THE GRAPE LEAFHOPPER <u>ERYTHRONEURA ZICZAC</u> (HOMOPTERA: CICADELLIDAE) AND ITS MYMARID (HYMENOPTERA) EGG-PARASITE IN THE OKANAGAN VALLEY, BRITISH COLUMBIA

by

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ABSTRACT

The leafhopper Erythroneura ziczac is the most important insect feeding on grape vines in the Okanagan Valley, B.C. Extensive leafhopper feeding reduces the effective photosynthetic area of leaves and can affect the quality and/or quantity of grapes. Hairy-leaved grape varieties do not support large leafhopper populations but unfortunately it is smooth-leaved varieties that produce grapes desired by the wineries. Virginia creeper is a common alternate host plant used by the leafhopper in the Okanagan Valley.

E. ziczac has two overlapping generations each year and overwinters in the adult stage under plant debris in and around the vineyards. Overwintered adults feed on many plants in early spring but move to grape vines for feeding and egg-laying soon after leaves appear. First generation adults appear in early July and second generation adults, that form the next overwintering population, appear in mid-August.

Predators do not have any significant effect on leafhopper numbers during the summer but predation may be a major mortality factor of overwintering leafhoppers. No parasites were observed in any of the nymphal stages or adult leafhoppers. The chief natural enemy of E. ziczac is a mymarid egg-parasite Anagrus epos. This tiny wasp overwinters in the eggs of other species of leafhoppers on wild rose and apple so that parasitism of the grape leafhopper can be influenced by the proximity of those plants to vineyards.

Numbers of leafhoppers in vineyards can be monitored using sticky boards. If spraying with chemical pesticides is considered necessary,

these should only be applied to parts of the vineyard where heavy infestations occur.

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Erythroneura ziczac	by	C. D. A., Ottawa
Nabis alternatus	by	C. D. A., Ottawa
Anagrus epos	by	R. L. Doutt, University of California, Berkeley C. M. Yoshimoto, C. D. A., Ottawa

I INTRODUCTION

Entomologists and grape growers have been aware for a number of years of a leafhopper feeding on grape vines in the Okanagan Valley of British Columbia. Marshall (1952) noted that a leafhopper (Erythroneura sp.) occurred in outbreak numbers at Osoyoos following the severe winter of 1950-51. In 1967 Madsen began a study at Westbank for identification and seasonal history of the leafhopper and to assess damage to quality and quantity of grapes (Madsen, 1968). He found that grapes from unsprayed vines had fewer grapes and were smaller than on sprayed vines. These grapes ripened sooner and some had shriveled before picking started. No significant difference in quality was shown by analysis for soluble solids, sugar, acidity or pH but yield from sprayed vines was decidedly greater. Measurements of grape sugar content by Van Dine (1923) showed a 27 percent reduction in sugar as compared with grapes from insect-free vines. This vineyard was under contract with a grape juice processor but the crop was rejected because of the low sugar content.

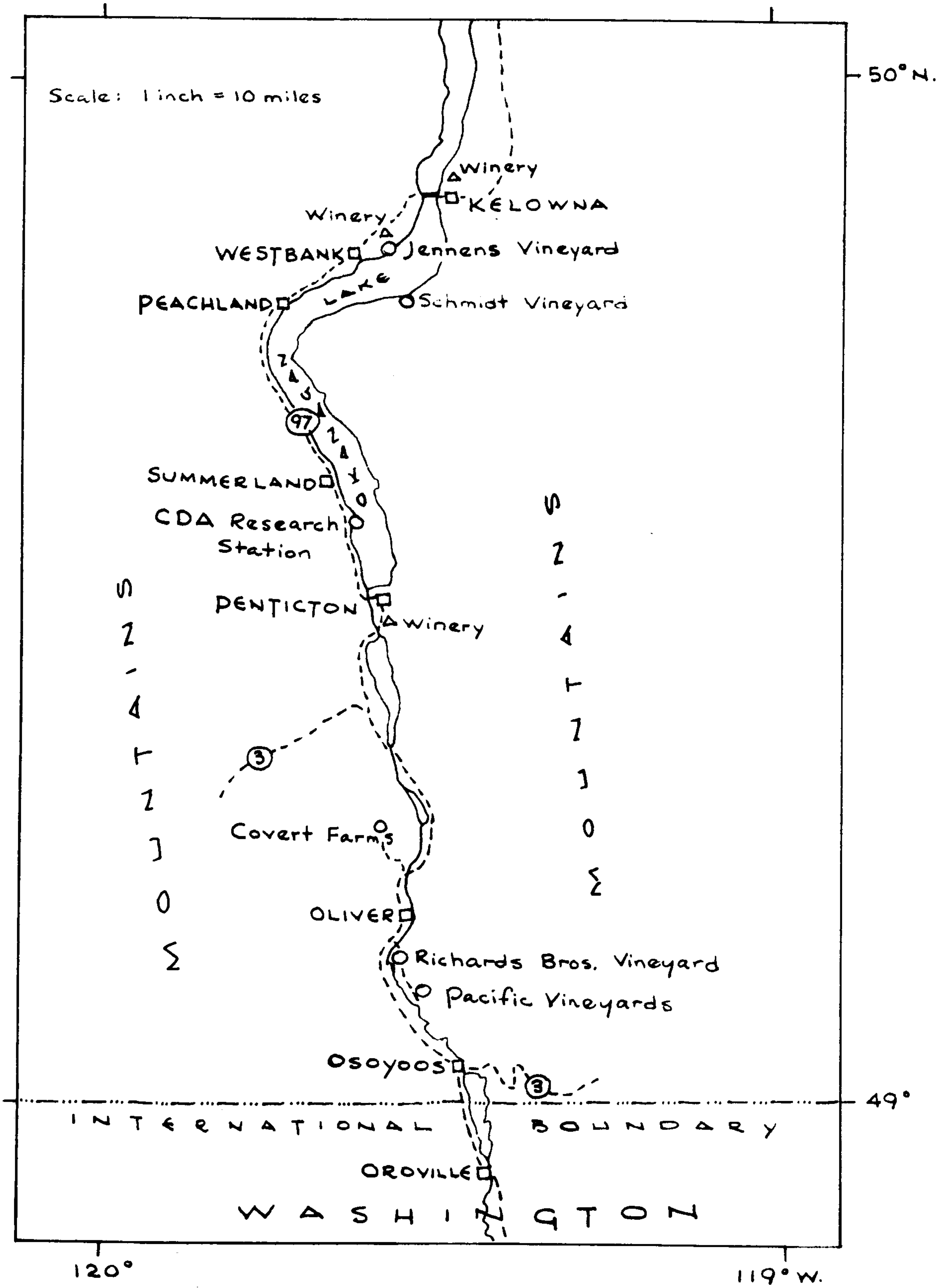
One grower at Oliver reported an unusually heavy leafhopper infestation in part of his vineyard in 1968 (La Bounty, 1969). Feeding damage was so severe that leaves turned brown and dropped well before harvesting commenced. Grapes were very stunted and had a sugar content of 8 to 9 percent instead of the normal 20 to 25 percent. The fruit was not worth picking and wood for the next year's bearing vines appeared unsound. Wood that does not mature properly appears to be susceptible to winter-kill.

Field observations by Madsen (1968) showed that the Okanagan leafhopper displayed characteristics typical of the many grape leafhoppers (Erythroneura spp.) studied throughout North America. By numbers and frequency of encounter throughout the Okanagan, the leafhopper is the only insect of economic importance to grape growers at the present time. Acreage of grape plantings has increased greatly since 1960 and the pest status of the leafhopper was the prime motivation for the present study.

During the growing seasons of 1969 and 1970 the bionomics and ecology of the Okanagan leafhopper were studied and cultural procedures were examined with the aim of finding practices that might reduce the need for chemical pesticides.

No leafhoppers of the genus Erythroneura have been shown to be vectors of plant virus diseases. If this is true for the Okanagan leafhopper, the only index for an economic threshold would be insect numbers. Species of Erythroneura feed on mesophyll tissue and this reduces the area of functional leaf surface. Stylets penetrate through epidermal tissue and removal of sap destroys the interior photosynthetic cells. A typical leafhopper nymph of the Erythroneura group was found to destroy an average of just over one square centimeter of leaf surface in reaching maturity and the adult continues to feed and cause damage until it dies (Runner and Bliss, 1923).

Fig. I Map of study area in the Okanagan Valley, British Columbia.



Scale: 1 inch = 10 miles
50° N.
Winery
KELOWNA
Winery
WESTBANK
Jennens Vineyard
LAKE
PEACHLAND
Schmidt Vineyard
OKANAGAN
97
SUMMERLAND
CDA Research Station
PENTICTON
Winery
MOUNTAINS
MOUNTAINS
3
Covert Farms
OLIVER
Richards Bros. Vineyard
Pacific Vineyards
Osoyoos
3
49°
INTERNATIONAL BOUNDARY
OROVILLE
WASHINGTON
120°
119° W.

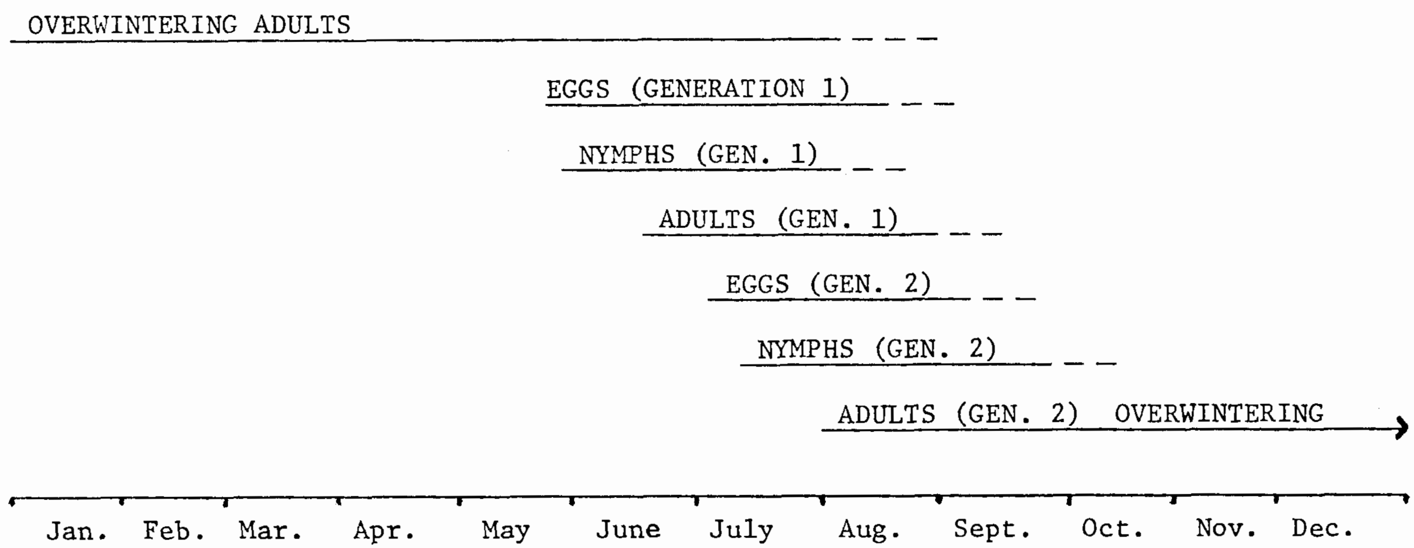
II LIFE HISTORY OF THE LEAFHOPPER

In 1968 the Entomology Research Institute at Ottawa confirmed Dr. Madsen's suspicion that the Okanagan grape-feeding leafhopper was *Erythroneura ziczac* Walsh. *E. ziczac* has a wide distribution throughout North America (Pepper and Mills, 1936). Beirne (1956) reported that it occurs across the southern part of Canada and noted that *E. ziczac* is generally less common in vineyards than related species. An exception was the Okanagan Valley where it appeared to be the only grape-feeding leafhopper.

During the present study *E. ziczac* was the only leafhopper using grape as a host plant although there were isolated instances of other species such as *Typhlocyba pomaria* apparently using vines as a temporary food source during dispersal. Many leafhopper species will feed on a variety of plants but oviposition and feeding by nymphs generally involves specific plants or types of plants. As suggested by Oman (1949), the term 'host plant' can conveniently distinguish those plants utilized for oviposition while 'food plant' refers to any plant used for incidental feeding by the adult but not normally for oviposition.

There are two overlapping leafhopper generations each year in the Okanagan Valley (Fig. II). Adult *Erythroneura ziczac* overwinter under grass and fallen leaves in or near the vineyards. They become active during warm spring weather before grape leaves appear so that other plants must be used as a temporary food source. All studies of life-histories of grape leafhoppers (*Erythroneura* spp.) indicate that over-wintering adults do not mate for about a week after they commence feed-

Fig. II Seasonal history of *Erythroneura ziczac* on grape vines in the Okanagan Valley, modified from Madsen, 1968.

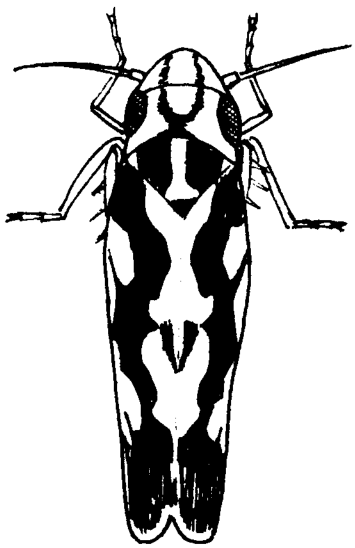

OVERWINTERING ADULTS
EGGS (GENERATION 1)
NYMPHS (GEN. 1)
ADULTS (GEN. 1)
EGGS (GEN. 2)
NYMPHS (GEN. 2)
ADULTS (GEN. 2) OVERWINTERING
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.

ing on host plants. In 1969, the first mating pairs were observed on grape vines at Oliver in mid-May and eggs were found a week later at the same location. The author was surprised to find at least a dozen pairs mating in their overwintering sites under leaves at Kelowna as early as April 21, 1970. It was a cool, cloudy day and vines had not shown any signs of leafing out. Pairs were also found mating at Oliver nine days later (vines still in bud stage), so feeding on the host plant evidently is not necessary to stimulate mating by E. ziczac.

The ovipositor of the female is used to insert eggs beneath the lower epidermis of mature leaves. After a few days a bluish coloration appears around the eggs and this often enables oviposition sites to be located without a lens. Eggs average about 0.65 mm long and resemble elongated beans that bulge above the surrounding epidermal tissue. They are laid singly or side by side in groups of up to ten, but most commonly in groups of two to four. A few days before hatching a red dot marking one eye appears near one end of the egg (Fig. III) (the embryo is oriented on its side). Eye-spots in each egg group all form at the same end. Nymphs emerge head-first by splitting the egg-case at the level of the leaf epidermis.

Mature leaves that are well marked with feeding scars, rather than new foliage, are the major oviposition sites. One large Himrod leaf at Kelowna (38 cm across) contained 1525 eggs. All leafhopper eggs observed were on the lower surface of leaves except for a few found on Bath vines at Oliver in 1970. Conditions were somewhat unusual in this instance as very dense upper foliage shaded some of the interior leaves

Fig. III Erythroneura ziczac. 1. Adult X 24. 2. Adult, lateral view X 28. 3. Leafhopper egg at eye-spot stage X 120. 4. Leafhopper egg after nymph emerged X 120.



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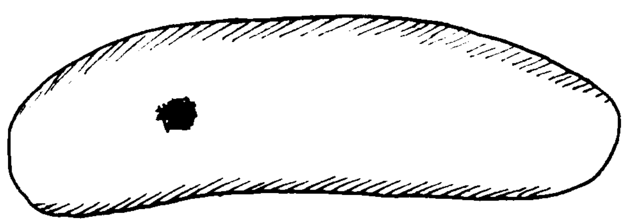

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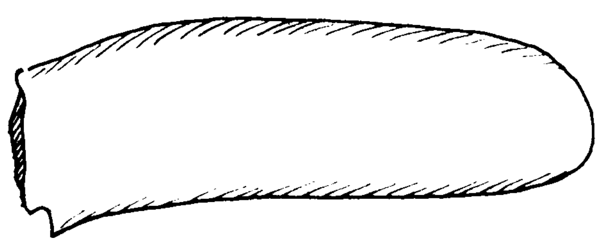

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and apparently affected them physiologically. These limp, hanging leaves lacked the usual toughness of the upper tissue and eggs were laid on both surfaces.

Nymphs emerge from 14 to 17 days after oviposition and the five nymphal instars require a total of 15 to 16 days to reach maturity. The first instars are pale yellow-green and are quite transparent. Size increase is accompanied by the appearance of two orange spots on the upper thorax and the development of wing pads. Adult insects (Fig. III) are slender, about 2.75 mm in length and hold the wings tightly over the body when resting. The specific name ziczac comes from the dark stripe that zigzags along the length of each front wing. The rest of the body is yellowish but there is a bit of variation to some of the dark markings of the upper parts. Most specimens have reddish or brown markings; a blue band on the leading edge of the forewing was not uncommon. No correlation for sex, generation or time of year could be made with any particular pattern of marking.

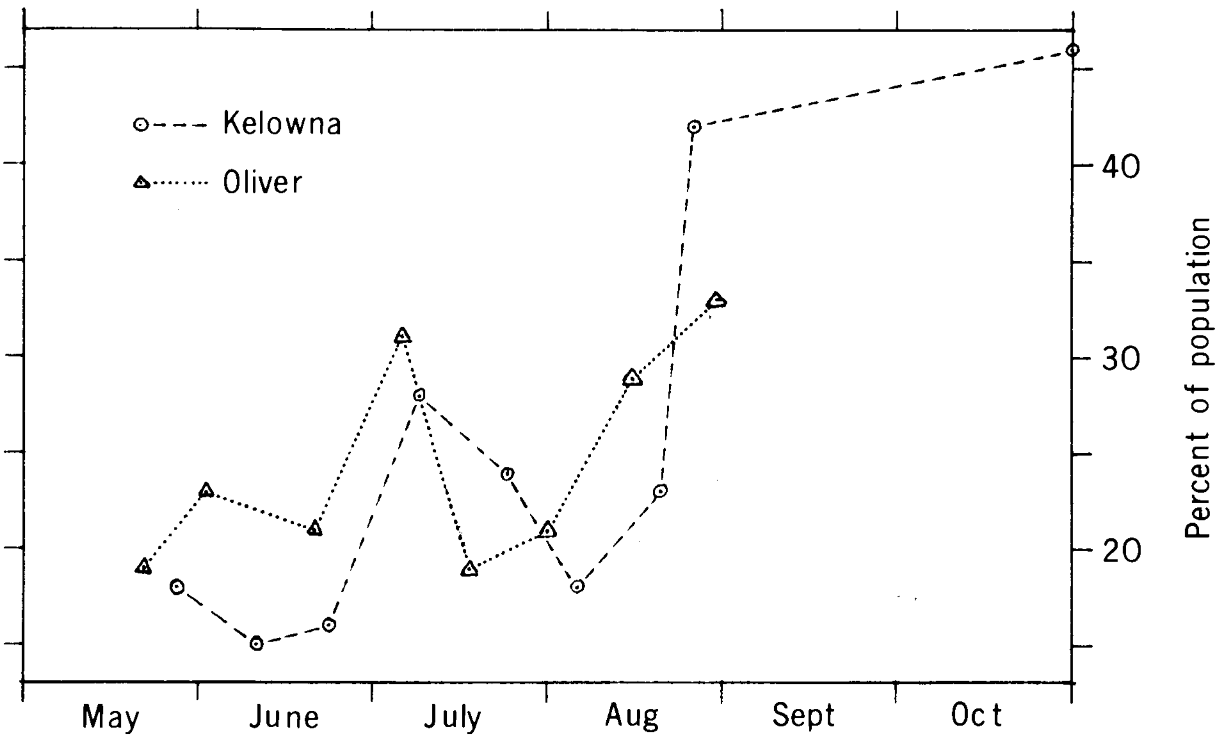
Fairbarn (1928), studying E. ziczac in Kansas, noted the insect had a first preference for Boston Ivy (Parthenocissus tricuspidata) and then for Virginia creeper (P. quinquefolia) with grape being used as a host plant in the absence of those two vines. Pepper and Mills (1936) mentioned injury to Virginia creeper vines in Montana by a minute, agile, light-coloured insect commonly known as the 'grape' leafhopper ("Erythroneura comes ziczac Walsh"). These Virginia creeper leaves became spotted through insect-feeding and in extreme cases vines were completely defoliated. Feeding by E. ziczac which caused this degree of damage to

Virginia creeper vines was observed by the present author at Peachland, B.C., in 1969.

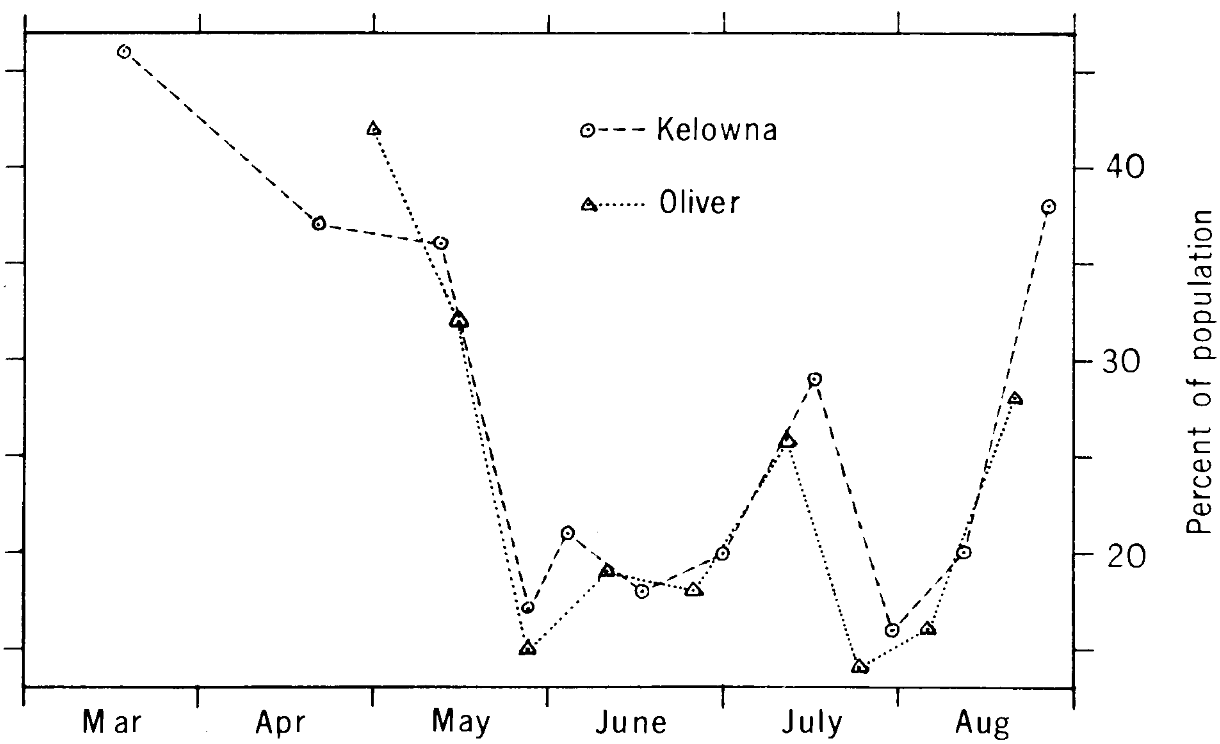
Host plants of *E. ziczac* observed in the Okanagan were grape, Virginia creeper, and an unidentified ornamental ivy growing on a hotel wall at Penticton. The last vine was infested rather sparsely and probably was not an ideal host plant because the leaves were thick and hard-surfaced. Incidental feeding by *E. ziczac* adults was noticed only in spring before host plants leafed out. Almost any available plant seemed acceptable but some seemed to be preferred. Dandelions near overwintering locations invariably attracted leafhoppers. Grass, strawberry, wild rose and many unidentified weed plants were also used by *E. zizac* as food sources.

The ratio of adult female to male *Erythroneura ziczac* varies rather noticeably during the year (Fig. IV). Overwintering males were found to comprise about 42 to 46 percent of the population but the percentage was appreciably lower during May-June. Excess males may be superfluous after the initial matings and their disappearance may leave more food resources available for the production of young. Males become more common again as the bulk of the first generation transforms to adults in July, and then decreases again slightly. Another rise in male percentage occurs as the overwintering population forms in August. The proportion of males averaged 24 percent (range 14 to 46) in more than 20,000 leafhoppers examined. The sex-ratio pattern is believed to confirm that two generations of *E. ziczac* are produced in the Okanagan each year. Some overwintered females die before the first generation nymphs transform but males die in greater numbers.

Fig. IV Percentage of male *Erythroneura ziczac* at Kelowna and Oliver in 1969 and 1970.


Kelowna
Oliver
40
30
20
Percent of population
May
June
July
Aug
Sept
Oct

A. 1969


Kelowna
Oliver
40
30
20
Percent of population
Mar
Apr
May
June
July
Aug

A. 1970

Overwintered adults were collected in 1969 to see how long they would survive and to find if they would oviposit on non-host plants. Leafhoppers were caged with food plants that the species utilizes in the field (dandelion, strawberry and grass) but, although survival was good, no oviposition was observed. Some of these insects were later transferred to grape or Virginia creeper leaves and oviposition commenced immediately. Some of the leafhoppers lived until late July when they died. Death occurred when temperatures in the laboratory rose to over 100°F.

Mating pairs were collected with an aspirator and placed in vials for transporting to the laboratory. Initial difficulty in keeping pairs alive was largely overcome by placing a small piece of grape leaf in the vial with the insects and using a styrofoam cooler filled with wet grass to keep the leafhoppers cool. Each pair was placed in a lantern-glass cage that had a cardboard ice-cream carton lid for a base and fine-mesh plastic screening cemented over the upper opening. A hole for introducing and removing the insects was cut in the screen with a cork-borer and closed with a cork. A grape leaf with its petiole in a vial of water was placed inside the cage before the pair was introduced. Grape leaves of many varieties were randomly used to see if there were any preferences for oviposition. Thick-leaved varieties with hairy undersurfaces had very light oviposition but the same female would subsequently lay many eggs on smooth thin-leaved varieties (Table 1).

Adult feeding did not appear to be hindered by heavy pubescence but oviposition was restricted. Movement and feeding by small nymphs was noticeably hampered by the presence of dense leaf hairs. Nymphs became

Table 1 Oviposition by three <u>Erythroneura</u> <u>ziczac</u> females on hairy- or smooth-leaved grape varieties. Dates show when mated pairs were first put into cages. (s) indicates smooth leaved variety, (h) indicates hairy leaved variety.

MATED	GRAPE VARIETY	DAYS	EGGS	TOTAL EGGS BY JULY 28
May 27	S9549 (s)	3	11	
	Reisling (s)	5	17	
	Diamond (h)	4	2	
	Foch (s)	6	22	122
June 2	Patricia (h)	6	4	
	Foch (s)	11	37	
	S9549 (s)	6	29	147
June 9	S9110 (s)	3	15	
	Patricia (h)	11	2	
	Reisling (s)	3	9	
	S9549 (s)	7	23	94

entrapped by droplets of their own excretion on the hairs as they fed. In the vineyards, a hairy variety such as Diamond would be almost free of leafhoppers while other relatively hairless varieties a few feet away would have large populations.

Counts of the average number of eggs laid per leaf per day showed that smooth-leaved hybrid varieties had noticeably more eggs than hairy-leaved varieties. This is shown in Table 2.

Importance of the oviposition rate for leaf types is related to the fact that all new commercial plantings and vine replacements in the Okanagan are of hybrid varieties. The same types of vines that are preferred by the leafhoppers produce the grapes that are preferred by the wineries. Six mated first generation females caged with grape leaves produced an average of 121.7 eggs (range 74 to 161). Pairs collected in May and June produced the majority of their eggs within about a month and oviposition had virtually ceased by late July.

Table 2 Rates of oviposition (eggs/leaf/day) on smooth- and on hairy-surfaced grape leaves.

SMOOTH LEAVES	EGGS/LEAF/DAY	STANDARD ERROR
Reisling	5.0	1.06
Foch	3.0	0.67
S9110	4.7	0.28
S9549	3.9	0.39
HAIRY LEAVES		
Diamond	0.5	0.0
Patricia	0.35	0.18

III FIELD OBSERVATIONS AND MONITORING

Initial leaf-sampling in 1969 was a modification of that used by Hartzell and Horsfall (1944). A plastic bag was used instead of a paper bag and ethyl acetate rather than calcium cyanide. The bag containing a dental roll saturated with ethyl acetate was quickly drawn over the selected leaf and the petiole cut. A short wait allowed the chemical to take its effect on insects present and the next leaf could then be collected. Ethyl acetate killed active and inactive stages of insects and also the grape leaves so that the contents of each bag were of no further use once counting was completed. The discovery of parasite exit-holes in leafhopper eggs during July resulted in the omission of ethyl acetate from the plastic bag during collecting. Living grape leaves could then be brought back to the laboratory and egg-parasites could be reared from leafhopper eggs present on the leaves.

Elimination of ethyl acetate from collection bags produced no problem of escaping insects since adults could be seen through the plastic bag and dispatched with light finger pressure. Counts of insects had to be made the next day however, since the leafhoppers fed and continued transforming while in the plastic bags. Leafhoppers could be kept in this manner for at least two weeks (if desired) or until mold began to severely damage the grape leaves.

Counts of leafhopper stages in vineyards during 1969 were made by collecting samples of 10 leaves randomly along a row of vines. Grape variety blocks were selected and the number of rows of vines was counted so that sampling rows could be picked and recorded before sampling started.

End rows were avoided since these rows are reported to have higher leafhopper counts than inner rows (Hartzell and Horsfall, 1944).

The only leaves that were collected were leaves between 3 and 5 inches across that could be slipped into the bag with a minimum of disturbance. Wind facilitated collecting because even the slightest breeze caused adult leafhoppers to cling to the leaves, thus minimizing their escape.

It was not known which stage(s) would prove most useful for sampling to find an economic level for leafhopper populations. Madsen (1968) and Jenson, Flaherty and Chiarappa (1969) counted only nymphal stages of leafhoppers. This can be done successfully in the vineyard without the necessity of collecting leaves for laboratory counting. Disturbing a leaf, such as by gently turning it over, causes the nymphs to cling motionless to the leaf for a time. Some of the larger nymphs will often move to the other side of the leaf but this does not cause problems in counting.

Initially it was decided to count adults, nymphs and eggs of leafhoppers but later it was decided to continue only nymph counts. There was always the possibility of adults escaping no matter how experienced one became at slipping the plastic bag over the leaf. Eggs are easy enough to count but only those which produce leafhoppers can actually effect the leafhopper population. Egg counts were therefore only used in the estimation of parasitism percentages at the end of the reproductive season.

In 1970, sticky-board sampling of adults was tried and this method appears to be very effective. The boards are six by twelve inch pieces of plywood, painted yellow on one side and coated with "Stikem Special", manufactured by Michel and Pelton Company of Emeryville, California. String was used to hang the boards initially but it was found that the wind twisted the string and it eventually broke. Heavy copper wire proved satisfactory and some boards were left out for four weeks with no problem. Boards were hung about two feet from the ground and five to ten feet from row ends to avoid end vines.

Boards were usually left on the vines for two weeks and the insects on them then counted. Occasionally they were left longer so that the grower could check leafhopper numbers himself. Catches for two weeks ranged from 0 to 2015 on individual boards with highest numbers found next to overwintering locations (clean-cultivated vineyards) and among vines with heavy undergrowth of grass and weeds that provided good overwintering sites. Once migration to the vines was finished, unsprayed vines in one vineyard retained fairly level leafhopper numbers for the rest of the season (Table 3).

Sampling vineyards before and after spraying showed how the grower could use boards to monitor leafhopper numbers (Table 4). Spraying at Oliver was timed to kill the maximum number of first-generation insects before transforming adults began laying eggs. The chemical pesticide, Sevin, did not appear to kill leafhopper eggs, whether parasitized or not, but almost obliterated active stages. Leafhoppers and parasites emerged from eggs laid prior to spraying.

Table 3 Numbers of adult *Erythroneura ziczac* caught on yellow sticky-boards at Covert Farms, Oliver, B.C. in 1970. Numbers in brackets indicate number of sticky boards and standard error.

VARIETY	AVERAGE LEAFHOPPERS/BOARD/7 DAYS		
	MAY	JULY	AUGUST
Bath	646 (5 - 135)	135 (5 - 23.2)	129 (2 - 31.4)
Reisling	145 (4 - 42)	20 (5 - 7.3)	43 (2 - 5.7)

Table 4 Numbers of adult *Erythroneura ziczac* caught on yellow sticky-boards at Richards Bros. Vineyard, Oliver, B.C. in 1970. Vines were sprayed with Sevin prior to second sampling date. Numbers in brackets indicate number of sticky boards and standard error.

VARIETY	AVERAGE LEAFHOPPERS/BOARD/7 DAYS		
	MAY	JULY	AUGUST
Reisling	212 (6 - 44.4)	0.2 (5 - .09)	8 (3 - 1.9)
S9549	40 (9 - 9.3)	0.13 (4 - .11)	0.75 (2 - .18)

IV NATURAL CONTROL OF THE LEAFHOPPER

A. Predators

Various predators are present in the vineyard during the year and these undoubtedly take a large number of leafhoppers. Lacewing and ladybug larvae and adults are found in the vineyards but neither in large numbers nor continuously. Lacewing larvae placed on leaves with leafhopper nymphs can usually catch one nymph rather easily if it is encountered while feeding. Leafhopper nymphs cease feeding after they become aware of the intruder's presence and even the smallest nymph can easily escape the reach of the slower predator.

A nabid (*Nabis alternatus*) was often seen on the vines. This insect was noted as an egg predator at Kelowna by Madsen (1969). *N. alternatus* was observed taking adult *Erythroneura ziczac* but probably is more effective as a predator of leafhopper eggs. Collapsed eggs with punctures in them were often found but the predator was not observed at work. The nabid overwinters as an adult in the same habitat as *E. ziczac* adults and many dead leafhoppers were found while sampling these sites. An unidentified staphylinid beetle was also numerous in the overwintering trash in late fall but its value as a predator was not determined.

There was a great number of different spiders present on the vines during the growing season and in the overwintering sites of *E. ziczac*. Hunting spiders were observed eating adult leafhoppers in the overwintering areas and also *E. ziczac* adults were observed caught in webs built among the grape vines in summer.

The value of predation in controlling leafhopper numbers during their reproductive season appears marginal with the possible exception of an effective egg predator. Nabis alternatus may be an only incidental predator of E. ziczac stages in spite of the frequency with which it occurs in the same habitat. In 1970 the bug was absent from vineyards in Kelowna from late March until early June. It is not known where the insect goes during this interval or for what purpose. The nabid is ubiquitous during the summer, at least, but it is probably a general predator that does not specialize on E. ziczac.

Predation is probably most valuable in reducing the population of overwintering adult leafhoppers. This seems to be the stage most vulnerable to natural mortality factors but this weakness soon disappears when the leafhoppers move to the host plants and commence reproduction.

B. Parasites

During 1969 and 1970 many thousands of Erythroneura ziczac adults and nymphs were studied under the microscope and not one was found to be parasitized. This agrees with the conclusions of Johnson (1914) who found adult parasitism to be very rare. Parasites of active stages of leafhoppers do exist in the Okanagan (Hamilton, 1970) but they apparently do not attack E. ziczac appreciably if at all.

After parasite exit-holes were found in leafhopper eggs and ethyl acetate was omitted from collection bags, close observation showed the presence of various stages of developing parasites in the egg. The earliest detectable stage is a small transparent larva which contains a number of white fat-globules. Only one larva was observed in any one E. ziczac egg. Size of the leafhopper egg must preclude the development of more than one parasite and if multiple oviposition occurs only one parasite could survive. During the dissection of Edwardsiana rosae eggs in 1970, two early larvae were found in one egg but it is unlikely that more than one would survive. Working with Anagrus atomus, a parasite of E. pallidifrons, MacGill (1934) observed multiple oviposition and partial development but never more than one adult emerged from a leafhopper egg.

The early larva is about half the length of the leafhopper egg and often thrashes about in the liquid contents, thereby probably assisting to keep certain materials available for food. There are six segments including the head with the terminal segment being much longer than the others. Large, curved, chitinized mandibles and long appendages (ventral to the mandibles) are present on the head segment. MacGill (1934) described ventral outgrowths on the sixth segment of Anagrus atomus larva but those on the Okanagan parasite seem to be more lateral than ventral. Appendages on the head segment are probably sensory but the function of those on the last segment was not certain. These might be sensory, respiratory and/or utilized as an assistance for movement. Larvae are known as the histeriobdelid stage through resemblance to a worm with that name (MacGill, 1934), and Mulla (1956) mentioned that several larval forms of A. epos are included by this term.

Observations at Summerland indicate the existence of at least three larval stages but the exact number was not definite. Information regarding the number of larval instars is rather sketchy, probably in part due to the small size of the insect. Late instars retain the mandibles and head appendages but the posterior appendages gradually get smaller. Over 80 percent of the interior of the leafhopper egg is taken up by the final larva and movement is limited to a rolling motion. MacGill noted that late larval instars of A. atomus often turn red. Doutt and Nakata (1965) noted the same thing for eggs parasitized by A. epos. This color change can be used to detect activity of the parasite. No color change was seen in parasitized leafhopper eggs observed during the present work other than the accumulation of white fat-globules. Mulla (1956) did not mention color change in eggs of Typhlocyba spp. containing larva of Anagrus epos.

As pupation starts, a white opaque body forms in the abdominal area of the forming adult that occupies about 80 percent of the leafhopper egg length. Following this, two red eye-spots appear and the coloration changes to brown as the parasite assumes its adult coloration. The parasite lies on its back so that both eyes are easily visible whereas the developing leafhopper nymph is on its side exposing only one eye clearly. To emerge, the mandibles are used to cut a neat round hole through the chorion and leaf epidermis at one end of the leafhopper egg. MacGill (1934) suggested the possibility that pupating larvae may spin a light cocoon as eggs that produce parasites do not collapse as do the eggs from which leafhoppers emerge. This was also noted with parasites of leafhopper eggs in the Okanagan but possibly larval exuviae might be responsible for differences in structural strength.

When a number of eggs in a cluster are attacked, parasite emergence holes can be at either end of an egg while leafhoppers always emerge from the same end. Leafhopper eggs must be oriented head (or tail) first as the female shifts sideways to insert a group of eggs since eye spots and emergence at one side were invariably consistent.

Parasite emergence is not accomplished rapidly. One wasp which had begun to chew an exit hole was observed periodically and after three hours had only produced a slight enlargement of the hole. Parasites that had died while trying to emerge were found occasionally.

The first adult Hymenopteran parasite was observed Aug. 8, 1969 and many more were subsequently collected and placed in 70 percent ethanol for identification. A number of female parasites were observed searching about the surface of grape leaves from which they emerged. The parasite moved about very rapidly considering its size, constantly tapping the leaf surface with its antennae. Considerable attention seemed to be given to areas where female leafhoppers had fed during oviposition. When a leafhopper egg was located it was tapped with the antennae for a time apparently to check suitability for oviposition. The female climbs onto a chosen egg and after straddling it along its length, thrusts the ovipositor through the egg chorion. Oviposition takes two to three minutes, after which the ovipositor is withdrawn and the wasp resumes its wanderings about the leaf.

Attempts to determine the development time of parasites from oviposition to emergence were not successful. Leafhopper eggs in which oviposition was actually observed (1969) were in the eye spot stage and must have been too far developed for successful parasitism. Oviposition was in eggs already on the leaf at the time of collection and the leaves were isolated for the purpose of rearing out parasites. These old eggs turned purple and collapsed after a few days so that neither the parasite nor the leafhopper hatched. Female parasites were alone on the leaf from which they emerged and could not have mated before they set about laying eggs. No feeding was observed at this time so the wasp must be ready for oviposition immediately after emerging. Parasites emerged from leafhopper eggs a few days after leafhopper nymphs hatched from unparasitized eggs in the same cluster (and therefore very close to the same age). As leafhoppers hatch in 14 to 17 days and if a few days is allowed for parasite oviposition, the development of the parasite must take between two and three weeks. Emergence of parasites soon after the leafhoppers hatch also indicates that only newly laid eggs are successfully parasitized.

MacGill mentioned difficulties in rearing Mymaridae from egg to adult and considering present success the author must agree. Plant tissue must be kept moist and if oviposition by parasites is achieved leafhopper eggs must be maintained in suitable condition for up to three weeks, avoiding mold that thrives in this warm, moist environment.

Adult parasites collected for taxonomic study in 1970 were placed in vials laid horizontally after streaking lengthwise with liquid honey using a single stiff brush bristle. Vials were placed with the streak up to avoid trapping the wasps which could walk over the surface of the honey while feeding without becoming stuck. A few insects did become trapped when their wings touched the honey while they were flying and some were inadvertently mired when blown out of the aspirator. Most adults lived about three days after hatching but some females survived for as long as seven days.

MacGill (1934) believed that the species was parthenogenetic for the greater part of the year. Five hundred and fifty A. epos from the different locations in the Okanagan were sexed and one-third were found to be males. As is typical with Hymenoptera, fertilized eggs of A. epos probably develop into females and unfertilized eggs into males. Some ovipositing parasites exercise the option of depositing fertilized or unfertilized eggs according to some stimulus such as size of prey or possibly frequency of encounter with males of her species.

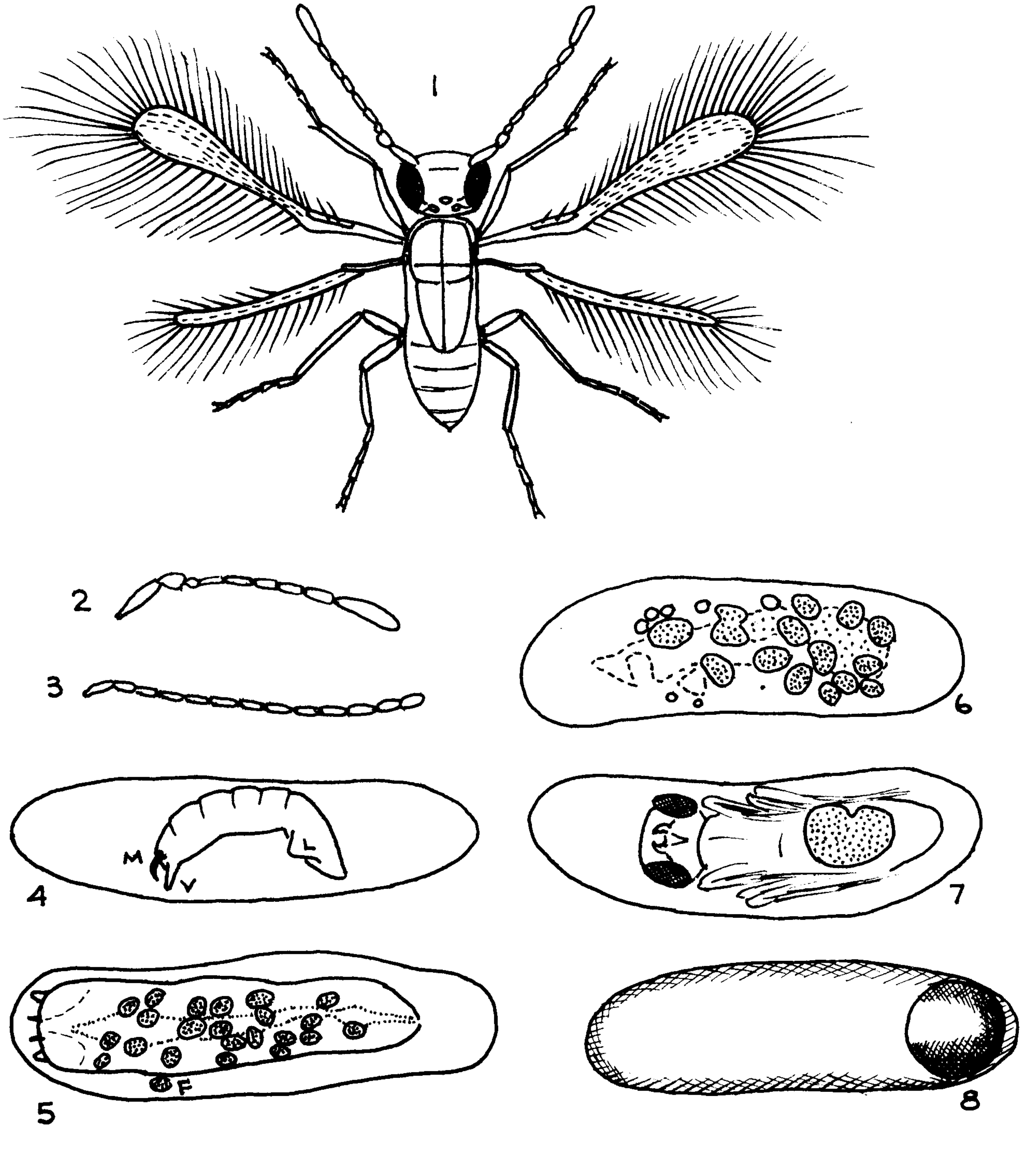
Anagrus epos females are light brown and average 0.608 mm in length (range 0.545 to 0.652 mm) while the males are darker and smaller, averaging 0.577 mm in length (range 0.509 to 0.631 mm). Other than their small size, the most striking structural feature is the fringe of long hairs around the margins of the wings that give this group of parasites the common name of 'fairy flies'. Recently emerged insects have bright red eyes that gradually darkened with age. Female antennae are nine-segmented with a large terminal segment forming a distinct club. Male antennae are longer than the female's and have thirteen segments but no terminal club.

Investigation during the summer of 1970 was concentrated on the parasite and its means of overwintering. As it is an egg parasite and

Fig. V

<u>Anagrus</u> <u>epos</u>. 1. Female X 80. 2. Female antenna X 100. 3. Male antenna X 100. 4. Early larva inside leafhopper egg (M, mandible; V, ventral appendage; L, lateral appendage). 5. Late larva, dorsal view (F, fat globules). 6. Start of pupation. 7. Adult showing orientation.

8. Emergence hole of parasite in leafhopper egg. 4-8 X 120.


1
2
3
M
V
L
4
F
5
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V
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8

E. ziczac overwinters as an adult, it seemed most likely that an alternate leafhopper host overwintering in the egg stage would be involved. The very poor condition of the fallen grape leaves pretty well precluded the possibility of the parasite overwintering as a pupa *in situ* in the *E. ziczac* egg.

A number of woody shrubs were collected from the Summerland area and the stems dissected in a search for overwintering leafhopper eggs During April 23 - 24 leafhopper eggs (*Edwardsiana rosae*) were found in wild rose growing next to Virginia creeper where parasitized *Erythroneura ziczac* eggs were found in 1969. Some of the leafhopper eggs in the wild rose stems were very obviously parasitized and closely resembled parasitized *E. ziczac* eggs on grape. Wild rose cuttings were caged in the laboratory and adult parasites which emerged May 13 - 15 were placed in ethanol for identification.

Further dissections of caged material after May 15 showed more parasitized eggs that were still in early stages. After two weeks had passed with no further emergences, it was suggested that two distinct hatches would occur. A double hatch might result from the time of parasitism during the previous fall, where temperatures might allow the first parasite eggs to develop until pupation. Eggs from later oviposition might remain dormant because of lower temperatures and not start development until spring. The second hatch did materialize on June 8 and continued until June 27. All unparasitized leafhopper eggs on wild rose cuttings hatched during the first week of May so the second hatch was not progeny of the first hatch. A large number of parasites emerged June 22 from E. ziczac eggs on caged Virginia creeper leaves collected near wild rose at Summerland. These parasites must have been the progeny of the first hatch of adult parasites from the adjacent rose canes.

It was known that an apple leafhopper (Typhlocyba pomaria) overwintered in the egg stage (Madsen, 1969). Apple twigs were collected from Summerland and Kelowna during May and dissections showed the presence of parasitized leafhopper eggs. Adult parasites started emerging June 8 and continued until the end of the month. No double hatch occurred from apple twigs. The parasite continues to attack T. pomaria eggs laid through the summer but these are in the main veins of the leaf. Overwintering eggs are inserted under the bark of new growth probably during the time leaves fall or later. It is not known if eggs of Edwardsiana rosae are parasitized in summer as the seasonal history of this non-economic leafhopper was not studied. There may be some difference between egg placement by the leafhoppers on apple or wild rose to account for the double hatch from wild rose.

One of the vineyards being studied at Kelowna was directly adjacent to a block of apple trees that supported a large population of apple leafhoppers. Grape leaves collected June 24 from vines next to apple trees showed a good degree of parasitism, with 18 of 20 leaves containing parasitized eggs and some parasite emergence holes.

Parasites from the four species: grape, Virginia creeper, wild rose, and apple were very much alike in appearance and are at least in the one genus. Specimens collected from grape in 1969 were sent to Ottawa where they were identified as Mymarids of the genus *Anagrus*, species near *epos* (Yoshimoto, 1969). Exact identification was not possible because of the lack of a specimen of *A. epos* for comparison. Additional parasites were sent to Dr. R. L. Doutt in California as he has been working with *A. epos* as a parasite of another 'grape' leafhopper, *Erythroneura elegantula* (Doutt and Nakata, 1965). In 1970 parasites from all four sources were sent to Ottawa and to Dr. Doutt to see if any progress in identification could be made.

R. L. Doutt is an authority in the taxonomy of Mymaridae but in a letter (1970) he stated he had almost abandoned hope of being able to identify species of *Anagrus* with any degree of confidence. The problem is compounded by the fact that morphological characters used to separate species are enormously variable and presumed species intergrade when a moderately large sample is examined.

After studying parasites from the Okanagan Doutt was inclined to think the four lots were morphologically indistinguishable from one another and were probably the same species that attacked *Erythroneura elegantula* on grape in California. The California parasite has been referred to as *Anagrus epos* or near *epos* with the realization that it might sometime be shown to be a separate species. Doutt has seen the original series of parasites used by Girault and notes that the

Californian species is certainly related to *epos*. There are differences in minor details which Doutt states do not impress him as being very significant. The Californian *Anagrus* is considered to be *epos* in a broad sense and the Okanagan parasites appear to be also a part of the *epos* complex.

Estimates of percentage of parasitism of *Erythroneura ziczac* eggs on grape (or Virginia creeper) are probably best made in September when egg-laying by the leafhopper should be finished. Removal of leaves from the vine earlier in the season will prevent further oviposition by leafhoppers but emerging parasites are free to attack eggs already on the leaves. Also a good number of eggs not immediately detectable as parasitized can often be seen as such after a few more days of development time. Grape leaves remain on the vines until frost kills them (October) and leafhopper eggs from early in the season can be readily detected while the leaves are green.

A number of leafhopper eggs turn purple and collapse but there may be more than one cause for this. Some eggs may not be viable or mechanical injury from leaf growth may kill them. In the laboratory, parasites were observed ovipositing in leafhopper eggs at the eye-spot stage and these eggs invariably darkened and collapsed. Apparently host development had proceeded too far for successful parasite development but the parasite egg or maybe oviposition itself kills the developing leafhopper. Many leaves which contained darkened leafhopper eggs had no sign of parasitism on other eggs present in a cluster.

Grape and Virginia creeper leaves examined from late August until early October showed varying degrees of parasitism. Leaves well-marked by leafhopper feeding were collected, as this was generally a good indicator of leafhopper oviposition. Five categories were used in evaluating percent parasitism: eggs from which leafhoppers hatched; leafhopper eggs remaining viable (but unlikely to produce adults because of the late date); eggs which will produce nothing; parasitized eggs; and eggs with parasite exit holes. Of 49 leaves examined, five showed no parasitism and two of them contained no leafhopper eggs. Leaves that escaped parasitism had six or fewer eggs on them while one leaf had 58 to 61 eggs parasitized and another had 59 to 79 eggs parasitized.

Under 30 percent of 4,163 eggs from six collections made between late August and early October were either viable or had produced leafhopper nymphs. Forty-seven percent either contained or had produced parasites, with incidence of parasitism ranging from 21 to 70 percent in the collections and from 0 to 100 percent on individual leaves. Twenty-two percent of the eggs died without producing either parasites or leafhopper nymphs. Some of these may have involved parasite oviposition in eggs that were too far advanced in development for successful parasitism. Other dead eggs had punctures indicating they had been killed by predator attack. Nine of 12 eggs on one leaf and 52 of 132 dead eggs in one collection had been killed in this way. The suspected predator was _Nabis alternatus_ although a lacewing larva (Chrysopidae) was observed puncturing eggs in the laboratory. Lacewing adults or larvae were not nearly as abundant as the nabid in the field.

V DISCUSSION AND CONCLUSIONS

At present most grape growers in the Okanagan depend on chemical sprays for control of leafhopper damage to vines. DDT, Thiodan and Guthion have been used but these are not apparently too successful now and a changeover to Sevin has been started. Sevin is certainly toxic to the active stages of the leafhopper but does not apparently affect the egg stage. Eggs parasitized before spraying also seem to be unaffected as adult parasites emerged from leaves collected a few days after spraying. Some British Columbia Department of Agriculture workers, however, are afraid of the possibility of problems with spider mites developing if Sevin is used too often (Allan, 1969). Mites are present in vineyards but are encountered very infrequently at present. If spraying is done only once during any year it is quite likely that a mite problem would not develop but multiple applications may not be a wise course.

Another spraying practice which may be neither prudent nor necessary is the covering of the whole vineyard rather than spot applications in blocks where leafhopper populations are high. The common feeling seems to be that it is just as easy to spray the whole vineyard as a part of it and that spraying is always necessary.

If the growers could sample leafhopper numbers they could spot any potential trouble areas and plan a spraying program for only these areas. Yellow sticky-boards might be practical sampling devices as very little experience is needed to pick out *Erythroneura ziczac* adults from any other insects which might be caught on the boards. The yellow sticky-boards may be obtained from the British Columbia Department of Agriculture Branches in the Okanagan as they are used for detecting cherry fruit fly infestations in the Okanagan and are purchasable at a nominal cost ready to use.

Boards would have to be hung out at most only three times during a season: from May 15 to June 1, when leafhoppers move to the vines; July 1 to July 15, when the first generation adults reach a peak; from August 7 to August 21, when the second generation adults appear. Most spraying is done against the first generation adults so that usually one sampling period in July may be adequate. Some growers had success by spraying for the overwintering adults as soon as they start feeding on the vines. Timing is much more critical at this stage as it is desirable to wait until the maximum number of insects are feeding but before oviposition starts in earnest. The second generation adults might be safely ignored as low leafhopper numbers at this date couldn't do much harm to the vines. Sticky boards could be used to monitor the overwintering population of leafhoppers if they were hung up for a time after the grape harvest was completed. Vineyards that were clean-cultivated in spring stayed free of _E. ziczac_ until the leafhopper moved in from overwintering sites around the vineyard. The wisest course might be to wait as long as possible before cleaning up fallen leaves. Pruning is done in December and this time (barring snow) might be best for a general clean-up and cultivation. Hopefully, leafhoppers that were uprooted from their wintering sites would be too lethargic to move to new locations. Cold by itself cannot be a significant mortality factor but many leafhoppers found dead in March were in damp leaves. Mold was often associated with this situation so that dampness may have a positive though indirect effect that might be manipulated.

Different grape varieties may show varied tolerance to leafhopper damage but moderate infestations of healthy vines do not reduce production. It is believed that spraying can be omitted where the leafhopper catch on sticky-boards does not exceed 100 adults over a seven day period. This number might possibly be adjusted slightly downward in the case of young vines or vines severely affected by cold during the previous winter. Spindly or sickly vines should probably be provided with better irrigation or nutrition rather than applying spray against leafhoppers.

Control programs for grape leafhoppers outlined by the the California Agricultural Extension Service (1967) assert that low insect numbers do not need treatment. Low numbers were assessed as ten nymphs or less per leaf on those leaves with most evident feeding. The most workable method of carrying out this sampling would probably be to pick ten-leaf samples along individual rows with immediate counting. Leaves could be retained (to check leaf total) in plastic bags. Not much experience is needed for leaf selection and the process could be done quickly. Weekly nymph counts starting in mid-June using randomly selected rows throughout the vineyard should give the grower a good indication of population trends.

The presence of substantial numbers of parasites in the Okanagan suggests an alternative to the use of chemicals for leafhopper protection. Doutt and Nakata (1965) state that in California Anagrus epos can successfully keep populations of Erythroneura elegantula to non-economic levels. In California, A. epos overwinters in eggs of an non-economic leafhopper on wild blackberries and the introduction of these next to vineyards has proven very beneficial. Parasitism has been shown to be directly proportional to the distance between vines and wild blackberry plantings (Doutt, Nakata and Skinner, 1966).

A parallel situation involving A. epos and leafhoppers from grape, apple and wild rose apparently exists in the Okanagan. It is quite likely that further searching would show that more leafhopper species are involved as alternate hosts of the parasite because of its wide distribution through the Okanagan. Leafhopper eggs were not found in woody plants studied for parasitism, other than apple and rose, but the search should have been expanded wider to include particularly additional domestic trees and canes as Typhlocyba pomaria utilizes Prunus spp. as well as apple as a host, Edwardsiana rosae will oviposit on apple, plum and Rubus spp. and another possibility, Typhlocyba quercus, uses cherry as a host (Beirne, 1956). A number of leafhopper studies have shown the presence of egg parasites but most information on the latter tends to be collected incidently to the leafhopper investigation. Anagrus epos has been recorded as an egg-parasite of

Erythroneura plena Beam., E. elegantula Osb., Edwardsiana prunicola (Edw.), E. rosae (L.), Typhlocyba quercus (F.) and T. pomaria McA. in the United States (Mulla, 1956). Mulla noted that one investigator proposed that Anagrus epos was responsible for reducing the annual broods of Erythroneura elegantula from the normal three to two in California and that twenty-five to 95 percent of the leafhopper eggs in some vineyards were parasitized and the reproductive potential of the host was greatly impaired.

Possibilities for the use of wild rose to boost parasite incidence are obvious, in view of the success with wild blackberries in California. The proximity of wild rose to Virginia creeper at Summerland must have influenced the high incidence of parasitism and the subsequent effect on leafhopper egg numbers. Grape vines were grown in a screened insectary at Summerland in 1969 for the purpose of supplying 'clean' leaves for oviposition and rearing of leafhoppers. E. ziczac adults soon found these vines and attempts to remove them with an aspirator were soon abandoned. Futility was rewarded when parasitized eggs were discovered and this source actually yielded the first adult parasite collected. Only a few hundred feet separated the insectary and the Virginia creeper-wild rose association which was much closer than any grapes grown in the area. Wild rose is presently considered to be a weed and is usually found only along road allowances and in non-cultivated areas.

Growing apple trees and grape vines together for mutual protection might be even more appealing to some growers. Typhlocyba pomaria is an economic species on apple and currently is sprayed to control its numbers. Madsen (1969) has begun a study of this leafhopper to determine its seasonal history and pest status at Kelowna and Summerland. Generally orchards and vineyards are set apart in large blocks but results might prove interesting if some system of interplanting grape vines and apple trees were devised.

An unusual situation developed at Oliver in 1970 but circumstances were not typical of commercial vineyards. Sticky boards produced some of the highest leafhopper counts made but no spraying was done. Vines were in good condition with heavy foliage and the grower reported unusually high tonnage (15 tons per acre) with a low 15 percent sugar content. Parasites were present both years of the study but apparently too late in the season to check leafhopper numbers substantially. Thinning out excess grape bunches early in the season would have been possibly the wisest choice since 11 or 12 tons per acre is considered a heavy crop. Leafhoppers in the numbers found must have had some effect on the inability of the vines to raise the sugar content but the usual practice of spraying was not done. If parasites had been present early enough in good numbers, demands on the vines by leafhoppers might have been reduced enough to achieve the minimum sugar content of about 18 percent desired by the wineries. This vineyard is on a bench about a mile from cultivated areas in the valley and with an intervening belt of pine trees between. There were no apple trees on the 300 acres involved and no wild rose was found around the periphery so parasites must have come from the valley below. Soil is almost pure sand and only irrigation allows the growing of grapes and vegetables in what would be considered desert conditions. Parasites were found by late June in continuous-cultivation areas but were not seen until over a month later in the isolated vineyard.

It is evident that if Erythroneura ziczac numbers are unchecked, the leafhopper can affect the productivity of vineyards in the Okanagan. Two cultural procedures would tend to keep leafhopper populations below their present average levels: destroying the insects by attacking them in their overwintering sites in the vineyards which would not affect the parasite (predators are considered ineffectual); and by providing the parasite with nearby overwintering hosts by growing wild rose and apple in or close to the vineyards. Sevin is presently a potent leafhopper poison but its use should be limited to emergency situations so that its effectiveness can be prolonged. Growers should use yellow sticky boards to sample adult leafhoppers, spraying only if counts exceed 100 per seven-day exposure and spraying only in the areas with high counts. Alternatively, nymph counts should be made with no spraying unless the count exceeds an average of ten nymphs (on leaves with the most apparent feeding) for ten leaves picked along a row.

APPENDIX 1

A GRAPE LEAFHOPPER, *ERYTHRONEURA ZICZAC* (HOMOPTERA: CICADELLIDAE), AND ITS MYMARID (HYMENOPTERA) EGG-PARASITE IN THE OKANAGAN VALLEY, BRITISH COLUMBIA

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Abstract

The leafhopper *Erythroneura ziczac* Walsh is the most important insect on grape in the Okanagan Valley, B.C. Hairy-leaved varieties of grape are relatively resistant to attack. The leafhopper has two overlapping generations a year and overwinters in the adult stage. Its chief natural enemy is a mymarid egg-parasite, *Anagrus epos* Girault, which overwinters in the eggs of other species of leafhoppers on wild rose and apple so that intensity of parasitism of *E. ziczac* can be influenced by proximity of those plants to vineyards.

Introduction

Erythroneura ziczac Walsh feeds on Virginia creeper and Boston ivy (*Parthenocissus* spp.) in addition to grapevine (*Vitis* spp.). It has a wide distribution in North America. Its life-history was described by Runner and Bliss (1923), Fairbairn (1928), and Pepper and Mills (1936). In Canada it has been regarded primarily as a pest of Virginia creeper and is normally less common on grapevines in Ontario and Quebec than are some other species of *Erythroneura* (Beirne 1956). It is the only grape-feeding species of leafhopper found so far in the Okanagan Valley, the main grape-growing area of British Columbia. It was apparently noted as a pest there first in 1951 (Marshall 1952) and was later surveyed by Madsen (1968).

It is now the most abundant insect on grape in the Okanagan Valley where its economic significance has increased in recent years because of the development of the local wine industry. The bionomics and ecology of the leafhopper were investigated in the summers of 1969 and 1970 to see if there were aspects that might be manipulated by cultural procedures to prevent the development of damaging leafhopper populations and thereby to reduce needs to apply chemical pesticides.

Life-history and Habits

There are two generations a year in the Okanagan Valley. They overlap, so that all stages may be found from May and September: the eggs from May to July (first generation) and July to September (second generation), the nymphs from May to August (first) and July to October (second), and the adults from June to August (first) and August through the winter to June or July of the following year (second).

The adults overwinter among fallen leaves and grass, especially under decaying grape leaves left under the vines. They become active before the first grape leaves appear in the spring and feed on the leaves of early plants, especially dandelion. Mated pairs were found first in mid-May and the first eggs about a week later. Eggs are laid on the undersides of the vine leaves and hatch in 14 to 17 days. Nymphal life is 15 to 16 days. Most males die soon after mating. The proportion of males, which averaged 24% (range 15 to 46) in over 20,000 leafhoppers examined, was highest from about August to April or May and again in July. This was one indication that there were only two broods annually.

The nymphs and adults feed on the mature leaves, mainly on the undersides, and tend to avoid strong direct light. Leaf hairs hamper the movements of and feeding by the small nymphs but not the adults. Both adults and nymphs cling motionless to the leaves when disturbed. The adults fly actively between the leaves when the temperature is above 75°F and when there is no perceptible breeze.

Erythroneura ziczac is a mesophyll feeder. Each nymph destroys an average of just over 1 sq. cm of leaf surface during its life, and in 1969 numbers of nymphs averaged just over 10 per leaf in 42 samples of 10 leaves each taken at intervals between 2 June and 29 August in two vineyards and ranged up to 47 on individual leaves. The amount of leaf surface destroyed by the adult could not be measured.

Consequences of heavy infestations are that the fruit may be inferior and the wood may not mature properly so that the buds or canes are susceptible to winter-kill or produce poor crops. Results of a severe infestation near Oliver in 1968 were that the leaves turned brown and dropped before harvesting began, the grapes were not worth harvesting because they were stunted and had a sugar content of 8–9% instead of the normal 20–25%, and the wood for the next year's bearing canes appeared unsound (La Bounty, pers. comm.). A severe infestation of Virginia creeper resulted in complete defoliation.

Varieties of grapevines that have leaves with hairy undersurfaces that inhibit egg-laying tend to have much smaller populations than other varieties. Counts of average numbers of eggs per leaf per day showed that relatively hairless hybrid varieties received from four to 25 times the number received by hairy American varieties. The figures were, for the American varieties, Diamond 0.5 and Patricia 0.2 and 0.7, and, for the hybrid varieties, Reisling 3.4 and 3.0, Foch 3.7 and 3.4, S9549 3.3, 3.7 and 4.8, and S9110 5.0. Laboratory tests confirmed that the leafhopper would lay few eggs on varieties Diamond and Patricia but many on the hybrid varieties. A possible increase in the importance of the leafhopper as a pest is indicated by this, as only hybrid varieties are used in new commercial plantings and in vine replacements in the Okanagan Valley.

Wide differences in the sizes of populations on different varieties of vines were indicated also by the numbers of leafhoppers caught on yellow sticky boards, such as are used in the Okanagan to survey for cherry fruit fly infestations, suspended in the vineyards. In one unsprayed vineyard the average numbers caught per board in 7-day periods in May, July, and August were 646, 135, and 129 among variety Bath and 145, 20, and 49 among variety Reisling. In another, the corresponding figures were 286, 63, and 12 for Reisling and 72, 23, and 1 for variety S9549. Data on similar comparisons between other varieties was insufficient, either because the vineyards were sprayed or because the boards fell or were removed prematurely. A general impression gained from the surveys with sticky boards is that damage was not sufficient to warrant spraying when the average number of leafhoppers caught per board in a 7-day period was under about 100. This estimation is for the peak numbers of the first generation adults that appear about the second week of July.

Mortality

Under 30% of 4163 eggs from six collections made between late August and early October were either viable or had produced leafhopper nymphs. Forty-seven per cent of the eggs either contained or had produced a parasite which was identified by R. L. Doutt and by C. M. Yoshimoto as *Anagrus epos* Girault (Hymenoptera: Mymaridae) or a species close to it. The incidence of parasitism ranged from 21 to 70% in the collections and from 0 to 100% in individual leaves. Twenty-two per cent of the eggs died without producing either parasites or leafhopper nymphs.

Some of them were killed by the parasite as the eggs turn purple and collapse if they are in the eye-spot stage when the parasite oviposits in them. Other dead eggs had punctures indicating that they had died from predator attack. Nine of 12 eggs on one leaf and 52 of 132 dead eggs in one collection had been killed in this way. The suspected predator was *Nabis alternatus* Parsh. (Hemiptera: Nabidae) which was common on the vines and was seen by Madsen (pers. comm.) to attack leafhopper eggs. Some of the collapsed eggs had apparently not been killed either by the parasite or by predators but had the appearance of being crushed by growth of the leaf tissue. This is apparently a hazard of laying eggs in young leaves rather than in mature leaves that have finished growth.

No indication of parasitism was noted in over 20,000 adult leafhoppers that were examined microscopically or in the nymphs.

Nabis alternatus was seen to attack nymphs and adults but appeared to be insignificant in importance as a predator on the vines. Chrysopid larvae attacked the nymphs but were usually easily evaded by them. Insignificant numbers of the adults were captured by spiders. Small nymphs on hairy leaves sometimes were trapped on the leaf hairs by their own excretions.

Many dead leafhoppers were found in the hibernation sites, especially in damp leaves. There were indications that some had been killed by predators. *Nabis alternatus* hibernates as an adult in the same situations as do the leafhoppers and may have been partly responsible.

Clean cultivation of vineyards destroys the overwintering adults or drives them away: surveys using sticky boards showed that in clean-cultivated vineyards the leafhoppers appeared in the spring first at the ends of the rows of plants, indicating migration from outside the vineyard, whereas they were present throughout vineyards where dead vine leaves were on the ground since the previous autumn. Chemical pesticides vastly exceeded in importance all other causes of mortality. In one vineyard an average of 181 adults per week per board were caught on sticky boards before spraying and an average of 0.2 afterward. In another, the corresponding figures were 325 and 0.5.

The Egg-parasite

The most important natural enemy, the egg-parasite *Anagrus epos,* is the same species that attacked eggs of *Erythroneura elegantula* Osb. on grape in California (Doutt, pers. comm.). *A. epos* has also been recorded as an egg-parasite of *Erythroneura plena* Beam, *Edwardsiana prunicola* (Edw.), *E. rosae* (L.), *Typhlocyba quercus* (F.), and *T. pomaria* McA. in the United States (Mulla 1956).

The female parasite moves about rapidly, constantly tapping the leaf surface with its nine-segmented, clubbed antennae. It tends to pay much attention to areas where the leafhoppers had fed. When it finds an egg it taps it with the antennae for a while and then inserts the ovipositor in it for 2 to 3 minutes. The females that were observed did not mate or feed before laying eggs. One third of 550 parasites examined were males, which have 13-segmented antennae that are not clubbed.

The parasites emerged from the leafhopper eggs a few days after leafhopper nymphs emerged from unparasitized eggs of about the same age. As the leafhopper eggs hatch in 14 to 17 days the development of the parasite must take between 2 and 3 weeks.

The parasite has three larval stages, similar to those illustrated by Mulla (1956). The first stage is about half the length of the egg, which averages

0.65 mm. It thrashes about quite often in the liquid content of the egg. The final instar almost fills the egg-shell and its movement is limited to a rolling motion. The egg assumes a whitish appearance when the pupa is first formed, then two red eye-spots appear, and finally the egg turns brownish. The fully-formed parasite lies on its back and uses its mandibles to cut a round emergence hole in the egg and in the leaf tissue around it, a process that takes several hours and which some parasites do not survive. Eggs from which parasites emerge are recognizable because they have round exit holes and do not collapse whereas those that produced leafhoppers are split at one end and collapsed.

As *E. ziczac* overwinters in the adult stage it seemed most likely that the parasite overwintered in another species of leafhopper that overwinters in the egg stage. This is what happens in California where *Anagrus epos* parasitizes eggs of *Erythroneura elegantula* on grape in summer and overwinters in eggs of *Dikrella cruentata* Gillette on wild blackberry (*Rubus* sp.) (Doutt *et al.* 1966).

In the Okanagan eggs of *Edwardsiana rosae* that were found on wild rose in April 1970 were parasitized by what was subsequently determined as the same species that attacks *E. ziczac*. The wild rose was growing close to Virginia creeper on which parasitized eggs were found in 1969. The same parasite was reared in May from eggs of *Typhlocyba pomaria* on apple close to a vineyard that in June had good parasitism of *E. ziczac* eggs. Both *E. rosae* and *T. pomaria* overwinter in the egg stage and it is safe to assume that they are important, if not the main, overwintering hosts of the parasite that from June to September attacks *E. ziczac* on grape and Virginia creeper.

In vineyards that had wild rose or apple nearby, parasitized leafhopper eggs were found almost immediately after egg-laying started in the spring whereas in vineyards at higher altitudes that were surrounded by desert conditions, where there was no wild rose, the first egg-parasitism appeared slightly more than a month later in the season.

There were two separate hatches of parasites that overwintered in eggs of *E. rosae*. The first was in mid-May. Dissections of parasitized eggs that did not hatch then revealed parasite larvae still in early stages of development. The second hatch, which came from such larvae, started in the second week of June. It is suggested that the time when the parasite eggs are laid in the autumn determines when they hatch in the spring: those that are laid sufficiently early to develop to the pupal stage before winter produce adults in May while eggs that are laid later do not start developing until the spring and do not produce adults until June. This mechanism would assist the parasite to overcome differences between different places or years when *E. ziczac* lays its first eggs in the spring.

Conclusions

Two cultural procedures would tend to keep the grape leafhopper populations to below their present average levels: destroy overwintering sites in and near the vineyards, which would destroy the leafhoppers without harming the egg-parasite; and provide the parasite with overwintering hosts by growing their host plants, wild rose, which at present is treated as a weed in the Okanagan, and apple in or close to the vineyards, which would facilitate egg-parasite survival without affecting *E. ziczac*.

A possible way of preventing economic harm by the leafhopper effectively would be to develop hybrid varieties of grapevines that both are good wine grapes and have leaves with hairy undersurfaces that prevent or restrict feeding.

It seems inevitable that sooner or later species of grape leafhoppers additional to *E. ziczac* will be spread or be accidentally imported into the Okanagan Valley from grape-growing areas of Eastern Canada, where at least eight species of *Erythroneura* feed on grapevines or Virginia creeper (Beirne 1956), or from California.

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