Elongate Hemlock Scale and its Natural Enemies in the Southern Appalachians

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ABSTRACT

The development and distribution of the elongate hemlock scale, *Fiorinia externa*, and its natural enemies on eastern hemlock, *Tsuga canadensis*, were evaluated from forest and urban sites established in eastern Tennessee and western North Carolina. This species is widespread throughout the area and has two overlapping generations annually. A heavy infestation level ranging from 3.7 to 4 on a scale of 0 to 4 was found on eastern hemlocks at four sites. The density of *F. externa* ranged from 2.6 to 7.0 individuals per needle.

The hymenopteran parasitoid, *Encarsia citrina*, parasitized the elongate hemlock scale at all sites. Parasitism rates were variable among the forest and urban sites. Parasitism at the urban sites ranged from 17.9% to 41.3%, while the rate at the forest sites ranged from 20% to 23.9% over the season. Eight predators (neuropterans *Coniopteryx* sp. and *Hemerobius stigma* and the coccinellids *Chilocorus stigma, Harmonia axyridis, Rhyzobius lophanthae, Scymnillus horni*, and two unidentified lady beetle species) were collected and evaluated in feeding behavior, survival, development, and reproduction tests using various densities of the elongate hemlock scale.

KEYWORDS

Elongate hemlock scale, eastern hemlock, biological control, *Fiorinia externa.*

INTRODUCTION

The Southern Appalachian ecosystem represents a sensitive forest system currently significantly impacted by invasions of exotic insect pests. This region includes some of the largest remaining remnants of eastern hemlock, *Tsuga canadensis* (L.) Carriere, in the world

with about 3,820 ha located within the Great Smoky Mountains National Park (GRSM) in Tennessee and North Carolina. The exotic hemlock woolly adelgid, *Adelges tsugae* Annand, is a pernicious pest causing destruction to eastern hemlocks throughout the eastern U.S. and now threatens the eastern hemlocks in eastern Tennessee and western North Carolina. Also, the exotic elongate hemlock scale (EHS), *Fiorinia externa* Ferris, has become a significant pest of eastern hemlock in several areas, often co-existing with the hemlock woolly adelgid (McClure 1980b). EHS was first described in 1942 (Ferris 1942) from material collected earlier in Baltimore, Maryland, and Queens, New York (Davidson and McComb 1958, Takagi 1963, Talerico et al. 1967). This exotic species is now established in 14 states throughout the eastern U.S. as well as Canada, Asia, and Europe. EHS was recently discovered infesting eastern hemlocks in the GRSM and in Knox Co., Tennessee (Buck 2004). The host range of EHS includes species of *Abies, Cedrus, Picea, Pinus, Pseudotsuga, Taxus,* and *Tsuga,* with the latter taxa containing common hosts of EHS in the eastern U.S. (Kosztarab 1996, McClure and Fergione 1977). Although scale insect populations normally occur at low levels, changes in conditions and management practices that impact the natural enemy complex often enhance population outbreaks (Rebek and Sadof 2003, Sheffer and Williams 1987). EHS are small, cryptic scale insects capable of inflicting substantial damage to the host tree resulting in loss of plant vigor, dieback, needle drop, or death. Its waxy covering allows EHS to maintain a favorable humidity level, prevents rapid temperature changes, and functions as a protective barrier against chemical applications and natural enemies (Lambdin 2004).

The majority of information on the seasonal development of EHS and the impact of beneficial control agents was developed for populations in the northeastern U.S. (McClure 1977b, 1978b, and 1981). Several differences exist in the recorded information on EHS for the northern states compared to more southern distribution regarding their overwintering habits, number of generations annually, synchrony of parasitoid to host, and degree of parasitism. EHS is reported to have only one complete generation annually in Connecticut (McClure 1980b and 1981), although an occasional partial generation is reported to occur in warmer years (McClure 1978b and 1980b). However, it has two generations annually in Maryland (Davidson and McComb 1958) and Virginia (Kosztarab 1996). This scale insect is reported to overwinter as immatures, adult females, eggs, or in all stages (Kosztarab 1996, McClure 1977b and 1978b, Stimmel 1980). McClure (1977b) reported that EHS overwintered in the egg stage and later (McClure 1978a, Kosztarab 1996) as eggs and fertilized adult females. Also, McClure (1980b) noted that EHS was able to out-compete *Nuculaspis tsugae* (Marlatt), a second exotic species occurring on eastern hemlock in Connecticut. However, in Tennessee, *N. tsugae* has not been reported, but the native hemlock scale, *Abgrallaspis ithacae* (Ferris), has been documented on the needles of eastern hemlock (Lambdin and Watson 1980), and is commonly found throughout the region. While nitrogen fertilization of hemlock trees enhanced EHS population size (McClure 1977a, 1980a), the survival, development rate, and fecundity of EHS were reported to be negatively correlated to an increase in population size (McClure 1979b, 1980a, and 1980b). Control of EHS by insecticides or insecticidal soaps is limited to areas accessible to equipment required for application. Also, chemical applications that did not completely cover the tree were found to result in a resurgence of the EHS, which had a resulting faster developmental and fecundity rate than on unsprayed trees (McClure 1977a).

NATURAL ENEMIES

Biological control is a proven tool for managing certain species of herbivorous pests. However, a limited understanding of invasive pests and their natural enemy complex often hinders our ability to use them effectively. Recorded beneficials impacting populations of EHS include the parasitoids: *Encarsia citrina* (Craw), *Aphytis aonidiae* (Mercet), and *Prospaltella* sp.; and as predators: the mirids, *Atractotomus magnicornis buenoi* Drake and *Phytocorus* sp., a coniopterygid, *Conwentzia pineticola* Enderlein, and coccinellids *Chilocorus stigma* (Say) and *C. kuwanae* Silvestri (Davidson and McComb 1958, McClure 1979a and 1979b). The parasitoid *E. citrina* was reported to reduce populations of EHS up to 72% in Connecticut forests (McClure 1978a, 1978b, 1981, and 2003). When EHS and *N. tsugae* co-existed on the same host plant, McClure (1981) reported EHS out-competes its competitor by increasing their density and by a host shift by *E. citrina* that parasitizes *N. tsugae.* Also, the combination of parasitoids of *E. citrina* and *A. aonidiae* were reported to provide up to 96% control of EHS where two generations annually occur (McClure 1978a, 1979a, 1986) to only 2-55% parasitism in Connecticut and New York where only one generation per year occurs. Also, *C. kuwanae*, an egg predator of *Unaspis euonymi* (Comstock) recently introduced from Asia and successfully established in several parts of the U.S. (Drea and Hendrickson 1988, Lambdin 1995, Nalepa 1992, Van Driesche et al. 1998), is reported to feed on EHS.

OBJECTIVES

The objectives of this project were: (1) assess the densities, distribution, and development of EHS populations on eastern hemlock in forest and urban areas, and (2) identify and assess introduced and established natural enemies of EHS.

METHODOLOGY

OBJECTIVE 1

EHS-infested eastern hemlock trees at forest and urban sites in eastern Tennessee and Asheville, North Carolina were sampled monthly from June to December, 2004. Sites were selected with assistance from Rusty Rhea (USDA Forest Service, Asheville, North Carolina), Bill Hascher (Biltmore Estates, Asheville, North Carolina), and Charles Limebarger (Director, Lynnhurst Cemetery, Knoxville, Tennessee). In eastern Tennessee, one urban site at Lynnhurst Cemetery in Knoxville consisted of over 362 EHS-infested trees. In western North Carolina, one urban site was located on the grounds at the USDA Forest Service Headquarters and one urban and one forest site was located at the Biltmore Estates in Asheville. An infestation rating for EHS (0 = none, 1 = sporadic [1-3 limbs], 2 = light [4-6 limbs], 3 = moderate [7-10 limbs], and 4 = heavy [11+ limbs]) on eastern hemlock was conducted for each tree sampled. At the Lynnhurst and Biltmore forest and urban sites, infested trees were divided into four blocks, each consisting of ca. 50 trees, while the site at the USDA Forest Service Headquarters in Asheville, North Carolina, consisted of three heavily-infested trees. To assess density and development of EHS at each site, four branch samples (15-20 cm long, representing each

cardinal direction) were taken monthly from each of three trees per block, placed into plastic bags, labeled, and taken to the laboratory and processed. Data were recorded from 100 needles (50 from new growth and 50 from old growth) per cardinal direction for each tree per block that included stage of development, number of live and dead specimens per stage, and location on new or old growth needles.

To determine development time and number of generations of EHS, specimens from 12 branch samples (15-20 cm long) (one sample per tree per site) were removed every three to five days throughout the development period for each generation and monthly during the over-wintering period. Specimens were observed under a stereoscope, and data recorded for date, tree, block, site, number of specimens per stage, mortality per stage, and fecundity, and entered into Excel files for statistical analysis.

OBJECTIVE 2

Parasitoids were obtained and identified from collections of EHS on 100 needles from each of four branch samples (15-20 cm long from each of the four cardinal directions) from three trees in four blocks at each site, taken to the laboratory, and observed with a stereoscope to determine the number of live and dead parasitoids of male and female EHS. Parasitoid exit holes on the dorsum of the EHS were counted as an indicator of successful parasitoid emergence. From the remaining samples, 100 randomly selected EHS specimens from each site were processed, cleared in Essigs Aphid Fluid, mounted on slides, and examined for parasitoids. Also, two samples per tree (30 cm long) for five trees from five blocks per site were collected, taken to the laboratory, and placed into Plexiglas emergence cages to capture emerging parasitoids to establish the number of emerging parasitoids for each tree per site. Selected newly-emerged parasitoids were processed and observed using an electron microscope to evaluate morphological structures to identify the species. Data recorded included: number and date of emergence, parasitism rates per tree per block per site, seasonality numbers, and percent survivorship of parasitoids. Analysis of variance was performed to assess differences among trees and sites for numbers of EHS and parasitoids obtained, number of parasitoids emerging per host, development period, and survivorship of parasitoids from lab tests.

Established predators were obtained from four beat sheet samples from three trees at five blocks per site. Direct observations (at least one hour per site on each sampling date) of the foliage were conducted to determine predators associated with EHS. Predators collected were returned to the laboratory and maintained in 3.8L glass jars with moistened filter paper inserted to maintain humidity and ventilated by lids covered with polyester mesh. EHS-infested cuttings were placed in Floralife® floral-foam blocks (from Hummert International) with the base wrapped in Parafilm. These species will be evaluated in the future for predatory capabilities against EHS.

RESULTS

From May through December, 2004, 724 samples representing 168,253 EHS specimens on over 64,620 needles were collected to assess the density and distribution of EHS and search for potential biological control agents.

EHS BIOLOGY AND DEVELOPMENT

EHS has two complete overlapping generations per year at sites within the southern Appalachians. The spring peak for crawler emergence occurred in June, while the fall peak occurred in late October into November. Fall peak emergence for males occurred in August, coincident to the highest number of adult females. Gravid adult females were most numerous in late May and October-November. In this dimorphic species, females have three stages of development, while males have additional prepupal and pupal stages. Each female produced 12-16 eggs, which hatched over time.

Crawlers settled on the underside of needles on either side of the mid-vein. They tended to settle under the linear waxy filament produced by the needle to protect the stomates, which continued to develop over the dorsum of the immatures, disrupting the outline of their bodies. Crawlers insert their stylets into the stomata to extract nutrients from the needle. Upon developing into the second instar stage, both male and female lose their legs and eyes, and the antennae are reduced to one-segment. Females produce a grayish-brown waxy covering or test, while males produce a white test with parallel sides. Upon ecdysis, the adult female retains the exuviae of the second instar and continues development within this pupillarial casing. Males complete their prepupal and pupal stages within the test produced during their second stage. Upon maturity, winged adult males back out of their test through a flap located on the posterior end of the test. Males do not feed and live only 24 to 72 hours upon emergence. Although capable of flight, males tend to walk across the needles seeking out females for mating.

EHS POPULATION DENSITY

EHS infestation rating on host trees at the study sites ranged from 3.7 at the Lynnhurst urban site to 4.0 at the other three sites implying a well-established, heavy population. Several of the trees are exhibiting dieback and a few have died from these heavy infestations. While as many as 12 specimens were observed on EHS-infested needles, only 2.5 to 7 specimens survived to maturity. Data from samples evaluated from the four cardinal directions of the host trees at the four sites were variable depending upon site. However, the lowest numbers of EHS per site generally occurred on the northern side of the host tree, while the highest numbers occurred on the western side (Figure 1).

EHS NATURAL ENEMIES

Encarsia citrina was the only parasitoid of EHS recovered and represents the first documentation of this species in Tennessee. Newly-emerged specimens were processed and observed using an electron microscope. This endoparasitoid was widely distributed in both urban and forest sites in eastern Tennessee and western North Carolina. Parasite emergence holes were documented on male and female host tests, although the former represented less than 1% of the parasitism rate. In field samples, the parasitism rate was highly variable at the various sites. Successful emergence of parasitoids as evidenced by exit holes in the host at the three urban sites ranged from 16 to 33%, while the rates at the forest site ranged from 20 to 22% throughout the observation period (Figure 2). An additional 2.0, 6.5, and 8.3% of the hosts at the USDA Forest Service, Biltmore Estate urban, and Lynnhurst urban sites, respectively,

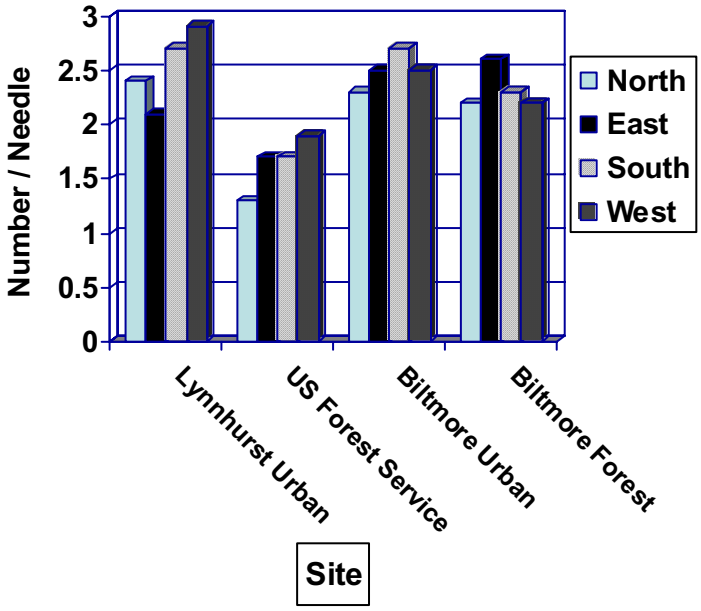

Figure 1. Average number of elongate hemlock scales at each cardinal direction at four sites.

and 2.5% at the Biltmore forest site were killed by parasitoids in the larval or pupal stages, increasing the mortality rate at all sites (Figure 3). Parasitoid peak emergence occurred in August. The population appeared to be lower in the forest sites over the season compared with those in the urban sites.

Female *E. citrina* lays eggs as late first and second instars. Only one adult wasp develops fully from each host. Upon entering the pupal stage, the parasitoid positions itself on its back with its dorsum toward the venter of the host. The adult chews a subcircular hole in the center of its host, emerging by placing its prothoracic legs through the hole followed by its head and pulling itself out of the host. Host finding involves flight to clusters of scales. A short hop-like flight pattern is used to move from needle to needle in search of suitable hosts. Females use their antennae tapping on the scales for host recognition. Emerging parasitoids were found from June through November. The overwintering stage of the parasitoid has not yet been determined.

Eight predators were collected from EHS-infested eastern hemlocks at the four sites from July to December 2004. These include the neuropterans *Coniopteryx* sp. and *Hemerobius stigma* Stevens and the coccinellids *Chilocorus stigma*, *Harmonia axyridis* Pallas, *Rhyzobius lophanthae* Blaisdell, *Scymnillus horni* Gordon, and two unidentified lady beetles. The two neuropteran species and *H. axyridis*, although commonly collected from eastern hemlock, did not feed on EHS during feeding tests. Fifty coccinellid specimens were collected from 180 beat sheet samples from August to December 2004. In three feeding tests with *C. stigma*, only minimal feeding damage to EHS prey offered was recorded. However, *R. lophanthae*, *S. horni*, and the three unidentified lady beetle species did successfully feed on EHS.

Of those predators collected, the lady beetles R. *lophanthae* and *S. horni* are recognized predators of armored scale insects capable of chewing through the hard waxy test of the EHS.

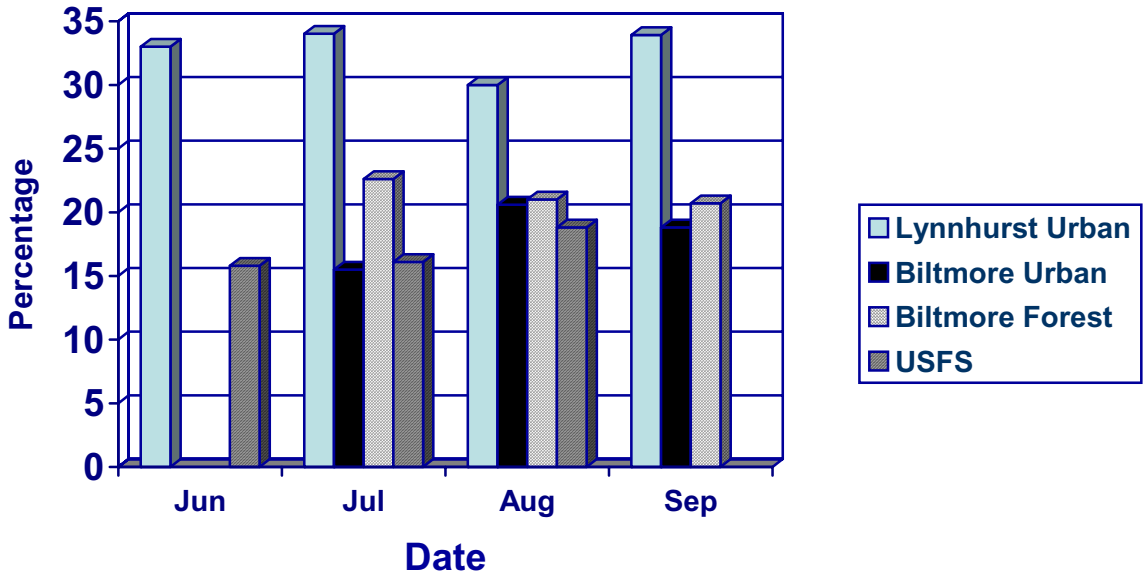

Figure 2. Percentage of paratism of the elongate hemlock scale by *Encarsia citrina* at urban and forest sites.

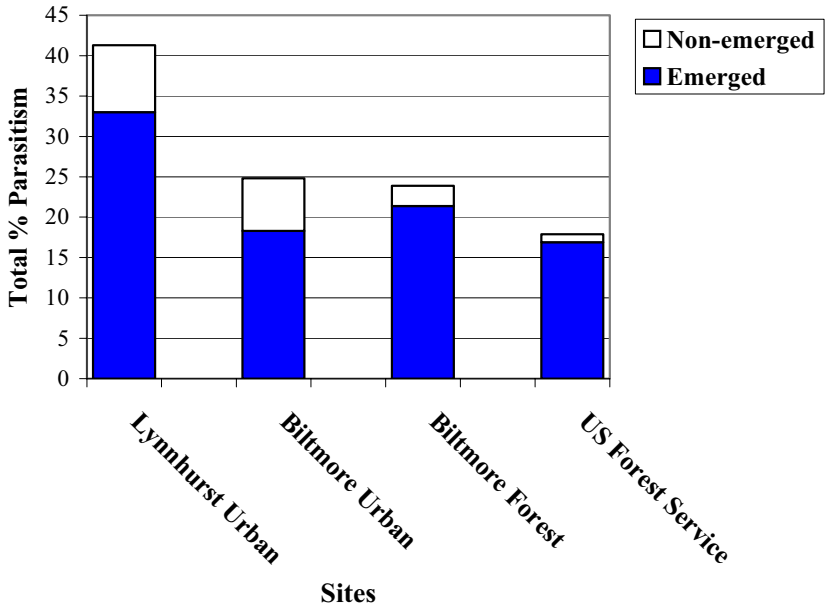

Figure 3. Percentage of emerged and non-emerged *Encarsia citrina* from elongate hemlock scale at urban and forest sites.

From beat sheet and branch cutting samples, both larvae and adults actively fed on prey throughout the summer, fall, and winter. In preliminary prey trials, *R. lophanthae* damaged 93% of adult EHS offered during 19 trials. This predator feeds on all stages of the prey and females lay their eggs singly or in clusters of 1 to 3 near or under the damaged scale tests. Stathas (2000) reported this predator consumed from 426 to 708 prey specimens during its lifespan.

Development and behavioral information for *S. horni* is lacking. From preliminary data, this predator was found to damage 48% of adult scales provided in three trials. Also, one of the undetermined species of coccinellids was observed to damage 17% of the scale specimens offered during three trial periods.

CONCLUSIONS

From June through December, 2004, development of EHS was investigated at four sites and feeding behavior of predators collected was initiated. Although EHS has now been collected from several counties within the southern Appalachians, their presence within a given area appears sporadic. However, populations in infested areas left uncontrolled can build to damaging levels. Populations of EHS are well-established at the study sites and the heavy infestations have killed several trees within the Lynnhurst Cemetery site. The parasitoids and predators established within the sites play an important role in regulating the pest populations. EHS was found for the first time at four locations in Knox County, Tennessee. The discovery of the parasitoid *E. citrina* and the predators *R. lophanthae* and *S. horni* represent new state records.

The discovery of *R. lophanthae*, *S. horni*, and the two unidentified coccinellid species may provide control opportunities against this invasive pest. Of these, *R. lophanthae* has been documented to effectively control diaspidid pests in over nine countries including the US. This predator is reported to have high fecundity (>600 eggs/female) and consumption rates, lacks larval parasitoids, and is active throughout the year (Stathas 2000). The discovery of this established predator presents the opportunity for augmentative releases to control EHS.

The lower population density of EHS per tree at the forest site compared to the urban site at the Biltmore Estates may be a result of a combination of factors, including natural enemies more effectively regulating the pest population. However, the parasitism rate in the forest appeared to be lower than the rate recorded in the urban sites. *E. citrina* emerged throughout the developmental cycle of EHS. Because EHS has two generations within the region, *E. citrina* appears to be highly synchronized with the pest populations. This parasitoid was considered to be the most important natural enemy of oystershell scale in Canterbury, North Carolina, during 1959-1960. It caused an average 40% parasitism from July to December, increasing from 10% in July to 85-100% in November. Future studies will be important in determining the impact of EHS on eastern hemlock in the southern Appalachians. The documentation of potential natural enemies that specifically feed on diaspidids may provide the opportunity for mass releases of these agents to manage the pest.

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