A MONITORING SYSTEM AND DEVELOPMENT OF ECOLOGICALLY SOUND TREATMENTS FOR ELM LEAF BEETLE

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Abstract. Elm leaf beetle *(Xanthogaleruca luteola)* damage can be predicted in time to determine if treatment is necessary by determining the percentage of 30 cm (1 ft). branch terminals with ELB eggs. Sampling must be done and treatment decisions made separately for each ELB generation. When over 45% of branch terminals have ELB eggs in the week when egg density is at a maximum, treatment is warranted for the first generation; in the second generation when 30% of branches have eggs. Monitoring degree-days allows sampling and treatments to be scheduled for maximum efficiency and effectiveness. Environmentally acceptable treatments under development include release of the egg parasite *Tetrastichus gallerucae*, trunk banding with insecticide, and foliar spraying with *Bacillus thuringiensis* formulations. These methods have been developed primarily for English elm in northern and central California.

The elm leaf beetle, *Xanthogaleruca luteola* (ELB) is one of the most important urban tree pests in the United States. It is rated second in importance in the west and third nationwide, based on ranking of urban insect pests by city managers (15). In California, an estimated 2.5 million elms have been planted (14) and ELB is the most commonly treated pest on those elms (9).

The ELB was introduced into the eastern US in the 1830s and reached California in the 1920s. The beetles overwinter as adults in sheltered places, including buildings, and emerge in spring to feed and lay eggs on elm foliage. The yellow eggs are laid in clusters averaging 15 to 20 each. Larvae, the most damaging stage, develop through three instars on the foliage. Larval feeding can be distinguished from adult damage because larvae "skeletonize" the foliage, leaving a thin membrane instead of holes all the way through the leaf. Full-grown larvae crawl down the trunk and pupate near the base of the tree. In northern and central California where we work the ELB has from one to three generations per year depending on weather. Damage is greater on English elm than on Siberian elm in California, as beetles prefer English elm and Siberian elm is less susceptible to ELB feeding damage (11, 6). Thus we have concentrated our studies on English elm.

Since 1984 we have sampled over 200 elms in more then 25 cities in northern and central California. This paper presents an ELB monitoring system for damage prediction and treatment decision-making, and reports on tests of promising environmentally sound control stategies.

Temperature monitoring. The best times to sample and treat ELB can be determined by monitoring heat accumulation, expressed in degree-days (DD) (9; also see reference 1). We sampled eggs, three larval stages, and adults throughout the season at numerous sites and years, while monitoring DD above the ELB developmental threshold of 11 °C (50°F) starting 1 March at each site. Accumulated DD was recorded at the time of peak density of each life stage, and the mean DD for each stage calculated for all sites and years. These values (Fig. 1) can be used to predict when a stage will be most numerous at a particular site. Weather data can be obtained from nearby weather stations, on-site instruments (some of which calculate DD directly), or daily maximum/minimum temperatures from a local paper. Computer programs are available (see reference 1) to calculate DD from these data. In our studies, we measured accumulated DD at some sites using Omnidata Inc. Biophenometers. At other sites we calculated DD using data from nearby weather stations connected to theUniversity of California IPM computer system (12).

ELB monitoring. A 30 cm (1 ft) elm branch terminal was the sampling unit on which the moni-

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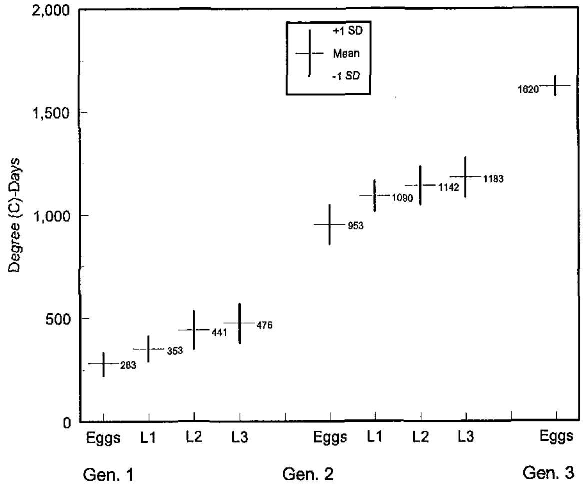

Figure 1. Elm leaf beetle degree-day development in California. Life stages vs. degree-days above 11°C from March 1 (means and standard deviations for 19 sites over a 6 year period).

toring system is based. ELB eggs were used for damage prediction because of convenience (they hold still) and sampling them allows time to make treatment decisions before the damaging larval stage occurs. After originally counting individual eggs, then clusters, we have now determined that recording presence or absence of eggs on each sample unit is adequate for damage prediction. Because we found significant differences in egg density between cardinal directions but not between upper and lower crown (16), branches are now taken from the more easily sampled lower crown in 8 segments per tree. These are north, east, south, and west, in both the inner crown (from trunk halfway to drip line) and the outer crown.

We began by sampling a small number of trees intensively (up to 120 branches/tree) on small pilot study sites, but found that damage was not adequately predicted for larger sites because of variation between trees. After a computer simulation of different combinations of numbers of trees and branches per tree, we developed a scheme that offers a good compromise between sampling effort and precision for sites of different sizes. This scheme (Table 1) gives the number of trees to be sampled and the number of branches to be examined per tree, depending on the site. Trees for sampling (the same trees should be sampled on each date) should be chosen randomly. Large sites may be divided into sections and trees chosen randomly within those sections so that sample trees will pick up any spatial variation in ELB density. For example, a 60-tree site could be divided into three 20-tree sections and five sample trees chosen per section.

We rate combined adult and larval damage on each 30 cm branch terminal, on a scale of zero to ten, where ten equals 100% defoliation. Damage is rated by comparing it to a visual standard (Fig. 2). Managers may wish to rate damage using this method, or may use the less labor intensive and less accurate method of visually rating the whole

Table 1. Suggested sample size for elm leaf beetle egg sampling on English elm in different size stands. Eight segments per tree sampled: north, east, south and west; inner and outer crown.

TOTAL TREES	SAMPLE TREES	SAMPLES/ TREE	SAMPLES/ SEGMENT	TOTAL SAMPLES	% TREES
3	3	40	5	120	100%
4	4	32	4	128	100%
5	5	32	4	160	100%
6	6	24	3	144	100%
7	6	24	3	144	86%
8	7	24	3	168	88%
9	8	16	2	128	89%
10	8	16	2	128	80%
11	8	16	2	128	73%
12	8	16	2	128	67%
13	8	16	2	128	62%
14	8	16	2	128	57%
15	8	16	2	128	53%
16	9	16	2	144	56%
17	9	16	2	144	53%
18	9	16	2	144	50%
19	9	16	2	144	47%
20	9	16	2	144	45%
21	9	16	2	144	43%
22	10	16	2	160	45%
23	10	16	2	160	43%
24	10	16	2	160	42%
25	10	16	2	160	40%
26	10	16	2	160	38%
27	10	16	2	160	37%
28	10	16	2	160	36%
29	10	16	2	160	34%
30	10	16	2	160	33%
40	12	16	2	192	30%
50	15	16	2	240	30%
60	15	16	2	240	25%

Criteria: 1)Minimum of 128 total branches
2)Minimum 25% of trees sampled.

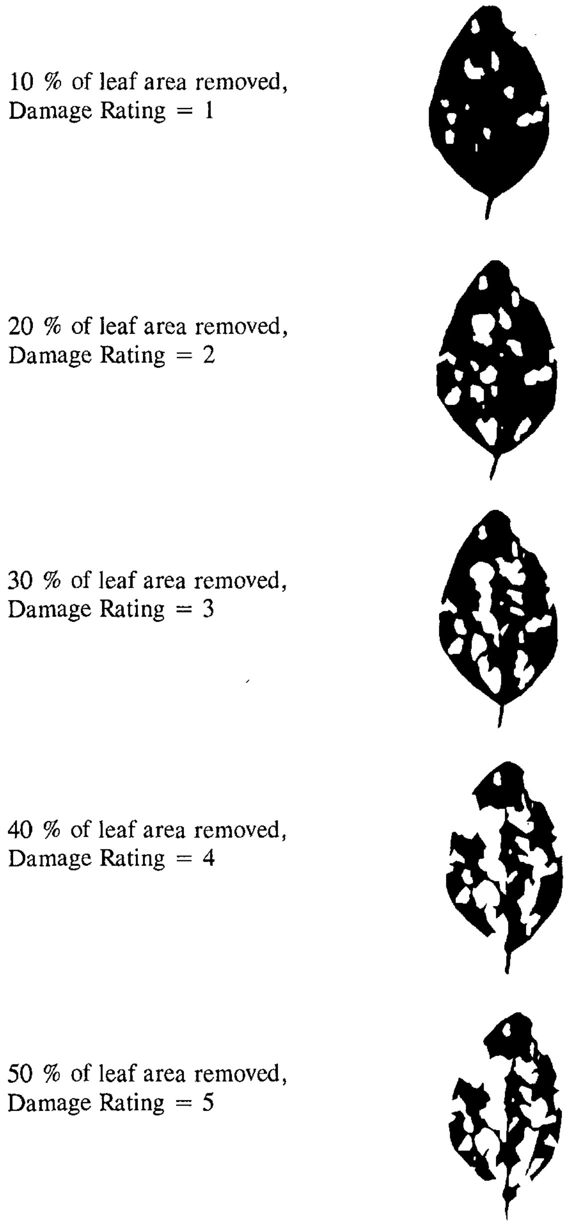

Figure 2. Standard for visual comparison to estimate elm leaf beetle apparent damage (rated 1-10 where 10=100%). Defoliation of 60-90% was estimated by comparison to the darkened areas of 40-10% of leaf area removed (i. e. 70% damage is the dark area of the "30% of leaf area removed" figure).

tree from 0-10 to estimate damage from each ELB generation. For sites with one ELB generation, generation damage is measured at the end of the season in fall. For sites with multiple generations, damage around the egg peak (or at the end of the season for the last generation), minus damage at the prior egg peak, reflects the effect of the previous generation.

Originally we hoped to predict ELB damage and the need for control throughout the season by sampling eggs in the first generation only. However first generation sampling did not predict season-long damage adequately due to differences in generational patterns between years and sites. The damage in all four years at Cloverdale, CA (Fig. 3) was well above the acceptable level but it would have been impossible to predict from the very low first generation samples in 1988 or even the moderate egg level for the first generation of 1989. Thus each ELB generation needs to be sampled; we recommend sampling weekly starting about 50-100 DD before the predicted egg peak for each generation (eg. 183-233 DD for

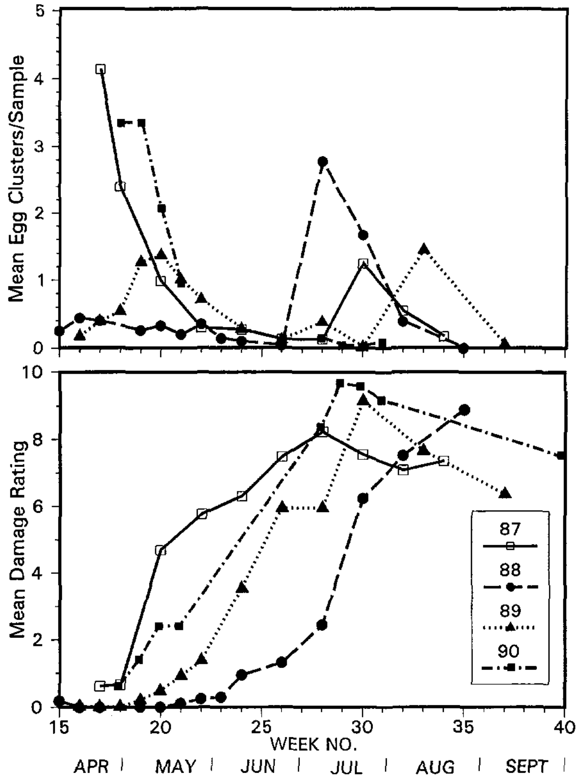

Figure 3. Elm leaf beetle egg cluster and damage means per sample vs. time on English elm for 4 years at Cloverdale, Sonoma Co., CA, 1987-1990.

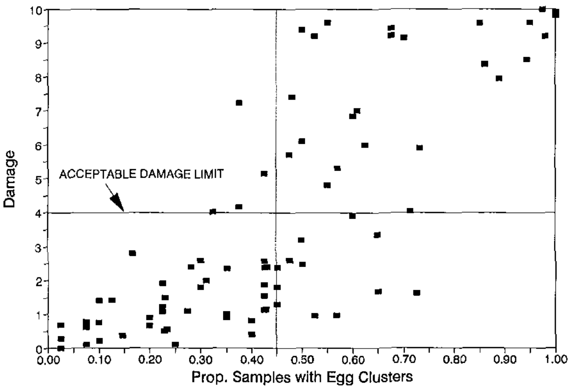

Figure 4. Percent of samples with viable elm leaf beetle eggs at egg peak and resulting damage to English elm in generation one, northern California, 1986-1989. Each point is one tree with 40 branch tip samples; less than 10% of trees below the 0.45 line had damage above level four.

generation one, 853-903 DD for generation two, etc.). Weekly Sampling should continue until the percentage of branches with eggs peaks and then falls, or until 100 DD have acuumulated after the predicted peak time. With accurate weather data, this will usually mean sampling three to four times per generation.

Since there were no established treatment thresholds we arbitrarily chose a damage rating of 4 based on our experience with homeowners and tree managers. In the first generation, if less than 45% of the branch samples have viable eggs then the damage at the end of that generation will be in the acceptable range (damage rating 4 or less than 40% defoliated), with a probability of error of 10% (Fig. 4). In generation 2 the maximum percentage of branches infested for acceptable damage was about 30%. This difference may be due to errors in determining the magnitude of the second egg peak in our early work, when the second generation was sampled only every two weeks. Continuing research will clarify the relationship between egg density and damage in the second and later generations.

Treatments

Parasitoid introductions. *Tetrastichus gallerucae* is a tiny wasp that parasitizes ELB eggs. Female *Tetrastichus gallerucae* parasitize from 50-90% of the eggs in each egg cluster (17) and usually also feed on remaining eggs, effectively destroying the cluster. The parasitoid was credited with largely suppressing an ELB outbreak in Paris, France in 1904 (10). In southern California the parasitoid has been established and has significantly reduced ELB defoliation (R.F. Luck, University of California at Riverside, personal communication. We developed a rearing method to supply large numbers of *T. gallerucae* for release (2). To date we have released approximately 300,000 parasitoids, of 5 different European strains, from 6 sources, at 25 locations in several different northern and central California climate types (Fig. 5) (5).

The parasitoid has the ability to build up high populations during the season. At one of our sites, 95% of ELB egg clusters were parasitized after a single release of 1000 parastiods in May, 1986 (4). The following year only one egg cluster was found and no detectable defoliation occurred. However at most sites it has failed to overwinter, and when it has overwintered has not been detectable until late in summer, sometimes reaching

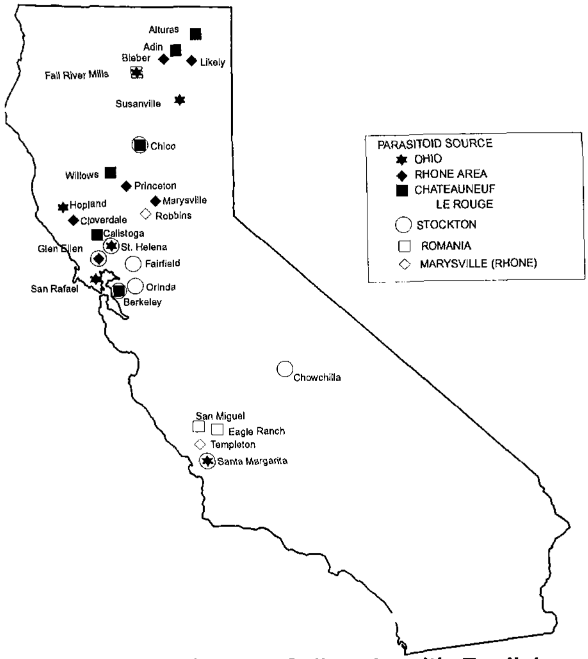

Figure 5. Locations in California with English or Siberian elms where we have released *Tetrastichus gallerucae*, an egg parasitoid of elm leaf beetle, from 6 sources.

high populations then. In contrast, when *T. gallerucae* was being collected in Europe it was easily found in the first ELB generation in spring. The reason for its different performance in California is unknown, as the climate is similar enough that overwintering should not pose a problem. Previous laboratory and field studies indicate that few individuals of the introduced strains have the longevity to overwinter.

In the absence of overwintering populations of *T. gallerucae*, inoculative releases of the parasitoid in spring could be combined with compatible early-season control measures until parasitoid populations increase later in the year. A large-scale insectary program would be required for widespread use of such releases. Another option would be to ship field-collected parasitoids from southern hemisphere release sites in the fall, for release in the northern hemisphere in our spring.

Bacillus thuringiensis. Foliar application of two different formulations of this bacterial insecticide (Mycogen Corp. M-one and M-Trak) was made at several sites each season from 1989 to 1991. Use of degree-day monitoring was effective in timing *Bt* applications to affect the vulnerable early larval stage. Although there were reductions in ELB populations in each trial, damage to the treated areas did not differ significantly from untreated areas. It is possible that multiple applications may be effective but the cost might be prohibitive for most managers. Several companies are working on other Bt formulations that may be more effective than those we tested in this study.

Trunk banding with insecticide. This control method uses a chemical insecticide in a way that is compatible with most natural enemies, including *T. gallerucae*, and introduces much less insecticide into the environment. It targets last-instar larvae as they migrate down the trunk to pupate. In an earlier study (7) we applied a 2% active ingredient solution of carbaryl to the trunks of elms in a one-half meter band around the trunk, 2.5 to 3 meters above the ground. About 2 liters of solution were used per tree using a hand pump sprayer.

The efficacy persisted for at least 15 weeks and encompassed two ELB generations. Significantly more mortality occurred among prepupal larvae that had migrated to the base of the tree on treated than on untreated English and Siberian elms (7). While satisfactory damage control (less than 40% defoliation) was attained on Siberian elm, banding did not provide satisfactory control on English elm. Banding may be effective for English elm in combination with other measures, or when ELB populations are low to moderate. Also, it may be necessary to treat English elms several years in succession before an effect is noted (3). This method is not usable for the first ELB generation, since it acts after first generation larval feeding has occurred.

Summary

Each ELB generation must be monitored individually. Time of egg peak is predicted and egg sampling scheduled by monitoring heat accumulation measured in degree-days above 11°C (Fig. 1). Sampling in each generation should begin 50-100 DD before the predicted egg peak and continue weekly until eggs peak or 100 DD after the predicted peak. Number of trees sampled, and branches per tree, must be adjusted depending on site size (Table 1); the sample unit is a 30 cm (1 ft) branch terminal for which only presence or absence of eggs is recorded. If more than 45% of the branch terminals have ELB eggs at the first generation maximum, treatment should be planned for that generation, using methods described here or other methods. For the second generation the unacceptable damage threshold is 30% branches with eggs. Treatments should be timed using DD monitoring. Damage may be recorded on a per branch or per tree basis in order to monitor accuracy of damage prediction or the success of any treatments applied.

We emphasize that this monitoring method is still being refined and may change with further field testing, especially for damage prediction beyond the first generation. Also, the method was developed for English elm in northern and central California and adjustments may need to be made for other areas. However, these techniques now permit tree managers to determine if control is necessary; their use alone will result in a substantial decrease in the use of chemical insecticides for ELB control.

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Literature Cited

1. Ascerno, M.E. 1991. *Insect phenology and integrated pest management.* J. Arboric. 17(1).
2. Clair, D.J., D.L.Dahlsten, and E.R. Hart. 1987. *Rearing Tetrastichus gallerucae (Hymenoptera: Eulophidae) for biological control of the elm leaf beetle, Xanthogaleruca luteola.* Entomophaga 32:457-461.
3. Costello, L.R., S.R. Scott, J.D. Peterson, and C.J. Adams. 1990. *Trunk banding to control elm leaf beetle.* J. Arboric. 16:225-230.
4. Dahlsten, D.L, S.H. Dreistadt, J.R. Geiger, S.M. Tait, D.L. Rowney, G.Y. Yokota, and W.A. Copper. 1990. Elm leaf beetle biological control and management in northern California. California Department of Forestry and Fire Protection, Sacramento, California. 16 pp.
5. Dahlsten, D.L., D.L. Rowney, and S.M. Tait. In press. Development of integrated pest management programs in urban forests: the elm leaf beetle. From a paper presented at the 12th International Plant Protection Congress, Symposium No. 22, Forestry: Integrated Pest Management Programs. Rio de Janeiro, Brazil, 16 August 1991.
6. Dreistadt, S.H. and D.L. Dahlsten. 1989. *Density-damage relationship and presence-absence sampling of the elm leaf beetle (Coleoptera: Chrysomelidae) in northern California.* J. Environmental Entomology 18:849-853.
7. Dreistadt, S.H. and D.L. Dahlsten. 1990. *Insecticide bark bands and control of the elm leaf beetle (Coleoptera: Chrysomelidae) in northern California.* J. Econ. Entomol. 83:1495-1498.
8. Dreistadt, S.H. and D.L. Dahlsten. 1991. *Establishment and overwintering of Tetrastichus gallerucae (Hymenoptera: Eulophidae), an egg parasitoid of the elm leaf beetle (Coleoptera: Chrysomelidae), in northern California.* Environmental Entomol. 20:1711-1719.
9. Dreistadt, S.H., D.L. Dahlsten., D.L. Rowney, S.M. Tait, G.Y. Yokota, and W.A. Copper. 1991. *Treatment of destructive elm leaf beetle should be timed by temperature.* California Agriculture 45(2):23-25.
10. Howard, L.O. 1908. *The importation of Tetrastichus zanthomelaenae (Rond.)* J. Econ. Entomol. 1:281-289.
11. Luck, R.F. and G.T. Scriven. 1979. *The elm leaf beetle, Pyrrhalta luteola, in southern California: its host preference and host impact.* Environmental Entomology 8:307-313.
12. Morse, J.G. and A.J. Strawn. 1986. Users' manual for degree-day utility (a program on the statewide UCIPM computer system). UCIPM Publication 3. University of California, Davis.
13. O'Brien, K. 1986. *Scouting beans.* Agrichemical Age. April:8.
14. Svihra, P. 1980. Dutch elm disease in California. Univ. California, Div. Agricultural Sciences Leaflet 21189. Berkeley, California.
15. Wu, Z., S. Jamieson, and J. Kielbaso. 1991. *Urban forest pest management.* J. Arboric. 17(6).
16. Clair, D. J. 1986. Bionomics of the elm leaf beetle, *Xanthogaleruca luteola*(Müller) in northeastern California. Ph. D. dissertation, University of California, Berkeley.
17. Ehler, L. E., R. L. Bugg, M. B. Hertlein, H. P. Sauter, and K Thorarinsson. 1987. *Patch-exploitation patterns in an egg parasite of elm leaf beetle.* Entomophaga 32(3):233-239.

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Zusammenfassung. Der Schaden, der durch Ulmenblattkäfer (ELB) (*Xanthogaleruca luteola*) verursacht wird, ist frühzeitig vorhersehbar. Indem man den Prozentsatz von 30 cm langen Astspitzen, die mit ELB-Eiern bedeckt sind, feststellt, kann man bestimmen, ob eine Behandlung notwendig ist. Die Stichproben und die Entscheidungen über eine notwendige Behandlung müssen für jede ELB-Generation separat durchgeführt werden. Wenn mehr als 45% der Astspitzen zum Zeitpunkt der Größten Eierdichte mit Eiern bedeckt sind, ist die Behandlung der ersten Generation angebracht; bei 30% Befall muß die zweite Generation behandelt werden. Eine Aufzeichnung der Tage mit erfolgreicher Behandlung gestattet es, das Probenziehen und die Behandlung für eine maximale Effizienz und Effektivität fahrplanmäßig aufzuzeichnen. In Entwicklung befindliche umweltfreundliche Behandlungsmethoden umfassen das Aussetzen des Eiparasiten *Tetrastichus gallerucae*, Stammbandagen mit Insektiziden und Besprühen der Blätter mit *Bacillus thuringiensis*-Lösungen. Diese Methoden wurden in erster Linie entwickelt für die Behandlungen von englischen Ulmen in Nord- und Zentralkalifornien.