

Efficacy of Foliar Applications, Trunk Injections, and Soil Drenches in Reducing Populations of Elongate Hemlock Scale on Eastern Hemlock

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Abstract. We examined the efficacy of two approaches for controlling elongate hemlock scale on eastern hemlocks in an arboretum. One approach relied on foliar applications of an insect growth regulator, pyriproxyfen, and horticultural spray oil when crawlers were abundant. The second approach evaluated soil drenches and trunk injections of the systemic insecticides imidacloprid, dinotefuran, and acephate. Foliar applications of pyriproxyfen and horticultural oil provided superior levels of control of elongate hemlock scale compared with soil drenches, trunk injections, or implants of insecticides in the year that applications were made. After foliar sprays, population reductions were rapid and, in the case of pyriproxyfen, lasted into the second growing season. By the third year, significant differences in elongate hemlock scale populations were no longer found among trees treated with insecticides and those that were not. Imidacloprid applied as a soil drench had limited efficacy in reducing populations of elongate hemlock scale on one date in the first season. Acephate implants and trunk injections of dinotefuran did not reduce the abundance of elongate hemlock scale relative to untreated trees. Arborists can achieve high levels of control of elongate hemlock scale with foliar sprays of pyriproxyfen or horticultural oil applied when crawlers are abundant in spring.

Key Words. Acephate; dinotefuran; *Fiorinia externa*; horticultural oil; imidacloprid; plant health care; pyriproxyfen; systemic insecticides.

Several sucking insects in the order Hemiptera attack and kill hemlocks native to North America, including eastern hemlock, *Tsuga canadensis*, and Carolina hemlock, *Tsuga caroliniana*, in natural and managed landscapes. The hemlock woolly adelgid, *Adelges tsugae* (Adelgidae), is the most important pest of hemlocks. At least four species of armored scales (Diaspididae) attack *T. canadensis* in the eastern United States. Included in this list are three exotic species: elongate hemlock scale (EHS), *Fiorinia externa* Ferris; *Nuculaspis tsugae* (Marlatt); and cryptomeria scale, *Aspidiotus cryptomeriae* Kuwana. The elongate hemlock scale and *N. tsugae* are serious pests of hemlocks and several other conifers in the Northeast and Midatlantic regions (McClure and Fergione 1977; Stimmel 1986) (Figure 1). Cryptomeria scale has increased in importance in recent years in the Midatlantic region and is often observed at damaging levels in landscapes (Stimmel 1986; Gardosik 2001). A fourth native armored scale, the hemlock scale, *Abgrallaspis ithacae*, is uncommon in the Northeast and Midatlantic region and rarely reaches damaging levels on either species of eastern hemlock (Stimmel 2000). EHS can decimate hemlocks (Garrett 1965; Wallner 1962; McClure and Fergione 1977; McClure 2002) causing discoloration of foliage, thinning and dieback of the canopy, and, ultimately, death of the tree. The death of trees in urban landscapes results in significant economic loss. The loss of stands of hemlocks in forests threatens delicate upland watersheds and eliminates unique sources of germplasm when ancient hemlocks die.

Davidson and McComb (1958), Garrett (1965), and Wallner (1962) were among the first to describe the biology, damage, and management of EHS in Maryland and New York, U.S., respectively. McClure and Fergione (1977) and McClure (1978) pro-

vided detailed accounts of the distribution, abundance, and biology of elongate hemlock scale and *N. tsugae* and their natural enemies in Connecticut. McClure (2002) provided the following summary of the biology of elongate hemlock scale: “The elongate hemlock scale completes two generations each year in the Southern and Mid-Atlantic States, but usually only one in the Northeast. Its life stages are broadly overlapping everywhere, so crawlers can be found throughout the spring and summer. Crawlers are the only stage capable of dispersing and establishing new infestations. Dispersal between trees is primarily by wind and birds. Females have three stages of development after the egg, while males have five. Within a day or two after hatching, crawlers of both sexes settle beneath the thin waxy cuticle on the lower surface of the youngest hemlock needles and begin to feed. The first-stage nymph for both sexes secretes a cover around itself as it grows. It then molts into a second feeding stage, continues to grow and add to its cover. The second-stage female then molts into the adult feeding stage. The second-stage male molts into a non-feeding prepupa and spins a cocoon, where it pupates before it emerges as an adult. The adult male mates with the female and dies soon thereafter without feeding. The adult female lays about 20 eggs within her cover. When crawlers hatch, they exit through a small opening at the posterior end of the cover. Elongate hemlock scale usually overwinters, either as an egg or as an inseminated adult female.”

In Virginia and Maryland, U.S., EHS completes two generations each year (Garrett 1965; Kosztarab 1996). Early attempts to control EHS focused on the use of contact insecticides such as dimethoate applied at the emergence of crawlers (Davidson and McComb 1958; Wallner 1962). Well-timed applications of contact insecticides such as horticultural oil or dimethoate applied to



Figure 1. Elongate hemlock scale is one of the most destructive armored scales attacking hemlocks and other conifers in the United States.

foliage kill crawlers and provide control (McClure 1977a; Stimel 2000; McClure 2002). This approach is most useful in landscape settings where trees can be completely covered and are not obstructed or near water. McClure (1977a) found that incomplete coverage of the canopy resulted in rapid resurgence of EHS resulting from elimination of mobile natural enemies or enhanced host quality resulting from relaxation of intraspecific competition. Unfortunately, foliar applications to large trees in urban settings are often complicated or impossible as a result of proximity of buildings, presence of vehicular and pedestrian traffic, and restrictions related to pesticide movement and exposure to nontarget organisms. Similarly, in remote locations in natural forest stands such as at the headwaters of small mountain streams, it may be impossible to access infested trees by vehicles with hydraulic applicators. In these situations, systemic insecticides may provide the only means of administering insecticides. The purpose of this study was to examine the efficacy of two approaches for controlling EHS: 1) foliar applications of the insect growth regulator pyriproxyfen (Distance; Valent Corporation, Walnut Creek, CA) and horticultural spray oil (Horticultural Oil; Lesco, Cleveland, OH); and 2) soil and trunk injections of the systemic insecticides imidacloprid (Merit; Bayer Environmental Science, Research Triangle Park, NC; Imicide; J.J. Mauget Corporation, Arcadia, CA), dinotefuran (Valent Corporation), and acephate (Acecaps 97; Creative Sales, Incorporated, Freemont, NE).

The objectives of this study were threefold. First, studies were conducted to determine if single applications of insecticides listed previously provided significant control of EHS. Second, investigations were made to determine differences in scale populations to applications of insecticides over the course of a single growing season. Finally, scale populations were examined on treated and untreated trees 1 and 2 years after the initial application of insecticides to determine if the abundance of EHS was reduced on trees treated with insecticides for more than 1 year.

MATERIALS AND METHODS

Several hundred specimens of *T. canadensis* populate the grounds of the United States National Arboretum in Washington,

DC. Before the study, we identified 115 hemlocks infested with EHS. Sixty-three hemlocks were selected for use in this study. Trees were selected on the basis of proximity to each other, similarity in size, history of pesticide treatments, and accessibility for pesticide applications and sampling. Trees were excluded if insecticide applications posed risks such as drift to adjacent properties, residues on vehicles, or exposure of visitors to the arboretum. All hemlocks were mature trees, parts of managed landscape plantings, and ranged in size from 11 cm (4.4 in) to 94 cm (37.6 in) diameter at breast height (dbh). They had not been treated with any insecticides for at least 5 years before the experiment and received no insecticide applications other than those in this study. Trees were randomly assigned to one of seven experimental regimes. Nine trees were left untreated to serve as controls. Nine trees received a foliar application of pyriproxyfen (Distance) at a rate of 0.24 L per 378.5 L (8 oz per 100 gal). Nine trees received a foliar application of horticultural spray oil (Lesco Horticultural Spray Oil) at a rate of 2 gal per 100 gal (2 L per 100 L). Foliar sprays were applied to runoff with an FMC/John Bean sprayer (FMC, Houston, TX). Nine trees received a basal soil drench of imidacloprid (Merit 75 WP) at a rate of 1.96 g per 2.54 cm dbh (0.07 oz per in dbh) applied in 1.9 L per 2.5 cm per in dbh (0.5 gal per in dbh). When present, mulch was removed before application of Merit and replaced after the application. Nine trees received injections of imidacloprid formulated as Imicide delivered by Mauget injection using 3 mL (0.1 fl oz) capsules. The number of capsules used per tree was determined by measuring the dbh in inches, dividing this number by two, and injecting the tree with the resultant number of capsules. Injection sites were evenly spaced around the circumference of the tree. Holes were drilled at a slight downward angle at the root flare area (approximately 6 to 8 in [15 to 20 cm]) aboveground level using a clean 11/64 in (0.4 cm) drill bit. Holes were drilled to a depth of 3/8 to 1/2 in (0.60 to 1.3 cm). Nine trees received applications of acephate formulated as Acecap 97 implants. The number of implants was determined by multiplying the dbh of the tree in centimeters by 3.14 and dividing the product by 10.16. Holes for implants were made at 4 in (10.2 cm) intervals starting approximately 12 in (30.5 cm) inches aboveground level and spiraling up and around the tree using a clean 3/8 in (0.95 cm) drill bit. Holes were drilled at a right angle to trunk to a depth of 1.25 in (3.2 cm). Nine trees received applications of 10% dinotefuran with Arborjet injection systems. Trees were treated with 10% dinotefuran formulation at 4 mL per 2.54 cm (0.14 fl oz per in) dbh. Two of the smallest diameter trees were treated using the air hydraulic injector at 5 mL (0.17 fl oz) per injection site. These trees received three injections evenly spaced around their circumference. Holes were drilled at a right angle to the trunk to a depth of 0.63 in (1.6 cm). Remaining trees were treated with the Arborjet Tree I.V. system. These trees received one injection site per in (2.5 cm) dbh. Holes were drilled at a right angle to the trunk to a depth of 0.63 in (1.6 cm). An average volume of 70.5 mL (2.38 fl oz) of dinotefuran was applied per tree.

Davidson and McComb (1958) were the first to report "that active crawlers and all stages developmental stages of both males and females are present throughout the year" in Maryland. Davidson and McComb (1958) noted and McClure (1978) later confirmed that peak periods of crawler activity occurred in late spring and early summer (May to July) and in late summer and early fall (August to November). Oil is a contact insecticide and

pyriproxyfen is a growth regulator. Both are recommended for use against scale crawlers (Raupp and Davidson 2003). At weekly intervals, we monitored EHS populations. In early June, most eggs had hatched and active and settled crawlers were abundant on new foliage. We timed applications of oil and pyriproxyfen to coincide with high densities of these life stages.

There are no published accounts regarding how rapidly imidacloprid, dinotefuran, or acephate are transported through roots or the trunk to the canopy of hemlocks at levels lethal to EHS. However, Ford et al. (2007) reported rapidly increasing levels of water use in eastern hemlocks in the northeastern United States between May and July. Systemic insecticides were applied between the middle of May and the middle of June when water use is high and translocation of insecticides is also likely to be high. Merit was applied as a soil drench on 20 May 2004. Imicide and Acecaps were applied on 3 June 2004. Arborjet applications of dinotefuran were made on 9 June 2004. As a result of the prolonged period of egg production by bivoltine scales (Davidson and McComb 1958; McClure 1978), settled crawlers and second instar nymphs were present on trees for more than 4 months between the application of systemic insecticides and the last date that scales were sampled in October 2004. To ensure that we did not miss lethal effects of systemic insecticides as a result of slow uptake or distribution, we sampled populations of scales for two additional years, 2005 and 2006.

To determine the effects of insecticides on EHS, we removed branches with hand or pole pruners from four cardinal locations on each tree. Branches were sampled from 1 to 4 m (3.3 to 13.2 ft) above the ground. Abundance of EHS was estimated by counting the number of living scales on 500 needles of terminal, young growth. We counted scales only on young growth in the lower crown because young needles in this stratum are highly preferred for colonization by EHS (McClure 1977b). This sampling regime was validated for estimating density of EHS by McClure (1977a, 1977b, 1977b) and used to study seasonal phenology, dispersal, parasitism, and competitive interactions of elongate hemlock scale (McClure 1977a, 1977b, 1977b, 1978, 1980, 1991; McClure and Fergione 1977). After branch samples were removed, they were refrigerated, taken to the laboratory, and examined microscopically. To determine viability of scales, a probe was used to remove the scale cover and pierce each scale. Scales that bled were counted as living. Those that did not bleed were considered dead. The number of living scales per 500 needles was the estimate of scale abundance. Trees were sampled on 7 July, 8 August, 7 September, and 7 October 2004; on July 7, 6 September, and 6 October 2005; and on 11 July, 7 August 7, and 12 September 2006.

Before the analysis, data were examined for normality using a Shapiro-Wilk test and homogeneity of variance using a Bartlett's test (Zar 1999; Statistix Analytical Software 2005). During the first year of the study, 2004, raw data did not conform to the assumptions for analysis of variance and were modified with a log₁₀ transformation. Effects of insecticide applications were examined within each sample date using a one-way analysis of variance followed by a least significant difference test to separate means (Zar 1999; Statistix Analytical Software 2005). During the second and third years of the study, 2005 and 2006, raw data did not conform to the assumptions for analysis of variance and were modified with a log₁₀ transformation. Although this transformation corrected for normality, homogeneity of variance could not be achieved through transformations. Therefore, to

evaluate the efficacies of insecticides and determine if levels of control differed, we compared treatments for each date samples were collected in 2005 and 2006 with a Kruskal-Wallis nonparametric analysis of variance (Zar 1999; Statistix Analytical Software 2005). After the analysis, all pairwise comparison tests were used to determine which treatment means differed within each date (Statistix Analytical Software 2005).

RESULTS

In 2004, at least one of the insecticides significantly reduced numbers of EHS relative to untreated trees on all dates: 7 July 2004, $F_{6,56} = 3.00$, $P < 0.01$; 8 August, $F_{6,56} = 6.87$, $P < 0.0001$; 7 September, $F_{6,56} = 5.15$, $P < 0.0001$; and 7 October, $F_{6,56} = 3.46$, $P < 0.005$. Of all materials tested, pyriproxyfen provided the most reliable and prolonged levels of control (Figure 2). Abundance of scale on trees treated with pyriproxyfen differed from untreated trees on all sample dates. The abundance of EHS on trees treated with horticultural oil differed from untreated trees on two of four dates and trees treated with imidacloprid as Merit differed from untreated trees on 7 October, the last date trees were sampled in 2004. The most dramatic difference between untreated trees and those treated with insecticides occurred on 7 September when trees treated with pyriproxyfen, and horticultural oil had 98% and 95% fewer scales than untreated trees, respectively (Figure 2). This reduction was likely the result of the destruction of scales in the first generation in June when insecticides were applied. Fewer surviving scales limited recruitment of the second generation of scales later in the year.

In 2005, scale populations were highly variable and only trees treated with pyriproxyfen had significantly fewer scales than untreated trees on the sample date of 6 September, Kruskal-

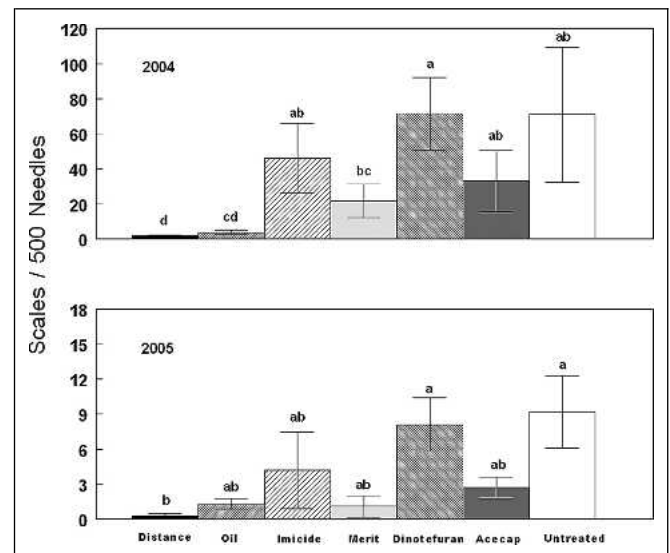


Figure 2. Densities of elongate hemlock scale on trees treated with Distance (pyriproxyfen), horticultural oil, Imicide (imidacloprid), Merit (imidacloprid), dinotefuran, Acecaps (acephate), and untreated (control) trees in September 2004 and 2005. Bars represent means and vertical lines are standard errors. Within each year, means that share a letter do not differ by a least significant difference test ($P < 0.05$) (2004) or an all pairwise comparison test ($P < 0.05$) (2005).

Wallis statistic = 22.67, $P < 0.0001$ (Figure 2). In 2006 only on the third sample date, 12 September, was a marginal level of significance found in the abundance of EHS among treatments; Kruskal-Wallis statistic = 12.77, $P < 0.047$. An all pairwise comparison test failed to resolve differences among treatment means. Numerically, trees treated with pyriproxyfen, horticultural oil, and imidacloprid (Merit) had the fewest scales.

DISCUSSION

Early attempts to control EHS with mixtures of malathion and DDT met with limited success as a result of the multigenerational nature of this scale (Davidson and McComb (1958). Wallner (1962) was the first to report acceptable levels of control using foliar applications of dimethoate, carbaryl, and phosphamidon. These insecticides resulted in reductions of scales of 100%, 75%, and 89%, respectively. Dimethoate continues to be an effective insecticide for controlling elongate hemlock scale in nurseries and Christmas tree plantations. Heller and Kline (2005a) reported high levels of control of elongate hemlock scale on Fraser fir with multiple applications of dimethoate.

The efficacy of horticultural oil as a management tool for armored scales on narrow-leaved evergreens such as hemlocks and pines is inconclusive. McClure (2002) recommended thoroughly drenching hemlocks during spring and again in summer, if needed, with horticultural oil to reduce populations of EHS in managed landscapes. However, Heller and Kline (2005b) found single applications of horticultural oil ineffective in reducing populations of EHS on Canaan fir, *Abies balsamea* var. *phanerolepis*. In the same study, a spring application of Distance also failed to control EHS (Heller and Kline 2005b). Applications of horticultural oil and chlorpyrifos provided moderate control of a related species of armored scale, *Chionaspis heterophyllae*, on needles of scots pine, *Pinus sylvestris* (Fondren and McCullough 2005).

Regarding the use of imidacloprid (Merit) to control armored scales on conifers, Cooper and Cranshaw (1995) found that imidacloprid failed to provide control of pine needle scale on Austrian pine. Sadof and Sclar (2000) and Rebek and Sadof (2003) also found imidacloprid (Merit, Marathon) applied as a soil drench did not control euonymus scale on *Pachysandra terminalis* or *Euonymus fortunei*, but like in the current study, pyriproxyfen (Distance) provided good levels of control of euonymus scale (Rebek and Sadof 2003).

In summary, foliar applications of pyriproxyfen and horticultural oil provided superior levels of control compared with soil drenches, trunk injections, or implants of insecticides for the control of EHS in a landscape setting. After foliar sprays, population reductions were rapid and lasted into the second growing season. We doubt that prolonged reductions were the direct result of residual toxicity of these materials because we found no evidence for long residual activity of oil or pyriproxyfen in the literature. Instead, it appears that once scale populations are reduced, several months or even years may pass before populations of EHS rebound. Imidacloprid applied as a soil drench shows some efficacy in reducing populations of EHS. The possibility that imidacloprid can reduce populations of EHS is intriguing. To document this effect convincingly will require further testing with a much larger sample of trees or with a sample of trees less variable in abundance of EHS than those used in this study. Acephate implants and trunk injections of dinotefuron did not reduce the abundance of EHS relative to untreated trees.

Acknowledgments. We thank two reviewers for comments that improved the manuscript. We thank Kate Laskowski for technical assistance. We thank the U.S. Forest Service, Forest Health Technology Enterprise Team for supplying funds to conduct this research. We also thank F.A. Bartlett Tree Expert Co., Creative Sales, Inc., Arborjet Environmental Horticulture, and U.S. National Arboretum for providing materials, study sites, and labor that supported this research.

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Résumé. Nous avons étudié l'efficacité de deux approches de contrôle de la cochenille de la pruche sur la pruche du Canada au sein d'un arboretum. Une approche se base sur l'application foliaire d'un régulateur de croissance de l'insecte, le pyriproxifen, et l'application d'huile horticole lorsque les larves sont abondantes. La seconde approche se base sur l'injection dans le sol et le tronc d'insecticide systémique, soit l'imidacloprid, le dinotefuron et l'acephate. Les applications foliaires de pyriproxifen et d'huile horticole ont donné des degrés élevés de contrôle de la cochenille de la pruche, et ce comparativement aux injections dans le sol ou le tronc ou encore la pose d'implants d'insecticide durant l'année où les traitements ont été faits. Après les vaporisations foliaires, les réductions de populations ont été rapides et, dans le cas du pyriproxifen, le traitement a duré jusque lors de la seconde saison de croissance. Lors de la troisième année, des différences significatives dans les populations de cochenille de la pruche n'étaient plus observées entre les arbres traités avec des insecticides et ceux non traités. L'imidacloprid appliqué par injection dans le sol avait une efficacité limitée pour diminuer les populations de cochenille de la pruche à une date fixe durant la première saison de croissance. Les implants d'acephate et les injections dans le tronc de dinotefuron n'ont pas diminué l'abondance de cochenille de la pruche par rapport aux arbres non traités. Les arboriculteurs peuvent atteindre des degrés élevés de contrôle de la cochenille de la pruche avec des applications foliaires de pyriproxifen ou d'huile horticole lorsque les larves sont abondantes au printemps.

Zusammenfassung. Wir untersuchten die Effizienz von zwei Versuchen, die Hemlocktannenschildlaus auf Hemlocktannen in einem Arboretum zu kontrollieren. Ein Versuch basierte auf Blattbehandlungen durch einen Wachstumsbegrenzer für Insekten, Pyriproxifen, und einem Pflanzenöl, nachdem die Insekten geschlüpft waren. Der zweite Versuch bewertete Bodengräben und Stamminjektionen mit den systemischen Insektiziden Imidacloprid, Dinotefuron und Acephat. Die Blattanwendungen mit Pyriproxifen und Pflanzenöl brachten im gleichen Jahr im Vergleich zu Bodengräben, Stamminjektionen und systemischen Insektiziden beste Ergebnisse bei der Kontrolle von der Schildlaus. Nach der Blattbehandlung reduzierte sich die Population drastisch und im Fall von Pyriproxifen und hielten sich auf diesem Level bis in die zweite Wachstumsperiode. Im dritten Jahr wurden keine signifikanten Unterschiede in den Schildlauspopulationen auf den behandelten und unbehandelten Bäumen mehr gefunden. Imidacloprid, appliziert als Bodenlösung zeigte eine begrenzte Effizienz bei der Reduktion der Populationen. Acephat-Implantat und Stamminjektionen mit Dinotefuron konnten die Population von Schildläusen auf behandelten Bäumen im Vergleich zu unbehandelten Bäumen zu reduzieren. Arboristen können mit Blattbehandlungen durch einen Wachstumsbegrenzer für Insekten, Pyriproxifen, und einem Pflanzenöl, nachdem die Insekten geschlüpft waren die höchsten Grade bei der Kontrolle von Hemlocktannenschildläusen erzielen.

Resumen. Examinamos la eficacia de dos enfoques para controlar la escama del abeto en un arboretum. Una aproximación fue la de aplicaciones foliares de un regulador del crecimiento del insecto, pyriproxifen, y aspersión de aceite horticola cuando las ninfas fueran abundantes. El segundo enfoque evaluó zanjas en el suelo e inyecciones al tronco de insecticidas sistémicos: imidacloprid, dinotefuron, y acephate. Las aplicaciones foliares de pyriproxifen y aceite horticola dieron niveles superiores de control de la escama comparados con las zanjas, las inyecciones o implantes de insecticidas, en el año en que se hicieron estas aplicaciones. Después de las aplicaciones foliares, las reducciones de la población fueron rápidas y, en el caso de pyriproxifen, tardó hasta la segunda estación de crecimiento. Para el tercer año, no continuaron diferencias significativas en las poblaciones de la escama entre los árboles tratados con insecticidas y los no tratados. Imidacloprid aplicado en zanjas en el suelo tuvo limitada eficacia en la reducción de las poblaciones de la escama en una fecha en la primera estación. Los implantes de acephate y las inyecciones al tronco de dinotefuron no redujeron la abundancia de las escamas con relación a los árboles no tratados. Los arboristas pueden alcanzar altos niveles de control de la escama con aplicaciones foliares de pyriproxifen o aceite horticola cuando las ninfas sean abundantes en la primavera.