Elm leaf beetle adult feeding on foliage. The adults make small round holes in leaves. Photo by K. M. Daane.

Climatic Influences on Elm Leaf Beetle and Its Control Through Introduced Parasitoids and Insecticide Bands

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The elm leaf beetle (ELB) *Xanthogaleruca luteola*, was accidentally introduced from Europe into the United States in the 1830s, and was first reported in California in the 1920s. ELB is the third most important urban forest insect pest in the western U.S. and fifth in importance nationwide. For the estimated 2.5 million elms planted in California ELB is the major pest, and chemical foliar sprays are currently used extensively in densely populated areas to control it.

ELB adults typically spend the winter months inactive in buildings or other hiding places and become active on elm trees, primarily English and Siberian elms, in the spring when higher temperatures occur. The timing of beetle activity is highly dependent on temperature. After feeding on foliage for a few weeks the female beetles lay eggs in clusters. The eggs hatch in about a week, and the larvae voraciously attack the foliage. Most of the damage to the trees occurs from larval feeding. After several weeks and two molts, the mature larvae crawl down the trunk or drop from the leaves to the ground where they transform to the inactive pupal stage for several weeks. Adults emerge from the pupae and begin the egg-laying cycle to start another generation. In California, there may be one to several generations per year depending on the location.

Our project is aimed at developing a management system for this pest based on population level monitoring, climate, and environmentally sound control methods. Since 1986, our ELB studies have been conducted in California's northern and central coast ranges, in the Central Valley, and in the northeast mountain area.

Using Temperature Data for Timing of Sampling and Treatment

The timing of each elm leaf beetle life stage at a site depends primarily on heat accumulation over 11°C, the minimum temperature for ELB development. This heat accumulation can be expressed in units as degree-days above 11°C, or °D11°C. (The number of degree days in a day approximately equals that day's average temperature minus the threshold temperature, which in this case is 11°C.) Degree-days can be calculated accurately by using local daily minimum and maximum temperatures in a computer program (presently available at no cost on the UC IMPACT system). Since average temperatures in winter and early spring in northern and central California are usually near or below the minimum temperature, we began heat accumulations for our sites on March 1. We sampled a set of trees at each site once every week so we could relate peaks in each ELB stage to accumulation of heat units for that site. Those data enabled us to predict the time of ELB stages at any site based on degree-days accumulated. Monitoring degree-days can help determine when to sample eggs, release parasites or apply insecticides.

Insect development differs both within and between trees, even at the same site. The microclimate in the tree is likely to differ from temperatures in the standard weather shelters. The relationship between monitored temperatures and insect development will also vary through the season, in part because increasing defoliation will reduce the extent of canopy shading as the season progresses. Because of these variables we recommend that sampling be undertaken at least 50-75 degree-days before the peak values are reached.

Egg Density and Damage Prediction

Sampling elm leaf beetle eggs in spring provides a cost-effective means of predicting foliage damage later in the season and is a basis for making management decisions when most options are still open. Peak presence of first generation egg clusters occurs at about 275 degree-days, or from April to June at the sites in this study. Sampling consists of looking for egg clusters in 40 one-foot-long branch tips per tree, with those tips taken from the inner and outer portions of the lower crown in the four cardinal directions. Each sample is also rated on a 0-10 scale for visual damage due to ELB feeding. In 1986 and 1987, the maximum number of first generation eggs predicted foliage damage to English elm and to a lesser extent to Siberian elm. Maximum egg numbers did not predict damage in 1988, probably because of differences in the pattern of egg laying apparently due to early warm and late cool weather as compared to 1986 and 1987.

The time required to count each tiny beetle egg (about 0.5 millimeters in diameter) would discourage monitoring in an operational program, particularly since the monitoring to identify the egg peak must be done on multiple samples from more than one tree on several dates. Therefore, the relationship between egg presence or absence and foliage damage was investigated to develop a more efficient sampling method.

Sampling branch terminals for presence or absence of first generation elm leaf beetle eggs did not predict damage to Siberian elm, but did significantly predict damage to English elm in 1986 and 1987. Egg presence-absence predicted damage to a lesser extent in 1988. If less than 20 percent of English elm branch terminals were infested with first generation eggs, cumulative foliage damage by late in the season usually did not exceed an apparently tolerable 30 to 40 percent.

Our research indicates that monitoring only first generation eggs may not be enough to predict damage over the entire season. When numbers of first generation eggs are low, the second generation egg peak (at about 870 degree-days) should also be monitored to detect a possibly high second generation.

Parasitoid Wasp Releases

In Europe a small wasp, *Tetrasticus gallerucae*, is an important control agent of ELB. The parasitoid female lays its eggs inside the beetle eggs. Several strains of this wasp were reared in insectaries in large numbers. The Stockton strain, originally from Morocco, was previously released in Northern California and has survived in Stockton for several years. In 1987, it was released for this project on English elms in a Sacramento Valley site and a coastal site. The Ohio strain, originally collected in Europe, was released on Siberian elms in a coastal site and an inland mountain site. Two strains collected in France were also released at several sites. In 1988, more than 30,000 of the parasitoids were released. Since early season releases increase the probability of recovery, about one third of the wasps were released before the end of May.

By the fall of 1988, *Tetrasticus gallerucae* parasitoids had been recovered from all sites in which they were released earlier that year. This was an improvement over previous years when recoveries were made at only about half of the release sites. On three of the sites large releases near the first generation egg peak resulted in significant reductions of the viable egg numbers during the second generation. In the two Siberian elm sites damage ap-

Elm leaf beetle egg cluster. Note parasitic wasp on lower right of egg mass. Photo by K. M. Daane.

Late stage elm leaf beetle larva feeding on foliage. Photo by K. M. Daane.

peared to be effectively reduced, while one of the English elm sites was still completely defoliated, and another was partially defoliated.

Before 1989, only 1 or 2 parasitized ELB egg clusters were found after winter at 3 of 17 release sites in Northern California. In 1989, however, at one site where a French strain was last released in 1987, 88 percent of ELB egg clusters were parasitized at the end of summer. This parasitism occurred too late in the season to prevent serious defoliation, but probably reduced defoliation the following spring by reducing overwintering ELB.

Periodic paratisitoid colonization may significantly reduce ELB populations, but satisfactory control by overwintering *Tetrasticus gallerucae* has not yet occurred. Laboratory studies indicate that for the strains we are currently using only a small percentage of the parasitoids survive for 6 months as adults or immature parasitoids in host eggs. Further research with different strains that may be better adapted to our climate is necessary.

Insecticide Bark Banding

Another treatment that takes advantage of the behavior of the ELB mature larvae is the application of an insecticide band to the bark about 2.5 meters above the ground. The insecticide, a 2-percent solution of carbaryl (Sevin SL) is applied in small quantities by hand spraying at this height where most other organisms, including humans and most beneficial insects, will not come in contact with it. The ELB larvae, however, migrate down the trunk and across the band when they are ready to pupate. We tested this method at two sites by banding about half the trees (30-40) at each site.

One carbaryl application to bark killed most mature larvae crawling down the trunk for at least two ELB generations or 14 weeks. Banding significantly reduced ELB damage on Siberian elm in northeast California with damage to treated Siberian elms not exceeding 30-40 percent. There was a significant reduction in damage on some banded English elms, but many were still severely defoliated. When we observed large larval numbers on some English elm, we noted many larvae dropping directly to the ground from the foliage rather than crawling down the trunk.

Recommendations

While further testing is underway to refine the relationships between temperature, elm leaf beetle populations, and damage, it is clear that sampling ELB populations at the times indicated by temperature monitoring is an effective means of allocating resources for control of ELB damage. Parasitoid releases show some potential for long-range control of the pest population, especially if strains can be found that will overwinter in Northern California in sufficient numbers. A recently developed strain of a bacterial insecticide (*Bacillus thuringiensis*) which may selectively control ELB is being tested, but meanwhile, bark banding with carbaryl can be effective on the moderate ELB populations usually found on Siberian elms.

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