Service programs. Emamectin benzoate is an insecticide that acts by adversely affecting the nervous system. This insecticide is registered for national use on a variety of agricultural commodities. The anticipated uses of emamectin benzoate in Forest Service programs is limited to one formulation of emamectin benzoate, Tree-äge, and one application method, tree injection. Relatively little information is available on the transport of emamectin benzoate in trees following tree injection and uncertainties with the movement of emamectin benzoate in ash trees following tree injection is a dominant factor in the current Forest Service risk assessment in terms of adequately assessing exposures to humans and other nontarget species.

Human Health

In terms of potential human health effects, the most plausible exposure scenarios are those for workers applying emamectin benzoate in a manner that is consistent with labeled directions including the proper use of chemical resistant gloves. If workers handle emamectin benzoate with care and effectively use chemical resistant gloves, no substantial or significant risks to workers are anticipated. If workers fail to effectively use chemical resistant gloves or if workers do not effectively and rapidly respond to accidental exposures, adverse effects in workers, possibly including degenerative changes in nerve tissue, could occur.

Substantial exposures to members of the general public do not appear to be plausible although quantitative estimates of expected exposures and hence quantitative estimates of risks cannot be developed at this time. Based on accidental exposure scenarios associated with the spill of emamectin benzoate into a pond, the central estimates of hazard quotients are below the level of concern (HQ=1). The upper bound estimates of the hazard quotients range from 0.6 to 3. The inability to estimate exposures to members of the general public associated with the normal and expected use of emamectin benzoate – i.e., injection into ash trees – is a serious limitation in this risk assessment. Nonetheless, the upper bound HQ for all of the accidental exposure scenarios is only 3. Thus, in the normal use of emamectin benzoate, about one-third of the emamectin benzoate that is injected into an ash tree would need to be transported to surface water in order for the HQs associated with non-accidental exposures to reach a level of concern. It does not seem reasonable to assert that this level of exposure would or could occur.

Ecological Effects

As with the human health risk assessment, the ecological risk assessment for emamectin benzoate is dominated by uncertainties in the exposure assessment. Because of limited information on the transport of emamectin benzoate in trees following tree injection and the lack of information on the transport of emamectin benzoate in ash trees, reliable estimates of exposures in nontarget species associated with the injection of emamectin benzoate into ash trees cannot be made. The inability to estimate expected exposures of nontarget species limits confidence in the risk characterization for nontarget species.

Uncertainties in the exposure assessments associated with the potential contamination of surface water in the normal use of emamectin benzoate for the injection of ash trees is addressed with an accidental spill scenario. Based on the accidental spill scenario, no risks are apparent for mammals, birds, fish, aquatic plants, or tolerant species of aquatic invertebrates. The lack of risk in the accidental spill scenarios for these groups of organisms suggests that the contamination of surface water associated with the normal use of emamectin benzoate to inject ash trees is not likely to adversely impact these organisms. Risks to sensitive species of aquatic invertebrates, however, are apparent in the accidental spill scenario with an upper bound HQ of 120. Thus, in the event of an accidental spill of a significant amount of emamectin benzoate into a pond, adverse effects including mortality could be anticipated. The high hazard quotients for sensitive species of aquatic invertebrates associated with the accidental spill scenario also prevent a clear risk characterization for this group of organisms in the normal use of emamectin benzoate. At least in situations in which high doses of emamectin benzoate are used or a relatively large number of trees are treated near surface water, risks to sensitive species of aquatic invertebrates can neither be discounted nor characterized clearly.

While uncertainties associated with contaminated surface water can be addressed reasonably well, other exposure pathways are problematic. The most likely exposures for mammals or birds involve the consumption of bark, stem tissue, or seeds of ash trees as well as the consumption of herbivorous insects that may feed on ash leaves. Only the pathway involving the consumption of herbivorous insects is developed quantitatively. Under worst-case exposure assumptions, risks to mammals are marginal (an upper bound HQ of 1.1) and risks to birds are negligible (an upper bound HQ of 0.03). For herbivorous insects, however, the risk characterization is well-defined. Both tolerant and sensitive species or populations of herbivorous insects are likely to be adversely affected if they feed on ash trees injected with effective doses of emamectin benzoate.

While the risk characterization for emamectin benzoate is dominated by uncertainties in the exposure assessments, it is worth noting that the most relevant toxicity studies on aquatic organisms and birds are limited to relatively standard bioassays on relatively few species of organisms compared to other more fully studied pesticides. In addition, no data are available on reptiles, amphibians, or soil invertebrates." (Durkin 2010)

Environmental Fate

Burkhard et al. 2014. Emamectin benzoate, an insecticide derived from the avermectin family of natural products, has a unique translocation behavior in trees when applied by tree micro injection (TMI), which can result in protection from insect pests (foliar and borers) for several years. Active ingredient imported into leaves was measured at the end of season in the fallen leaves of treated horse chestnut (Aesculus hippocastanum) trees. The dissipation of emamectin benzoate in these leaves seems to be biphasic and depends on the decomposition of the leaf. In compost piles, where decomposition of leaves was fastest, a cumulative emamectin benzoate degradation half-life time of 20 d was measured. In leaves immersed in water, where decomposition was much slower, the degradation half-life time was 94 d, and in leaves left on the ground in contact with soil, where decomposition was slowest, the degradation half-life time was 212 d. The biphasic decline and the correlation with leaf decomposition might be attributed to an extensive sorption of emamectin benzoate residues to leaf macromolecules. This may also explain why earthworms ingesting leaves from injected trees take up very little emamectin benzoate and excrete it with the feces. Furthermore, no emamectin benzoate was found in water containing decomposing leaves from injected trees. It is concluded, that emamectin benzoate present in abscised leaves from horse chestnut trees injected with the insecticide is not available to nontarget organisms present in soil or water bodies.

Yang et al. 2018. Injection of Cyhalodiamide and Emamectin benzoate in Pinus massoniana trunk on March 25 th of 2015 in Jiangxi province for determination of physiological properties and protective enzymes in leaves of tested trees. The result showed that content of chlorophyll and total soluble sugar of injected trees decreased, but that of MDA increased. Trees injected by Cyhalodiamide had decrease of chlorophyll content by 10.3% in the 4 th day, of total soluble sugar content by 15% in the 8 th day, while of MDA content increase by 42% in the 4 th day. The activity of SOD in trees injected the two pesticides had a curve of up-down-up-down. Cyhalodiamide had significant effect on SOD and PAL activities, the activity of SOD increased 39.5% in the 4 th day, and that of PAL 40.7% in the 8 th day after trunk injection.

References (70)

Acimovic, SG, BM Cregg, GW Sundin, and JC Wise. 2016. Comparison of drill- and needle-based tree injection technologies in healing of trunk injection ports on apple trees. Urban Forestry & Urban Greening. 19: 151-157.

Ali-Bob, M. 2019. Management of the Red Palm Weevil Rhynchophorus ferrugineus (Olivier) using sustainable options in Saudi Arabia. Arab Journal of Plant Protection, 37(2): 163-169.

Aubihl, E. 2019. Density-Dependent Survival of White Ash (Fraxinus americana) at the Allegheny National Forest. Thesis. Miami University. 39 p.

Berger, C., and F. Laurent. 2019. Trunk injection of plant protection products to protect trees from pests and diseases. Crop Protection. 124:

Bhandari, B. P.,and C. Cheng. 2016. Trunk injection of systemic insecticides to control stem and leaf gall wasps, *Josephiella* species (Hymenoptera: Agaonidae), on Chinese banyan (Rosales: Moraceae) in Hawaii. Florida Entomol. 99: 172–177.

Bhandari, B. P.,and C. Cheng. 2018. Lobate lac scale, *Paratachardina pseudolobata* (Hemiptera: Keriidae), in Hawaii's urban landscape: Hosts and management. Interntnl J. of Trop Insect Sci. 38: 71-76.

Bi, Z., Y. Gong, X. Huang, H. Yu, L. Bai, and Hu. 2015. Efficacy of Four Nematicides Against the Reproduction and Development of Pinewood Nematode, *Bursaphelenchus xylophilus*. J. Nematol. 47: 126–132

Bick, E.N. and S. Bernick. 2014. Efficacy of a novel emamectin benzoate formulation for emerald ash borer control. Pp 18-19. In J. Buck, G. Parra, D. Lance, R. Reardon, and D. Binion (eds) 2014 Emerald Ash Borer National Research and Technology Development Meeting. FHTET 2015-07.

Bick, E.N., C. Haugen, S. Bernick, and D. A. Herms. 2017. Efficacy of soil and trunk applied systemic insecticides for three years after application for control of emerald ash borer (Coleoptera: Buprestidae) on green ash. Arthropod Mgt. Tests. 42:1-2.

Bick, E.N., N.J. Forbes, C. Haugen, G. Jones, S. Bernick, and F. Milller. 2018. Seven-Year Evaluation of Insecticide Tools for Emerald Ash Borer in *Fraxinus pennsylvanica* (Lamiales: Oleaceae) Trees. J Econ Entomol. 111(2):732-740.

Billings, R.F., D.M. Grosman and H.A. Pase III. 2014. Soapberry Borer, *Agrilus prionurus* (Coleoptera: Buprestidae): An Exotic Pest Threatens Western Soapberry in Texas. Southeastern Naturalist. 13: 105 - 116.

Bras, A., M.A. Auger-Rozenberg, P. Pineau, P. Lorme, A. Roques, M. Laparie, and J. Rousselet. 2017. Effect of emamectin benzoate tree micro injection on the survival rate of the first larval instar of the box tree moth [Conference poster]. 6e COMAPPI, Conférence sur les Moyens Alternatifs de Protection pour une Production Intégrée, Lille, France, 21-23 mars 2017.

Burkhard, R., H. Binz, C.A. Roux, M. Brunner, O. Ruesch, and P. Wyss. 2014. Environmental fate of emamectin benzoate after tree micro injection of horse chestnut trees. Environmental Toxicology and Chemistry. 34: 297-304.

Byrne, F.J., J. Almanzor, I. Tellez, A. Eskalen, D.M.Grosman, J.G..Morse. 2020. Evaluation of trunk-injected emamectin benzoate as a potential management strategy for Kuroshio shot hole borer in avocado trees. Crop protection. 132:

Campbell, W. C., R. W. Burg, M. H. Fisher, AND R. A. Dybas. 1984. The discovery of ivermectin and other avermectins, pp. 5-20. *in* P. S. Magee, G. K. Kohn & J.J. Menn [eds.]. Pesticide synthesis through rational approaches. ACS Symp. Ser. No. 255. American Chemical Soc., Washington, DC.

Chaowattanawong, P., P. Punyawattoe, N. Chaiyasingh, S. Supornsin, W. Sucharitamjariyangkul, C. Thongsam, and V. Sangwan. 2020. Trunk Injection Application by Abamectin and Emamectin benzoate for Controlling Black Head Caterpillar, Opisina arenosella Walker in Nam-Hom Coconut. Thai Ag. Res Journal. 38:

Chen, X., J. Pan, T. Shen, F. Wei, H. Liu. 2009. Screening of Trunk-injection Pesticides on Bursaphelenchus xylophilus and Effect of Pesticides on the Field, Jiangxi Forestry Science

Chen, Y., M.L. Flint, T.W. Coleman, J.J. Doccola, D.M. Grosman, D.L. Wood, and S.J. Seybold. 2015. Impact of the goldspotted oak borer, Agrilus auroguttatus, on the health of coast live oak before and after treatment with two systemic insecticides. Pest Manag Sci. 71:1540-1552.

Chihaoui-Meridja, S., A. Harbi, K. Abbes, H. Chaabane, and A. La Pergola. 2020. Systematicity, persistence and efficacy of selected insecticides used in endotherapy to control the red palm weevil Rhynchophorus ferrugineus (Olivier, 1790) on Phoenix canariensis.

Coleman, T.W., S.L. Smith, M.I. Jones, A.D. Graves, and B.L. Strom. 2017. Efficacy of Systemic Insecticides for Control of the Invasive Goldspotted Oak Borer (Coleoptera: Buprestidae) in California. J. Econ. Entomol. 110: 2129–2139.

Cook, S.P., B.D. Sloniker, M.L. Rust. 2013a. Using systemically applied insecticides for management of ponderosa pine cone beetle and *Dioryctria* coneworms in seed orchards. Western Journal of Applied Forestry. 28: 66-70.

Cook, S.P., B.D. Sloniker, M.L. Rust. 2013b. Efficacy of two bole-injected systemic insecticides for protecting Douglas-fir from damage by Douglas-Fir tussock moth and fir coneworm. Western Journal of Applied Forestry. 28: 166-169.

Coslor, C.C. 2017. Refining trunk injection strategies for control of foliar insect pests and disease in Michigan apple orchards. Ph.D. Dissertation. Michigan State University. 92 pp.

Coslor, C.C., G.W. Sundin, and J.C. Wise. 2019. The efficacy of trunk injections of emamectin benzoate and phosphorous acid for control of obliquebanded leafroller and apple scab on semi-dwarf apple. Crop Protection. 118: 44-49.

Coslor, C.C., C. Vandervoort, and J.C. Wise. 2019a. Control of insect pests using trunk injection in a newly established apple orchard. International Journal of Fruit Science. 19: 151-164.

Coslor, C.C., C. Vandervoort, and J.C. Wise. 2019b. Insecticide dose and seasonal timing of trunk injection in apples influence efficacy and residues in nectar and plant parts. Pest. Management Science. 75: 1453-1463.

Cranshaw, W. 2020. Insecticides Used to Control Emerald Ash Borer on Residential Shade Trees. Colorado State University Extension Fact Sheet 5.626. 6 p.

Davis, M.J. and J Elkinton. 2018. Efficacy of two systemic insecticides with stem gall wasp, *Zapatella davisae* (Hymenoptera: Cynipidae) on black oak. J. Econ. Entomol. 111:

De Andrade, R.B., K. Abell, J.J. Duan, P. Shrewsbury, D.S. Gruner. 2021. Protective neighboring effect from ash trees treated with systemic insecticide against emerald ash borer. Pest Manag. Sci. https://doi.org/10.1002/ps.6041.

Doccola, J.J. and P.M. Wild. 2012. Tree Injection as an Alternative Method of Insecticide Application. P. 61-78. In. S. Soloneski (Ed.) Insecticides - Basic and Other Applications.

Doccola, J.J., S.L. Smith, B.L. Strom, A.C. Medeiros, and E. von Allmen. 2009. Systemically Applied Insecticides for Treatment of Erythrina Gall Wasp, *Quadrastichus erythrinae* Kim (Hymenoptera: Eulophidae). Arb. & Urban For. 35(4): 173-181.

Doccola, J.J., D.R. Smitley, T.W. Davis, J.J. Aiken and P.M. Wild. 2011. Tree Wound Responses Following Systemic Insecticide Trunk Injection Treatments in Green Ash (Fraxinus pennsylvanica Marsh.) as Determined by Destructive Autopsy. Arb. & Urban For. 37: 6-12.

Doccola, J.J., D. Smitley, T. Davis, M Duyar, and Steven Ashley. 2016. Protection of large diameter ash trees against EAB in the urban environment using TREE-äge®, a tree-injected insecticide. 2016 Emerald Ash Borer National Research and Technology Development Meeting.

Doccola, J.J., S.L. Smith, J.B. Fischer; and B.L. Strom. 2020. Evaluation of Stem-Injected TREE-äge® (4% Emamectin Benzoate) for Protecting Western White Pines (Pinus monticola) from Mountain Pine Beetle (Dendroctonus ponderosae Hopkins) (Coleoptera: Curculionidae: Scolytinae). Arboriculture & Urban Forestry . 46: 333-346.

Durkin, P.R. 2010. Emamectin benzoate Human Health and Ecological Risk Assessment FINAL REPORT. Syracuse Environmental Research Associates.

Eatough Jones, M., J. Kabashima, A. Eskalen M. Dimson, J.S. Mayorquin, J.D. Carrillo, C.C. Hanlon, and T.D. Paine. 2017. Evaluations of Insecticides and Fungicides for Reducing Attack Rates of a new invasive ambrosia beetle (*Euwallacea* Sp., Coleoptera: Curculionidae: Scolytinae) in Infested Landscape Trees in California. *J. Econ. Entomol*. 110: 1611–1618.

Evans, H.F., D. Williams, G. Hoch, A. Loomans, and M. Marzano. 2020. Developing a European Toolbox to manage potential invasion by emerald ash borer (Agrilus planipennis) and bronze birch borer (Agrilus anxius), important pests of ash and birch. Forestry Internat. J. For. Res. 93: 187–196.

Fang, JS., X.F. Yang, J.N. Tang, YF Zhu, YH Zheng. 2009. Effects of different insecticides against Matsucoccus matsumurae by trunk injection. J. Jiangsu Forestry Science & Technology. 36: 5-7.

Feltmeyer , A. (2020). Characterization of Injection Wound Damage Associated with Propiconazole Treatments of Northern Pin Oaks. Thesis. University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/217127.

Ferry, M., R. Cousin, D. Chabernaud and F. Ferrero. 2019. An effective strategy to obtain very rapidly the red palm weevil decline in an area planted with ornamental palms. Arab Journal of Plant Protection, 37(2): 188-197.

Fettig, C.J., R.E. Burnside, C.J. Hayes, and M.E. Schultz. 2011. Field evaluations of emamectin benzoate for control of birch leafminer (Hymenoptera: Tenthredinidae) in Interior Alaska. J. Entomol. Sci. 46: 339-341.

Fettig, C.J., R.E. Burnside, and M.E. Schultz. 2013. Injection of Emamectin Benzoate Protects Paper Birch from Birch Leafminer (Hymenoptera:Tenthredinidae) for Two Field Seasons. J. Entomol. Sci. 48:166-168.

Fettig, C.J., D.M. Grosman, and A.S. Munson. 2013. Advances in insecticide tools and tactics for protecting conifers from bark beetle attack in the western United States. In: S. Trdan (Ed.) Insecticides. In Tech, Rijeka, Croatia p.

Fettig CJ, Munson AS, Grosman DM, and Bush, PB. 2014. Evaluations of emamectin benzoate and propiconazole for protecting individual *Pinus contorta* from mortality attributed to colonization by *Dendroctonus ponderosae* and associated fungi. Pest Mgt. Sci. 70: 771 - 778.

Fettig, C.J., D.C. Blackford, D.M. Grosman, and A.S. Munson. 2017. Injections of Emamectin Benzoate Protect Engelmann Spruce from Mortality Attributed to Spruce Beetle (Coleoptera: Curculionidae) for Two Years. J. Entomol. Sci. 52: 193-196.

Fettig, C.J., A.S. Munson, D.M. Grosman, and D.C. Blackford. 2020. Evaluations of Bole Injections for Protecting Engelmann Spruce from Mortality Attributed to Spruce Beetle (Coleoptera: Curculionidae) in the Intermountain West. J. Entomol Sci. 55 (3): 301–309.

Fidgen, J.G. N.T. Kittelson T. Eckberg J. Doccola C. Randall. 2013. Field Note: Emamectin Benzoate Reduces Defoliation by *Choristoneura occidentalis* Freeman (Lepidoptera: Tortricidae) on Three Host Species. Western Journal of Applied Forestry. 28: 170–173.

Flower, C.E., J.E. Dalton, K.S. Knight, M. Brikha, and M.A. Gonzalez-Meler. 2015. To treat or not to treat: Diminishing effectiveness of emamectin benzoate tree injections in ash trees heavily infested by emerald ash borer. Urban Forestry & Urban Greening. 14: 790-795.

Flower, C.E., J. E. Dalton,K.S. Knight, and M.A. Gonzalez-Meler. 2016. Effectiveness of emamectin benzoate injections on ash trees in various stages of decline.

Flower, C.E., E. Aubihl, J. Fant, S. Forry, A. Hille, K.S. Knight, W.K. Oldland, A.A. Royo, and R.M. Turcotte. 2017. In-situ Genetic Conservation of White Ash (*Fraxinus americana*) at the Allegheny National Forest. Pp 165-169 In: Sniezko, Richard A.; Man, Gary; Hipkins, Valerie; Woeste, Keith; Gwaze, David; Kliejunas, John T.; McTeague, Brianna A., tech. cords. Proceedings of Workshop on Gene Conservation of Tree Species—Banking on the Future. Chicago, Illinois, USA May 16–19, 2016.

Good, B.M. 2013. Likely Successors of Ash Species in Response to the Emerald Ash Borer in Ohio Forests. Masters Thesis. Wright State University. 98 pp.

Gous, SF and B. Richardson. 2008. Stem injection of insecticides to control herbivorous insects on *Eucalyptus nitens.* New Zealand Plant Protection 61: 174-178.

Greene, S.J. 2019. Cost and benefits of protecting ash (Fraxinus spp.) trees on the Michigan State University campus from emerald ash borer (Agrilus planipennis fairmaire) (Coleoptera: Buprestidae). Thesis. Michigan State University.

Grosman, D.M. and W.W. Upton. 2006. Efficacy of systemic insecticides for protection of single trees against southern pine bark beetles (Coleoptera: Curculionidae, Scolytinae) and wood borers (Coleoptera: Cerambycidae). J. Econ. Entomol. 99: 94-101.

Grosman, D.M., A. Eskalen and C. Brownie. 2019. Evaluation of Emamectin Benzoate and Propiconazole for Management of a New Invasive Shot Hole Borer (Euwallacea nr. fornicatus, Coleoptera: Curculionidae) and Symbiotic Fungi in California Sycamores. J. Econ Entomol. Accepted for publication.

Grosman, D.M., F.A. McCook, W.W. Upton, and R.F. Billings. 2002. Systemic insecticide injections for control of cone and seed insects in loblolly pine seed orchards – 2 year results. So. J. Appl. For. 26: 146-152.

Grosman, D.M., W.W Upton, A. Mangini, C Rosier, T. Slichter, J. Tule and J Watkins. 2007. Systemic insecticide injections: New, effective option for protecting pine seed orchard crops from insect pests. Proceedings of the Joint Meeting of the Southern Forest Tree Improvement Conference and Western Forest Genetics Association. Galveston, TX. June 19-22, 2007.

Grosman, D.M., S.R. Clarke, and W.W. Upton. 2009. Efficacy of two systemic insecticides injected into loblolly pine for protection against southern pine bark beetles (Coleoptera: Curculionidae). J. Econ. Entomol. 102: 1062-1069.

Grosman, D.M., C.J. Fettig, C.L. Jorgensen, and A.S. Munson. 2010. Efficacy of two systemic insecticides for protection of western conifers against *Dendroctonus* bark beetles (Coleoptera: Curculionidae, Scolytinae). W. J. Appl. For. 25: 181-185.

Grosman, D.M. and D.L. Cox. 2018. Method for protection of Trees. US Patent App. 16/108,768. Pub. No.: US 2018 / 0360044 A1

Habib, D.M., N. Mouna, and H. Wiem. 2017. Red Palm Weevil (Rhynchophorus ferrugineus) Chemical Treatments Applied on Ornamental Palms in Tunisia:Results of Extensive Experiments. Internat. J. Ag. Innov. Res. 5: 1062-1068.

Hanavan, R.P. and M Heuss. 2019. Physiological Response of Ash Trees, Fraxinus spp., Infested with Emerald Ash Borer, Agrilus planipennis Fairmaire (Coleoptera: Buprestidae), to Emamectin Benzoate (Tree-Äge) Stem Injections. Arboriculture & Urban Forestry 45(4):132–138.

Herms, D.A. 2010. Multiyear evaluations of systemic insecticides for control of emerald ash borer. *In*: D. Lance, J. Buck, D. Binion, R. Reardon, and V. Mastro, compilers, *Proceedings of the Emerald Ash Borer Research and Technology Development Meeting, October 20-21, 2009, Pittsburgh, Pennsylvania*, pp. 71-75. USDA Forest Health Technology Enterprise Team, FHTET-2010-01. 136 pp.

Herms, D.A. 2012. Insecticide options for protecting ash trees from emerald ash borer. In: *2012 Recertification Conferences for Ohio Pesticide Commercial Applicators*. Eds: J. Kick-Raack and C. Folck. Columbus: Ohio State University Extension.

Hong, J., Z. Wenyi, P.Lu, W. Jiabing, J. Dun, M. Zhaojun, Y. Shanchun. 2016. Efficiency of seven bio-insecticides to control *Pissodes nitidus* by trunk injection. J. Northeast Forestry University.

Huang, J., J. Zhang, Y. Li, X-H Shi. 2016. Evaluation of the effectiveness of insecticide trunk injections for control of Latoia lepida (Cramer) in the sweet olive tree Osmanthus fragrans. PeerJ 4:e2480 https://doi.org/10.7717/peerj.2480.

Jansson R.K. and K. Rabatin. 1998. Potential of foliar, dip, and injection applications of avermectins for control of plant-parasitic nematodes. Journal of Nematology 30:65-75.

Jansson R.K., Brown R., Cartwright B. Cox D., Dunbar D.B., Dybas R.A., Eckel C., Lasota, J.A., Mookerjee P.K., Norton J.A., Peterson R.F., Starner V.R., & White S., 1996. Emamectin benzoate : a novel avermectin derivate for control of lepidopterous pests. Proceedings : the management of Diamondback Moths and other crucifers pests. Chemical control 171-177. Entomology. Cornell University.

Kamadal S.M., B.B. Kumara, B.C. Hanumanthaswamy, C.M. Kalleshwaraswamy . 2018. Efficacy of selected insecticides against coconut black headed caterpillar, Opisina arenosella (Walker) under laboratory and field conditions. J. Entomol. Res. 42: 223-228.

Kellar, M. 2018. Management Strategies of New Invasive Insect Pests of Landscape Plants in Hawai'i. Thesis. University of Hawai'I at Manoa. 57 p.

Kim, DS, SM Lee, SH Lee, KS Choi. 2011. Insecticidal activity of Monochamus alternatus adults by trunk injection of systemic insecticides. Korean Society of Applied Entomology

Kiss, M., I Hachoumi, V. Nagy, M Ladanyi, A Gutermuth, A Szabo, C Soros. 2020. Preliminary results about the efficacy of abamectin trunk injection against the walnut husk fly (Rhagoletis completa) J. Plant Dis. Protection. https://doi.org/10.1007/s41348-020-00393-z.

Lobbate, L. 2020. Phenology, Density and Distribution of the Invasive Asian Chestnut Gall Wasp (Dryocosmus kuriphilus Yasumatsu) and Evaluation of Two Systemic Insecticides in Michigan Chestnut Orchards. Thesis. Michigan State University.

Lai, Y. 2017. Theory and Practice of Controlling and Extinguishing Pine Wilt Disease. Ag. Sci. Tech. 18: 332-343.

Lee, S.M., D S Kim, S G Lee, N C Park and D.W. Lee. 22009. Selection of Trunk Injection Pesticides for Preventive of Pine Wilt Disease, Bursaphelenchus xylophilus on Japanese Black Pine (Pinus thunbergii). Korean J. Pesticide Sci. 13: 267-274.

Lee, S.C., H.R. Lee, D.S. Kim, J.H. Kwon, M.J. Huh and I.K. Park. 2020. Emamectin benzoate 9.7% SL as a new formulation for a trunk-injections against pine wood nematode, *Bursaphelenchus xylophilus*. J. For. Res. 31: 1399-1403. https://doi.org/10.1007/s11676-018-00873-x.

Lee, D-H., D.Y. Suh, S-T. Seo, S-H. Lee. 2020. Insecticidal Activity of Japanese Pine Sawyer (Monochamus alternatus) and Pine Sawyer (Monochamus saltuarius) Using Abamectin and Emamectin benzoate. J. For. And Environ. Sci. 36: 255-258.

Leibee, G L., R K. Jansson, G Nuessly and J L. Taylor. 1995. Efficacy of emamectin Benzoate and Bacillus thuringiensis at Controlling Diamondback Moth (Lepidoptera: Plutellidae) Populations on Cabbage in Florida. *The Florida Entomologist*. 78: 82-96.

Lewis, P.E. and R.M. Turcotte. 2015. Use of chemical protection and host tree reduction to control an emerald ash borer infestation in West Virginia. J. Biodiversity Management Forestry 4:1-5.

Liguori, R., R. Correia, C. Thomas, B. Decaudin, J. Cisneros, and A. Lopez. 2010. Emamectin benzoate (Affirm). A modern insecticide for the control of lepidoptera larvae on fruits, grapes and vegetables crops. Commun Agric Appl Biol Sci. 75(3):247-53.

Li, Q., SY Zhang, HK Qui, M. Chen, Y. Yuan. 2016. Field efficacy of six trunk-injected pesticides on Bursaphelenchus xylophilus.J. Zhejiang A&F University. 33: 718-723.

Lin, X, Y. Jiang, L. Zhang, and Y. Cai. 2018. Effects of insecticides chlorpyrifos, emamectin benzoate and fipronil on *Spodoptera litura* might be mediated by OBPs and CSPs. Bull. Entomol. Res. 108: 658-666.

Liu, H. 2018. Under siege: Ash management in the wake of the emerald ash borer. J. Int. Pest Mgt. 9: https://doi.org/10.1093/jipm/pmx029.

Lu, F., K. Guo, A. Chen, S. Chen, H. Lin, and X. Zhou. 2020. Transcriptomic profiling of effects of emamectin benzoate on the pine wood nematode Bursaphelenchus xylophilus. Pest Management Science. 76(2):747-757.

Mashal, M.M. and B.F. Obiedat. 2019. The efficacy assessment of emamectin benzoate using micro injection system to control red palm weevil. Heliyon. 5

Mayorquin, J.S., J.D. Carrillo, M. Twizeyimana, B.B. Peacock, K.Y. Sugino, F. Na, D.H. Wang, J.N. Kabashima, and A. Eskalen. 2018. Chemical Management of Invasive shot hole borer and Fusarium Dieback in California sycamore (*Platanus racemosa*) in Southern California. Plant Disease. 102:

McCullough, D.G., D.L. Cappaert, T.M. Poland, A.C. Anulewicz, P. Lewis, and J. Molongoski. 2008. Evaluation of Non-Invasive Trunk Sprays and Trunk-Injected Emamectic Benzoate. In: Mastro, Victor; Lance, David; Reardon, Richard; Parra, Gregory, comps. Emerald ash borer research and development meeting; 2007 October 23-24; Pittsburgh, PA. FHTET 2008-07. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team: 40-42.

McCullough, D.G. and R.J. Mercader. 2012. SLAM in an urban forest: evaluation of potential strategies to SLow Ash Mortality caused by emerald ash borer (*Agrilus planipennis*). International Journal of Pest Management 58: 9-23.

McCullough, D.G., R.J. Mercader and N.W. Siegert. 2015. Developing and integrating tactics to slow ash (Oleaceae) mortality caused by emerald ash borer (Coleoptera: Buprestidae). The Canadian Entomologist. 147: 349-358.

McCullough, DG, R. Mercader, and T. Poland 2011a. Systemic Insecticides for EAB Control Across Varying Scales: Trees to Landscapes. pp. 46-48. **In**: K. McManus and K.W. Gottschalk, eds., Proceedings 22nd U.S. Department of Agriculture Interagency Research Forum on Invasive Species 2011. USDA Forest Service Northern Research Station Gen. Tech. Rep. NRS-P-92.

McCullough, D.G., T.M. Poland, A.C. Anulewicz, P. Lewis and D. Cappaert. 2011b. Evaluation of *Agrilus planipennis* control provided by emamectin benzoate and two neonicotinoid insecticides, one & two seasons after treatment**.** Journal of Economic Entomology 104(5): 1599-1612.

McCullough, D.G., T. M. Poland, A. C. Anulewicz, P. Lewis, and J. Molongoski. 2009. Evaluation of emamectin benzoate and neonicotinoid insecticides: two-year control of EAB? *Proceedings of the Emerald Ash Borer Research and Technology Development Meeting, October 20-21, 2009, Pittsburgh, Pennsylvania*, pp. 69-71. USDA Forest Health Technology Enterprise Team, FHTET-2010-01. 136 pp.

McCullough, D.G., T.M. Poland and P.A. Lewis. 2015. Lethal trap trees: a potential option for emerald ash borer (*Agrilus planipennis* Fairmaire) management. Pest Mgt. Sci. 72: 1023-1030.

McCullough, DG. T.M. Poland, A.R. Tluczek, A. Anulewicz, J, Wieferich and N.W. Siegert. 2019. Emerald Ash Borer (Coleoptera: Buprestidae) Densities Over a 6-yr

Period on Untreated Trees and Trees Treated With Systemic Insecticides at 1-, 2-, and 3-yr Intervals in a Central Michigan Forest. J. Econ. Entomol. 112: 201-212.
McCullough, DG. 2020. Challenges, tactics and integrated management of emerald ash borer in North America. Internat J. For. Res. 93: 197-211.
Mercader, R.J., D.G. McCullough, A.J.Storer, J.M.Bedford, R. Heyd, N.W. Siegert, T.M. Poland, and S. Katovich. 2015. Evaluation of the potential use of a systemic insecticide and girdled trees in area wide management of the emerald ash borer. Forest Ecology and Management. 350: 70-80.
Mercader, R.J., D.G. McCullough, A.J.Storer, J.M.Bedford, R. Heyd, N.W. Siegert, S. Katovich, and T.M. Poland. 2016. Estimating local spread of recently established emerald ash borer, *Agrilus planipennis*, infestations and the potential to influence it with a systemic insecticide and girdled ash trees. Forest Ecology and Management. 366: 87-97.
Mercader, R.J., N.W. Siegert, A.M. Liebhold and D.G. McCullough. 2011. Simulating the effectiveness of three potential management options to slow the spread of emerald ash borer populations in localized outlier sites. Canadian Journal of Forest Research 41:254-264.
O'Brien, E.M. 2017. Conserving Ash (Fraxinus) Populations and Genetic Variation in Forests Invaded by Emerald Ash Borer Using Large-scale Insecticide Applications. Ph.D. Dissertation. The Ohio State University. 199p.
O'Brien, E.M. and D.A. Herms. 2014. Preserving ash regeneration and stable age structure by protecting mature ash during the emerald ash borer invasion. P. 89-90. In: 2014 Emerald Ash Borer National Research and Technology Development Meeting, Wooster, OH October 15 & 16, 2014.
Olsen, D.G. 2018. Emerald ash borer (Coleoptera: Buprestidae) host expansion; trading an optimal host for enemy free space? Masters Thesis. University of Kentucky. https://doi.org/10.13023/ETD.2018.088. .
Poland, T.M., R.A. Haack, and T.R. Petrice, D. L. Miller,L.S. Baur, and R. Gao.2006. Field Evaluations of Systemic Insecticides for Control of Anoplophora glabripennis (Coleoptera: Cerambycidae) in China. J. Econ. Entomol. 99(2): 383-392.
Poland, T.M., D.G. McCullough, D.A. Herms, L.S. Bauer, J.R. Gould, and A.R. Tluczek. 2011. Management tactics for emerald ash borer: chemical and biological control. **In**: K. McManus and K.W. Gottschalk, eds., *Proceedings 21st U.S. Department of Agriculture Interagency Research Forum on Invasive Species 2010*, pp. 46-49. USDA Forest Service Northern Research Station Gen. Tech. Rep. NRS-P-75.
Poland, T.M., T.M. Ciarmitaro, D.G. McCullough. 2016. Laboratory Evaluation of the Toxicity of Systemic Insecticides to Emerald Ash Borer Larvae. *J. Econ. Entomol.*, Volume 109: 705–716.
Potter, D.A., L. Foss, R.E. Baumler, and D.W. Held. 2005. Managing Eastern tent caterpillars *Malacosoma americanum* (F) on horse farms to reduce risk of mare reproductive loss syndrome. Pest Management Science. 61: 3-15.
Rodrigues and Pena. 2012. Chemical control of the red palm mite, Raoiella indica (Acari: Tenuipalpidae) in banana and coconut. Exp Appl Acarol. 57:317–329.

Sadof, C.S., G.P. Hughes, A.R.Witte, D.J. Peterson, and M.D. Ginzel. 2017. Tools for Staging and Managing Emerald Ash Borer in the Urban Forest. Arboriculture & Urban Forestry 2017. 43(1):15–26.

Sadof, C.S., L. Mockus, and M.D. Ginzel. 2020. Factors influencing efficacy of an area-wide pest management program in three urban forests. Urban Forestry & Urban Greening. 58:

Shin, WS, YH Jung, CM Lee, DS Kim, DW Lee. 2015. Development of Effective Screening Method for Efficacy Test of Trunk Injection Agents Against Pine Wood Nematode, Bersaphelenchus xylophilus in Japanese Black Pine, Pinus thunbergia.19:440-449.

Smitley, D.R., J.J. Doccola, and D. L. Cox. 2010. Multiple-year Protection of Ash Trees from Emerald Ash Borer with a Single Trunk Injection of Emamectin Benzoate, and Single-year Protection with an Imidacloprid Basal Drench. Arb. & Urban For. 36(5): 206-211.

Sousa, E., P. Neves, and M. Vieira. 2013. Prevention of pine wilt disease induced by *Bursaphelenchus xylophilus* and *Monochamus galloprovincialis* by trunk injection of emamectin benzoate. Phytoparasitica. 41: 143-148.

Stone, J., IH Sutherland, CS Sommerville, RH Richards, and KJ Varma. 1999. The efficacy of emamectin benzoate as an oral treatment of sea lice, *Lepeophtheirus salmonis* (KrÒyer), infestations in Atlantic salmon, *Salmo salar* L. Journal of Fish Diseases. 22: 261–270.

Su, C., S. Liu, S. Cao, S. Yin, C. Zhou, S. Gao, C. Jia, Y. Ji, Y. Lui. 2020. Self-assembled bovine serum albumin nanoparticles as pesticide delivery vectors for controlling trunk-boring pests. J Nanobiotechnol 18, 165 (2020). https://doi.org/10.1186/s12951-020-00725-z

Takai, K., T. Soejima, T. Suzuki, and K. Kawazu. 2000. Emamectin benzoate as a candidate for a trunk-injection agent against the pine wood nematode, *Bursaphelenchus xylophilus.* Pest Manag. Sci. 56: 937-941.

Takai, K., T. Soejima, T. Suzuki, and K. Kawazu. 2001. Development of a water-soluble preparation of emamectin benzoate and its preventative effect against the wilting of pot-grown pine trees inoculated with the pinewood nematode, *Bursaphelenchus xylophilus.* Pest Manag. Sci. 57: 463-466.

Takai, K., T. Suzuki, and K. Kawazu. 2003. Development and preventative effect against pine wilt disease of a novel liquid formulation of emamectin benzoate. Pest Manag. Sci. 59: 365-370.

Takai, K., T. Suzuki, and K. Kawazu. 2004. Distribution and persistence of emamectin benzoate at efficacious concentrations in pine tissues after injection of a liquid formulation. Pest Manag. Sci. 60: 42-48.

Tanis, S.R. 2013. Host plant interactions between emerald ash borer and five fraxinus species. Ph.D. Dissertation. Michigan State University. 174 pp.

Tanis, S.R. and D.G. McCullough. 2016. Evaluation of Xylem Discoloration in Ash Trees Associated with Macroinjections of a Systemic Insecticide. Arboriculture & Urban Forestry. 42: 389-399.

Vannatta, A.R., R.H. Hauer and N.M. Schuettpelz. 2012. Economic Analysis of Emerald Ash Borer (Coleoptera: Buprestidae) Management Options. J. Econ. Entomol. 105: 196–206.

Van Woerkom, A.H., S.G. Acimovic, G.W. Sundin, B.M. Cregg, D. Mota-Sanchez, C. Vandervoort, J.C. Wise. 2014. Trunk injection: An alternative technique for pesticide delivery in apples. Crop Protection. 65: 173-185.

Wang, J-H Wang, S-C Che, L-F Qiu, G. Li, J-L Shao, L. Zhong, G-F Zhang, H Xu. 2020. Efficacy of Emamectin Benzoate Trunk Injection Against the Asian Long-Horned Beetle [Anoplophora glabripennis (Coleoptera: Cerambycidae)] J. Econ. Entomol. 113: 2340–347.

Wheeler, C.E. 2020. Control of Pear Psylla in Pears and Black Stem Borer in Apples with Trunk Injection. Thesis Michigan State University. 87 pp.

Williamson, R.C. and F. Miller. 2009. Emerald ash borer: insecticide options for protecting ash trees from emerald ash borer and their effectiveness. *Tree Care Industry Magazine* 20(6):8-17.

Wise J.C., A.H. VanWoerkom, S.G. Aćimović, G.W. Sundin, B.M. Cregg and C. Vandervoort. 2014. Trunk Injection: A Discriminating Delivering System for Horticulture Crop IPM. Entomol Ornithol. Herpetol. 3: 126.

Wyka, S.A., J.J. Doccola, B.L. Strom, S.L. Smith, D.W. McPherson, S.G. Aćimović, and K.D. Klepzig. 2016. Effects of Grosmannia clavigera and Leptographium longiclavatum on Western White Pine Seedlings and the Fungicidal Activity of Alamo®, Arbotect®, and TREE-äge®. Arboriculture & Urban Forestry 2016. 42(2): 84–94.

Yang. D-C;F-F. Hao, Y. Zhang, L-P. Zhang, F-G. Luan, J-P. Zeng. 2018. Effect of Trunk Injection of Pesticides on Physiological Properties and Protective Enzymes in Leaves of Pinus massoniana. J. Zhejiang.

Zhang, J., J. Li, J. Huang, Y. Tang, and X. Shi. 2018. Effects of tree species and crown size on the absorption and conduction of insecticides applied by trunk injection. Chinese J. Pesticide Sci.20: 529-534.

Zhang, X., Q. Han, T. Wang, L. Wu, A Chen. 2019. Preparation of 10% emamectin benzoate soluble granule for trunk injection and its control efficacy on pine wilt disease. Chinese J. Pesticide Sci. 21: 538-544