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 cryptome- ria scale, *Aspidiotus cryptomeriae* Kuwana. The elongate hemlock scale and *N. tsugae* are serious pests of hemlocks and several other conifers in the Northeast and Mid-Atlantic regions (McClure and Fergione 1977; Stimmel 1986) (Figure 1). Cryptomeria scale has increased in importance in recent years in the Mid-Atlantic region and is often observed at damaging levels in landscapes (Stimmel 1986; Gardosik 2001). A fourth native armored scale, the hemlock scale, *Abgrallaspis ithace*, is uncommon in the Northeast and Mid-Atlantic 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) provided 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...
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; Imiticide; J.J. Maugnet 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 over the course of a single growing season. Finally, scale populations were examined 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 Imiticide delivered by Maugnet 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 flair area (approximately 6 to 8 in [15 to 20 cm] above ground 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 Acecaps 97 implants. The number of implants was determined by multiplying 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 flair area (approximately 6 to 8 in [15 to 20 cm] above ground 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 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. Nine 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 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 imidaclopid, 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, 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 imidaclopid 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-
Walls 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 (2005b) 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. planerolepis. 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 Sciar (2000) and Rebek and Sadof (2003) also found imidacloprid (Merit, Marathon) applied as a soil drench did not control euonymous scale on Pachysandra terminalis or Euonymous fortunei, but like in the current study, pyriproxyfen (Distance) provided good levels of control of euonymous 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 dinotefuran did not reduce the abundance of EHS relative to untreated trees.

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**LITERATURE CITED**


McClure, M.S., and M.B. Fergione. 1971. *Fiorinia externa* and *Tsugaspodius* (Homoptera: Diaspididae); distribution, abundance, and

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