Dennis, D.S. and R.T. Lavigne. 1975. Comparative behavior of Wyoming robber flies II (Diptera: Asilidae). Univ. Wyoming Agric. Exp. Sta. Sci. Monogr. 30:1-68.
James, M.T. 1937. The genus *Comantella* Curran (Diptera: Asilidae) Pan-Pacific Entomol. 13:61-63.
Kelley, C.C. and R.H. Spilsbury. 1949. Soil survey of the Okanagan and Similkameen valleys, British Columbia. Report No. 3 of the British Columbia survey. B.C. Dept. Agriculture and Dominion Dept. Agriculture, Ottawa. 88 pp.
Lavigne, R.J. and F.R. Holland. 1969. Comparative behavior of eleven species of Wyoming robber flies (Diptera: Asilidae). Univ. Wyoming Agric. Exp. Sta. Sci. Monogr. 18:1-61.
Lavigne, R.J. and D.S. Dennis. 1985. Ethology of three coexisting species of *Efferia* (Diptera: Asilidae) in Mexico. Proc. Entomol. Soc. Wash. 87(1):146-160.
Stone, A., C.W. Sabrosky, W.W. Wirth, R.H. Foote, and J.R. Coulson. 1965. A catalogue of the Diptera of America north of Mexico. U.S. Dept. Agriculture, Agriculture Handbook No. 276. Washington, D.C. 1696 pp.

BIOLOGY OF *Erythroneura elegantula* AND *E. ziczac* (HOMOPTERA: CICADELLIDAE) ON *Vitis vinifera* IN SOUTHCENTRAL WASHINGTON

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ABSTRACT

The western grape leafhopper, *Erythroneura elegantula* Osborn, and the Virginia creeper leafhopper, *Erythroneura ziczac* Walsh, were the only species of leafhoppers found colonizing grapevines, *Vitis vinifera* (L.), in southcentral Washington. Other Cicadellids collected did not colonize. Where the mymarid parasitoid, *Anagrus epos,* was found, the predominant leafhopper was *E. elegantula*. In the absence of *A. epos, E. ziczac* seemed to be the more abundant. *E. ziczac* quickly dominated a mixed population of both species in a greenhouse. On heavily damaged grape leaves, *E. ziczac* eggs remained surrounded by green tissue whereas *E. elegantula* eggs were not. This suggests the presence of a repellent or anti-feedant with *E. ziczac* eggs. Development time for *E. elegantula* averaged 402.6 D° which is much shorter than previously published times, and for *E. ziczac* averaged 390.5 D°.
Keywords: *Erythroneura elegantula, Erythroneura ziczac, Vitis vinifera,* wine grapes, leafhopper biology

INTRODUCTION

Doutt and Nakata (1973) believed that *Erythroneura elegantula,* the western grape leafhopper (WGLH) infested *Vitis californica* Bentham in California before the cultivation of *V. vinifera*. It was probably introduced into the Pacific Northwest on cultivated grapevines. Wolfe (1955) described WGLH as the leading insect pest of grape in Washington; it has the same distinction in California (Jensen and Flaherty, 1981).

Erythroneura ziczac, the Virginia creeper leafhopper (VCLH) was described by Walsh from a single specimen collected in Illinois (Beamer, 1936). It was recognized early as a minor pest of grape (Wirtner, 1904) and apple (DeLong, 1931), and as a principal insect pest of Virginia creeper and Boston ivy (Fairbairn, 1928; Pepper and Mills, 1936). VCLH occurs throughout the U.S. and southern Canada (Metcalf, 1968) but like WGLH is probably new to the Pacific Northwest,which has no native Vitaceae (Hitchcock and Cronquist, 1973). VCLH was recognized as the worst pest of *V. vinifera* grapes in British Columbia by McKenzie and Beirne in 1972.

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MATERIALS AND METHODS

Collection and identification.

Erythroneura adults and nymphs were collected in June and July of 1983 on *V. vinifera* in vineyards at the Irrigated Agriculture Research and Extension Center, Prosser, and also at Paterson, Grandview, and Cold Creek (Fig. 1). Fifty leaves were collected, placed in plastic bags, and examined in the laboratory. Sweep net samples, taken from at least 200 m along one side of vineyard rows during each of four visits to each site, were also placed in bags and examined in the laboratory. Identification was based on 150 males chosen randomly from about 10,000 *Erythroneura* adults taken, plus 83 males reared from nymphs. These were dissected for identification, using the method of Oman (1949) and the keys of Beamer (1936).

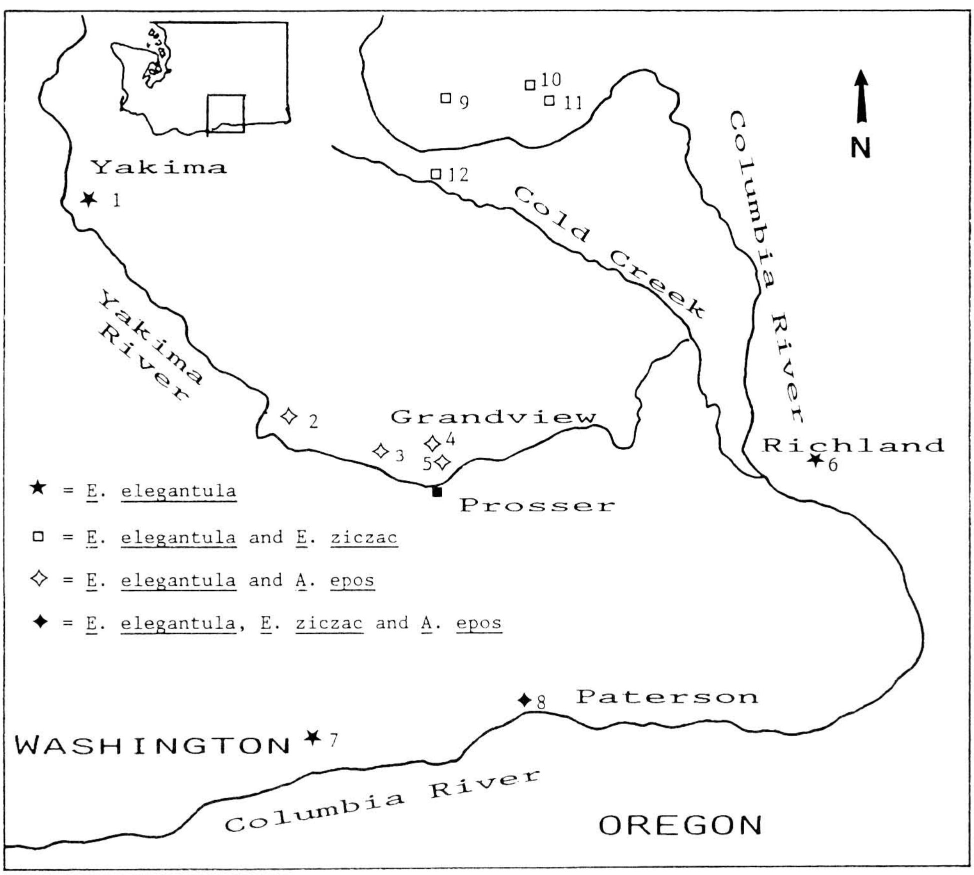

Figure 1.Known distribution of *E. elegantula, E. ziczac* and *A. epos* on southcentral Washington *V. vinifera*.

Temporary Food Plants.

Overwintering *Erythroneura* adults were collected in Tulgren funnel samples of vineyard debris, about 20 kg each, from Prosser, Grandview and Cold Creek on 28 Feb., 1983. *Erythroneura* spp. were not found in similar samples taken on 15 Apr., a date preceding *V. vinifera* bud break. At that time vegetation within and up to 200 m from the edges of vineyards plus a vineyard at Paterson, was sampled with a sweep net. Plants yielding *Erythroneura* spp. were identified using the keys of Hitchcock and Cronquist (1973).

Survey for *Erythroneura* spp., arthropod predators and parasitoids.

At least 50 m of each vineyard margin was sampled with a sweep net and 200 leaves taken during Sep. and early Oct. 1984 at 12 vineyards. The sites are shown in Fig. 1. Leaf and sweep net samples were also collected during the growing seasons of 1983 and 1984 at Prosser and Cold Creek. Vine leaves were examined for the presence of *Erythroneura* immatures and evidence of *A. epos*. Cicadellid species were determined using the keys of Oman (1949), Beirne (1956), and Beamer (1936). Other Arthropoda were sent to appropriate authorities for identification. Voucher specimens have been placed in the insect collection at Washington State University, Pullman.

Development and Mortality of Immature *Erythroneura* spp.

The development rate and mortality of immature WGLH and VCLH in the absence of natural predators and parasitoids were compared on vines at Prosser in Jul., 1985. Air temperature was recorded at a height of 1.5 m. The hourly values used were averages of field data measured every 10 sec. Using the developmental threshold of 10.3°C (50.5°F) determined for WGLH in California (Cate, 1975), physiologic time was calculated as the area under a temperature curve using a Fortran computer program.

Eggs of known age were obtained by confining 15-20 individuals of each species in leaf cages for 24 h. Mature, exposed leaves were selected free from *Erythroneura* spp. damage to avoid previously laid eggs. Upon selecting a mature leaf with no indication of leafhopper feeding injury, the shoot was cut leaving that leaf terminal. A single leaf cage similar to that used by Pickett *et al.* (1987) was tied on the shoot and leafhoppers added. Cage effect on leaf temperature was examined using an Omnidata® model DP212 2-channel temperature recorder (±0.2°C) to measure air temperature beneath a caged leaf and a neighboring leaf. Temperatures were recorded simultaneously every 0.5 h for 160 h.

Nymphs were counted when they reached instar V. Some were then placed individually on the underside of a leaf in a clip-on cage of 2.5 cm inner diam. modified from DeBach and Huffaker (1971). Data from leaf cages found later to contain arthropod predators were not used. The number of eggs deposited was determined by counting the unhatched eggs and empty chorions with a dissecting microscope (20X). The nymphs in the clip-on cages were examined daily. The date of death or imaginal molt, and the sex of emerged adults were recorded.

RESULTS AND DISCUSSION

The western grape leafhopper (WGLH), and the Virginia creeper leafhopper (VCLH), were the only *Erythroneura* pests of *Vitis vinifera* found. No immature cicadellids of other species were found on grapevines and 11 other species of adult leafhoppers identified, caused no noticeable damage. The characters distinguishing WGLH and VCLH in the field are shown in Fig. 2.

E. comes and *E. elegans*, both reported from *Vitis* spp. in Washington (Frick, 1952; Wolfe, 1955; Capizzi *et al.*, 1985) were not found. Some species of *Erythroneura* are difficult to distinguish from *E. comes*, and certain early workers considered them to be variations of that leafhopper (Robinson, 1926). We believe that difficulty in identifying *Erythroneura* spp. has

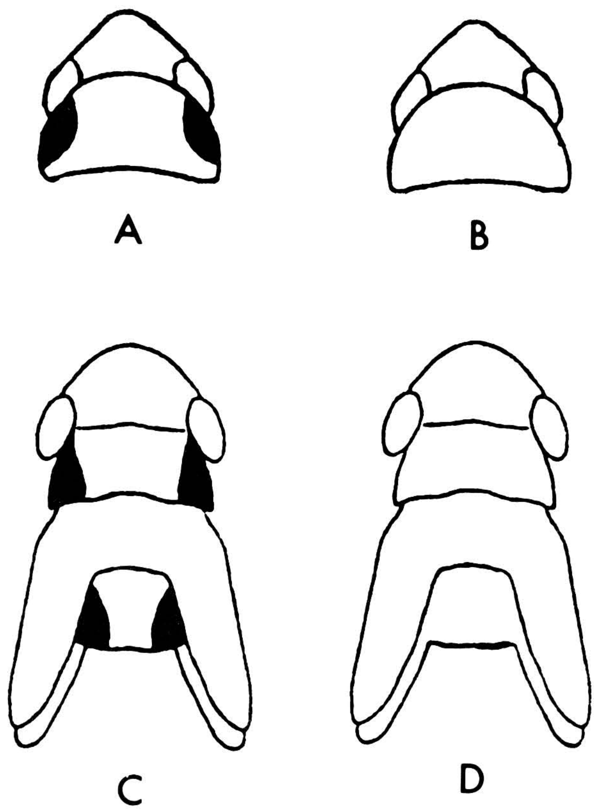

Figure 2.Characters for distinguishing *Erythroneura* spp. found in southcentral Washington vineyards are: *E. ziczac* adults (A) have dark lateral pronotal spots; nymphs III-V (B) have red spots on dorsum. *E. elegantula* adults (B) and nymphs (D) have no dark pigmentation on the dorsum.

resulted in incorrect reports of *E. comes* from west of the Rocky Mountains. *E. comes* has been reported from throughout the western U.S. and Canada (Gillette, 1898; Essig, 1926; Knowlton, 1933; Wolfe, 1955), but those authors did not describe distinguishing characters. Moreover, current workers in Washington, Oregon, and California have not seen *E. comes* (P.W. Oman and R. L. Doutt, 1985, pers. comm.), and no specimen labeled *E. comes* collected in the West was found in the collections of Washington State University or Oregon State University. The University of California at Berkeley, had a single specimen labeled *E. comes,* collected there in 1914 (J. Chemsak, 1985, pers. comm.). That specimen was found to be female and so could not be identified to species.

Temporary Food Plants.

In areas with cold winters, *Erythroneura* spp. overwinter as adults in plant debris, most often in the leaves of the host plant. Overwintering forms may become active during any brief warm period and move to temporary food plants. They are often found on temporary food plants just before and after their host plants growing season.

Cate (1975) conducted a spring survey and found that *Rubus* spp., *Prunus dulcis*, sagebrush and storksbill served as temporary food plants for WGLH. Adults were found on dandelion, pear, *Medicago* spp., willows, hops and in greatest density on balsam-root, *Balsamorhiza sagittata*. Immature forms were not found on these plants. WGLH's apparent preference for balsam-root as a temporary food plant suggests that it might serve as a trap crop. Clean culture in vineyards could increase WGLH movement to balsam-root in early spring.

VCLH was collected on dandelion only, which was also found to be a preferred temporary food plant by McKenzie and Beirne (1972). Since it occurred on *V. vinifera* in rather barren areas, it probably had other temporary food plants. VCLH adults that had escaped from colony cages were observed feeding on hops in a greenhouse. After WGLH was found in large numbers on balsam-root, an effort was made to sample balsam-root near vineyards with VCLH. However, no balsam-root was found within one km of vineyards containing VCLH.

Both leafhopper species had other host plants near Prosser. WGLH bred on Concord grapes, *Vitis labrusca* and VCLH on Virginia creeper, *Parthenocissus quinquefolia*.

Survey for *Erythroneura* spp. and the parasitoid, *Anagrus epos*.

The known distribution of *Erythroneura* spp. and *A. epos* on Washington grapevines in 1984 is shown in Fig. 1. WGLH is ubiquitous on grapevines in southcentral Washington. VCLH was not found on *Vitis* spp. in the Yakima Valley proper, although it was reported from a vineyard at Sunnyside, (Wolfe, 1955). *A. epos* was abundant on grapevines in the lower Yakima Valley and a single parasitized egg was found at Paterson, near the Columbia River. Most vineyards peripheral to the Yakima Valley are on recently reclaimed desert. The absence of *A. epos* from these still relatively barren areas may be explained by the lack of winter hosts.

Mortality.

The percent mortality of immature WGLH and VCLH is given in Table 1; 547 WGLH eggs produced 152 fifth instars, of which 71 produced 69 adults; 683 VCLH eggs produced 152 fifth instars, of which 84 produced 69 adults. The various factors responsible for mortality were not evaluated. Some eggs failed to develop and were considered by Cate (1975) to be infertile. He found that they darkened as they became infected with *Aerobacter* sp. and *Monila* sp. Our observations indicated that most nymphal mortality was associated with molting.

Table 1.

Percent mortality of immature WGLH and VCLH on *V. vinifera* var. Grenache at Prosser, Washington, 1985.

Species	Egg-instar IV	Instar V	Total
WGLH	53.2	6.1	56.1
VCLH	77.8	17.6	81.3

Developmental Rates of *E. elegantula* and *E. ziczac*.

Cate (1975) found that WGLH had two and a partial third, or three generations/year at various locations in California. He reported that development was completed in 844 D° during the proper limits of daylength (see below) while Jensen and Flaherty (1981) reported 980 D°. The generations became increasingly asynchronous during the growing season. Females caged at 21°C (70°F) deposited an average of 1.31 eggs/day for a mean total of 28.2.

WGLH adults entered reproductive diapause when exposed to daylength less than 13.6 h in late summer. Diapausing females were unmated, and the gonads of both sexes were undeveloped. Gonad development resumed when daylength increased to 11.6 h but was very slow until grape foliage became available. Laboratory studies showed a preoviposition period of 192 D° at 27°C (80°F) and 246 D° at 21°C (70°F).

A WGLH nymph destroyed a mean total of 43.6 mm^2 leaf surface to maturity at 21°C (70°F). At this temperature the adult consumed an average of 6.72 mm^2/day.

Pepper and Mills (1936) found that VCLH completed one and a partial second generation/ year on Virginia creeper, *P. quinquefolia* (L.), in Bozeman, Montana. McKenzie and Beirne (1972) found that non-diapausing adult males were short-lived; two peaks in male density indicated that the species was bivoltine in British Columbia. Fairbairn (1928) believed at least three, probably four generations per year occurred on Virginia creeper in Kansas. He observed the developmental rates of VCLH but made no reference to temperature; the preoviposition period averaged 5.15 days, the egg stage averaged 8.1 days and nymphal stadia were 3 or 4 days.

McKenzie and Beirne (1972) found that a VCLH nymph destroyed about one cm^2 total leaf surface. Oviposition rates were lower on American varieties of *Vitis labrusca* than on *V. vinifera* and its hybrids. Younger nymphs were seen to be entangled in the leaf hairs of American grapes.

The mean physiological time between oviposition and imaginal molt for WGLH and VCLH is given in Table 2. Males of both species became adults before females (pooled t test, $P < 0.05$), a characteristic common in Cicadellidae (DeLong, 1971).

VCLH developed in less time that WGLH (pooled t test, $P < 0.05$). The occurrence of VCLH at higher latitudes than WGLH (Metcalf, 1968; McKenzie and Beirne, 1972) may partly reflect this.

Table 2.

Developmental time, in day-degrees above 10.3°C, of *Erythroneura* spp. on *V. vinifera* var. Grenache at Prosser, Washington, 1985.

	n	mean D°	s
WGLH males	31	398.2	15.0
WGLH females	36	406.3	14.5
WGLH total	67	402.6	15.2
VCLH males	33	386.2	12.6
VCLH females	36	394.4	10.2
VCLH total	69	390.5	11.8

WGLH developmental time was less than half of that reported by Cate (1975) who recorded development at constant temperatures. Development of an insect may take less physiological time under fluctuating temperatures (Siddiqui and Barlow, 1973), such as were used here. Shortened developmental time, perhaps resulting from a lowered developmental threshold, could be an adaptation to a shorter growing season, but such an extreme difference was unexpected. Precautions were taken so that cage interiors were not warmer than the surrounding air temperature. The average temperatures within the cage and beneath the adjacent leaf were 11.6 and 11.8°C. The difference was considered insignificant (paired t test, $t = 0.15$, $P < 0.1$, 319 df). A repetition of this experiment using WGLH from California and Washington might eliminate uncertainty in comparing populations.

Competition between *Erythroneura* spp.

Because WGLH and VCLH feed on *V.* vinifera in an apparently identical manner, and are seen on the vine at the same time of year, they may compete for grapevines in southcentral Washington. If this is the case, the distribution of *Erythroneura* spp. on grapevines (Fig. 1) indicates that WGLH is the more successful competitor. Although no experiments were conducted placing WGLH and VCLH in direct competition, certain observations suggest a mechanism for WGLH success.

VCLH occurs in vineyards where *A. epos* is rare or absent. The relative density of arthropod predator species was not measured but all predators collected on *V. vinifera* at Prosser, where only WGLH was found, were also collected at Cold Creek, where both leafhoppers were found. VCLH was not seen among the tens of thousands of WGLH collected on grapevines at Prosser, but was easily found on Virginia creeper nearby.

During this study, WGLH and VCLH were raised on caged *V. vinifera* in a greenhouse. Cultures were begun by introducing adults from the mixed population of WGLH and VCLH at Cold Creek. Each inoculum was first sorted in an effort to introduce only one species, but often included a small percentage of the other species. Eleven cages originally containing a large majority of WGLH, after several months with no additional input, contained a large majority of VCLH. The reverse never occurred.

Adults of both *Erythroneura* spp. escaped occasionally when the cages were opened, and flew to uncaged *V. vinifera* in the same greenhouse. These escaped leafhoppers multiplied until the uncaged vines were heavily damaged. At that time, the leafhoppers on the uncaged vines were almost exclusively VCLH. No evidence of *A. epos* was found in the greenhouse.

Competition between WGLH and VCLH in the greenhouse was not carefully controlled, but the outcome was so striking that we considered VCLH to have held a competitive advantage. When these observations are considered along with the known distributions of WGLH, VCLH and *A. epos* in the field, we concluded that VCLH is kept from grapevines in most of southcentral Washington by the wasp. Oviposition behavior varies between WGLH and VCLH. VCLH may lay eggs singly or in clusters, WCLH lays eggs only singly. A cluster of VCLH eggs may provide a more powerful chemical stimulus than a single egg for a searching *A. epos* female.

An Egg-associated Antifeedant.

When grape leaves supporting VCLH became chlorotic from feeding injury, the egg clusters were found to be surrounded by an undamaged area of leaf tissue. We suspected that the egg cluster exerted an antifeedant effect. The antifeedant theory was further investigated by confining nymphs and adults of both leafhoppers, separated by stage and species, on grape leaves with eggs of either spp. using the clip-on cages described earlier. After each caged leaf area had turned white with feeding damage it was examined under a dissecting microscope (20X) for undamaged tissue surrounding any eggs. Nymphs and adults of both spp. did not feed near the eggs of VCLH, but did feed near the eggs of WGLH. This antifeedant effect, perhaps chemical in nature, may disperse VCLH nymphs from crowded oviposition sites. If feeding by *Erythroneura* spp. can cause egg mortality by desiccation, then VCLH may have a reduced egg mortality when leafhopper density is high.

No efforts were made to isolate or characterize the anti-feedant, but the possibility exists for the development of a selective leafhopper control, based on repellency or other characteristics of an antifeedant.

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REFERENCES CITED

Beamer, R. H. 1936. Species of *Erythroneura* of the *comes* group. Univ. Kans. Sci. Bull. 24:261-307

Beirne, B. P. 1956. Leafhoppers (Homoptera: Cicadellidae) of Canada and Alaska. Can. Entomol. Suppl. 2. 180 p.

Cate, J. R. 1975. Ecology of *Erythroneura elegantula* Osborn in grape ecosystems in California. Unpubl. Ph.D. Thesis, Univ. Calif. Berkeley. 349 p.

Capizzi, J., G. Fisher, H. Homan, C. Baird, A. Antonelli, and D. Mayer. 1985. Pacific Northwest Insect Control Handbook. Cooperative Extension of Oregon, Idaho, and Washington. 316 p.

DeBach, P. and C. B. Huffaker. 1971. Experimental techniques for evaluation of the effectiveness of natural enemies. pp. 113-142 *In* C. B. Huffaker (ed.). Biological Control. Plenum, New York. 511 p.

DeLong, D. M. 1931. The more important species of leafhopper affecting the apple. J. Econ. Entomol. 24:1214-1222.

Doutt, R. L. and J. Nakata. 1973. The *Rubus* leafhopper and its egg parasitoid: an endemic biotic systsm useful in grape pest management. Environ. Entomol. 2:381-386.

Essig, E. O. 1926. Insects of Western North America. MacMillan, New York. 1035 p.

Fairbairn, V. M. 1928. The life history of *Erythroneura ziczac* Walsh (Homoptera, Cicadellidae). J. Kans. Entomol. Soc. 1:79-84.

Frick, K. E. 1952. The value of some organic phosphate insecticides in control of grape mealybug. J. Econ. Entomol. 45:340-341.

Gillette, C. P. 1898. American leafhoppers of the subfamily Typhlocybinae. U.S. Nat. Mus. Proc. 20:709-773.

Hitchcock, C. L. and A. Cronquist. 1973. Flora of the Pacific Northwest. Univ. Wash. Press, Seattle. 730 p.

Jensen, F. L. and D. L. Flaherty. 1981. Grape leafhopper, pp. 98-110. *In* D. L. Flaherty, F. L. Jensen, A. N. Kasimatis, H. Kido, and W. J. Moller (eds.). Grape Pest Management. Div. Agric. Sci. Univ. Calif. Pub. 4105. 312 p.

Knowlton, G. F. 1933. Notes on injurious Utah insects - 1932. Utah Acad. Sci., Arts and Letters Proc. 10:159-162.

Metcalf, Z. P. 1968. General catalogue of the Homoptera. Fasc. 6. Cicadelloidea. Part 17. Cicadellidae. USDA, ARS. 1513 p.

McKenzie, L. M. and B. P. Beirne. 1972. A grape leafhopper, *Erythroneura ziczac* (Homoptera: Cicadellidae), and its mymarid (Hymenoptera) egg-parasite in the Okanagan valley, British Columbia. Can. Entomol. 104:1229-1233.

Oman, P. W. 1949. The nearctic leafhoppers (Homoptera: Cicadellidae), a generic classification and checklist. Entomol. Soc. Wash. Mem. 3. 253 p.

Pepper, J. H. and H. B. Mills. 1936. The Virginia creeper leafhopper. Mont. Agric. Exp. Stn. Bull. 314. 5 p.

Pickett, C. H., L. T. Wilson, D. Gonzalez, and D. L. Flaherty. 1987. Biological control of variegated grape leafhopper. Calif. Agric. 41:14-16.

Robinson, W. 1926. The genus *Erythroneura* north of Mexico. Univ. Kans. Sci. Bull. 16:101-155.

Siddiqui, W. H. and C. A. Barlow. 1973. Effects of some constant and alternating temperatures on population growth of the pea aphid (Homoptera: Aphididae). Can. Entomol. 105:145-156.

Wirtner, P. M. 1904. A preliminary list of the Hemiptera of western Pennsylvania. Ann. Carnegie Mus. 3:183-232.

Wolfe, H. R. 1955. Leafhoppers of the state of Washington. Wash. Agric. Exp. Stn. Circ. 277. 37 p.

ERRATA

In the paper entitled "Semiochemicals..." by S.M. Salom & J.A. McLean (Vol. 85:34 - 39, 1988), some typesetting errors appeared on p. 37 under RESULTS. In **Experiment 1**, line two, Pkw 0.01 should read P >0.01. On the same line, P 0.05 should read P >0.05. The > sign is also missing from the same type of statistical presentation in **Experiment 2**, lines two, three, and fifteen (last line, p. 38).