THE BIONOMICS AND MONITORING OF *CAMPYLOMMA VERBASCI* (MEYER) ON APPLE IN THE OKANAGAN VALLEY, BRITISH COLUMBIA

by

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in the Department

of

Biological Sciences

SIMON FRASER UNIVERSITY

January 1986

Approval

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Degree: Doctor of Philosophy

Title of Thesis: The bionomics and monitoring of Campylomma verbasci (Meyer) on apple in the Okanagan Valley, British Columbia

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Title of Thesis/Project/Extended Essay

The bionomics and monitoring of Campylomma verbasci (Meyer)

on apple in the Okanagan Valley, British Columbia

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ABSTRACT

Campylomma verbasci (Meyer) is a serious but intermittent pest of apples in British Columbia. The objective of this study was to develop reliable monitoring methods through investigation of its biology, damage and behaviour. Observations were made and experiments conducted in 17 orchards in the Okanagan Valley during 1982-1984.

The overwintering hosts were apple and pear; 3-4 generations/year were found on apple and several summer hosts, primarily common mullein, Verbascum thapsus L. Population levels and damage by C. verbasci in 1983 were correlated with the density of mullein in 9 orchards in 1982. However, this result was not confirmed in 4 experimental plots in 1983-1984.

First generation nymphs damaged >1% of the apples in 17 of 40 samples of 4 major varieties, in commercial orchards, and C. verbasci was among the top 3 pests in 22 samples. Economic injury levels of 1 and 4 nymphs/tap are proposed for Golden Delicious and Red Delicious varieties, respectively.

Limb-tap sampling was 1.9-5.3 times more efficient than cluster sampling in determining nymphal density at economic levels, and its estimates were not affected by temporal, spatial, or varietal factors within orchards. However, sampling prior to the peak of emergence, on average 11 days after full bloom, can give inaccurate estimates of nymphal density and damage. Similarly, an overwintering 'hatching' sample method, developed in Nova Scotia, did not predict nymphal density or damage.

The spatial dispersion of C. verbasci on apple was contagious and was described using Iwao's regression and Taylor's power law methods. Optimal sample sizes of 47, 29 and 19 taps/0.5 ha were calculated for densities of 1, 2, and 4 nymphs/tap, respectively. A constant-precision level sequential

count plan and a sequential decision plan were developed to reduce sampling to >=5 taps/0.5 ha.

Field experiments revealed significant responses by males to females, female extracts and captured volatiles, demonstrating the presence of a sex pheromone, and showed that trap colour or shape had significant effects upon the catch of both sexes. These responses could be exploited in monitoring adult numbers late in the season, to provide forecasts of damaging levels in orchards the following year.

ACKNOWLEDGEMENTS

I deeply appreciate the guidance of Dr. J.H. Borden throughout the research and writing of this thesis, and thank Drs. R.D. McMullen and B.D. Roitberg for their advice and helpful reviews of the manuscript. Many useful discussions were also held with R.C. Corcoran, J.M. Vakenti and Dr. H.F. Madsen.

Specialised equipment and assistance provided by the following people is gratefully acknowledged: R. Fryer, T.C. Hubscher and C. A. Spinney in summer field work; Drs. J.W. Hall and R.D. Routledge for answering many statistical questions; G.A. Wardle, Dr. A.P. Gaunce, and Dr. H.D. Pierce, Jr., for supplying equipment and advice on the collection of insect volatiles; D.W.A. Hunt and D.R. Miller for advice on the preparation of insect extracts; Dr. C.J. Walters for microcomputer software; G.J.R. Judd for measuring the % reflectance of coloured cards and Y. Poitras for information on paints; and J.M. and M.E. Neary for photocopying many articles on C. verbasci from sources in Nova Scotia.

Field facilities, office space and experimental sites were provided in Summerland by the Centre for Pest Management, Simon Fraser University, and the Research Branch of Agriculture Canada. I thank the Director and the staff of the Research Station for their assistance, particularly K.H. Neer of the Libraries Division.

The research was funded by an NSERC Postgraduate Scholarship, a B.C. Science Council G.R.E.A.T. award, educational leave from Agriculture Canada, and NSERC Operating and Strategic Grants to Drs. J.H. Borden, A.C. Oehlschlager, and K.N. Slessor.

I appreciate the cooperation of many people in the fruit industry, particularly the growers who permitted research in their orchards. Above all, I thank my wife, Tina, for her understanding and support throughout my studies.

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I. Introduction

British Columbia produces 45% of the Canadian apple crop (Bodnar 1984), approximately 6% of the apples grown in North America (Westwood 1978). The orchards are concentrated primarily in 3 interior valleys, the Creston, Similkameen, and particularly the Okanagan Valley. The problems of marketing large volumes of fruit, produced at a great distance from the buyers, has resulted in extremely high quality standards and a low tolerance for any damage (Smith 1976). However, the financial returns from high-quality fruit are considerably greater than for most agricultural crops (McKibbon 1978; BCMAF 1984) and fruit-growers employ extensive programs of pest control in order to protect their investments; until recently, crop protection as a proportion of production costs was higher in the B.C. interior (21%) than the national average of 17% (Fischer 1970). Although precise statistics are not kept in B.C., in Ontario only one other food crop receives annually as much pesticide (17 kg/ha) as apples (Roller 1979); in general apples receive more pesticide/unit area than all other crops, throughout North America (Pimentel et al. 1978; Croft and Hoyt 1983).

The reduction of pesticide use in orchards is, therefore, a useful contribution by applied biologists. This is particularly true of the Okanagan Valley, where a shortage of suitable land has led to homes and tourist accommodation being in close proximity to orchards. Considerable experience in the application of pest management (Beirne 1967) has achieved a major reduction in pesticide use in the last 10 years, based upon the monitoring of individual orchards and treatment only when necessary (Madsen et al. 1975; Madsen and Carty 1977, 1979; Madsen and Madsen 1982; Agriculture Canada 1983).

Monitoring of the populations of 10-13 arthropod pests has been recommended during the last 10 years (Madsen et al. 1975; Haley 1977;

Agriculture Canada 1983), but although considerable biological data exist for several of the pests very little is known about the others. The most recent survey of arthropod pests of apple in B.C. (Downing et al. 1956) identified 50 species causing economic losses on a regular or sporadic basis. Most research is concentrated on a small number of 'key' pests as only a few of the potential pests are important at a particular time (Croft 1975; Morgan and Madsen 1976; Thistlewood 1981). One serious intermittent pest is the "mullein bug", Campylomma verbasci (Meyer).

C. verbasci is a small, grey-brown, plant bug found in parts of Europe, Asia, and North America. In Canada, it is both predaceous and phytophagous on fruit crops (Kelton 1982) and is frequently reported as a pest of apples, during and after the bloom stage[1]. Serious damage is reported from Canada and the U.S.A., and monitoring for the insect is an important component of pest management programs in British Columbia (Madsen and Procter 1982; Agriculture Canada 1983; BCMAF 1985), Ontario (Hagley et al. 1978; McEwen 1983) and Nova Scotia (MacLellan 1979; Hardman et al. 1984). However, it has received only minor attention as one of a complex of true bugs occurring in orchards.

C. verbasci has been the subject of taxonomic study (e.g. Kelton 1982) and limited research into the predators of arthropod pests of apple in Europe (Collyer 1952, 1953a,b; Niemczyk 1978) and of pear in B.C. (McMullen and Jong 1967a,b, 1970). Only Boivin and Stewart (1982b,c, 1983a-d, 1984) have studied C. verbasci on apple in North America, as one of of a group of 5 mirids in Quebec. Moreover, their research found only low population levels, and was conducted in a single experimental orchard of an apple cultivar (McIntosh) that is not sensitive to injury.

The problem posed by C. verbasci is one of sporadic, unexplained, outbreaks and occasionally high levels of damage, that are at present unpredictable. Current monitoring techniques are regarded as costly and unreliable, so that pesticides are often applied upon mere detection of the bug (MacPhee 1976; Hikichi et al. 1979; OMAF 1981a), resulting in some controversy over their necessity. The lack of biological data and a reliable monitoring method for C. verbasci was described as a major stumbling-block for pest management in B.C., in a 2-year evaluation by J.M. Vakenti and F.E. Peters[2]. Researchers from the western U.S.A. and across Canada have privately expressed a need for more information on the insect (S. Aquafresca[3], E.A.C. Hagley[4], A. Hikichi[5], A.W. MacPhee[6], pers. comms.), and I received first-hand knowledge of problems caused by the 'mythical mullein bug' when working in Ontario apple orchards (Thistlewood et al. 1981; McKay et al. 1982).

The basic objectives of this thesis were: (1) to describe the seasonal abundance, distribution, and associations of C. verbasci in and around apple orchards, (2) to determine the relationship between insect number and fruit damage, and (3) to develop an improved method of monitoring or forecasting population levels.

II. Literature Review

TAXONOMY

Classification of plant bugs (Miridae) is based primarily upon the tarsal claw scheme proposed by Reuter (1910), as elaborated by Knight (1918), Carvalho (1955), and Kelton (1959). Kelton (1980, 1982) recently studied and revised a portion of the Miridae of Canada in 2 monographs, based on those of the prairie provinces and fruit crops.

Campylomma verbasci (Meyer) belongs to the sub-family Phylinae, characterized by having: 1) straight hair-like parempodia between the tarsal claws; 2) pulvilli on the claws; 3) male genitalia with rigid ductus seminis; and 4) a distinctive left clasper (Kelton 1982). The subfamily is represented in Canada by the tribe Phylini, of which 10 species in 7 genera occur on fruit crops. Three of these species are predaceous, and 7, including C. verbasci, are both predaceous and phytophagous (Kelton 1982).

The immature stages of C. verbasci were described and illustrated by Leonard (1915) and Collyer (1953a). The adults were described or illustrated several times: from England (China 1932; Collyer 1953b), from 3 regions of the U.S.A. (Leonard 1915; Knight 1923, 1941, 1968) and from Canada (Bouchard et al. 1982; Braimah et al. 1982; Kelton 1982).

C. verbasci has no approved common name in either Europe (Collyer 1955; Niemczyk 1978; Alford 1984) or North America (Werner 1982). However, Ross and Caesar (1920) used the name "mullein leaf bug" in the first account of serious damage caused by C. verbasci and numerous reports from North America have used variations on this name since then.

ZOOGEOGRAPHY

C. verbasci is holarctic in distribution. In Europe it ranges from

Switzerland (Baggiolini & Wildbolz 1965) north to south-eastern Norway (Austreng & Somme 1980) and from England (China 1932) east to at least Leningrad (Sukhoruchenko and Tolstova 1981). In Asia it occurs in the southern U.S.S.R., Turkestan and Caucasia (Vassiliev 1914). The American distribution corresponds to Koeppen's (1936, cited by Scudder 1978) "Dfb" climatic subgroup and C. verbasci has been found in 9 northern states of the U.S.A. and in 5 Canadian provinces (Table 2.1). It is notably absent from the midwestern states and the prairie provinces.

BIOLOGY

Overwintering habit

C. verbasci overwinters in the egg stage in the bark of young wood of several rosaceous trees and shrubs, primarily apple, Malus spp., pear, Pyrus spp., and in B.C. wild rose, Rosa spp., and Saskatoon berry, Amelanchier cusickii Fer. (McMullen and Jong 1970). The most common oviposition site on apple is in lenticels of the current year's growth. The eggs are banana-shaped, measuring 0.8 x 0.3 mm, and only the operculum is exposed outside the wood. In Nova Scotia, the eggs' mean freezing point is -32°C (MacPhee 1964), well below the normal range in Canadian orchards.

The eggs hatch over a 2-week period when the apples are in bloom[1], beginning usually in the first or second week of May in B.C. They hatch at the same time in England and Poland, but Steiner et al. (1970) did not find C. verbasci until June in Southern Germany. Jonsson (1983) and Skanland (1980) found the first nymphs in May and June, respectively, in Norway at 60° latitude.

Development

The nymphs pass through 5 instars, requiring 16 days in the laboratory

Table 2.1 Reported distribution of *C. verbasci* in North America

Country	State or Province	References
U.S.A.	Colorado	Quist 1980; Knight 1968
	Connecticut	Knight 1923
	Idaho	Knight 1968
	Illinois	Knight 1941
	Iowa	Tate 1933
	New York	Parrott 1913
	Oregon	Knight 1968
	Pennsylvania	Horsburgh & Asquith 1968
	Washington	Hoyt 1973
Canada	British Columbia	Downes 1927
	New Brunswick	Kelton 1982
	Nova Scotia	Pickett 1938
	Ontario	Ross & Caesar 1920
	Quebec	Kelton 1982

at 23°C (Niemczyk 1978) or 23 days at 21°C (McMullen and Jong 1970), from eclosion to the imaginal moult. The pale green nymphs are smaller than most mirids on fruit trees and move rapidly. They are distinguished by their shape, size, and the presence of black spines on the tibiae and femora.

First generation adults are found from the beginning of June in British Columbia and most of Europe. In B.C. and Poland, almost all of the adults migrate to herbaceous plants to feed and reproduce over the summer (McMullen and Jong 1970; Niemczyk 1978). In other regions many of the adults remain in the orchard trees and oviposit in the current year's shoots (Collyer 1953a,b; Alford 1984). The adult life span is approximately 25 days and the females produce between 10-40 eggs during that time. The first summer eggs hatch 8 days following oviposition and hatching continues for a further week (Niemczyk 1978).

Summer Generations

Two generations a year usually occur in England, Poland, Germany (Steiner et al. 1970), Nova Scotia (Gilliatt 1935; MacPhee 1976) and Quebec (Boivin and Stewart 1983a). In Norway there is usually one generation per year (Skanland 1980) and in Quebec 3 generations occasionally occur (Bouchard et al. 1982). Three or 4 generations are found in British Columbia (McMullen and Jong 1970).

The principal herbaceous hosts of C. verbasci are common mullein, Verbascum thapsus L., and potato, Solanum tuberosum L., throughout its distribution. Common mullein is usually described as the major host (Venables 1938, 1939; Pickett 1938b; Knight 1941, 1968; McMullen and Jong 1970; Carroll and Hoyt 1984) but nymphs or adults have been found on a variety of plants in the summer (Table 2.2). Rarely has some damage to

Table 2.2. Plants reported as summer hosts of C. verbasci

Plant	Region	References
Verbascum thapsus	International	multiple
Solanum tuberosum		"
Carduus spp.	England	China 1932
Echium spp.		"
Quercus robur		Southwood & Leston 1959
Althaea rosea		" "
Beta vulgaris	U.S.S.R.	Vassiliev 1914
Brassica nigra	Illinois	Knight 1941
Verbena stricta		"
Hordeum vulgare	Washington	Fye 1983
Triticum spp.		"
Beta vulgaris	Nova Scotia	Pickett 1938a
Stachys lanata		"
Oenothera spp.		"
Nepeta cataria		"
Nursery crops		" ; Agriculture Canada 1940
Solanum nigrum	British Columbia	McMullen & Jong 1970
Verbena bracteata		" "
Stachys palustris		" "
Zea mays var. rugosa		" "
Rubus spp.		Tonks 1952
Trifolium spp.		Venables 1940c
Ipomoea spp.		"
Vitis vinifera		Madsen & Morgan 1975
Cirsium arvense	Canada	Maw 1976
Taraxacum officinale		"
Centaurea diffusa		"

potato (Tate 1933; Gilliatt 1931; Pickett 1938a; Lord 1971), sugar beets and nursery crops (Vassiliev 1914; Pickett 1938a) been reported.

The adults return to their woody overwintering hosts in late August and September and remain active in most regions until October. Overwintering eggs are laid from mid-September until mid-October in British Columbia.

Diet

The nymphs have the typical piercing-sucking mouth-parts of true bugs and cause injury to some fruit varieties by feeding on the flower parts following fruit set. More commonly they prey on the wide variety of small arthropods and eggs present on apple in the spring and such prey is believed to be necessary for normal development (McMullen and Jong 1970; Niemczyk 1978). The nymphs and adults are described as useful predators in both Europe and North America (Table 2.3). Significant feeding has been observed on Psylla mali Schm., Psylla pyricola Forster, Tetranychus telarius (L.), T. mcdanieli McG., T. pacificus McG., Eriophyes pyri (Pagenstecher), Aphis pomi DeG., Rhopalosiphum fitchii (Sand.), Anuraphis rosea (Forbes), Cydia pomonella (L.), Phenacoccus aceris (Signoret), and Bryobia praetiosa Koch. The European red mite, Panonychus ulmi Koch, is frequently reported as a major component of the diet of C. verbasci and Niemczyk (1978) observed the nymphs killing an average of 580 P. ulmi during their development.

ECONOMIC STATUS

A world perspective

In North America C. verbasci is unique in being significant as both a predator and a pest on apple (Kelton 1982). Thus its economic status is the difference between the economic benefits from predation and the economic loss from damage. It has never been reported to damage fruit in Europe, where it

Table 2.3. Relative importance of C. verbasci in the predator complex of apple orchards in Europe and North America

Region	Predator status	Preferred prey[a]		References
		Mites	Aphids	
England	minor	++	+	Collyer 1953a, b
Fed. Rep. Germany	average	++	+	Steiner et al. 1970
Switzerland	average	+	+	Baggiolini & Wildbolz 1965
Norway	major	++	+	Skanland 1980; Jonsson 1983
Poland	average	++	+	Niemczyk 1978
Connecticut	minor	+		Garman & Townsend 1938
Oregon	minor	+		P. Westigard[b], pers. comm.
Pennsylvania	minor	+		Horsburgh & Asquith 1968
Washington State	minor	+	+	Hoyt 1973; Carroll & Hoyt 1984
British Columbia	minor	+	+	McMullen 1973
Ontario	average	+	++	Hagley 1974, 1978
Nova Scotia	minor	++	+	Pickett 1938; Lord 1949, 1971
Quebec	minor	+	+	Bouchard 1982; Braimah 1982

[a] Predation by C. verbasci : + = feeding reported, ++ = feeding common or important.

[b] Southern Oregon Expt. Station, Oregon State University, 569 Hanley Road, Medford, Oregon 97501.

is regarded as a predator of some importance. Counts of C. verbasci are taken in Germany (Steiner et al. 1970), Switzerland (Baggiolini and Wildbolz 1965; Sechser et al. 1984) and Norway (Jonsson 1983) when predator populations are assessed for pest management purposes, and it is an abundant and useful predator in English apple orchards (Collyer 1953a,b; Alford 1984).

Ross and Caesar (1920) first described and photographed extensive damage to apples in Norfolk County, southern Ontario. This characteristic damage (Pickett 1938a; McMullen 1973; MacLellan 1979; Madsen and Procter 1982) arises from feeding injury during a short period following petal fall. Small corky warts appear on the surface of the fruitlets at points where the nymphs have fed. Many of the apples are subsequently deformed by bumps or depressions and are shed. Those that remain often fail to reach a commercial size or are unmarketable because of scars or malformation.

Large numbers of nymphs can be distributed uniformly in an orchard, but the greatest damage appears on certain 'susceptible' fruit varieties (Table 2.4) (Pickett 1938a,b). Serious damage has been reported from many regions in North America (Table 2.5.). In addition, C. verbasci has been shown to transmit fireblight, Erwinia amylovora (Burr.), between apple seedlings (Stewart 1913; Stewart and Leonard 1915) and small trees (Gossard and Walton 1922).

History in Canada

The Canadian Agricultural Insect Pest Review includes reports of C. verbasci in 34 of the 61 issues since 1922. Serious damage has been reported from all regions except Quebec where the amount of damage is unclear (Boivin and Stewart 1982b).

C. verbasci was reportedly a serious pest in Nova Scotia in the late

Table 2.4. Apple cultivars susceptible to damage from C. verbasci in regions of North America since 1970

Region	Variety	References
Washington State	Golden Delicious	Hoyt 1973
New York	Red Delicious	J. Brann[a], pers. comm.
Nova Scotia	Red Delicious	McLellan 1979 (for the period 1953-1977)
	Northern Spy	
	Ribston	
	Wagener	
Ontario	Red Delicious	Hagley & Hikichi 1973
British Columbia	Red Delicious	McMullen 1973;
	Golden Delicious	Madsen et al. 1975;
	Spartan	Madsen & Carty 1977

[a]P.O. Box 359, Sopchoppy, Florida 32358; formerly Extension Entomologist, N.Y. State

Table 2.5. Selected reports of damage by C. verbasci in commercial orchards of North America

Region and period of damage	Annual crop losses	Reference
Colorado		
present	minor-moderate	Quist 1980
New York		
1972	minor	J. Brann[a], pers. comm.
Nova Scotia		
1938	50,000 barrels	Pickett 1938
1953-1977	0 - 0.7%	MacLellan 1979
1965-1969	7.7 - 12.4%	MacLellan 1977
Ontario		
1919	0 - 75%	Ross and Caesar 1920
1974-1975	50,000 bushels	Agriculture Canada 1974, 1975
1979	0 - 15%	Hikichi et al. 1979
British Columbia		
1970-1971	severe	McMullen 1973
1973-1975	0 - 13%	Madsen et al. 1975
1980	0.1 - 24%	Agriculture Canada 1980

[a]Footnote, Table 2.4

1930's and through the 1940's (Pickett 1938a,b; McDonald 1939; Pickett and Patterson 1940; Twinn 1938, 1941, 1944; Cameron 1941; Gardiner 1941; Neary 1941-53; Patterson and Neary 1948-51; MacNay 1948-58), and in the 1960's (MacLellan 1977). From 1953 to 1977 an average of 0.3% of the fruit in selected orchards was damaged annually, despite monitoring and spraying; during this period C. verbasci exceeded the economic threshold 7% of the time and was consistently described as a serious pest (MacLellan 1979). More recently, Hardman et al. (1984) reported that 'stinging bugs' [C. verbasci and/or another mirid, Atractotomus mali (Meyer)] exceeded the economic threshold in 40% of 160 orchards from 1980-1982. These 'stinging bugs' were the primary target of pesticide applications in 19.8% of the orchards during the 3-year period.

Whereas Gilliatt (1935) concluded that C. verbasci was not "a predator of any great consequence" in Nova Scotia, Lord (1949) claimed it was an "effective predator" of the European red mite, P. ulmi, and probably of the clover mite, B. praetiosa, during 1944-1949. Lord noted that "this species at least balances its economic damage with the benefits it gives in the control of the red mite". Other reports (MacNay 1948; Patterson and Neary 1948-51) describe it as the most common predator of European red mites. Confounding the issue, Lord (1971) later described C. verbasci as "not of major consequence as a control agent for mites" in the field or the laboratory.

Ontario orchards have suffered serious damage from C. verbasci since 1919 and monitoring for C. verbasci is an annual component of the apple IPM program (OMAF 1981b; McEwen 1983). It appears in 2 papers describing, respectively, the major pest species (Hagley and Hikichi 1973) and the

predaceous species (Hagley 1974) of apple orchards in Ontario. In the former study, damage approached 100% in some commercial sites, and in the latter C. verbasci was a "very effective" aphid predator.

In British Columbia, Downes (1927) reported the earliest collections of C. verbasci as 1917 on Vancouver Island and 1924 in Penticton. It was not listed by Ruhmann (1936) as a pest nor by Downing et al. (1956) in an exhaustive study of pests of tree fruits in B.C. Venables (1938, 1939, 1940 a,b,c) first mentioned it as readily found on, and feeding intensively in, trees infested with European red mites, Pacific mites (T. pacificus), and aphids. He described it as the main controlling factor for European red mite and produced the first photographs of nymphs and adults feeding on mites (Venables 1940b). Several studies in the 1960s subsequently ignored C. verbasci as a predator of mites. However, McMullen and Jong (1967a,b, 1970) found that it was a useful predator of several insects and mites on pears.

Venables (1938) made the first reference to damage in the Okanagan Valley and noted it was "suspected that it causes injury to young apples in early spring as well as being predatory". Severe damage to apples from C. verbasci was found in B.C. in 1970 and damage was widespread in 1971 (McMullen 1973). Damage has since been regularly observed, and C. verbasci was ranked as one of 10 important apple pests by Madsen et al. (1975). Similarly, Haley (1977) reported it to be one of 14 major pest problems in a survey of 69 North Okanagan growers. J.M. Vakenti recently reported (Agric. Canada 1980) that high populations of the insect in 1978 and 1979 caused damage in commercial orchards ranging from 0.15-24.4% of the crop, even where pesticides were applied for control.

III The seasonal development and distribution of *Campylomma verbasci* in and around apple orchards of the Okanagan Valley.

INTRODUCTION

The development of pest management programs for the most serious arthropod pests of apple in the Okanagan Valley has commonly led to reductions of 50% in insecticide use against the major pest complex (Madsen et al. 1975, Madsen and Carty 1977). The programs have replaced 'calendar' spraying with regular assessment of the pest populations and treatment triggered by 'action thresholds'.

Concomitant with the development of programs for the major pests and reduction of risks for the grower is an increased awareness of the status of minor and irregular pests of apple, particularly *Campylomma verbasci*. The paucity of published information on this insect has reduced the credibility of Canadian extension workers and pest management consultants because of unexpected damage (Madsen et al. 1975; Hikichi et al. 1979; Agric. Canada 1980). Vakenti and Peters[2] specifically criticized the lack of information on the biology and development of *C. verbasci* on apple, and on when sampling should occur.

A field study was conducted in and around apple orchards in 1982-1984, with the following objectives: to determine the frequency of occurrence of *C. verbasci* in a variety of apple orchards, and on the different plant hosts in and around the orchards; and to follow the development and seasonal abundance of the insect on apples where it was found.

MATERIALS AND METHODS

Weather during the study

Weather records were supplied by the Agriculture Canada Research

Station, Summerland, British Columbia (49°34'N, 119°39'W, elevation 454 m). Compared with a 67-year average (Drought and Amyot 1983, 1984, 1985), the weather in 1982 was cooler than normal, the growing season 10% shorter than usual, and annual rainfall was 156% of normal. July was a month of record low mean temperature with a record amount of rainfall and rainy days.

The winter of 1982-1983 was much warmer than usual but the rest of 1983 was again cooler, and the growing season 10% longer, than usual. Rainfall in 1983 was twice the norm and June and July had more rainy days than normal. July again set a record low mean temperature and had exceptionally low sunshine hours.

The winter of 1983-1984 was marked by records for the latest killing frost in the fall, and the lowest temperatures in December. The bloom period of 1984 was cool and wet; April was colder than normal, and the mean temperature in May was nearly the lowest ever. Precipitation in May was 156% of normal and the number of days with rain from March to June was twice the norm, equal to the record. The few days without rain were very windy.

Description of study sites

The seasonal development of C. verbasci was followed in and around 21 blocks of apples in 17 orchards (Fig. 3.1, Table 3.1). Previous attempts to study the insect in British Columbia have been frustrated by its unexpected absence from carefully selected sites (Madsen et al. 1975, Madsen and Carty 1977; H.F. Madsen[7], R.D. McMullen[8], pers. comms.). To lower this risk a large number of sites were investigated in 1982, and subsequent efforts were concentrated in blocks with apparently perennial populations of C. verbasci.

Four commercial apple orchards (sites 2,3,6,9) were selected in March, 1982 from those having previous damage from "Campylomma" as reported by

Fig. 3.1. Study sites in the Okanagan Valley of British Columbia

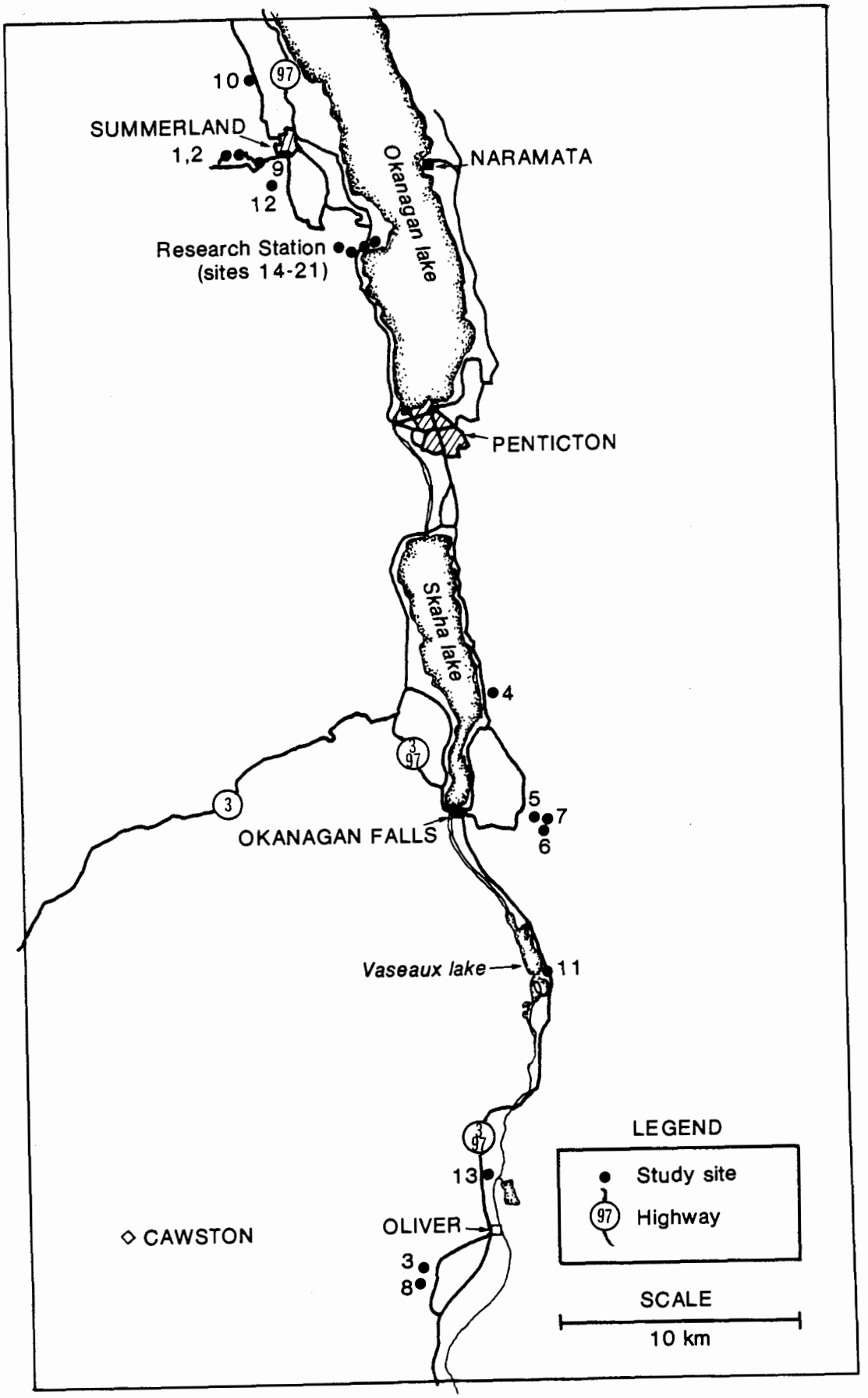

10
97
SUMMERLAND
1,2
9
12
Okanagan lake
NARAMATA
Research Station
(sites 14-21)
PENTICTON
Skaha lake
4
3
97
3
5
7
6
OKANAGAN FALLS
Vaseaux lake
11
3
97
13
OLIVER
CAWSTON
3
8
LEGEND
Study site
97
Highway
SCALE
10 km

Table 3.1. Major characteristics of study sites in the Okanagan Valley during 1982-84

Site[a]	Location	Area (ha)	Apple varieties[b]	Tree size[c]	Age (yrs)	Spacing (m x m)	Pesticide regime[d]	Mgmt. type[e]	Study period
1	Summerland	1.0	G,R,S	S	5-25	6.1 x 6.1	2	3	82/5-83/6
2	"	1.0	G,R,S	S	5-25	4.3 x 4.3	2	3	82/5-83/6
3	Oliver	0.5	G,R	SD	14	3.6 x 6.1	3	4	82/5/83/6
4	Okanagan Falls	0.3	R	SD	16	4.9 x 4.9	3	4	82/5-83/6
5	" "	0.5	G,R,S,	S	15-35	6.1 x 6.1	2	3	82/5-83/6
6	" "	1.0	G,R	S	5-35	6.1 x 6.1	2	3	82/5-83/6
7	" "	0.5	mixed	S	25-35	mixed	1	1	82/5-82/9
8	Oliver	0.8	G	SD	13-15	2.5 x 4.2	1	4	82/5-83/6
9	Summerland	1.5	G,M	SD	16-20	1.5 x 4.0	3	4	82/3-84/9
10	"	1.0	R,S,M,	SD	15-25	mixed	3	4	82/5-83/6
11	Vaseaux Lake	0.5	G,R,S	S	20-30	6.1 x 6.1	1982=1 1983=3	1982=3 1983=4	82/5-83/6
12	Summerland	0.5	R,M	S	25 +	5.5 x 5.5	2	3	82/5-84/9
13	Oliver	1.0	mixed	S	10-35	mixed	1	3	82/3-82/9
14,15	Simon Fraser	0.1	R,M	SD	<25	3.1 x 3.1	1	2	82/9-84/10
16,17, 21	Morgan	0.14x2	R,S,M,N,RR	SD	12	2.4 x 4.3	1	2	83/5-84/10
18,19	Red Delicious	0.25x2	R	SD	21	2.4 x 4.3	1	2	83 5-84/10
20	Goldens	0.14	G	SD	21	2.4 x 4.3	1	2	84/3-84/10

[a]Sites 14-21 at Agriculture Canada Research Station, Summerland. Trout Creek site.
[b]Apple varieties: R-Red Delicious, G-Golden Delicious, S-Spartan, M-McIntosh, RR-Red Rome.
[c]Tree size - S-standard, SD-semidwarf variety rootstock
[d]Pesticide regimes = 1 unsprayed/organic, 2 low input commercial, 3 high input commercial.
[e]Management systems = 1 unmanaged/abandoned, 2 low input research, 3 low input commercial, 4 high input commercial.

extension horticulturists and packing houses. Six were selected at random from the same localities (sites 1,5,7,8,10,12), 2 more (sites 11,13) were selected because of their "organic" management methods and one orchard (site 4) was added in May when a pest management consultant (R.C. Corcoran[9]) advised me of high counts of C. verbasci. Studies in sites 7 and 13 ceased in September 1982 and the remainder were followed through to the summer of 1983. A further 9 sites (1-6,8,10,11) were then abandoned and replaced by 3 orchards each having 2 or more blocks of interest (sites 14-21). Regular examination continued until July 1984.

The management of these sites differed in economic expectation, horticulture and pest control practices (Table 3.1). One site (7) was virtually abandoned and non-commercial orchards (14-21) were usually not sprayed, fertilized, or well tended. Six commercial orchards (1,2,5,6,11,13) received minimal management and pesticides for at least one year while 6 (3,4,8,9,10,12) received intensive management or generous amounts of pesticides.

Extensive sampling occured in stonefruit blocks and vineyards adjacent to the study sites on 14 occasions from 1982-1984, when C. verbasci nymphs or adults were abundant in the apple blocks.

Field investigations of native flora were made in the Okanagan Valley from Osoyoos to Westbank, to Princeton in the Similkameen Valley, in Manning Park, and in wooded mountain areas on either side of Okanagan Lake up to 2,000 m elevation. Observations were made at irregular intervals from March to October in 1982-84. Seventy-four plant surveys were made in areas bordering on study sites and 30 elsewhere in southern B.C.

Alternate host studies

A garden (20 x 20 m) containing a variety of herbaceous and woody plants (Appendix A) was cultivated at the Agriculture Canada Research Station in 1982 and 1983. Aphids and mites obtained from orchards and natural hosts were regularly released onto the garden to ensure a variety of prey for C. verbasci. However, 2 applications of insecticidal soap (Safer Agro-chem Ltd., Victoria, B.C.) were required to control excessive numbers of aphids and white apple leafhoppers, Typhlocyba pomaria (McAtee), endangering the broad bean and wild rose plots in 1982. Certain plots were badly damaged by yellow-bellied marmots, Marmota flaviventris avara (Bangs), and California quail, Lophortyx californicus (Shaw), in 1983. During July, 150 pairs (1982) or >200 pairs (1983) of healthy adult C. verbasci were released at random onto plants selected from all plots in the garden.

Plants were checked weekly in 1982 from mid-July, when nymphs were appearing on summer hosts elsewhere. Data on growth, health, and all associated arthropods were recorded in 1982 but in 1983 the plants were assessed bi-weekly and only examined for the presence of C. verbasci.

In addition, monthly inspections for C. verbasci were made in 2 commercial "organic" gardens, close to orchards and containing fruit trees, in Summerland and Oliver from June to September, 1982.

Sampling Methods Within Orchards

Sampling occurred approximately every 10 days from March through October in 1982, from April through September in 1983, and from April through June in 1984. Sampling was done weekly during the pink to fruit set stages of apple development[1] if weather permitted.

The primary technique was the limb-tap method, commonly used for

collecting or monitoring mirids and other arthropods of fruit trees (McMullen and Jong 1970; Hoyt 1973; Madsen et al. 1975; Kelton 1982). It requires 3 sharp taps of a tree limb located between waist and eye level, made with a rubber mallet over a tray measuring 45 x 45 cm. Any arthropods caught on the tray were immediately counted. One limb-tap sample/tree was taken from at least 25 trees selected at random through a site, and the limbs were selected in rotation around 4 sides of the trees. The distribution of developmental stages of C. verbasci and adult sex ratio was assessed by collecting the first 40 insects and subsequently all those on each alternate tray. They were preserved in 80% ethanol and identified to developmental stage using Leonard's (1915) key.

Sweep-net samples of plants on the orchard floor, consisting of at least 50 sweeps of a 40 cm diameter net, were taken randomly throughout the orchards at regular intervals. On several occasions parts of plants or trees, such as flower or leaf clusters, small limbs or shoots, were placed in paper or plastic bags in chilled coolers, refrigerated at 1-2°C, and examined shortly after collection.

At each orchard visit the population levels of the major arthropod groups were noted on an index of 1-5, where 1 is zero and 5 is an unusually high level, based on limb-taps and visual observations. Similar methods are used by pest management consultants in the Okanagan Valley (Vakenti and Peters[2]; R.C. Corcoran[9], pers. comm.).

Sampling took place when the ambient temperature was at least 16°C and occurred between 0730 and 1800 h, with most sampling in the morning. Samples were not taken when the foliage was wet, on the same day as mowing in the site, or for 2 days following the use of an airblast sprayer in the site.

Information was collected from the growers concerning cultural practices and spray materials applied. Dates of the major phenological stages of the foliage and fruit were noted according to the system of Chapman and Catlin (1976) and full bloom dates for the districts of the sites were obtained from extension horticulturists.

Sampling methods outside orchards

Representative flora (Lyons 1974) and common weeds (Mulligan 1978) of the dry interior zone of B.C. were checked frequently. Cuttings from woody plants were brought into the laboratory in early spring, at the pink stage of apple blossom development, placed in water and checked 2-3 times a week for insect activity. Perennial trees and bushes were checked with the limb-tap technique and by a drop cloth or sweep-net method; herbaceous plants, shrubs, and grasses were examined visually or by the sweep-net method (Anderson 1962 a,b; Martin 1977; Southwood 1978).

In addition to the plant surveys, many observations were recorded from groups of common mullein, Verbascum thapsus, plants. Collections of associated arthropods were made and the numbers, distribution, sex ratio and developmental stage of C. verbasci noted. Emergence traps were placed over mullein rosettes in 12 sites in early April 1983. They were metal cylinders 23 cm high and 26 cm diameter, covered at the top with mosquito netting secured by a metal band; a 3 cm diameter tube at one edge led into a small plastic bag which was easily exchanged. A weekly collection of the insects emerging from the rosettes was made until 25 June when the first adult C. verbasci were noted on uncaged mullein plants.

RESULTS AND DISCUSSION

Occurrence in apple orchards

Nymphs and adults of C. verbasci were found consistently in 16 of 17 orchards during 1982-1984, and overwintering populations were found in apple trees every year in all but one orchard (site 10). These results indicate that C. verbasci is now widespread in apple orchards of the Okanagan Valley, and no longer occurs only sporadically as reported earlier (McMullen 1973; Madsen et al. 1975; Haley 1977). In support of these results, Vakenti and Peters[2] found C. verbasci in 35 of 42 orchards in 1979 and its damage was widespread from Vernon to Osoyoos in 1985 (Anon., 1985; M. Sanders[10], pers. comm). It was not found in one orchard (site 10) that was intensively sprayed and also subject to spray drift of synthetic pyrethroids from pear orchards on 3 sides. The general arthropod level in site 10 was lower than elsewhere and it is likely the pesticide regime precluded their survival in the orchard.

No significant difference (ANOVA, $P<0.05$) was observed in the population density of C. verbasci among 2-5 varieties of apple in each of 5 orchards (Sites 1-2, 6, 14-17, and 21) in May 1983. Further observations in several orchards with extremely high populations of C. verbasci in 1985 support these data. The results confirm the observation of Pickett (1938a) that C. verbasci is uniformly distributed among varieties and as numerous on those that are not damaged by the bug as those that show damage.

Similar counts of first generation C. verbasci were often found in neighbouring orchards with similar management regimes. For example, Sites 1 and 2 received similar cultural and pesticide treatments from the same grower and had identical peak counts of 2.4/tap in 1982, and 1.4/tap in 1983. Yet

the 2 orchards were separated by 200 m, a house and garden, horse pasture, ravine and shade trees. Conversely, population differences were observed between neighbouring orchards under contrasting management methods, such as the intensively sprayed site 3 and the well-kept but "organic" site 8 that existed side by side.

In addition to populations of C. verbasci in trees bearing fruit, large numbers of nymphs and adults were observed on young non-bearing trees at an orchard in Westbank in July, 1982. Their feeding on tissue at the terminals caused some damage, confirming earlier reports of damage to tree nurseries (Pickett 1938a; Patterson and Neary 1950).

Occurrence outside apple orchards

The only overwintering hosts found were apple and pear. As McMullen and Jong (1970) noted, the occurrence of populations of C. verbasci on herbaceous summer hosts many miles from fruit trees indicates the presence of other overwintering hosts, not detected in my study which was based around orchards. However, in the arid conditions of the Okanagan Valley the irrigated, fertilized and well-tended fruit orchards are probably far better oviposition sites for searching females than dry, stunted wild plants. The hosts outside orchards probably serve only as a refuge for the insect.

The common mullein, V. thapsus, was the major herbaceous plant host during 1982-1984. Hundreds of C. verbasci were found on common mullein, and in uncultivated areas nymphs were found only on this plant. Six adults were found on potato, Solanum tuberosum L., in an unsprayed home garden. Single adults were also found in uncultivated areas on one occasion each on vetch, Vicia americana Muhl., saskatoon berry, Amelanchier cusickii Fer., and privet bush, Ligustrum spp.

The extremely low recovery of C. verbasci from hosts other than common mullein outside orchards was surprising. A wide variety of plants are associated with the insect (Table 2.2) and McMullen and Jong (1970) described 5 other plants as summer hosts in B.C. Some plants, such as loganberry (Tonks 1952) and grape (Madsen and Morgan 1975) have been associated with C. verbasci on the basis of a single adult, and it may be that more fall into this category. However, the majority of reports describe common mullein as the principal summer host outside Europe (Ross and Caesar 1920; Pickett 1938a,b; Venables 1938, 1940; Knight 1941; Leonard 1965; McMullen and Jong 1970; Carroll and Hoyt 1984). A clear preference was revealed in the experimental garden in 1982, despite the random release of 150 pairs of adults onto all types of plants. Cumulative counts of all stages of C. verbasci were 2770 on 34 common mullein plants and 23 on other hosts (Table 3.2).

All stages of C. verbasci were collected from common mullein on a longitudinal transect from Vernon to Osoyoos, on a latitudinal transect from Princeton to Creston, up to 1600 m on Apex Mountain, and from many isolated areas of the Okanagan-Kootenay region. The plants were found up to 110 km west of Princeton but C. verbasci was not found west of Princeton, although Tonks (1952) collected the bug from Lulu Island on the Pacific Coast.

Overwintering generation

When varieties and districts are pooled, the first nymphs were detected on apple trees 2-3 days following full bloom in 1982-1984 ($\bar{x}$ = 2.5 $\pm$ 1.7 days, n = 14)[11], and the peak count of first generation nymphs usually occurred 11 days after full bloom (10.9 $\pm$ 1.6 days, n = 14) (Table 3.3). However, the time of emergence varied considerably between years (Fig. 3.2),

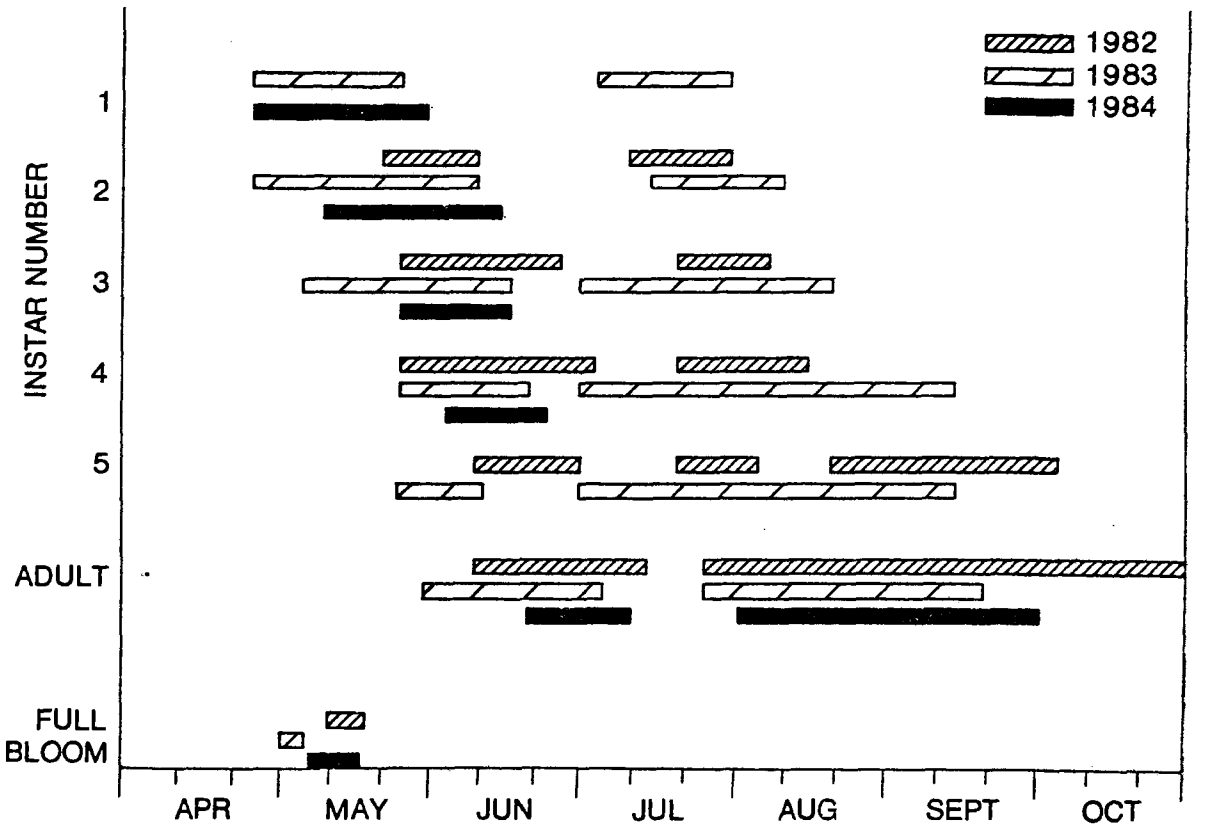
Table 3.2. Total numbers of C. verbasci counted and rereleased on plants in an experimental garden, following the initial release of 150 pairs of adults randomly onto all plants. Samples were taken on 14 occasions from 3 July to 26 October 1982

Type of plant	No. samples with C. verbasci	Cumulative no.	
		Nymphs	Adults
Potato	6	3	8
Eggplant	5	7	2
Sweetcorn	1	0	1
Catnip	1	0	2
Common mullein	14	1430	1340
All others (Appendix A)	0	0	0

Table 3.3. Dates of full bloom, first detection and first generation peak counts of C. verbasci for 2 apple varieties in 3 Okanagan districts in 1982-1984

District	Year and variety	Full bloom date	C. verbasci	
			Date detected	1st gen. peak
Oliver	1982			
	Golden Delicious	10 May	10 May	10 May
	Red Delicious	12 May	19 May	28 May
	1983			
	Golden Delicious	30 April	10 May	17 May
	Red Delicious	1 May	10 May	10 May
Penticton-Okanagan Falls	1982			
	Golden Delicious	16 May	19 May	29 May
	Red Delicious	16 May	13 May	23 May
	1983			
	Golden Delicious	4 May	11 May	11 May
	Red Delicious	4 May	29 April	18 May
Summerland	1982			
	Golden Delicious	18 May	11 May	28 May
	Red Delicious	18 May	18 May	28 May
	1983			
	Golden Delicious	5 May	19 May	30 May
	Red Delicious	6 May	9 May	18 May
	1984			
	Golden Delicious	13 May	12 May	20 May
	Red Delicious	14 May	12 May	20 May

Fig. 3.2. Developmental stages of C. verbasci in the Okanagan Valley in relation to the full bloom period for Delicious apple varieties, 1982-1984



and in 1982 in one orchard in the Oliver district, the peak count occurred on the date of full bloom (Table 3.3). The close synchrony of emergence of the first generation is indicated by the peak count and first detection occurring simultaneously on 3 occasions in the more southern districts. Large increases in counts routinely occurred between samples taken every 7 days in the spring. For example, at site 4 in 1982 the population increased from 0.84/tap on 13 May, to 4/tap on 16 May and 9.8/tap on 19 May. Jonsson (1985) reports a similar pattern of emergence for C. verbasci in Norway.

Nymphs were found in one or more orchards of every district, each year, on or before the date of full bloom. However, the first generation peak was usually observed approximately 8 days after the first nymphs were found (8.4 $\pm$ 1.5, n = 14) in a district. Thus it is possible to gain an incorrect estimate of the population density when sampling early, as C. verbasci numbers can increase sharply in the following week.

These results confirm the validity of the timing of monitoring in Ontario, where it is recommended that sampling begin in late bloom and continue for 2 weeks post-bloom every second day (OMAF 1981b). The recommended technique in British Columbia is to sample (once) at petal fall by the limb-tap method. Using this technique, Madsen et al. (1975) were "caught out" with unexpected damage and to avoid such problems Madsen and Carty (1977) later recommended a lower treatment level for C. verbasci found in a sample.

In 2 large pest management programs in Ontario (Hikichi et al. 1979; McEwen 1983) and B.C. (Vakenti and Peters[2]; Agric. Canada 1980), more than 50 orchards were sampled annually by a small team during the bloom period in order to recommend whether or not insecticides should be applied, as soon

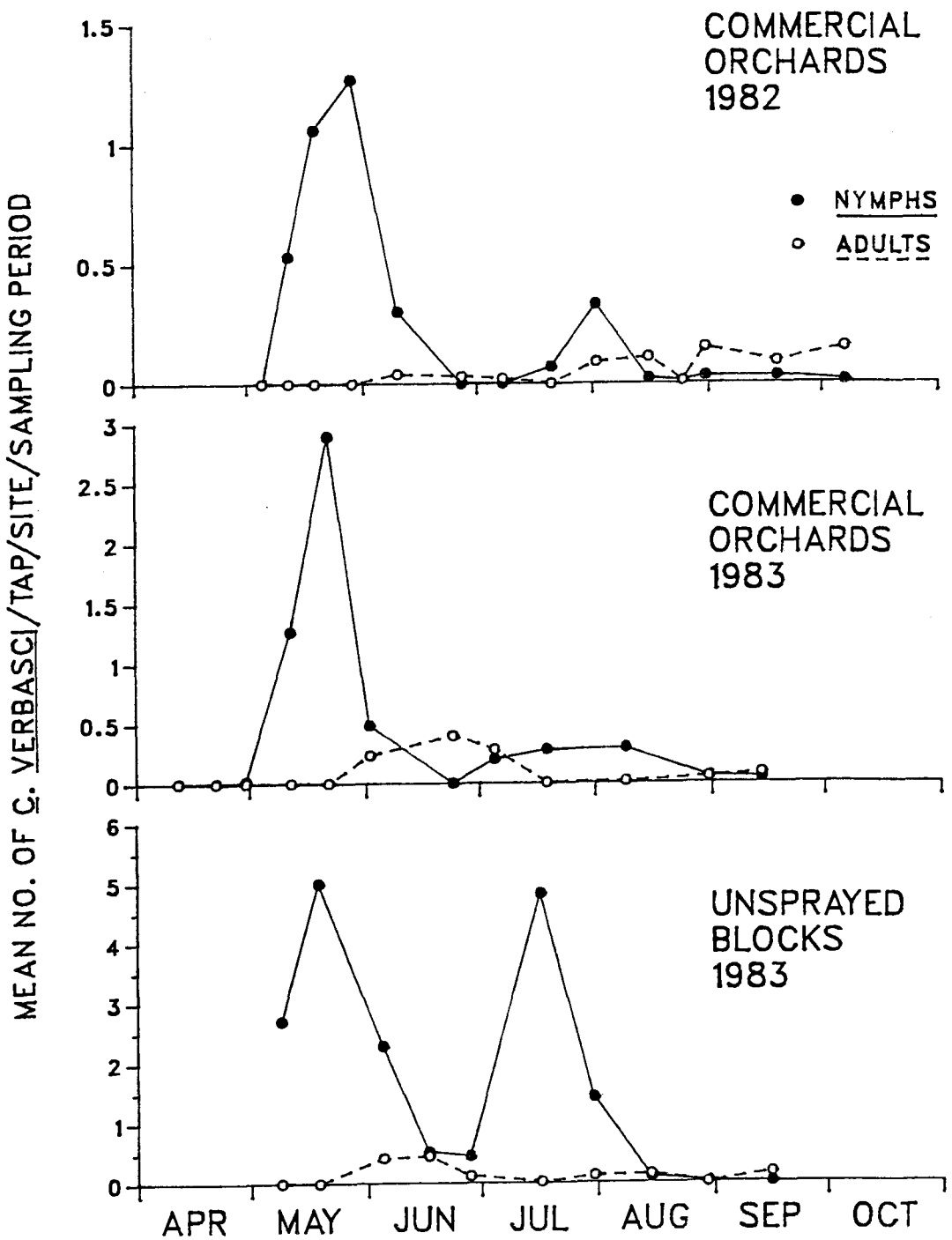
after petal fall as possible. It is highly probable that the unexpectedly high levels of damage from apparently low populations of C. verbasci, experienced by Madsen et al. (1975) and in the 2 large programs, were due to early sampling which missed the nymphs emerging later on. Indeed, Vakenti and Peters[2] found direct evidence of this in one seriously damaged orchard, but reported an inability to sample many orchards repeatedly; none was checked more than once for C. verbasci, early in bloom.

Practically speaking, there is sufficient time to check only a small number of orchards from late bloom onwards, in a typical pest management program, owing to the intensity of sampling required (Chapters IV, VI), as MacPhee (1976) also noted in Nova Scotia. Alternatively, it would be possible to concentrate on selected orchards and to sample those repeatedly if methods of forecasting or quickly identifying orchards with large overwintering populations were available. Such methods are discussed by by MacPhee (1976), and also in Chapters VI-IX.

Seasonal development

Sample counts were adjusted to represent the number of C. verbasci/tap in a sample of 40 trees/ha and plotted as a mean of all sites/sampling period (Fig. 3.3). The same population trends were found throughout the Okanagan Valley but a difference of 4-7 days was observed between an event occurring in the southern and northern extremes of the study area. Population peaks occurred at least twice each year (Fig. 3.3) in late May and July, and in some southern orchards (Sites 3,5,6,8) a third generation of nymphs, barely apparent in the mean data was observed in 1982. The cool, wet summers of 1982 and 1983 may explain the absence of a third generation, whereas McMullen and Jong (1970) found 3 generations/year on pear. However, 2 summer

Fig. 3.3. Relative abundance of C. verbasci in the Okanagan Valley 1982-1983, expressed as the mean/tap of all sites within each sampling period



generations occurred in quick succession on common mullein in Summerland (Chapter VIII), confirming McMullen and Jong's (1970) findings of 3 or 4 generations/year in the Okanagan Valley as a whole.

The sex ratio of 1632 adults obtained in 25 collections from all hosts averaged one male/female ($\bar{x}$ = 1.17 $\pm$ 0.16) and is similar to the value of 1.0 suggested by Niemczyk (1978) from 317 adults in Poland ($\bar{x}$ = 0.87 + 0.22), and sex ratios in other plant bugs such as Lygus lineolaris (P de B.) (Boivin and Stewart 1983b).

Differences between years

The general level of C. verbasci, expressed as a limb-tap count, was higher in 1983 than in 1982 (Fig. 3.3). Comparing commercial orchards, the mean numbers of first generation bugs/tap at a given site ranged from 0 to 9.8 in 1982 and from 0 to 21.1 in 1983. Other insect and mite levels were lower in commercial orchards in 1983 than in 1982 with the exception of the western flower thrips, Frankliniella occidentalis (Pergande), during bloom in Summerland.

The apparent increase in C. verbasci observed in 1983 may be related to the summer weather and/or the amount of prey available in 1982, just as Vakenti and Peters[2] suggested that favourable weather and abundant prey in 1979 were associated with increased numbers of C. verbasci in 1980. Several authors (Collyer 1953c, 1955; Lord 1971; Niemczyk 1978) have noted that C. verbasci numbers increase as its animal prey increases in abundance, and others suggest that it searches for, and aggregates in, areas with high prey populations (Venables 1940; Collyer 1953b,c; Hagley 1974, 1978; R.D. McMullen[8], pers. comm.). Some agreement was observed between the levels of prey in 8 sites and the number of overwintering C. verbasci, but was not

experimentally or quantitatively tested.

Association with pesticides

Summer generations of C. verbasci were found on trees in all sites, except 5 and 10, and populations were greater in unsprayed than in commercial sites. The differences may be explained either by the higher prey populations or greater survival of C. verbasci in unsprayed and 'organic' sites than commercial ones, but it was not possible to separate the impact of insecticides from prey population differences, between sites. However, the diversity of arthropods found in the unsprayed, and 2 of the organic, orchards was considerably greater than that in the average commercial site. Infestations of apple aphid, Aphis pomi, European red mite, Panonychus ulmi, white apple leafhopper, and western flower thrips were common to all sites but the predaceous and parasitic fauna differed greatly, as Madsen and Madsen (1982) also found.

The occurrence of two or more generations of C. verbasci in 10 commercial orchards indicates that the regular spray programs do not eliminate the bug; each orchard received 1-3 organophosphate insecticide applications, primarily of azinphos-methyl (Guthion or APM), or of phosmet (Imidan) or phosalone (Zolone). Azinphos-methyl is currently recommended for control of C. verbasci in British Columbia (BCMAF 1985) although basudin (Diazinon) is preferred (R.D. McMullen[8], R.C. Corcoran[9], pers. comms.). These results, and further observations of widespread damage in 1985 despite the use of azinphos-methyl, suggest that of the organophosphate insecticides only basudin should presently be recommended.

Resistance in C. verbasci to azinphos-methyl and some other organophosphates has been described in Ontario (Hickichi et al. 1979; OMAF

1980; McEwen 1983) and in Switzerland (Sechser et al. 1984). In Europe, C. verbasci is common in sprayed orchards and almost rare in unsprayed ones due, it is suggested (Collyer 1953c), to an ability to tolerate and recover well from pesticides and a lack of competitiveness with other mirids. The presence of summer generations of C. verbasci in European fruit orchards is routine (Collyer 1953a,b,c, 1955; Steiner et al. 1970; Baggiolini and Wildbolz 1965; Skanland 1980; Jonsson 1983; Alford 1984; Sechser et al. 1984), as it is now in British Columbia.

The frequency of occurrence and general population levels of C. verbasci observed in this study, together with its damage (Chapter V), support the suggestion of Barnett et al. (1976) that true bugs are increasing in importance as fruit pests. A survey by Croft and Whalon (1982) indicated that the new generation of synthetic pyrethroid insecticides are only moderately toxic to mirid bugs. Thus it is likely C. verbasci will continue to present a challenge for pest management programs in British Columbia.

IV The distribution of Campylomma verbasci nymphs on apple in the Okanagan Valley and its importance for sampling

INTRODUCTION

Sporadic damage from Campylomma verbasci (Meyer) can be devastating in orchards of British Columbia and elsewhere in North America (Table 2.5). Monitoring of the insect is required throughout a critical period on sensitive apple trees, cv. Red and Golden Delicious, in Canada and the Pacific Northwest (Hoyt 1973; Madsen et al. 1975; MacPhee 1976; Hagley et al. 1978; Hardman et al. 1984). Commercial pest management programs employ the limb-tap method of sampling to give reliable estimates of C. verbasci populations at a low cost. Counts of C. verbasci are also taken with the limb-tap method during routine assessment of predator populations in orchards of Nova Scotia (Lord 1949, 1968), Germany (Steiner et al. 1970), Switzerland (Baggiolini and Wildbolz 1965; Sechser et al. 1984), and Norway (Jonsson 1983). Yet this method is one of many sampling techniques that were empirically developed and applied without being tested for their applicability to pest management (Southwood 1978; Hoyt et al. 1983).

Monitoring and sampling techniques in pest management must be easy to use, economical and reasonably precise in estimating population size (Hoyt et al. 1983). It has been suggested that limb-tap sampling of C. verbasci is imprecise, may supply inadequate population estimates that lead to significant damage, or requires an excessive amount of time during a critical period for pest management programs (Madsen et al. 1975; MacPhee 1976; Vakenti and Peters[2]; Boivin and Stewart 1983a). Predicted increases in the importance of C. verbasci due to insecticide resistance (Agric. Canada 1980; McEwen 1983; Chapter III) and of plant bugs in orchards generally (Barnett et

al. 1976; Croft and Whalon 1982) suggested that an evaluation of sampling methods would be timely.

Arboreal insects present the most complex sampling situation in entomology (Southwood 1978). The major investigations of methods for sampling plant bug populations were by Collyer (1951), Muir (1958), Muir and Gambrill (1960), and Dempster (1961) who used chemical knock-down and capture-recapture methods; Steiner (1962), Steiner et al. (1970), Baggiolini (1965), Baggiolini and Wildbolz (1965), Baggiolini et al. (1967), and Lord (1965) who discussed visual and cluster counts, limb-tap, vacuum sampler, light trap, and mechanical shake-down methods; and Menzies and Hagley (1977) who used a mechanical trap. Prokopy et al. (1977, 1979, 1982), and Boivin et al. (1982) tried to assess plant bugs populations by using colored sticky traps to catch adults in flight.

Most of the methods are costly and none is free from error. Consequently, the density of plant bug nymphs is generally estimated with the simple and convenient limb-tap method, devised originally by an insect collector with an inverted umbrella (Southwood 1978).

Steiner (1962), Steiner et al. (1970), Baggiolini and Wildbolz (1965), and Malevez (1976) compared limb-tap counts with personal judgements of population levels of species in the trees. However, the only thorough examination of the method was by McCaffrey et al. (1984) who found it collected 85% of the total spider population present on trees in Virginia apple orchards. Boivin and Stewart (1983a) made a small study of its efficiency in recapturing nymphs of 5 mirid species placed on limbs, and Lord (1968) suggested that the accuracy and utility of the method varies with the species and population density, but did not discuss C. verbasci.

Development of a sampling program requires knowledge of the spatial distribution of the insect to identify the areas of the plant most frequented (Morris 1955, 1960; Wilson 1982). Nothing has been published on the distribution of C. verbasci in sensitive varieties of apple at the time when damage occurs, during and after bloom[1]. Boivin and Stewart (1983d) found no difference in the distribution of C. verbasci within or between 'McIntosh' apple trees, at one site in one year, using the limb-tap technique as a basis for comparison. However, Hull et al. (1976, 1977) and Parella et al. (1981) found that great differences can occur in distribution of a coccinellid beetle, Stethorus punctum (LeConte), in apple orchards and that the differences are related to prey population increases in particular trees or sites. Similarly, large numbers of C. verbasci have been found in trees infested with European red mite, Panonychus ulmi (Koch), at the time of oviposition of the overwintering eggs (Venables 1938, 1939; Lord 1949; Collyer 1953a,b; McMullen 1973, McMullen and Jong 1970).

The within-tree distribution of C. verbasci was discussed by Lord (1965, 1972), Jonsson (1983, 1985) and Boivin and Stewart (1983d). They reported that C. verbasci is more common in fruit clusters than leaf clusters of apple foliage, in varieties that do not show damage. If similar results were shown in sensitive varieties in British Columbia a method of population estimation could be developed using samples of flower clusters, of the type that LeRoux and Reimer (1959) proposed for 2 leafroller species on apple. It would provide a quantitative dimension that is lacking in the limb-tap technique and of great value in a sampling technique (Morris 1955; LeRoux and Reimer 1959; Lord 1968; Southwood 1978).

The objectives of this study were: to examine the distribution of C. verbasci nymphs and associated arthropods in Delicious variety apple trees; to assess the efficiency of the limb-tap method compared with 'absolute' samples; and to compare limb-tap and cluster sampling, for population estimation of C. verbasci in pest management programs.

MATERIALS AND METHODS

Investigations were conducted in 1982-1984 at the sites described earlier (Figure 3.1, Table 3.1). Site 15 was heavily utilised in 1984. Unless otherwise noted, all trees were selected randomly and subsamples were randomized within the main sample unit.

The limb-tap method (Chapter III; Madsen and Procter 1982) was employed to assess C. verbasci population density and individual records were kept from each tap rather than the total of a set of taps. Tree foliage was sampled using the cluster as a unit as it met Morris' (1955, 1960) criteria for a stable unit and can be sampled by choosing trees, branches, and clusters at random (LeRoux and Reimer 1959; LeRoux 1961). The entire foliage of apple trees is borne in clusters of 2 basic types: leaf clusters bearing only leaves, and fruiting clusters that bear blossoms or fruit in addition to the leaves. When fruiting clusters do not set fruit, or lose the fruit, they become similar to leaf clusters (Lord 1968, 1972). Clusters were collected individually in small cartons. Limbs were removed using a small saw and placed in very large plastic bags. Samples were stored at 1-2°C until examined.

Records were kept of the total cost in hours of taking, inspecting, and recording a sample. The time required for individual sample units was measured in minutes.

Distribution within trees

The distribution of first generation C. verbasci was examined on 3 occasions when high populations were encountered. 1) On 15 May 1983, 6 sets of 25 clusters were taken at random from site 15. Each set was a different type: inside and outside clusters of each of the following; leaf, flowers at bloom, flowers at petal fall. Inside clusters were taken from the inner 1/3 of the foliage near the trunk and scaffold limbs, and outside clusters from the peripheral foliage. All arthropods present in 10 or more clusters/set were counted, but only C. verbasci recorded in the remainder. 2) Ten trees at site 12 were selected on 18 May 1983 and from each 5 flower clusters were gathered. From 5 of the trees only flower clusters at bloom were taken and from the remainder only those at petal fall. 3) On 18 May 1984, leaf and flower clusters were collected from the peripheral foliage of 50 trees at site 4. One cluster of each type was collected/tree.

Collections of clusters of all types and of limb sections were also made on 8 other occasions at 5 sites in 1984, as described below.

Distribution between trees

On 2 July 1983, 40 trees were selected from 96 in the Red Delicious block (Sites 18 and 19, Table 3.1). Two limbs on opposite sides of each tree were checked with a limb-tap sample. Twenty trees were sampled at 0° and 180° orientation to the sun and 20 at 90° and 270°. Second generation C. verbasci nymphs were abundant.

During May 1984, limb-tap samples were taken from sites 1, 4, 15-17, and 20 at weekly intervals. One limb-tap was made in each compass quadrant of 10-27 trees/site.

Comparison of sampling methods

Data on the limb-tap technique were gathered in all sites from 1982-1984, for sample sizes between 1-4/tree and intensities of 10-286 trees in 0.5 ha plots. Data on cluster sampling were gathered in the 3 studies described earlier and in simultaneous comparisons of methods at sites 9, 15-17, and 20 from 4-20 May 1984, i.e. from pink to petal fall. On each occasion, 50% of trees were examined with both a limb-tap and collection of clusters from either of 2 randomly selected limbs/tree. In noncommercial sites, 1 limb was removed, near the trunk, from 12-18 trees to provide an 'absolute' count of C. verbasci on the limb.

Intensive study of site 15 occurred on 17 May 1984 (between full bloom and petal fall) using limb-tap, cluster and 'total' samples. The site was divided into 3 units from West to East, and the order samples were taken was randomized among units to decrease systematic errors (LeRoux and Reimer 1959). At each of 0730, 1200, and 1630 h, 9 trees were sampled with 1 limb-tap on a single limb; 9 others were sampled with a limb-tap from 4 limbs. Two of the latter limbs were stripped of clusters in the region of the limb-tap and 6 of the 9 trees had the tapped section of a third limb removed. Judgement of the numbers of clusters and amount of limb to remove was based upon opinions of the sampler and an observer; in case of doubt larger rather than smaller samples were collected. During the day, 18 limbs, 2327 clusters and 136 limb-taps were taken from a total of 54 of the 60 trees in the site. No tree was sampled more than once.

Temperatures were approximately 11°C at 0730, 15.5°C at 1200 and 17°C at 1630 h, and the relative humidity ranged from 55% to 35% as measured with a Fuess thermohygrograph.

Data analysis

The data were examined using graphic analysis (Anscombe 1973), correlation analysis, analysis of variance and linear regression (Draper and Smith 1981; Sokal and Rohlf 1981). Sample variances of the data were stabilized using the angular transformation for comparisons of precision (Southwood 1978) and $x^{1-b/2}$ for other analyses (Taylor 1961, 1971; Healy and Taylor 1962) where b is a function of the relationship between sample means and variances. Transformed data were used only if the assumptions of parametric statistics were grossly violated or major differences occurred in significance levels (LeRoux and Reimer 1959; Southwood 1978). Nonparametric methods (Conover 1980) were used when sample variances were greatly dissimilar.

RESULTS AND DISCUSSION

Distribution within trees

Using the limb-tap method, there were no significant differences (ANOVA, $P<0.05$ level) in the distribution of C. verbasci nymphs between compass quadrants, or 4 orientations relative to the sun, within Red Delicious trees. The nymphs were evenly distributed within trees and can be sampled reliably with one limb-tap, as recommended in British Columbia (Madsen and Procter 1982; Agric. Canada 1983). Boivin and Stewart (1983d) reported similar results with McIntosh trees in Quebec.

Use of a foliage sample requires finer distinctions than quadrants or sides of a tree. Examination of 60 limbs cut from trees and 2917 clusters of Red Delicious disclosed C. verbasci nymphs (55-85% first instar) only in leaf or flower clusters and not on the surfaces of the limbs. A similar result was reported by Niemczyk (1978) for small potted apple trees during

the summer generation. However, the numbers of C. verbasci nymphs found in clusters of different types or developmental stages were markedly different (Table 4.1); nymphs were consistently more common in flower clusters than leaf clusters, in all samples ($P<0.05$ level). The differences were seen over a 5-fold range of population densities but the nymphs occurred only in an aggregated spatial pattern with up to 22 in an individual cluster.

The results are contrary to the conclusion of Jonsson (1983) that first and second instar nymphs live only within blossom clusters. They support observations of Lord (1965, 1972) and Boivin and Stewart (1983c) that limbs with a higher proportion of flower clusters contain more C. verbasci than those with a low one and extend the results to apple cv. Red Delicious in spring. Jonsson (1983) also suggested that the number of flower clusters is a limiting factor for C. verbasci and other mirids in Norway, but 8.5-12.5% of nymphs were found in leaf clusters at 3 British Columbian sites (Table 4.1).

Further evidence of the aggregation of the nymphs within trees is shown by the relationship of the variance to the mean of 93 sets of limb-tap samples collected from sites containing nymphs of first generation C. verbasci (Chapter VI). Taylor and his colleagues have shown in a series of papers that the variance s^2, is related to the mean, m, of a sample by a power law such that $s^2=am^b$ (Taylor 1961, 1984; Perry 1981). The value of b is a constant, characteristic of the species, and is widely used as an index of aggregation (Bardner and Lofty 1971; Wratten 1974; Elliott 1977; Trumble and Oatman 1984; Mollet et al. 1984), whereas a is a scaling factor related to the sampling method. The observed value for b, 1.28 ($\pm$.05) is typical of insects with a distinctly aggregated spatial pattern (Taylor 1961, 1971).

Table 4.1. C. verbasci nymphs collected in clusters of different types, or of different developmental stages, during the bloom period in 3 Okanagan Valley sites

Site[a], date and cluster type	Sample size	C. verbasci Mean[b]	C. verbasci Std. error
Site 15, 15 May 1983			
Leaf			
- inside	25	0.04 a	0.08
- outside	25	0.28 ab	0.30
Flower at bloom			
- inside	25	0.48 b	0.32
- outside	25	2.08 c	2.07
Flower at petal fall			
- inside	75	0.40 b	0.27
- outside	25	0.48 ab	0.40
Site 12, 18 May 1983			
Flower at bloom	25	0.56 a	0.43
Flower at petal fall	25	1.24 b	0.67
Site 4, 18 May 1984			
Leaf	48	0.71 a	0.49
Flower at bloom	47	3.40 b	0.80

[a]Sites described in Table 3.1.

[b]Means followed by the same letter are not significantly different between samples at a site, $P<0.05$ (Duncan's multiple range test on transformed data, or Mann-Whitney test for 2 samples)

The possible causes of aggregated patterns of first generation, first and second instar C. verbasci are an uneven distribution of resources necessary for survival, differences in predation rates, or differences in the ovipositional behavior of females of the previous generation. The nymphs may feed on nectar or pollen in the flowers, as do other entomophagous Heteroptera (Stoner et al. 1975; Sholes 1984) or on associated arthropods, and so increase their survivorship. In 2 sites the nymphs occurred with high numbers of other arthropods and in particular were significantly correlated with the European red mite and the western flower thrips, Frankliniella occidentalis (Table 4.2). Mites are favored prey of C. verbasci (Table 2.3) and I have observed voracious feeding of the nymphs on Thysanoptera from several hosts. The results suggest a gathering, or increased survivorship, of C. verbasci in clusters where prey occur at moderate levels. However, the highest population density (3.4/flower cluster) was found in an orchard (site 4) containing very few arthropods other than C. verbasci, showing that the presence of animal prey is not critical for the sustenance of early instars.

C. verbasci nymphs were often discovered inside the tangled mass of webbing, frass and chewed plant parts produced by feeding of early season noctuid and tortricid larvae. A significant correlation was found at one site (Table 4.2) and in another the flower clusters with moth larvae contained significantly more C. verbasci than those without (Mann-Whitney $U=130.0$, $P<0.01$, $n=37,13$). This association has also been observed by H.F. Madsen[7] (pers. comm.). Moth feeding may provide shelter or create a flow of plant juices suitable for feeding of C. verbasci. Jonsson (1983) suggested that protection, from weather and natural enemies, given by flower clusters is crucial to the survival of C. verbasci and other mirids on apple. I

Table 4.2. Sample statistics and correlation coefficients associating C. verbasci with other arthropods in foliage clusters

Site[a], date, and subject of comparison	No. of clusters examined	Population level ($\bar{x}$ ± s.e.) Associated arthropod	C. verbasci	Correlation[b] R
Site 15, 15 May 1983				
Frankliniella occidentalis	85	0.7 (0.1)	0.9 (0.3)	-0.1
Panonychus ulmi	60	63.9 (7.4)	0.9 (0.4)	0.6***
Aphididae	60	1.9 (1.7)	0.9 (0.4)	0
Araneae	150	0.1 (0.02)	0.6 (0.2)	0.4***
Lepidoptera	150	0.4 (0.1)	0.6 (0.2)	0.3***
Site 12, 18 May 1983				
Frankliniella occidentalis	50	13.2 (1.8)	0.9 (0.2)	0.3*
Lepidoptera	50	0.3 (0.1)	0.9 (0.2)	0.2
Site 4, 18 May 1984				
Frankliniella occidentalis	47	0.3 (0.1)	3.4 (0.4)	-0.2
Frankliniella occidentalis	48	0.1 (0.01)	0.7 (0.2)	-0.1

[a]Sites described in Table 3.1.

[b]Pearson product moment correlation coefficient; probability *<0.05, ***<0.001.

assume that the shelter provided by a cluster damaged by moth larvae would be greater than that provided by undamaged clusters. The correlation of C. verbasci with a small number of Araneae on one occasion may be a statistical artifact, as very few spiders were found in clusters on other occasions, or both may have been protected from weather or natural enemies in the same clusters. The small spiders were never seen preying upon C. verbasci, but may in this instance have shared a common prey.

The hypothesis of preferential oviposition offers the best explanation for significant differences in numbers of nymphs consistently observed within trees (Table 4.1). The first instar nymphs are small (<1 mm), delicate, and unlikely to crawl a long distance searching for preferred clusters. Indeed, none was found on the surface of 60 limbs. Flower buds are differentiated in mid-June to mid-July (Westwood 1978), well before the females return to lay overwintering eggs, and have distinct characteristics. Flower buds have a higher nitrogen concentration, compared with other plant parts, for up to one month following petal fall (Davis 1931; Hansen 1971; Sutton 1984), and the reproductive development and fecundity of nymphs of C. verbasci and other Heteroptera is very dependent upon concentration and quality of available nitrogen (McMullen and Jong 1970; McNeill 1973, McNeill and Southwood 1978, McNeill and Prestidge 1982; Mattson 1980; Kiman and Yeargan 1985).

Preferential oviposition at the best nitrogen source would also explain the significant differences in C. verbasci density observed by Lord (1972) between flowering and non-flowering trees, because flowering rosaceous trees consistently have higher concentrations of nitrogen and other nutrients than do non-flowering trees (e.g. Davis 1931; Oland 1959; Hansen 1971; Sutton 1984).

The aggregated distribution of nymphs in this study would be explained by a clumped oviposition pattern in the female, common in mirids (Chittenden and Marsh 1910; Knight 1915; Sanford 1964; Lord 1968; McCaffrey and Horsburgh 1980), as Boivin and Stewart (1983d) also suggested from an analysis of spatial dispersion of C. verbasci.

Distribution between trees

Observations from the collection of over 400 sets of limb-tap samples suggest that nymphs of C. verbasci occur throughout orchard sites, in a 'clumped' pattern, and are found in localized parts of the orchards only when populations are low, <0.25/tap, usually at the edges.

Comparisons revealed no significant differences between Red Delicious trees (ANOVA, P <0.05) when the mean density of nymphs was >1/tap (Table 4.3). The interplant variance decreased as the population increased, suggesting that the spatial pattern became more even as the density of C. verbasci increased in the orchards. The 'clumped' spatial pattern is more obvious at low population levels, corresponding to the effect produced by a few females ovipositing within certain trees.

Accuracy of sampling

Accuracy is a measure of the difference between a sample result and the result that would be obtained from an absolute census under the same conditions (Ruesink 1980). The accuracy of the limb-tap method was estimated by comparing the proportion of C. verbasci nymphs collected in the limb-tap with the entire population, on a section of limb, including any remaining in clusters or on the limb surface. Paired comparison of the limb-tap and 'total' counts from 70 limb sections revealed significant differences (ANOVA, P<0.01). Linear regression of the number found in the taps (Y) against the

Table 4.3. Relationship between population density and between-tree variation in distribution of *C. verbasci* nymphs

Site and timing of sample[a]	Sample size		*C. verbasci* no./limb-tap	Between trees	
	Trees sampled	Samples per tree	$\bar{x}$ (± s.e.)	F-test[b] probability	% variance component[c]
Site 1, bloom	10	4	0.7 (0.3)	<0.05	35.7
Site 15, bloom	27	4	1.1 (0.1)	n.s.	13.5
Red Delicious, summer	40	2	2.0 (0.2)	n.s.	9.0
Site 4, bloom	10	4	7.0 (1.0)	n.s.	7.6

[a]Sites described in Table 3.1; Red Delicious block = Sites 18, 19 + buffer zone

[b]Nested ANOVA; data transformed by $\sqrt{(x + 0.5)}$

[c]Interplant variance as % of (intraplant + interplant variances)

total number (x) gave the equation, with standard errors (after removal of one outlier):

$$Y = -0.16\ (\pm\ 0.1) + 0.82\ (\pm\ 0.05)\ (x) \quad (R^2 = 0.83,\ n = 69) \qquad [1]$$

The difference in population estimates indicates that the limb-tap method is biased and underestimates the real population by approximately 18%. This result compares with average estimates of 85% of the population of spiders, in apple trees in Virginia, obtained using the limb-tap technique (McCaffrey et al. 1984). The explanation for the 18% error is due to the difficulty of sampling the early instars of C. verbasci, also noted by Lord (1965) and Boivin and Stewart (1983a), which cling to the clusters more than do other mirids. The majority of the nymphs discovered following a limb-tap were within the inner flower parts, a favored resting place (Table 4.4).

The true level of accuracy is not known as both this study and the spider study simulated absolute counts using the best possible approximation. The nature of large trees prevents a complete census of mobile insects and any method used as a standard of comparison is only an approximation of a complete sample. The methods used in this investigation are equivalent to those of other quantitative studies in orchards (Steiner 1962, Steiner et al. 1970; Lord 1965, 1968, 1972; Boivin and Stewart 1983a,d; McCaffrey et al. 1984) and it is possible that the true accuracy was higher than calculated because the 'total' method required collection of much material from the region of the limb when any doubt occurred. However, as Southwood (1978) remarked, errors are usually made in the direction of underestimation of a population.

Reliability of sampling

The reliability, or precision, of different sampling methods is often

Table 4.4. Position of first and second instar C. verbasci nymphs within clusters of apple during bloom, 1983

Position	Distribution, %	
	Site 15, 15 May (N = 91)	Site 12, 18 May (N = 46)
In corolla of flower	35	30
On flower stem	30	26
On cluster stem	15	22
On young leaf	13	15
On old leaf	7	7

compared with the relative variation, RV, ratio (Southwood 1978; Kogan and Pitre 1980; Ruesink 1980). The spread among observations obtained using each method is related to the sample mean using:

$$RV = (S\bar{x}/\bar{x})(100) \qquad [2]$$

where $\bar{x}$ is the average count of n samples within a unit and $S\bar{x}$ is the standard error of the mean. The mean value, $\overline{RV}$, of a method is calculated from a number of different samples. It is generally accepted that an $\overline{RV}$ of <25 for a method is suitable for pest management (Southwood 1978).

The results of sampling specific orchard blocks at intensities corresponding to 1-5 times the recommended levels for pest management programs in the British Columbia interior (Madsen and Procter 1982; Agric. Canada 1983) reveal that only where the nymphs occurred at their highest densities did any method provide an $\overline{RV}$ value <25, and the values did not differ greatly between methods (Tables 4.5 - 4.7). Similarly, the $\overline{RV}$ values obtained in limb-tap sampling of many orchards at 3 intensities from 0.5-2.5 times the recommended levels (Table 4.8) show that none of the sampling intensities consistently provided an $\overline{RV}$ value <25.

The results are explained by the spatial pattern of C. verbasci. Highly 'clumped' populations produce a much greater RV value than a randomly distributed population for the same number of sampling units, and RV is inversely related to sample size and population mean, as predicted by equation [2] (LeRoux and Reimer 1959; Southwood 1978). At low population levels large samples are required to provide an RV value <25. Most of the limb-tap samples were taken in orchards with low populations of C. verbasci, providing large RV values, as would be the case in a typical monitoring program.

Table 4.5. Relative variation, cost, and relative efficiency of 2 sampling methods for C. verbasci nymphs, compared simultaneously

Site and sampling method	No. samples in set	Sample size	Relative variation, RV of set[a]	Mean cost[b], C_s	Relative efficiency[c], RE
Site 15					
flower & leaf clusters	6	25	50.9	0.7	2.9
limb-tap	1	10	24.4	0.3	15.4
Site 12					
flower clusters	2	25	31.6	1.8	1.8
limb-tap	1	25	31.7	0.7	4.7
Site 4					
flower & leaf clusters	2	48	22.8	1.3	3.4
limb-tap	1	23	20.5	0.6	8.1
limb-tap	1	40	14.7	1.1	6.4
Sites 16, 17					
flower & leaf clusters	2	96	33.4	2.6	1.2
limb-tap	2	24	40.2	0.6	4.2

[a] RV = 100 (standard error of mean/mean)

[b] C_s = cost in h of taking, inspecting, and recording 1 sample

[c] $RE = 100/(\overline{RV})\ (C_s)$

Table 4.6. Population estimates and relative variation of limb-tap sampling at 3 intensities, and of a 'total' sampling method, for C. verbasci on 9 Red Delicious trees at 3 times of day (17 May 1984). Trees were chosen randomly from a block of 60 (Site 15) and sampled once only

Time	Method[a]	No. of samples/tree	No. of C. verbasci $\bar{x}$ (± s.e.)[b]	Relative variation, RV[c]
0730	limb-tap	1	2.22 (0.86)	38.8
	limb-tap	4	1.19 (0.21)	24.7
	limb-tap*	2	1.33 (0.38)	37.9
	total*	2	2.28 (0.35)	34.7
1200	limb-tap	1	1.56 (0.44)	28.6
	limb-tap	4	1.22 (0.29)	25.1
	limb-tap*	2	1.67 (0.32)	32.2
	total*	2	2.11 (0.26)	26.5
1630	limb-tap	1	2.00 (0.58)	28.9
	limb-tap	4	1.00 (0.30)	21.1
	limb-tap*	2	0.83 (0.29)	29.6
	total*	2	1.06 (0.25)	24.7

[a] Paired samples from the same limb sections are followed by *.
[b] Grand mean of all samples from 9 trees/time period.
[c] RV = 100 (std. error of mean/mean)

Table 4.7. Population estimates and comparative measures of limb-tap sampling at 3 intensities, and of a 'total' sampling method, for C. verbasci on 54 Red Delicious trees at Site 15, on 17 May 1984

Method[a]	No. of samples/tree	Overall means[b]: No. of C. verbasci ($\bar{x}$ ± s.e.)	Relative variation[c], RV	Cost[d] C_s	Relative efficiency[e], RE
Limb-tap	1	1.93 (0.36)	32.1	0.24	12.5
Limb-tap	4	1.14 (0.16)	23.6	1.0	4.4
Limb-tap*	2	1.28 (0.26)	33.2	0.5	6.3
total*	2	1.81 (0.34)	28.7	8.6	0.4
All methods (81 samples)		1.41 (0.13)	14.5	10.4	0.7

[a]Paired samples from the same limb sections are followed by *.
[b]Grand means of 9 trees/method/time period.
[c]RV = 100 (std. error of mean/mean).
[d]C_s = cost in h of taking, inspecting, and recording a sample.
[e]RE = $100/\overline{(RV)}$ x C_s.

Table 4.8. Relative variation, cost, and relative efficiency of limb-tap sampling 0.5 ha of apple trees at 3 intensities for C. verbasci, 1982-1984

		Overall means[a]		
No. samples	Sample size	Relative variation[b], $\overline{RV}$	Cost[c], C_s	Relative efficiency[d], RE
29	10-19	55.8	0.4	4.5
160	20-29	57.9	0.7	2.6
15	30-50	38.5	1.1	2.4

[a]Grand means of all samples
[b]$\overline{RV}$ = 100 (std. error of mean/mean)/No. of samples
[c]C_s = cost in n of taking, inspecting and recording a sample
[d]RE = $100/(\overline{RV}) \times C_s$

Because the aggregation of C. verbasci affects the reliability of small samples (Tables 4.6, 4.7) the population estimates provided by limb-taps from one site on one day varied from 0.83-2.22/tap. The recommended intensity of tapping is 40 limbs/ha, equivalent to sampling 6.1-14.0% of trees in a typical orchard of the Okanagan Valley (M. Sanders[10], pers. comm.). With a sample size of 9 trees in 60, equivalent to 15% of the trees, 2 of the estimates were at or above the treatment level for British Columbia of 2/tap (Madsen and Carty 1977; Agriculture Canada 1983). The results are disturbing as they reflect considerable variation around the overall means provided by intense sampling (Table 4.7). Only one sampling intensity, 36 taps, provided an $\overline{RV}$ value <25, corresponding to 60% of trees being sampled.

Sampling in commercial monitoring programs must be much less intense because of time constraints (Vakenti and Peters[2]), but the amount of sampling largely determines the precision of an estimate of mean density. Optimal sample sizes for constant precision levels, and methods to minimize the sampling required by fixed sample sizes, are considered in detail in Chapter VI.

Timing of Sampling

Estimates of mean population density obtained using each of 3 intensities of limb-tap sampling did not differ significantly from 0730-1630 during one day (Table 4.6; ANOVA, $P>0.25$). The clumped spatial pattern of the nymphs gave large confidence limits for the estimated mean density and contributed to the lack of differences between samples. This result is significant for sampling and decision-making as it shows that limb-tap samples of a population of C. verbasci near the treatment level, taken during daylight hours will give the same approximate mean density for a particular

intensity of sampling.

Paired comparison of the limb-tap and 'total' samples showed that accuracy of the limb-tap method increased from 0.77 (0730) to 0.82 (1200) and 0.89 (1630) during the day, but the levels of accuracy were not significantly different from one another (ANOVA, $P>0.25$). The changes did affect the RV of the limb-tap method (Table 4.6) which decreased by 3.6-10.0% during the day, depending upon sample size. The reliability, or mean precision, of the limb-tap method was 0.83 for the day, similar to a result of 0.85 for spiders on apple trees (McCaffrey et al. 1984) in a study showing that time of sampling had little effect on diurnal estimates of spider populations.

An increase in accuracy with time may be due to the effect of temperature upon activity of the nymphs, or a behavioural pattern such as movement away from the centre of the clusters for feeding, causing a greater number to be collected later in the day. Turnbull (1960) and McCaffrey et al. (1984) indicated that limb-tap sampling best estimates the population active at the time of sampling, not those resting or hiding.

Cost of Sampling

Both limb-tap and cluster sampling required collection and examination of a sample unit. The financial costs of sampling equipment were ignored but the tapping tray is simple and cheap whereas cluster examination requires a binocular microscope and a device for keeping samples cool.

The choice of limb-tap sampling by pest management personnel has considerable merit. Sets of limb-tap samples of 1-4/tree and 10-160 trees in 0.5 ha gave a mean cost of 1.6 min/tap over a wide range of *C. verbasci* population densities. Average costs of moving within and between trees were equal in 120 observations, due to the small size and high density of trees in

the interior orchards of British Columbia.

Although clusters were collected rapidly (0.5 min/cluster, n = 200), as little site selection was required, the cost of a cluster sample was very high, particularly where the proportion of flowers was large. Mean costs of examination and recording results, of 2917 Red Delicious clusters, were 0.7 min for leaf clusters and 3.7 min for flower clusters. Mean costs for both types were 1.1 min in a sample (n=2327) containing 75% leaf clusters, a typical value for apple (Lord 1972). The total costs/sample unit averaged 1.2 min, 4.2 min, and 1.6 min for leaf, flower, and both types of cluster, respectively.

Limb removal, which is unacceptable in commercial orchards but may be required in intensive population studies, was also costly. Selection, cutting and bagging of limb sections required approximately 15 min. On one occasion 18 sections bearing an average 7 flower and 35 leaf clusters required 68 min per limb for bark and foliage examination.

The limb sections were the regions sampled by individual limb-taps, indicating an average 42 clusters/tap. The cost of a single limb-tap is that of an average cluster, 1.6 min, but permits the detection of C. verbasci at lower population levels than by careful examination of a single cluster. Indeed, the frequency of detection at low population levels was always greater for the tap than the cluster method, per sample unit. In a typical study (sites 16, 17) only 8% of flower clusters and no leaf clusters contained nymphs, compared with 27% of the limb-taps. This is an important result when economic thresholds are low.

Efficiency of sampling

One method is more efficient than another if it yields more reliable

results/unit cost under specified conditions. The relative efficiency (RE) of a method was compared using the ratio:

$$RE = 100/(\overline{RV})(Cs) \quad [3]$$

where Cs is the cost of taking the n samples used to calculate the $\overline{RV}$ values. The RE depends upon the mean, total cost and standard error, so it is sensitive to changes in n and sampling cost unlike other ratios (Cochran 1977; Southwood 1978; Ruesink 1980).

Comparisons of methods in the same sites, at C. verbasci densities of 0.7-12/tap, revealed that the limb-tap method was always more efficient (by RE value) than cluster sampling and up to 31 times more efficient than an 'absolute' method (Tables 4.5, 4.7). Although methods involving collection of clusters were consistently more precise than the limb-tap method, the RE values were higher for limb-tap samples because cluster sampling was much more costly for a small gain in reliability; observed differences in RV values were <8% for the 2 methods, at any site, but the cluster sample was between 1.2-4.8 times as costly as the limb-tap method. On 3 other occasions, at low C. verbasci densities (<0.1/tap), limb-tap sampling collected the most nymphs at the least cost.

In conclusion, these results indicate that the limb-tap method is most useful in estimating population levels of C. verbasci. Lord (1968) found that the tapping technique did not reveal the true population peak for the mirid Hyaloides harti (Knight) on apple, and noted that its accuracy and usefulness varies with the species under consideration. However, as Morris (1960) noted, "sampling ... is only a tool which the entomologist should use to obtain certain information, provided there is no easier way to get the information". The limb-tap is clearly the most efficient, for pest

management purposes, of the sampling methods that are currently employed.

The relative efficiency of the limb-tap method also explains its recent substitution for a 100 cluster sample of apple foliage, for several lepidopterous pests (Madsen and Procter 1982). The cluster sample, although reliable enough for pest management programs, was very costly (Vakenti and Peters[2]) compared with a less reliable limb-tap method.

V. Damage and economic injury levels of *Campylomma verbasci* on apple in the Okanagan Valley

INTRODUCTION

The true bugs are increasing in importance as pests of deciduous fruit for reasons that are not clear (Barnett et al. 1976; Coutin et al. 1984; Chapter II). *Campylomma verbasci* has been the cause of considerable concern in pest management programs in B.C. and elsewhere owing to the sporadic nature of its damage and the unreliability of recommended treatment levels. Its damage, typical of that caused by mirid feeding (Fryer 1914; Knight 1918b, 1922; Petherbridge and Husain 1918; Smith 1921; Tingey and Pillemer 1977), is most serious on certain apple cultivars, particularly Red Delicious, Golden Delicious, and Spartan (Table 2.4).

Control of the damage is possible by insecticidal treatment of the nymphs at petal fall[1]. However, the numbers of *C. verbasci* required to trigger a treatment have been empirically arrived at, in common with many insects (Stern 1973; Hoyt et al. 1983) and in recent years the numbers have been consistently revised downward: in Nova Scotia from a mean count of 16.6 to 8 stinging bugs/tap (MacPhee 1976; MacLellan 1979; Hardman et al. 1984), and in B.C. from 5 to 2/tap (Madsen et al. 1975, Madsen and Carty 1977). Mere detection of the insect at the critical stage of fruit development can justify a pesticide application in Ontario orchards (Hikichi et al. 1979; OMAF 1981b, OMAF 1985).

The movement towards treatment upon detection is at odds with a concept basic to pest management, that most crops can tolerate significant levels of pest damage without large reductions in yield (Stern et al. 1959). This concept is particularly applicable to damage by *C. verbasci* in apple orchards

as in most cases only 3 to 5% of the flowers produced by a full-blooming tree are needed to produce a full crop of fruit (Knight 1922; HEAC 1960; Westwood 1978; Prokopy and Hubbell 1981), and over 80% of the fruit are shed during development (Hall 1974; Westwood 1978; Abbott 1984).

The "economic injury level", the lowest population level that will cause economic damage (Stern et al. 1959, Stern 1966, 1973; Headley 1972; Davidson and Norgaard 1973), is the basis for current treatment recommendations for C. verbasci in B.C. (Madsen and Carty 1977; Agric. Canada 1983) and elsewhere (Hikichi et al. 1979; MacLellan 1979; OMAF 1981b). Southwood and Norton (1973) showed that in general the relationship between the level of a pest population and the injury it causes is linear, whereas the pest injury-yield relationship is a sigmoid curve. For cosmetic pests, such as plant bugs, the population density causing damage is usually very low and any damage is equivalent to a yield loss (Brown et al. 1977; Pimentel et al. 1977; Hoyt and Tanigoshi 1983). Consequently, the population-injury relationship is linear for apple pests including the codling moth, Cydia pomonella (L.) (Wearing 1975; MacLellan 1979), and the tarnished plant bug, Lygus lineolaris (Prokopy et al. 1982). When the relationship can be described mathematically, an economic injury level can be determined with fixed confidence limits and used as an essential part of the pest management program.

Experimental studies of damage in orchard crops are confined to spider mites or sedentary insects, and are rare (e.g. Dutcher et al. 1984) or descriptive in nature (Knight 1918b, 1922; Boivin and Stewart 1982b). The approach taken in this study compares observed damage with population levels in a number of commercial and experimental orchards, and has yielded useful quantitative results for other orchard insects (LeRoux 1961; Baggiolini 1965;

Madsen et al. 1974; Wearing 1975; Allen 1978, 1979; Prokopy et al. 1982; Moreno and Kennett 1985).

The objectives of this study were: to discover the frequency and magnitude of damage from C. verbasci in commercial and unsprayed apple orchards; to determine whether a relationship exists between counts of C. verbasci during or after bloom and the level of damage observed; and to attempt to derive an economic injury level.

MATERIALS AND METHODS

Observations were made in 0.5 ha plots in the commercial and experimental orchards described in Table 3.1 and Figure 3.1, from 1982 to 1984. Data on the arthropod populations of each site were gathered using methods given in Chapter III. Pesticides and other materials were applied regularly in commercial orchards but had no apparent effect upon C. verbasci (Chapter III).

Identification of damage

Descriptions and photographs of the distinctive damage of C. verbasci to apples are available (Ross and Caesar 1920; Knight 1922; Pickett 1938a,b; Madsen and Procter 1982). My previous experience in Ontario and the occurrence of high levels of damage from C. verbasci in 1982 assisted in identification. Nevertheless, any damage that was not immediately identifiable was examined under the microscope or by entomologists at the Research Station in Summerland.

Harvest sample

The majority of the sites were in commercial orchards, where 100 fruit were picked randomly from each of 10 trees if time and the grower permitted. However, most of the samples were checked from the bins as picking occurs

sporadically, at times governed by fruit variety, weather, labour and whims of the grower. A minimum sample size was set at 500 apples/variety/site, with 100 or fewer apples from each bin, and the bins scattered through the site. Sample sizes of >1000/variety were achieved, but at several commercial sites < 500 apples were counted from certain varieties because of picking or shipping pressures, or the variety occurred only as a few trees in the site. Average sizes of the variety-site samples were (with standard error) annually: 1982, 522 $\pm$ 82; 1983, 520 $\pm$ 39; 1984, 675 $\pm$ 127 (Appendix B).

In experimental sites, every alternate tree was stripped during September to October and each apple was checked. The numbers of apples examined in experimental sites were 2,700-10,400 annually. Productivity was often low in experimental orchards particularly in McIntosh, Newtown, and Red Rome varieties (Appendix B).

All fruit were individually checked for scars and deformations. The cause of every blemish was noted in 1982 and 1983 but in 1984 only those inuries from C. verbasci were recorded. If the blemish was serious enough to cause the fruit to be "commercial" grade or less, by the rules of the "Canada Agricultural Products Standards Act", it was recorded.

The grades for apples are Canada Extra Fancy, Canada Fancy, Canada Commercial, and 4 lower grades. All fruit were graded according to these standards and 3 damage categories: 1) apples free from damage, 2) apples damaged by C. verbasci or other insects but not seriously, and 3) apples damaged seriously enough to reduce their grade to Canada Commercial ("C" grade) or lower. Fruit growers in B.C. receive very little or no money for "C" or lower grades and in most years the grading costs of such fruit exceed the income produced.

Results were gathered from 13, 16, and 9 sites in 1982-1984, respectively, and 35,544 apples were examined from 64 variety-site samples.

June drop sample

A survey of damaged fruit was made after the fruit had set but before "June drop" in 1982. Samples were taken during the first 10 days of June from 10 sites. The cluster was chosen as the sample unit on the tree as it contains the site at which damage occurs and can be sampled by choosing trees, branches, and clusters at random (LeRoux and Reimer 1959; LeRoux 1961; Lord 1965). Twenty trees were selected at random and 5 fruit clusters picked randomly from the interior and exterior of the foliage. The numbers of leaves and fruits/cluster were counted and the fruits separated, divided by size into 3 groups from each site, counted and weighed. The numbers and type of scar or deformation, and the positions of any C. verbasci damage were recorded. The proportion of C. verbasci damage in each size category was calculated. At 3 further sites, removal of clusters was not permitted and 100 fruit clusters were selected and visually examined in the field. Only those bearing scars or deformations were taken to the laboratory.

The productivity of orchards can vary according to management practices, such as thinning and fertilization, reflected both in numbers of fruit/cluster and in size (weight) of the fruit. A yield index was calculated to compare the apple material available to C. verbasci at the cluster level:

Yield index = no. of apples in 100 clusters x mass of apples in kg x 10^{-1}

In total 3594 small fruit were examined: 2717 fruit were collected off 100 clusters from each of 10 orchards ($\bar{x}$ = 271.7 $\pm$ 15.4) and 49 were collected from 865 examined on trees at 3 other sites. The weight of the

fruit samples varied from 0.21-1.28 kg and the yield index varied from 3.9 to 32.4.

Relationship of C. verbasci to damage

The limb-tap method (Chapters III, IV) was used to provide an estimate of C. verbasci populations present at a site during the first generation. The maximum number of nymphs found at a site was transformed to the number/tap, from 20 or more taps in an area of 0.5 ha. The data used to derive economic injury levels were the variety-site samples for which good assessments of the peak count were obtained; where it was not clear that the series of limb-tap samples during and after bloom included the peak of emergence they were omitted, leaving 56 sets of data (Appendix B).

Data analysis

The results were examined using graphic, analysis of variance and regression methods (Anscombe 1973; Draper and Smith 1981; Sokal and Rohlf 1981). Data were analysed before and after transformation, when necessary, to the angular form for proportions and square root (+0.5) for insect counts (Southwood 1978), using ANOVAR (Grieg and Osterlin 1978), MIDAS (Fox 1976) or an Apple IIe™ microcomputer programmed with the algorithms provided by Sokal and Rohlf (1981).

RESULTS

Harvest sample

Damage from C. verbasci was serious (>1% of apples graded 'C' or lower) in 42.5% of the variety-site samples in commercial orchards, during 1982-1984 (Table 5.1, Appendix B). C. verbasci was ranked in the top 3 of all causes of pest or disease damage, in 22 of 40 samples from commercial orchards (Table 5.2). Damage was detected in 90% of the samples from commercial

Table 5.1. Frequency of damage from C. verbasci in 40 variety-site samples from 11 commercial orchards in the Okanagan Valley, 1982-1984, by apple variety and severity of damage

	No. of samples with given levels of damage								
	% culled fruit[a]				% damaged fruit[b]				
Apple variety	0 - 1	1 - 5	5 - 10	>10	0 - 1	1 - 5	5 - 15	15 - 25	>25
Golden Delicious	4	7	2	2	1	3	7	2	2
Red Delicious	12	3			9	3	3		
Spartan	2	3			2	1		2	
McIntosh	5				4	1			

[a] "C" grade or lower, as defined by Canada Agricultural Products Standards Act.

[b] 1 or more blemishes.

Table 5.2. Frequency of C. verbasci causing serious fruit damage ("C" grade or less) in a ranking of all biological causes of damage, in 40 variety-site samples from 11 commercial orchards, 1982-1984

	No. of samples with serious damage[a] from C. verbasci of a given rank				
	Rank of C. verbasci damage				
Apple variety	1	2	3	≥4	No damage
Golden Delicious	7	5	3	0	0
Red Delicious	2	1	2	3	7
Spartan	2	1	1	1	0
McIntosh			1	1	3

[a]"C" grade or lower, as defined by Canada Agricultural Products Standards Act.

orchards, indicating an increase from the levels of 62% and 79% found in 2 areas of the Okanagan in 1980 (Vakenti and Peters[2]).

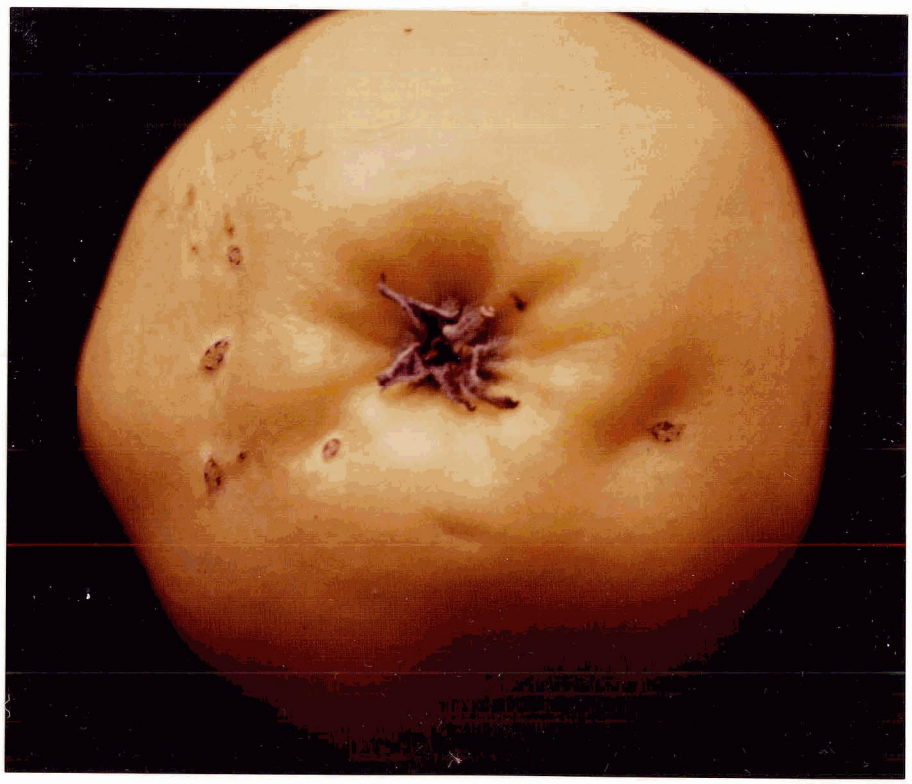
The results reflect the relative susceptibility of the Delicious apple varieties to damage from C. verbasci (Table 5.1) reported in the recent literature (Table 2.4). Damage to Golden Delicious (Figs. 5.1, 5.2) was often severe and on 11 occasions serious damage of >1% was found in commercial orchards. Although damage was frequently present on Red Delicious and Spartan it was not as noticeable as on Golden Delicious, hence the apples were not often down-graded. The Spartan variety was rarely grown in the study sites but suffered considerable damage.

Total damage from C. verbasci, including that not resulting in reduced grades, was high; in commercial orchards the number of apples injured by C. verbasci ranged from 0-9.7% for Red Delicious and from 0-49.4% for Golden Delicious. At site 9, 49.4% of 1000 apples were marked and 11.2% were damaged severely enough to be down-graded to "C" or lower. The damage assigned by the packing-house for 91 bins from this site averaged 19% "C" or lower, almost all from C. verbasci. Grading practices are notoriously variable at packing-houses according to the personnel, and quantity or quality of fruit available but other results indicated my counts, based on the grading regulations, were a realistic assessment.

The distribution of injury on 802 Delicious apples, randomly selected from bins in 5 commercial orchards with high levels of damage, followed a random, Poisson-type, distribution. The mean damage was approximately 2 marks/apple with between 5-14% having 5 or more injuries each, indicating that apples with serious damage can remain on the trees until harvest. Almost all the damage was found in the basal third of the fruit.

Fig. 5.1. Damage characteristic of C. verbasci on apple, cv. Golden Delicious at harvest

Fig. 5.2. Close-up of damage from C. verbasci on a Golden Delicious apple



June drop sample

Red and Golden Delicious apples were on average more frequently injured by C. verbasci than McIntosh or other varieties (Table 5.3). However, there were no significant differences (ANOVA, P=0.05) between varieties, in the proportion of apples blemished or number of injuries/fruit, within individual orchards. Up to 16 wounds were found on single apples of all varieties.

Pooling results for all varieties showed no significant relationship between damage and yield index although there was a weak trend to reduced damage as the yield index increased, suggesting that damage may be more frequent as the apple biomass available to C. verbasci decreases. The trend was more marked but not significant when only Delicious varieties were analysed ($R = -0.57$, $P<0.25$, $n = 8$). Similarly, there was no relationship between damage and the peak count of C. verbasci when all varieties were pooled nor for Delicious varieties alone. The damage at harvest (Y) was significantly related to the damage in the June drop sample (x) of the Delicious varieties, and the linear relationship was, with standard errors:

$$Y = -0.3(0.01) + 0.25(0.05)\ (x) \quad (R^2 = 0.8,\ P<0.005,\ n = 9)$$

but no such relationship was observed in McIntosh or Spartan.

The positions of 430 wounds examined in a random sample of 1253 fruit were similar for all varieties, and the proportions on different parts of the fruit were: stem 2%; upper third of the apple 19%; middle third 38%; basal third 24%; calyx and flower parts 18%.

Relationship of C. verbasci to damage

For both Delicious varieties, a strong linear relationship was found between peak limb-tap counts and the damage at harvest in commercial orchards (Table 5.4). No relationship was found in Spartan or McIntosh apples, and

Table 5.3. Distribution of damage from C. verbasci by variety of apple, in commercial orchards prior to 'June drop'

Apple variety	No. fruit examined	% damaged	Mean stings/fruit
Golden Delicious	240	24.2	1.6
Red Delicious	662	18.4	2.6
McIntosh	303	12.2	2.7
Others	49	8.2	4.3

Table 5.4. Regression of the proportion of culled fruit ("C" grade or lower), and the proportion of fruit with any damage, attributable to C. verbasci vs the mean no. nymphs/tap at the first generation population peak, in 44 variety-site samples from Okanagan Valley orchards, 1982-1984

Regression parameters	Apple variety	No. samples[b]	Linear regression statistics[a] a (± s.e.)	b (± s.e.)	R^2	P
Proportion of culled fruit vs mean/tap	Golden Delicious	15	0.06 (0.9)	3.03 (0.60)**	0.67	<0.001
	Red Delicious	13	0.06 (0.1)	0.13 (0.02)**	0.79	<0.001
	McIntosh	9	0.14 (0.08)	-0.002 (<0.01)	<0.01	0.84
	Spartan	7	1.76 (0.6)	-0.11 (0.23)	0.04	0.66
Proportion of damaged fruit vs mean/tap	Golden Delicious	15	0.74 (4.0)	9.24 (2.62)*	0.49	<0.005
	Red Delicious	13	0.74 (0.6)	0.43 (0.08)**	0.73	<0.001
	McIntosh	9	1.10 (0.4)	-0.03 (0.05)	0.04	0.59
	Spartan	7	7.75 (4.5)	-0.39 (1.64)	0.01	0.82

[a]Probability b = 0, *<0.005, **<0.001.
[b]Samples for Delicious varieties from 11 commercial orchards; for other varieties from all sites, including unsprayed orchards.
[c]Samples of <400 fruit/site excluded from calculations.

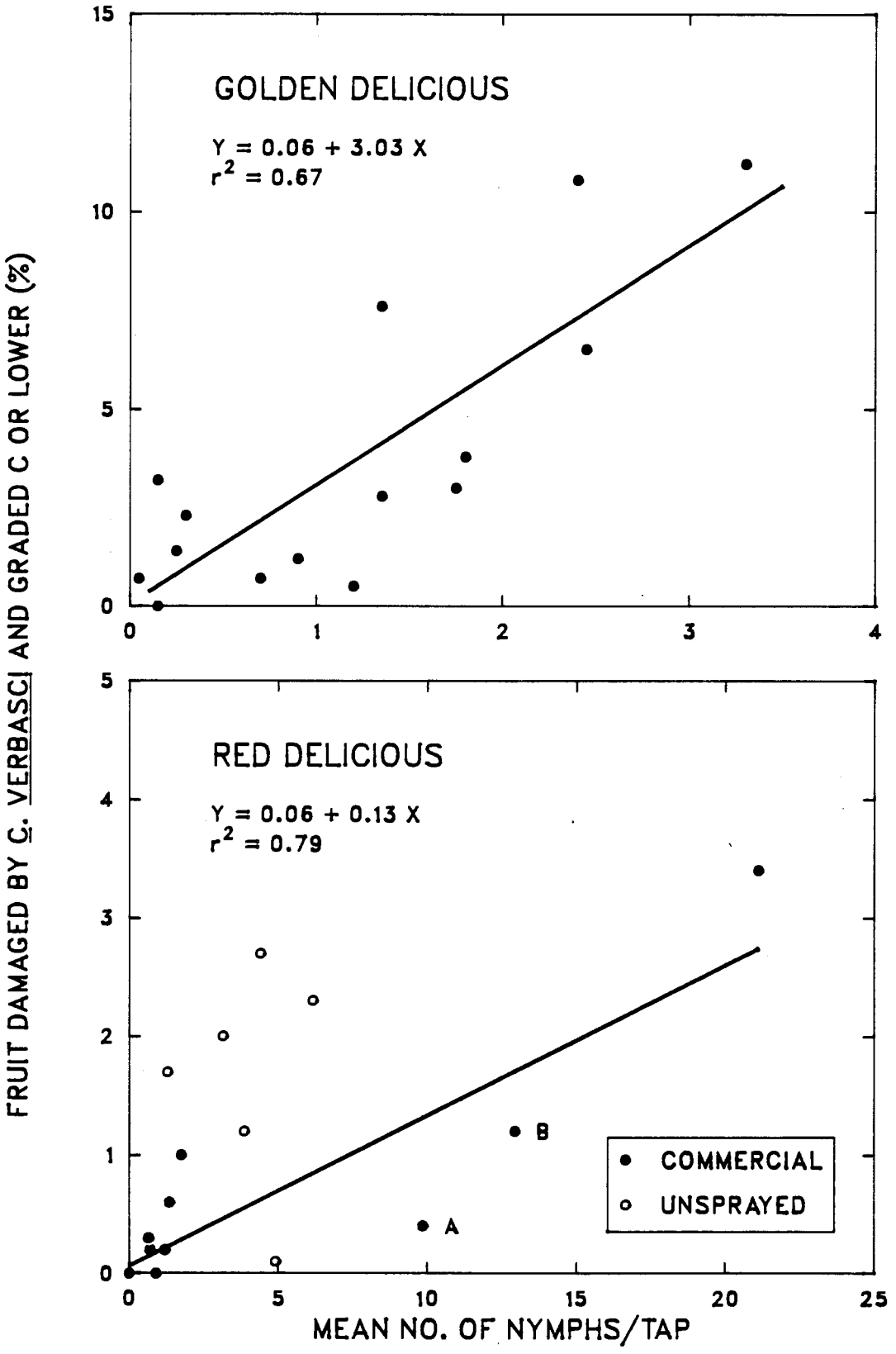
results from other varieties (Appendix B) were too few for analysis.

The proportion of damage in unsprayed sites (14-21) was much higher (Red Delicious, McIntosh, Spartan samples) or lower (1 Red Delicious sample, 1983) than that found in commercial sites at comparable population levels (Appendix B). However, the numbers of fruit/tree in the unsprayed sites were extremely low, ranging between 20-100 apples/tree; a very small fraction of normal productivity, owing to poor care and heavy infestations of other arthropods.

Consideration of the method used to fit linear regression lines, using least squares, is useful as the data for Golden Delicious are evenly distributed but those for Red Delicious are not and show some variation (Fig. 5.3). The highest counts of C. verbasci in Red Delicious came from commercial orchards with high populations in more than one year. Points A and B came from an orchard (site 4) where extensive hand thinning and culling during picking removed damaged fruit; the level of damage otherwise may have been higher than observed, leading to underestimation in these results. Considerable variation also came from unsprayed blocks (sites 14-21) but when these were included in the analysis, and/or points A and B excluded, the regression lines were not significantly different, and only the 95% confidence limits were widened.

The slope of the regression lines for serious ("C" or lower grade) damage is approximately one third the slope for total damage in both varieties of Delicious apple (Table 5.4). The slopes for Golden Delicious are 21 and 23 times as steep as those for Red Delicious, comparing total and serious damage respectively. This difference reflects the well-known sensitivity of Golden Delicious apples to any injury and the "disappearance" of C. verbasci injury on Red Delicious apples as they deepen in colour.

Fig. 5.3. Linear regressions of serious damage at harvest on the peak first generation counts of C. verbasci for Golden and Red Delicious apple varieties in commercial orchards, with data from unsprayed sites for comparison. Points A and B came from an orchard in which damaged fruit was removed by hand thinning and culling at harvest.


GOLDEN DELICIOUS
Y = 0.06 + 3.03 X
r² = 0.67
RED DELICIOUS
Y = 0.06 + 0.13 X
r² = 0.79
COMMERCIAL
UNSPRAYED
A
B
FRUIT DAMAGED BY C. VERBASCI AND GRADED C OR LOWER (%)
MEAN NO. OF NYMPHS/TAP

Economic injury levels

Estimates of values for the peak count of C. verbasci, obtained from the observed damage using inverse regression (Draper and Smith 1981; Sokal and Rohlf 1981), had wide confidence limits as the regression equations (Table 5.4) could only explain 67-79% of the total variation in the data, for the Delicious varieties.

The economic injury levels for Red Delicious are 25 times greater than those for Golden Delicious (Table 5.5). At an acceptable damage limit of 1% (Madsen et al. 1975; MacLellan 1979) they are 7.4 and 0.3 nymphs/tap, respectively, compared with currently recommended mean counts of 2 nymphs/tap for both varieties (Madsen and Procter 1982; Agric. Canada 1983). Support for an increase in the threshold for Red Delicious is given by the economic injury levels estimated when the unsprayed sites were included, or points A and B excluded, from the calculations. These varied from 3.85-5.0; only exclusion of the 3 points with the highest nymphal densities significantly altered the result.

Another way of examining economic injury levels is to calculate, using observed relationships (Table 5.4), the degree of damage predicted for each population density. The results (Table 5.6) indicate that at current treatment levels Red Delicious blocks are treated too frequently with pesticides, and Golden Delicious blocks will experience damage within the range of 4.6-7.6%, 19 times out of 20. If my results are representative of the Okanagan Valley, then replacement of the current, empirically derived, treatment levels by those found in this study would be useful in a pest management program. Several economic injury levels and predicted damage are given in Table 5.6 to assist the grower in tailoring the program to his own

Table 5.5. Estimated economic injury levels of C. verbasci nymphs for given proportions of serious damage

% fruit graded "C" or lower at harvest	Economic injury level (nymphs/tap)	
	Red Delicious	Golden Delicious
0.5	3.4	0.15
1	7.4	0.3
2	15.3	0.6
5	38.9	1.6
10	77.5	3.3

Table 5.6. Proportion of fruit graded "C" or lower at harvest, with 95% confidence interval, predicted from regression equations of Table 5.4 at given population densities of C. verbasci on 2 apple varieties

1st gen. peak nymphs/tap[a]	% fruit graded "C" or lower at harvest (± 95% c.i.)[b]	
	Red Delicious	Golden Delicious
0.2	0.09 (0 - 0.4)	0.8 (0 - 2.4)
0.5	0.13 (0 - 0.45)	1.6 (0.2 - 3.0)
1	0.19 (0 - 0.5)	3.1 (1.9 - 4.3)
2	0.32 (0.1 - 0.6)	6.1 (4.6 - 7.6)
4	0.57 (0.3 - 0.9)	12.2 (7.6 - 16.7)
5	0.70 (0.4 - 1.0)	15.2 (10.5 - 19.9)
8	1.08 (0.7 - 1.4)	unacceptable

[a] 40 limb-taps/ha at peak of emergence
[b] Confidence interval of the mean with a sample size of one.

situation.

As a general recommendation, the threshold numbers of nymphs/tap for treatment of C. verbasci should be altered immediately to 1 or less for Golden Delicious and 4 or more for Red Delicious. If future experience indicates continuing damage in Golden Delicious, or little damage in Red Delicious, the values found in this study should then be substituted.

DISCUSSION

The amount of damaged fruit on a tree at harvest is governed by 2 factors: the damage inflicted on the fruit and the response of the tree to the damage. Prokopy and Hubbell (1981) showed that damage from the tarnished plant bug, Lygus lineolaris, was possible from the green tip stage to 6 weeks after petal fall, but that apple was most sensitive from pink to 2 weeks after petal fall. The most sensitive period for apples coincides with the peak emergence of nymphs of C. verbasci in the Okanagan Valley (Chapter III).

The degree of damage prior to June drop was not simply related to the density of the population and may be affected by the availability of food such as pollen, nectar, plant nitrogen or animal prey (White 1978; Mattson 1980). Hoyt (1973) and Coutin et al. (1984) suggest that feeding of C. verbasci, or other plant bugs that are both phytophagous and predaceous, occurs on fruit when there is a shortage of prey; Lord (1971) observed that damage from C. verbasci is often found the year following the collapse of a mite population. However, little is known about the interaction of the prey/plant nitrogen resources in affecting damage, distribution, or survival of C. verbasci and my observations were inconclusive on this question (See also Chapters II-IV); damage was observed with and without alternate prey

during bloom. On the other hand, damage was considerably greater in sites with only few apples/tree (unsprayed sites) than in any orchard with a normal level of productivity, at comparable population levels.

The differing degrees of damage found on several apple varieties at harvest were not only due to differences in population levels. On numerous occasions I found similar first generation counts in trees of 2 or more varieties at the same site (Chapter III). Pickett (1938a,b) also remarked upon the uniform distribution of C. verbasci, the presence of numerous nymphs on varieties that were not marked at harvest, and the considerable variation in damage to 'non-susceptible' apples. These results suggest that different varieties in an orchard receive approximately the same damage early in the season and that susceptibility is controlled by the reaction of apple varieties to the injury.

Almost all the damage at harvest was found in the basal third of the fruit, whereas 60% of the damage occurred elsewhere, according to the results of the June drop sample. This difference suggests that fruit with damage near the stem may be shed efficiently, or that during growth of the apple the early malformations 'disappear' as they become proportionately insignificant; Boivin and Stewart (1982b) observed feeding punctures on 9 McIntosh apples early in the season but found no apparent damage at harvest.

Only in Delicious varieties was the damage in the June drop sample directly related to that at harvest, and they are the ones most commonly showing damage at harvest. The 'susceptibility' of these strains may be related to the way they shed injured fruit, or rather their inability to selectively drop them, during the normal shedding of flowers and fruit between bloom and harvest. Where there is a heavy set of fruit on a tree the

weak and injured drop first, but when a light fruit set and favorable growing conditions occur many injured fruits develop that would otherwise have dropped (Knight 1922). The variability present among cultivars in this system, together with different thinning and management practices, may also contribute to the heterogeneity of the results.

The relationship observed between the peak count of C. verbasci and the amount of damage to Delicious apples reveals the importance of the size of the overwintering population. Red and Golden Delicious apples constitute 33% of Canadian and 55% of B.C. apple production (Bodnar 1984), and if methods were developed to forecast or reduce the overwintering population density, it would not be necessary to monitor or treat a large number of apple orchards for C. verbasci.

VI Spatial dispersion, optimal sample size, and sequential sampling plans for *Campylomma verbasci* on apple

INTRODUCTION

During a short period in the spring, several decisions are made that are crucial for season-long pest management programs in Okanagan Valley apple orchards. Rapid estimation of population parameters of 5 insect pests, including *Campylomma verbasci*, is required so that appropriate pesticides can be applied shortly after the petal fall stage[1] of flower development. Serious problems have been experienced in the sampling of *C. verbasci* in British Columbia (Madsen et al. 1975; Vakenti and Peters[2]), Ontario (Hikichi et al. 1979) and Nova Scotia (MacPhee 1976), and a common criticism is that too many samples are required from numerous orchards during a short period of time.

At present, it is recommended that *C. verbasci* be sampled by 20 limb-taps in each 0.5 ha of sensitive apple varieties (Madsen and Procter 1982; Agriculture Canada 1983), an expedient number based upon past experience. Optimal sample sizes can easily be determined for simple random sampling (e.g. Karandinos 1976; Southwood 1978) to estimate the population reliably at a given mean density, such as the economic threshold. Without determination of an optimal sample size, the sample of 20 taps for *C. verbasci* may be too small to assess adequately the aggregated populations in a typical high-density apple orchard, or may be unnecessarily large. However, monitoring with a fixed sample size, to estimate population density with a given level of reliability, is costly because sample size and reliability are only critical for densities near the economic threshold. Exact estimation of a very small or large population is not required for pest

management purposes.

Sequential sampling plans can result in savings of up to 75% compared with fixed sample size procedures having comparable error rates (Waters 1955; Harcourt 1966; Pieters 1978). In this type of sampling program the number of samples required to classify an insect population level is determined as sampling progresses. Two types of sequential sampling have been developed: the sequential decision plan and sequential count plan (Allen et al. 1972).

Both plans require knowledge of the spatial dispersion (Elliott 1977) of the species in its habitat and an acceptable probability of error in the population estimate. In addition, the sequential decision plan requires an economic threshold or treatment level. The plans differ in that the sequential count plan provides an estimate of the population mean with a fixed degree of precision, whereas the sequential decision plan incorporates the economic threshold to classify population density into 3 categories, i.e. 'control required', 'continue sampling', or 'no control necessary'.

Conventional sequential sampling (Wald 1948) requires the fitting of a mathematical distribution such as Poisson or negative binomial (Anscombe 1949, 1950; Bliss 1953, Bliss and Owen 1958; Onsager 1976). However, Kuno (1969), Green (1970), and Iwao (1975) proposed distribution-free, sequential sampling plans based upon functions of the sample means and variances of a population, such as Iwao's (1968) regression of Lloyd's (1967) mean crowding index on the mean, or on Taylor's power law (Taylor 1961, 1965, 1971, 1984).

The purpose of this study was to examine the spatial dispersion of C. verbasci on apple, to provide optimal sample sizes for first generation nymphs, and to develop sequential sampling plans for use by researchers, pest managers or growers.

MATERIALS AND METHODS

During 1982-1984, data were collected from 21 blocks of apple in 17 orchards of the southern Okanagan Valley described by location, horticultural and management characteristics, and period of study in Fig. 3.1 and Table 3.1. Extensive sampling of many sites rather than intensive sampling at one site, and in as wide a range of conditions as possible, is recommended for development of spatial dispersion models and sequential sampling plans (Allen et al. 1972).

The limb-tap method (Chapters III, IV) was used to sample the population of C. verbasci in each block at approximately 7-10 day intervals, at intensities of 20-50 samples in 0.5 ha. In 1983 and 1984 all samples were recorded by individual limb-tap; in 1982, only samples in blocks of low C. verbasci density were recorded by individual tap as the amount of time required to record the results of high population counts exceeded the time available.

Spatial dispersion

The essential condition for a sequential sampling plan is that the spatial dispersion of the subject remains constant over a range of population densities. This usually entails the fitting of 2 or more mathematical relationships until one is found that appropriately describes the data.

Means (m) and variances (s^2) were calculated for each sample and inspected for fit to the Poisson distribution, where the variance is equal to the mean. Three measures of spatial pattern were then calculated: 1) A common K for the negative binomial distribution (Kc) was estimated by 2 methods, one approximate (Bliss and Owen 1958) and one more accurate using K values derived by maximum likelihood and a χ^2 goodness-of-fit test, from a

computer program provided by Davies (1971); 2) Lloyd's (1967) index of mean crowding, $\overset{*}{m}$, was calculated [$\overset{*}{m} \approx m + (s^2/m)-1$] and used in Iwao's (1968) regression of $\overset{*}{m}$ on m [$\overset{*}{m} = \alpha + \beta m$] where α is the index of basic contagion and β the density contagiousness coefficient (Iwao and Kuno 1971); 3) Taylor's power law coefficients, a and b, were calculated [log s^2 = log a + b log m] by linear regression. The intercept, a, is a scaling factor related to sampling whereas the slope, b, is a species-specific aggregation constant (Taylor 1961, 1971, 1984).

The data set was also stratified by sample size, year, C. verbasci generation, stage (young nymphs, older nymphs + adults, adults), apple variety (mixed vs. 'Delicious'), pesticide regime (intensive vs. organic and unsprayed), and orchard. The resulting equations were compared by the methods of Draper and Smith (1981) or Steel and Torrie (1980), i.e. Student's t-test and analysis of covariance, computed using ANOVAR (Grieg and Osterlin 1978) and MIDAS (Fox 1976) statistical packages. The regression coefficients were examined for significant differences from 0 using t-tests.

Linear regression was used to determine the parameters α, β, a, and b although this method requires that the independent variable is not subject to error. When both variables are subject to error, straight lines are estimated correctly by using alternative methods (e.g. Bartlett 1949; Ricker 1973), but Bliss (1971) showed that the difference between a line calculated by standard least squares regression and one estimated by a complicated alternate method (Bartlett 1949) is negligible, particularly where the coefficient of determination, r^2, of the line is high.

Optimal sample size

The optimum sample size required for population estimation depends on

the mean number collected/tap and can be estimated using equations provided by Ruesink and Kogan (1975), Karandinos (1976), or Ruesink (1980). The equation used was taken from Ruesink; the sample size, n, is related to the mean, m, for given levels of probability, P, as a % of the mean, c, by:

$$n = t^2 \, am^{b-2} \, (100/c)^2 \qquad [1]$$

where the degrees of freedom for t are (n - 1) and a and b are the coefficients from Taylor's power law. Southwood (1978) suggested that a value for c of 25% is sufficient for pest management, and of 10% for research purposes.

Sequential count plan

The point at which sampling can be terminated (Tn) for a constant precision, D, of the mean [$D = (s^2/n)^{-2}/m$], was determined using the equation derived by Green (1970):

$$\log Tn = [\log (D^2/a)/(b-2)] + [(b-1)/(b-2)] \log n \qquad [2]$$

where Tn is the stop line for sample size n, a and b are from Taylor's power law, and D is defined as above. For comparative purposes the stop line is plotted on an arithmetic scale; on a log/log plot it is a straight line.

Sequential decision plan

Iwao (1975) developed a sequential decision plan based on the parameters α and β of his regression method and the critical mean density, m_o, or treatment level. The methods of Iwao and Taylor are related (Xu 1985) by $\overset{*}{m} = m + am^{b-1} - 1$ and substitution of the variance expressed by Taylor's power law into Iwao's (1975) model provides the lines for sequential sampling (Ekbom 1985):

$$T_o = nm_o \pm t_\alpha [n(am_o^b)]^{-2} \qquad [3]$$

where T_o = upper (+) and lower (-) limits of the confidence interval for the

cumulative number of nymphs collected, n = number of samples, m_0 the critical mean density or economic injury level, and t_α is the value of Student's t-distribution with a probability of α for a 2-sided test and an infinite number of degrees of freedom. This equation differs from conventional sequential sampling (see Wald 1948) as it requires only 1 threshold, and the 2 error rates have the same value, α, for reasons given by Wilson et al. (1983a). Recently, Nyrop and Simmons (1984) showed that actual error rates and frequencies of wrong decisions are higher than the nominal error rates, for this type of plan, but are not unacceptable.

A weak point of sequential sampling is that when m is close to m_0 the cumulative count may lie between the upper and lower limits for many samples. However, Iwao (1975) showed that the maximum number of samples that must be taken, n max, i.e. the point at which the population level equals the critical mean density within a predetermined confidence band, is calculated by:

$$n \text{ max} = (t^2/c^2)(a\ m_0{}^b) \qquad [4]$$

where c is the confidence interval of the critical mean density, and the other variables are defined as above.

RESULTS AND DISCUSSION

Standardizing the dataset

Preliminary analysis of data from 275 samples (7,175 recorded taps) indicated slight differences in the intercepts of the regression equations calculated from samples of different sizes (20-24, 25-29, 30-39, 40-50 limb-taps), using both Iwao's regression (IR) and Taylor's power law (TPL) methods. Taylor (1961, 1971) suggests that the value of a, the intercept, is a scaling factor related to sampling so the data were standardized by using

only the first 20 taps in each sample to calculate means and variances. The taps were always collected randomly so truncation does not introduce a systematic error.

Spatial dispersion

The variances were plotted against the means of 275 samples and the relationship was significantly >1, indicating that the data do not follow a Poisson distribution. The use of a common K of the negative binomial is also not justified for C. verbasci according to 2 tests suggested by Bliss and Owen(1958); regression of y' [$y' = s^2 - m$] on x' [$x' = m^2 - s^2/n$] does not pass through the origin, and an inversely exponential relationship existed between the plots of y'/x' against the mean, m. Numerous other authors (e.g. Finch et al. 1975; Taylor et al. 1979) have shown that K can be density-dependent, and as the density of C. verbasci varies considerably (Appendix B), the calculation of a stratified K for different density ranges (Waters 1959) is not applicable for field use. Boivin and Stewart (1983d) also report K values varying between 0.49-1.79 for nymphs of C. verbasci, although based on only 19 samples.

Analysis was then confined to use of IR and TPL methods, in order to find a measure of spatial dispersion that is constant in all situations. Pooling the data revealed significant differences (P=0.1 level) only among regression coefficients of equations calculated using samples from different years (IR P=0.08, TPL P=0.01) and between the 2 generations of C. verbasci found annually (IR P=0.03, TPL P=0.05) (Table 6.1).

The 1982 data are incomplete as samples were recorded by individual limb-tap only in sites with low-density populations, and the incomplete recording of the range of densities actually observed, compared with other

Table 6.1. Results of linear regression using Taylor's power law and Iwao's regression methods for 1982-1984 data pooled in different categories

	Sample		Iwao's regression			Taylor's power law		
Category	n	Mean[a]	α	β	r^2	a	b	r^2
1982	109	.04	-.02	2.37	.59	1.02	1.0	.99
1983	142	.8	.14	1.57	.90	1.55	1.21	.93
1984	24	2.3	.87	1.44	.92	2.34	1.30	.94
Generation 1	126	.9	.23	1.58	.90	1.56	1.22	.89
Generation 2	149	.4	.05	1.55	.95	1.29	1.11	.95
Young nymphs	67	1.3	.25	1.53	.94	1.59	1.27	.89
Older nymphs & adults	165	.5	.11	1.63	.89	1.34	1.13	.93
Adults	43	.3	-.001	1.57	.73	1.42	1.13	.96
Mixed varieties	154	.6	.11	1.51	.93	1.35	1.13	.94
Delicious varieties	117	.7	.1	1.66	.92	1.57	1.21	.94
Sprayed orchards[b]	148	.4	.07	1.74	.93	1.30	1.12	.93
Unsprayed/organic[c]	127	.9	.21	1.48	.92	1.60	1.20	.94
1982 Gen. 1	33	.05	-.01	3.01	.73	1.06	1.0	.96
Gen. 2	76	.04	.003	1.19	.36	1.0	1.0	.99
1983 Gen. 1	69	.8	.12	1.66	.82	1.49	1.23	.86
Gen. 2	73	.7	.12	1.53	.95	1.63	1.22	.94
1984 Gen. 1	24	2.3	.87	1.44	.92	2.34	1.30	.94

[a]Grand mean of all samples of 20 limb-taps.
[b]Pesticide regimes 2, 3 from Table 3.1
[c]Pesticide regime 1 from Table 3.1

years, resulted in the above differences. When the 1982 data were excluded from the analysis, no significant differences were found between equations calculated from 142 samples in 1983 and 24 in 1984 (Table 6.2).

Equations were then calculated from the set of 166 points gathered in 1983-1984 and pooled by generation of C. verbasci, developmental stages, pesticide regimes, fruit varieties, and among 7 orchards with > 10 data points, for each method (Table 6.2). No significant differences ($P<0.1$) were found between the equations calculated from the pooled data sets by either method.

The observed values of α and β (Table 9.2) indicate that the basic component of the population is a single individual for adult C. verbasci ($\alpha \leqslant 0$) but is a group for nymphs ($\alpha > 0$), and that both single adults and groups of nymphs are distributed contagiously ($\beta > 1$) within the trees (Iwao 1968, 1977). The density-contagiousness coefficient (β) was slightly greater for older nymphs and adults than for young nymphs or adults alone. However, considering only the first generation results, both b and β values indicate that the general level of contagion is greater in intensively managed orchards than organic or unsprayed ones, and for 'Delicious' orchards than those of mixed cultivars (Table 6.2). The observed values of b are similar to those found in many moderately aggregated insects (Taylor 1961, 1970, 1971) and also reveal aggregation to be greater in the first generation than the second, and in young nymphs than older nymphs or adults, as expected on biological grounds (Chapters III, IV; Guppy and Harcourt 1970; Wilson and Room 1983; Xu 1985).

Choice of Taylor's coefficients, a and b, as a measure of spatial dispersion and basis of sampling plans was made using 3 criteria. The fit of

Table 6.2. Results of linear regression using Taylor's power law and Iwao's regression methods, for 1983-84 data pooled in different categories[a]

	Sample		Iwao's regression			Taylor's power law		
Category	n	Mean	α	β	r^2	a	b	r^2
1983 & 1984	166	1.0	.22	1.55	.91	1.68	1.24	.93
Generation 1	93	1.2	.31	1.55	.89	1.68	1.28	.88
Generation 2	73	.7	.12	1.53	.95	1.68	1.22	.94
Young nymphs	53	1.6	.35	1.51	.94	1.80	1.28	.92
Older nymphs and adults	84	.9	.23	1.59	.88	1.61	1.24	.90
Adults	29	.4	.005	1.55	.70	1.41	1.14	.95
Mixed varieties	72	1.2	.22	1.48	.93	1.61	1.24	.91
Delicious varieties	90	.9	.15	1.65	.92	1.73	1.25	.94
Sprayed orchards	70	.7	.17	1.71	.93	1.64	1.24	.92
Unpsrayed/organic	96	1.1	.27	1.47	.92	1.71	1.25	.93
1983-1984 Generation 1 only								
Sprayed orchards	47	1.0	.30	1.69	.92	1.68	1.31	.88
Unsprayed/organic	46	1.4	.45	1.36	.85	1.70	1.24	.87
Mixed varieties	46	1.0	.29	1.46	.86	1.56	1.21	.89
Delicious varieties	46	1.5	.31	1.60	.91	1.75	1.36	.88
Young nymphs	34	2.0	.53	1.48	.92	1.93	1.30	.89
Older nymphs and adults	49	.8	.18	1.73	.81	1.54	1.23	.84
Adults	10	.7	.08	1.41	.69	1.48	1.21	.93

[a]Footnotes, as in Table 9.1

the regression lines, measured by r^2 value, was very good for both methods (Tables 6.1, 6.2) but in 27 of 41 equations was better for TPL, whereas 2 values were equal and 12 equations were fitted best using the IR method. The standard errors of the regression coefficients were lower for the TPL method in all except 2 equations. Graphic analysis (Anscombe 1953) revealed a better fit and more even distribution of data along the regression line for the TPL method than the IR method, as shown in Figs. 6.1 and 6.2. Moreover, the IR method is based upon linear regression of mean crowding on the mean, but Taylor (1984) and Xu (1985) have shown curvilinear relationships to exist in several cases from the literature and use of the method has led to false conclusions or is often not valid (Taylor et al. 1978, Taylor 1984).

Values of a = 1.6864 and b = 1.2842 were used in the following sample plans. They were calculated from TPL regressions of 93 samples collected during the first C. verbasci generations, when damage occurs, of 1983 and 1984 and are not significantly different from other values in Table 6.2.

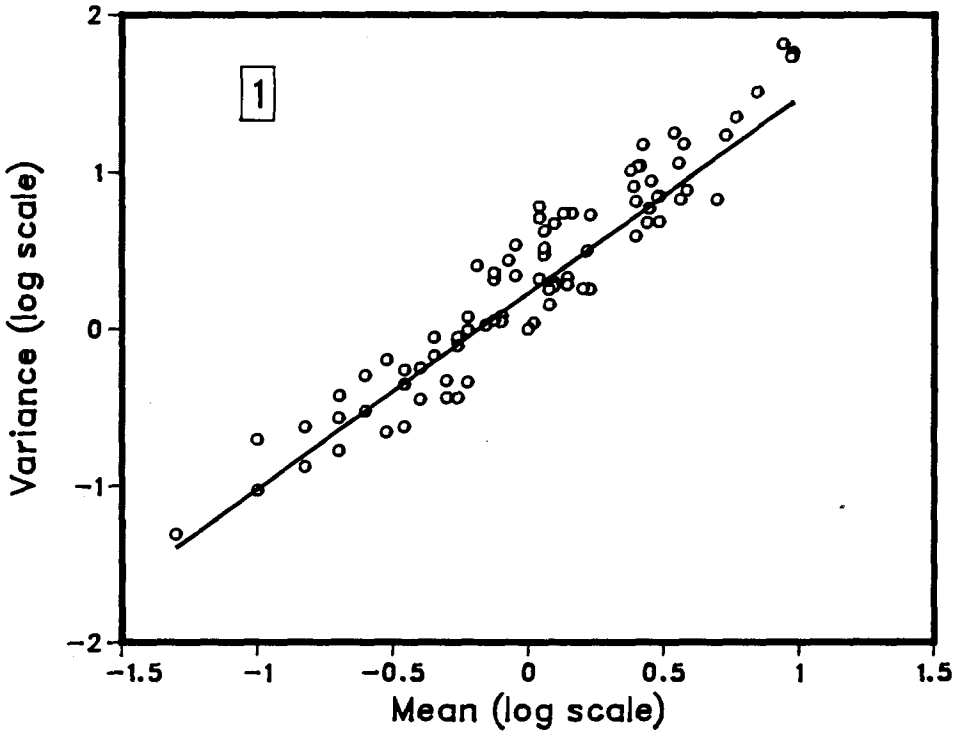
Optimal sample sizes

The optimum sample sizes for C. verbasci at 2 different levels of reliability, and for 2 levels of precision relative to the mean, are shown in Table 6.3. Sample sizes are given for a range of mean densities encompassing the current economic threshold and those estimated in Chapter V for Golden and Red Delicious apple varieties.

All but 2 of the sample sizes are larger than the currently recommended 20 samples in 0.5 ha. At a mean population level of 2/tap one could be 80% sure the estimated population level is within 25% of the true value using a sample size of 29 taps. At best the current sample is 69% of the required size at this mean density, and 42% that required for Golden Delicious apples

Fig. 6.1. Regression of the variance on the mean of 166 samples of 20 limb-taps, for C. verbasci using Taylor's (1961) method

Fig. 6.2. Regression of the mean crowding ($\overset{*}{m}$) on the mean of 166 samples of 20 limb-taps, for C. verbasci using Iwao's (1968) method


1
Variance (log scale)
Mean (log scale)
2
1
0
−1
−2
−1.5
−1
−0.5
0
0.5
1
1.5

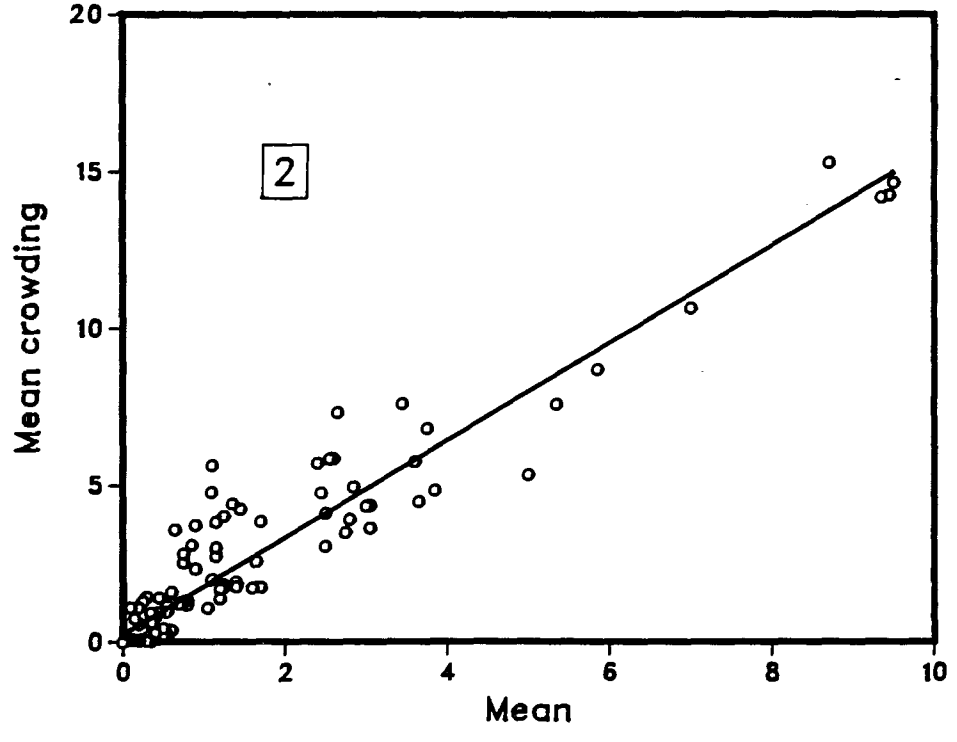

2
Mean crowding
Mean
20
15
10
5
0
0
2
4
6
8
10

Table 6.3. Number of samples required, for given values of probability, P, and precision, c, for limb-tap sampling of *C. verbasci* nymphs in 0.5 ha

Probability P%	Precision c%	No. samples at each population density (mean/tap)					
		0.3	0.5	1	2	4	7.4
80	10	656	455	277	172	105	68
	25	107	75	47	29	19	14
95	10	1534	1064	648	407	250	164
	25	256	181	114	75	51	43

at an economic threshold of 1.0/tap. The use of smaller sample sizes than required may explain some of the problems experienced with C. verbasci in the past (Madsen et al. 1975; Vakenti and Peters[2]), as a result of poor estimates of population density.

Sequential count plan

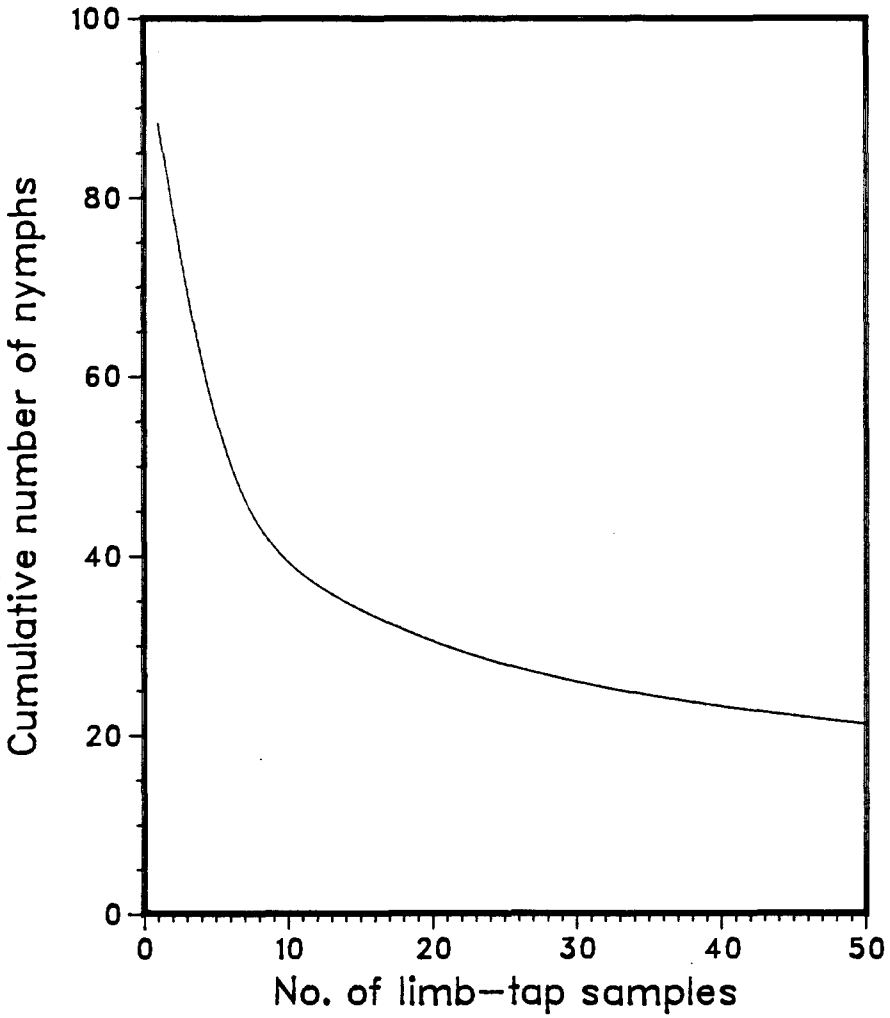
The critical stop line for this plan (Fig. 6.3) was calculated using a precision level of 25% of the mean as extremely large samples are required to achieve 10% precision (Table 6.3), and are not feasible in the field. Computer simulation showed that variations of ±.2 in a and ±.05 in b, sufficient to include most observed values (Table 9.2), had little effect on the results.

A person sampling C. verbasci would use Fig. 6.3 by plotting Tn (accumulated nymphs) and n (number of taps) after each tap was taken. When the plot falls above the line, sampling is stopped and the mean density (m) is within 25% of m = Tn/n.

Sequential decision plan

A sequential decision plan is easier for pest managers or growers to use than a sequential count plan, as the population density is classified into 1 of 3 categories following each limb-tap. However, it requires the use of an economic threshold, which varies with apple cultivar, the market the fruit are destined for, and the past experience of the decision-maker (Chapter V). Moreover, a choice of error rates must be made (reviewed by Allen et al. 1972; Wilson et al. 1983a; Nyrop and Simmons 1984). Error rates (probability levels) of 10-20% are common in sequential sampling programs (Waters 1955; Allen et al. 1972; Sevacherian and Stern 1972; Sterling 1976; Wilson et al. 1983b; Ekbom 1985) and are acceptable to fieldmen and pest managers in the

Fig. 6.3. Sequential count plan for C. verbasci at a constant precision level of 0.25 of the mean



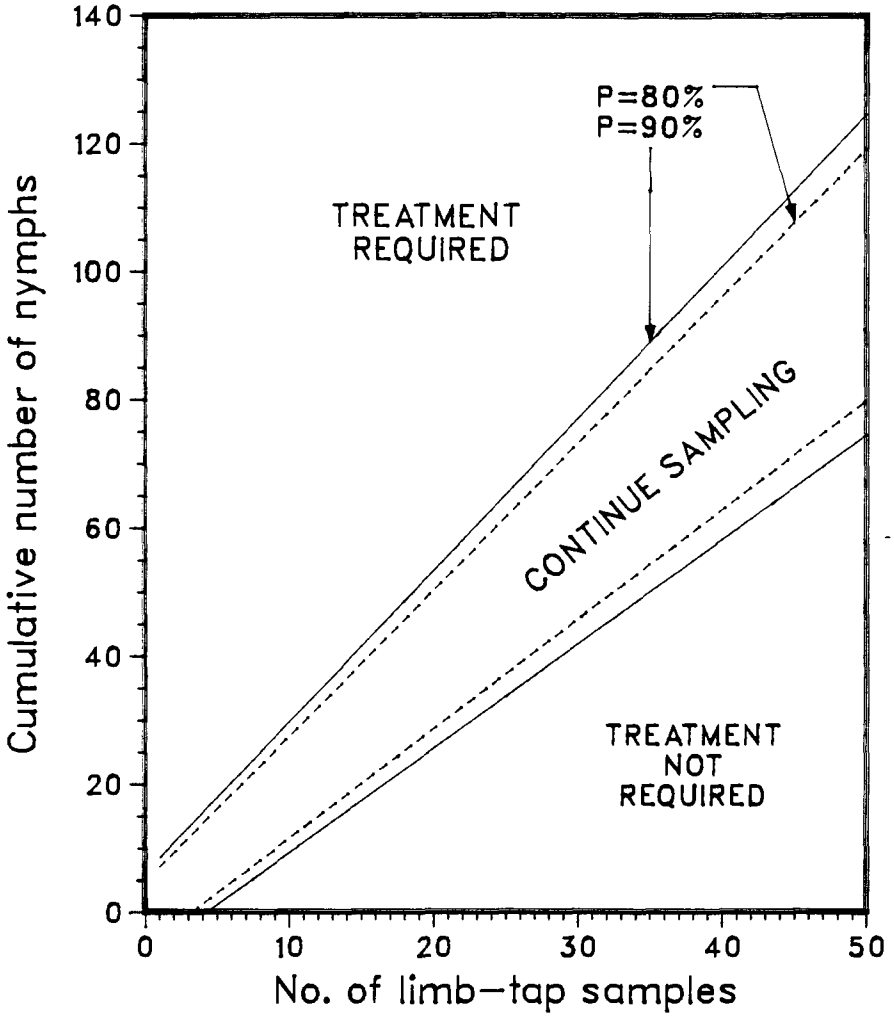
Okanagan Valley, as a compromise between accuracy and utility.

The sequential decision plan shown in Fig. 6.4 is calculated using an economic threshold of 2/tap, as currently recommended (Madsen and Carty 1977; Agriculture Canada 1983). Two levels of probability are shown, for 10% and 20% error rates. From my experience with >400 samples (some 8,000 limb-taps) in 3 years, at least 5 taps should be taken randomly throughout each 0.5 ha of a block of apples of similar varietal composition, age or size. A cumulative total count of nymphs outside the critical ranges of Fig. 6.4 indicates, with 80 or 90% probability, a density significantly different from the economic threshold.

Densities within the upper region indicate a population level requiring treatment, and those falling within the lower region indicate that the population will not cause serious damage. Sampling continues when the density remains within the central region until the stop line; n max, is reached, i.e. at 27 samples for the 20% level and 44 samples for the 10% level using a confidence interval of 0.5/tap or 25% of the mean. If the cumulative count is still within the central region when the stop line is reached, the mean density is not significantly different from the economic threshold and the decision-maker must choose whether to resample at a later date or make an immediate decision.

In the example given (Fig. 6.4), at a 20% error level, sampling could cease after 5 taps if <3 or >15 C. verbasci nymphs had been counted. If the results lay within the central region until 27 taps were taken, at that point >65 nymphs reveals a damaging level of C. verbasci, <40 indicates a non-economic level, and 40-65 nymphs would require a decision to take more samples, resample later, or treat with a pesticide. In homogeneous blocks

Fig. 6.4. Sequential decision plan for C. verbasci using an economic threshold of 2/tap, at 2 levels of probability, P



>0.5 ha, where many taps are made, the sequential count plan can also be used to provide an estimate of the population density with a fixed level of precision.

Sequential tables are more useful in the field than graphs (Sevacherian and Stern 1972). The tabular form of Fig. 6.4, together with my estimates of decision rules for Red and Golden Delicious, based upon economic thresholds derived in Chapter V, are provided in Tables 6.4-6.6. At least 5 samples should be taken at random throughout each 0.5 ha of a homogeneous apple block of the sensitive varieties, and cumulative counts falling on either side of the uncertainty band correspond to the treatment and non-damaging regions of Fig. 6.4.

CONCLUSIONS

Pest managers currently take a number of samples in an orchard and average the counts to provide an estimate of population density. Unfortunately, the aggregated spatial pattern of C. verbasci results in a large number of samples that must be taken in order to judge the mean accurately using conventional methods. This is accounted for in sequential sampling by using the observed variance-mean relationship to reduce the amount of sampling. The sequential sampling plans are based upon results from 93 samples gathered over a wide range of population densities in numerous sites for 2 years, and are part of a larger set of 275 samples, lending considerable strength to the generality of the relationship.

This sequential count plan will permit researchers and pest managers to describe the mean density more accurately than before, can be used in all apple cultivars, and may lead to a better understanding of the economic threshold and better decisions in the future. The sequential decision plan,

Table 6.4. Sampling form incorporating sequential decision rules and an economic threshold of 2 nymphs/tap, for a nominal error rate of 10%

Limb-tap number	Total number of nymphs	
	Don't treat if <	Treat if >
5	2	17
6	3	20
7	5	22
8	6	25
9	7	28
10	9	30
11	10	33
12	12	35
13	13	38
14	15	40
15	17	42
16	18	45
17	20	47
18	21	50
19	23	52
20	25	54

*** Stop sampling ***

If the total number of nymphs is >25<54 after 20 taps, the population density is not significantly different from 2 ± .5. For an 80% reliable estimate of the mean density take 9 more taps and divide the total count by 29. Or, if possible, re-sample in 3 days time.

Table 6.5. Sampling form incorporating sequential decision rules and an economic threshold of 1 nymph/tap, for a nominal error rate of 10%

Limb-tap number	Total number of nymphs	
	Don't treat if <	Treat if >
5	0	9
6	0	11
7	1	12
8	1	14
9	2	15
10	3	16
11	3	18
12	4	19
13	5	20
14	6	21
15	6	23
16	7	24
17	8	25
18	8	27
19	9	28
20	10	29

*** Stop sampling ***

If the total number of nymphs is >10<29 after 20 taps, the population density is not significantly different from 1 ± .25. For an 80% reliable estimate of the mean density, 27 more taps must be taken and the total count divided by 47. It is preferable to re-sample in 3 days time, if possible.

Table 6.6. Sampling form incorporating sequential decision rules and an economic threshold of 4 nymphs/tap, for a nominal error rate of 10%

Limb-tap number	Total number of nymphs	
	Don't treat if <	Treat if >
5	8	31
6	11	36
7	14	41
8	17	46
9	20	51
10	23	56
11	26	61
12	29	66
13	33	70
14	36	75
15	39	80
16	43	84
17	46	89
18	49	94
19	53	98

*** Stop sampling ***

If the total number of nymphs is >53<98 after 19 taps, an 80% reliable estimate of the population density is 4 ± 1. For a 90% reliable estimate take 8 more taps: don't treat if the number of nymphs is <94 and treat if the total is >122. Otherwise, re-sample in 3 days time if possible.

although only applicable to homogeneous blocks of sensitive cultivars, will allow control decisions to be taken with a smaller number of samples and greater degree of confidence than by any other means. The considerable reduction in sampling or increase in accuracy that is achieved with these plans should enable decision-makers to concentrate their effort in orchards close to the economic threshold.

VII Evaluation of an overwintering sampling method for predicting damaging levels of Campylomma verbasci

INTRODUCTION

Madsen et al. (1975) and Haley (1977) developed a complete pest management scheme for interior B.C. apple orchards, requiring population samples of 5 insects from each orchard between pink and petal fall growth stages of apple[1], normally the first 3 weeks in May. Many of the samples are time-intensive or, in the case of C. verbasci, should be repeated at intervals (Chapter III). Because of the difficulty of intensively sampling a number of orchards in a limited time, some of the methods were subsequently revised (Madsen and Carty 1977; Madsen and Procter 1982) but Vakenti and Peters[2] still found it impossible to sample 42 orchards adequately in the limited time available.

Sampling the population density of C. verbasci prior to the pink stage of apple is very difficult as it overwinters as an egg. Direct counts are tedious because the eggs are located deep inside bud scales, leaf bases, or bark of new growth, with only the operculum exposed (Collyer 1953b; Sanford 1964; McMullen and Jong 1970).

In response to this problem in Nova Scotia, MacPhee (1976) developed a "hatching" method which he described as reliably measuring and predicting the population levels of 2 mirid bugs, Atractotomus mali (Meyer) and C. verbasci, that regularly damage apples (MacLellan 1979). This method has gained some acceptance among extension staff (MacPhee 1976; R.J. Whitman[13], pers. comm.) and requires a sample of branches from each orchard to be held in water in a warm greenhouse and to be regularly examined for emerging C. verbasci. The sample is taken early in the spring and provides an estimate of population

density prior to the normal time of emergence in the field.

This chapter presents the results of an evaluation of the hatching method for British Columbia.

METHOD

Sixteen orchard sites (Table 7.1, Fig. 3.1, Table 3.1), were sampled by cutting 40 (1982) or 20 (1983) branches from each site, in mid-April at the silver- to green-tip stages of apple development. The branches, approximately 1 m in length (1983 mean length/20 branch sample = 23.8 $\pm$ 0.6 m), were held in water for 1 month and checked twice weekly by jarring them individually over a plastic sheet (100 x 120 cm) spread on a black surface. Any dislodged arthropods were immediately identified.

The orchards were repeatedly sampled through the bloom period using the limb-tap method (Chapters III, IV) to estimate the density of C. verbasci overwintering in the trees. At harvest the fruit was examined and the presence and severity of damage from C. verbasci was determined from approximately 500 apples of 1-3 varieties (Chapter V, Appendix B).

The experiment was repeated in 1984 but poor weather prevented the monitoring of C. verbasci in commercial orchards during the bloom period (Chapter III).

RESULTS

Fourteen C. verbasci nymphs emerged from the branches, with 8 produced from 2 samples (Table 7.1), and zero from 10 samples. The low frequency of C. verbasci is probably not due to dormant oil or other treatment of the orchards as 14 of the samples produced other insects or mites. Only in site 13 were branches extremely heavily coated with oil; none of them produced any arthropods. The owner of site 13 is an 'organic' grower and employs

Table 7.1. Arthropods produced from overwintering samples, compared with population estimates of C. verbasci provided by limb-tap sampling, and damage to apples from C. verbasci

Date and sample size	Sites sampled[a]	Arthropods emerging from cuttings		C. verbasci 1st gen. peak count ($\bar{x}$ no./tap)	% apple damage at harvest	
		C. verbasci	Other		Golden Delicious	Red Delicious
1982	6	0	7	0.3	5.1	-
40 branches/site	9	0	0	1.8	7.1	-
	13	0	0	1.0	-	-
1983	1	2	31	1.4	31.8	5.8
20 branches/site	2	1	13	1.4	29.0	0.5
	3	0	1	0.7	3.4	0.4
	4	0	3	0.7	-	0.6
	5	0	9	0.2	-	0
	6	0	2	0.9	7.6	0.2
	8	1	24	0.3	5.6	0.6
	9	0	10	3.3	49.4	-
	10	0	38	0	0	0.2
	11	3	28	1.2	5.5	0.6
	12	5	106	21.1	-	9.7
	14	0	15	5.1	(McIntosh = 1.0)	
	15	2	11	4.9	-	1.0

[a]Sites described in Table 3.1.

petroleum oils routinely throughout the year as a pest control method (Table 3.1).

Site 12, with the greatest C. verbasci emergence, contained the largest overwintering population, expressed as the mean limb-tap count at the peak of the first generation (Table 7.1); similarly, the site with the lowest tap count produced zero in the branch sample. However, the unreliability of the hatching method is shown in the 10 sites producing no nymphs from cuttings, that later had peak tap counts up to 5.1 C. verbasci/tap and very serious levels of damage. When the tap counts were grouped into sets by the numbers of nymphs emerging from the cuttings, no differences were found (Kruskal-Wallis test, adjusted $H=4.6$, $P > 0.1$), showing the variability of the population density associated with a particular branch sample.

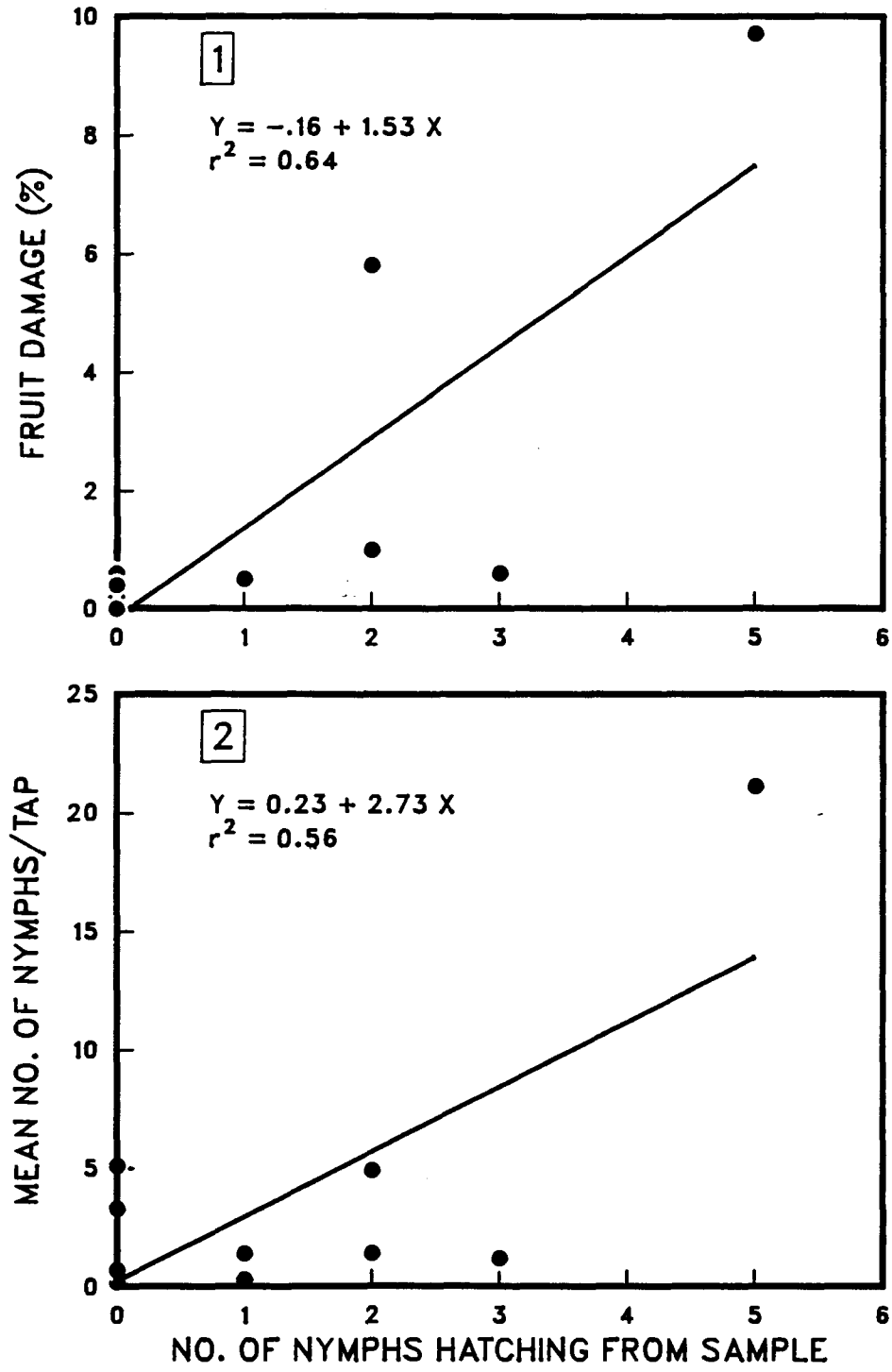
Comparison of the damage at harvest with numbers emerging from branch samples reveals no relationship for apple cv. Golden Delicious but a significantly linear relationship for cv. Red Delicious ($R^2 = 0.64$, $P < 0.01$, $N = 11$), although it is based primarily upon 2 high values (Fig. 7.1). Exclusion of the highest value resulted in a very weak trend, and no significant linearity, as is apparently the case for MacPhee's (1976) data.

The relationship between damage and population density of C. verbasci, expressed as a peak limb-tap count, was more linear and more closely correlated than that between damage and the hatching population in branch samples, for both varieties (Golden Delicious $R^2 = 0.68$, $P < 0.005$, $N = 9$; Red Delicious $R^2 = 0.72$, $P < 0.01$, $N = 11$), the opposite of results from Nova Scotia (MacPhee 1976).

A linear relationship (Fig. 7.2; $R^2 = 0.56$, $P < 0.01$, $N = 16$) was found between the 2 types of population samples, branch and limb-tap, although it

Fig. 7.1. Relationship between the proportion of Red Delicious apples with damage at harvest and the number of C. verbasci found in a 20-branch overwintering sample, in 11 commercial orchards

Fig. 7.2. Relationship between the first generation peak of C. verbasci, measured by the limb-tap method, and the number found in a 20-branch overwintering sample, in 13 commercial orchards.


1
Y = −.16 + 1.53 X
r² = 0.64
FRUIT DAMAGE (%)
0
2
4
6
8
10
0
1
2
3
4
5
6
2
Y = 0.23 + 2.73 X
r² = 0.56
MEAN NO. OF NYMPHS/TAP
0
5
10
15
20
25
NO. OF NYMPHS HATCHING FROM SAMPLE

is greatly influenced by a single high value. The slope of the line, b, implies an increase of 2.73 nymphs/tap for each nymph found in the branch sample.

Examination of the branch samples was time-intensive as branches were usually handled individually, with considerable care required to check the small foliage pieces under which C. verbasci nymphs try to hide. Identification of 312 small arthropods was required, using a hand lens of 16x magnification.

DISCUSSION

MacPhee (1976) was the first to show that the amount of damage to apples caused by mirid bugs is largely related to the density of the population (Chapter V). He went on to describe the 'hatching' method, or branch sample, as more useful and a better prediction of damage than the limb-tap count in Nova Scotia, based upon the results of observations in 8 orchards and some use by extension staff. I have earlier shown (Chapter V) that the limb-tap count is useful in B.C. and in this study it was a better predictor of damage for 2 varieties of apple, than the hatching method was for 1 variety. The value of the hatching method lies in its use as an early warning of high population density, to concentrate sampling in needy orchards and eliminate others, and it failed to meet this objective.

The hatching method cannot be considered reliable for estimating C. verbasci in B.C. when 6 samples from orchards, later having high populations and serious damage (>1%) produced no nymphs and one orchard (site 9) had 19% of the fruit culled at the packing house (Chapter V). The explanation for the failure of the method is probably due to the sample size of 20, 1 m branches being too small to adequately represent an orchard. The method may

be more reliable in Nova Scotia because of generally higher densities of C. verbasci in orchards (MacPhee 1976; Sanford 1976) and higher economic injury levels (MacLellan 1979; Hardman et al. 1984) than in B.C. (Chapters III, V). However, it is not clear that MacPhee (1976) really demonstrated a reliable method; if one extreme value is excluded from his 8 observations one has poor data upon which to predicate the linear regressions and economic injury levels provided. Similarly, in the absence of a single high value for the 'Red Delicious' variety (Fig 7.1) there would be only a weak relationship among my remaining data.

There are weak associations between hatch counts, population density, and damage at harvest in these results. However, the sample size of 20 branches is too small to prove useful in B.C. Few pest managers have the space to keep, separated in warm rooms, more than this amount of material from each of the 30-50 orchards in a typical program, nor do they have the time to check regularly for small C. verbasci nymphs. I conclude that the hatching method is unreliable for pest management in B.C., and impractical on a larger scale.

VIII The associations between Campylomma verbasci, its damage, and common mullein, Verbascum thapsus, in apple orchards of the Okanagan Valley

INTRODUCTION

The common mullein, Verbascum thapsus, (Scrophulariaceae) was the principal summer host for Campylomma verbasci in the Okanagan Valley during 1982-1984 (Chapter III). This plant is an important host throughout Europe (Southwood and Leston 1959) and North America (Leonard 1915; Ross and Caesar 1920; Knight 1941; McMullen and Jong 1970), where comparisons of the distributions of V. thapsus (Fig. 2 in Gross and Werner 1978) and C. verbasci (Table 2.1; Chapter II) reveal close similarity.

V. thapsus is a common Canadian weed (Mulligan 1978) and a host for numerous pests, notably plant bugs, and microorganisms damaging to crops (Cockerell 1901; Chittenden and Marsh 1910; Butler 1923; McAtee 1924; Bruckart and Lorbeer 1976; Scott 1977; Bendixen et al. 1979, 1981; Khattat and Stewart 1980; Manuel et al. 1981, 1982; Fye 1982; Jones and Sullivan 1982; Shaffer and Rock 1983; Powell et al. 1984; M. Maw[12], pers. comm.). It is a monocarpic perennial (Reinartz 1984a,b,c) with a low vegetative rosette up to 60 cm in diameter succeeded by a stout flowering stem 0.3-2 m tall, having a spike-like raceme bearing numerous white or yellow flowers that each bloom for 1 day. Populations may extend over several hectares or along roads and railways, in open or disturbed soil [for a detailed review of its biology see Gross and Werner (1978)].

Until now, only taxonomic attention has been given to the association with C. verbasci but it is interesting for 2 further reasons: the impressive ability of C. verbasci to search out and colonize V. thapsus in remote locations (Chapter III) and because an increasing body of information links

pest insect numbers to the presence of non-crop plants in or around agricultural crops, particularly ground cover vegetation in perennial crops.

In order to exploit the obviously close association between C. verbasci and V. thapsus for management purposes, a study of their relationship within and between orchards was required. This chapter presents the results of 2 series of investigations conducted in commercial orchards and experimental sites between 1982 and 1984. The first section describes the distribution of C. verbasci on individual V. thapsus within a study site. The second examines the relationship between the 2 organisms in sites with differing densities of V. thapsus.

1. DISTRIBUTION OF C. VERBASCI ON V. THAPSUS

Materials and Methods

The distribution of C. verbasci was examined in the Okanagan Valley from July to November 1982, June to September 1983, and June to August 1984. Detailed studies occurred in experimental garden plots in 1982 (Chapter III) and the Simon Fraser University (SFU) block in 1983-1984, where populations of V. thapsus numbering 34 (1982), 239 (1983), and 137 (1984) were maintained. Plants were tagged, mapped and sampled at weekly intervals in 1982; bi-weekly in 1983 and 1984. The data recorded were: plant dimensions, flowers, health, type and number of associated arthropods and their positions, presence/absence of plant wounds and exudates. The study covered the periods of dispersal, colonization, and establishment of first generation C. verbasci adults on V. thapsus.

In addition, the distribution of C. verbasci on an isolated group of plants was studied. Fifty V. thapsus were transplanted in June 1984 from field sites into large plastic pots (380 x 300 mm) filled with pebbles and

fine sand. The pots were covered with aluminum foil to reduce heating and placed on cleared ground 1 m apart. The plants were examined on 10 July, 18 July, and 20 July and any C. verbasci found on them were removed. On 20 July, 36 were moved to a prepared site in the centre of a recently mown hay field and pots were randomly placed in a square lattice design 4 m apart. All existing V. thapsus were removed from the perimeter of the field and for at least 400 m from the site, in all directions. The plants were well tended until 17 August when all C. verbasci were counted and removed. From 16 stakes placed in a square 10 m around the plants, 160 female C. verbasci were released at 1700 on 17 August and 146 females were released at 1600 on 18 August. The C. verbasci population was counted and removed on 19 August and on 22 August the plants were examined thoroughly.

More than 2100 sets of observations, from samples of plants where C. verbasci were present, were analysed using graphic (Anscombe 1973), parametric correlation (Snedecor and Cochran 1980; Sokal and Rohlf 1981) and nonparametric correlation (Conover 1980) methods.

Results

C. verbasci populations never occurred in regular or random spatial patterns but were always 'clumped', with up to 360 on a single plant. As many as 12,675 C. verbasci were counted on V. thapsus in an orchard (SFU block; 19 June 1983) but very rarely were adults noticed on other plants in the ground cover vegetation (Chapter III).

Adults were rare on V. thapsus rosettes or plants <30 cm tall and nymphs were never found on rosettes. Few C. verbasci were found elsewhere than on the racemes; in June, on some plants with high populations (>100), up to 30% of the adults were in the lower 2/3 of the plants, but from July onwards

adults were only rarely found on the undersides of leaves. The peak growth of V. thapsus occurs in the early spring (Gross and Werner 1978; Reinartz 1984a,b,c; personal obs.) and by July growth was only in the inflorescence (Fig. 8.1) and continued until mid-September. As C. verbasci adults dispersed from the trees onto V. thapsus in June and July the number on plants was generally correlated (Pearson product-moment correlation, $P<0.01$) with plant height and diameter, as was the number of nymphs early in the summer (Table 8.1).

The peak flowering period of the plants occurred in July and August (Fig. 8.1) when the correlations of number of C. verbasci were lower with height or diameter and greatest with raceme length and number of flowers (e.g. Tables 8.1, 8.2), particularly in axillary racemes. These were generally greener and more turgid, more fragrant, and had more flowers and nymphs/unit length than the terminal raceme. The number of C. verbasci nymphs on axillary racemes was also frequently correlated ($P < 0.05$) with raceme length (Table 8.1). The number of adult females was positively correlated (except in experimental plot, Table 8.2) with raceme length from July onwards. Both sexes, particularly females, were numerous on particular plants for periods of up to 60 days, even if removed and re-released as in the experimental plot (Table 8.2, 17-19 August, female $R = 0.53$, $P<0.01$), suggesting a preference for certain plants within a cohort, probably led by females (see Chapter IX).

The numbers of adult males were consistently correlated with the numbers of females on the plants. Following the removal of all adults and release of 96 females into the experimental plot, 129 males were observed on the plants within 48 h in a spatial pattern highly correlated with females (Table 8.2).

Fig. 8.1. The development of 34 V. thapsus in Summerland, and the numbers of C. verbasci counted and rereleased on the plants from July to October 1982. Values are totals/sample date.

A) Plant height, including inflorescence

B) Inflorescence length, including secondary racemes

C) Number of flowers open

D) Number of C. verbasci

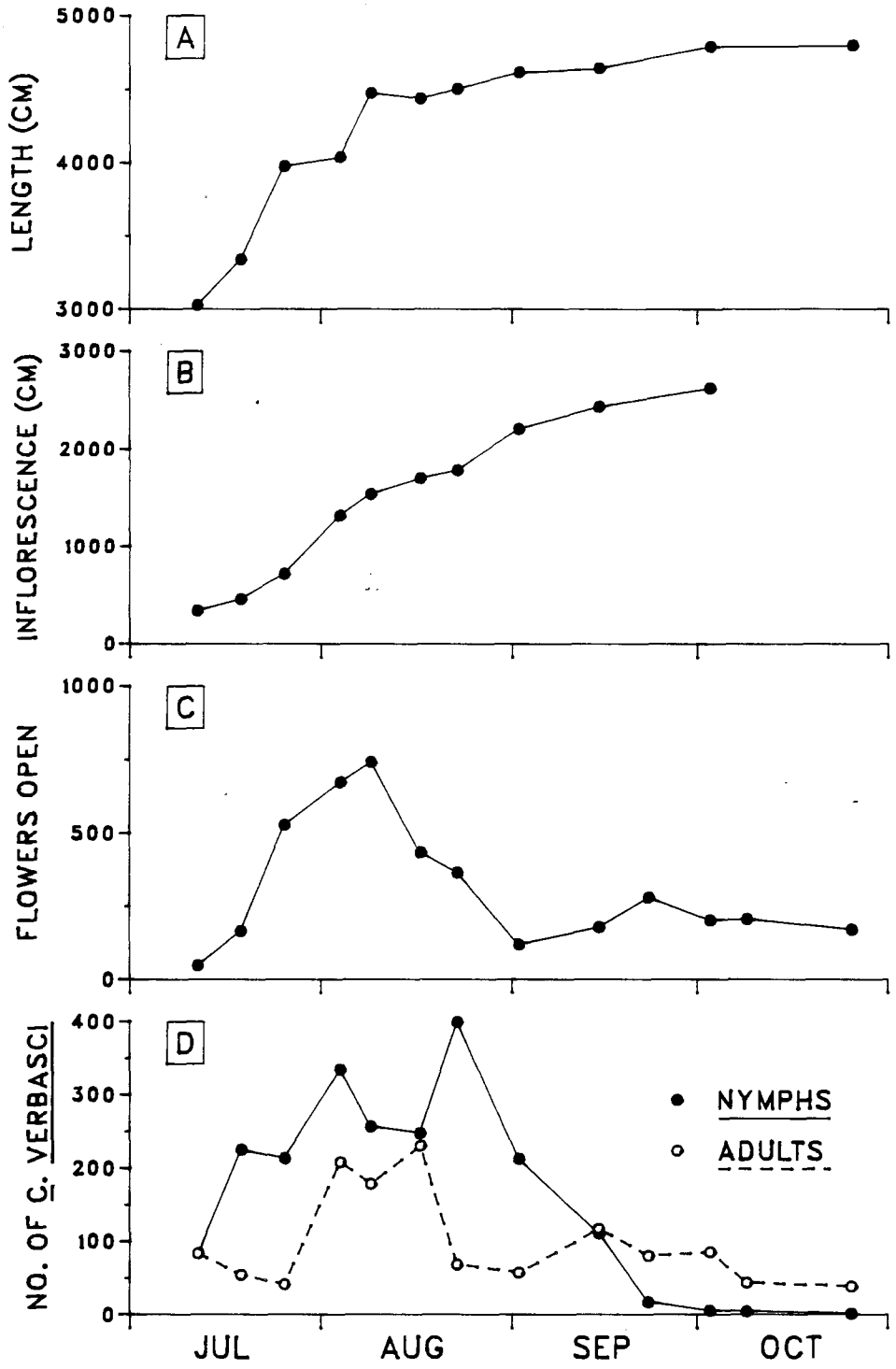

A
LENGTH (CM)
5000
4000
3000
B
INFLORESCENCE (CM)
3000
2000
1000
0
C
FLOWERS OPEN
1000
500
0
D
NO. OF C. VERBASCI
400
300
200
100
0
NYMPHS
ADULTS
JUL
AUG
SEP
OCT

Table 8.1. Correlation coefficients[a] of 2 stages of C. verbasci with selected characteristics of 34 V. thapsus in 1982

C. verbasci stage	Date[b]	Plant height (cm)	Inflorescence[c]					
			Length in cm			No. flowers open		
			Primary raceme	Axillary racemes	Total	Primary raceme	Axillary racemes	Total
Nymphs	12 July	.71**	.7 **	0	.68**	.13	0	.13
	19 "	.42*	.19	-	.19	-.1	-.1	.12
	26 "	.4 *	.37**	.59**	.35*	.12	.52**	.1
	4 Aug.	-.2	-.2	.43*	0	-.2	.47**	0
	9 "	.12	.08	.69**	.18	0	.28	.08
	17 "	.24	.1	.34*	.24	0	-.1	0
	23 "	.23	0	.34*	.1	.1	-	.1
	2 Sept.	.1	.16	.73**	.23	0	.51**	.04
	15 "	.15	.32	.83**	.35*	.04	.53	.05
Adults	12 July	.5 **	.38*	0	.4 *	.47**	0	.47**
	19 "	.35*	.13	-	.13	.15	-.1	-.1
	4 Aug.	.54**	.53**	.93**	.67**	.2	.93**	.45**
	9 "	.18	.22	.79**	.58**	.32	.46**	.69**
	17 "	.16	.22	.9 **	.32	.38*	.76**	.49**
	23 "	.21	.32	.84**	.4 *	.34*	-	.54**
	2 Sept.	.36*	.52**	.64**	.5 **	.33	.6 **	.4 *
	15 "	.23	.12	.88**	.45**	.27	.65**	.26
	3 Oct.	.14	.23	-	.45**	.43*	-	.57**

[a] Spearman's coefficient of rank correlation, Rho: * = P <0.05, ** = P <0.01.
[b] Samples with <50 C. verbasci of the given stage were excluded.
[c] Correlation coefficients for primary, axillary, and total raceme lengths were calculated individually.

Table 8.2. Correlation coefficients of numbers of males with numbers of female C. verbasci, and of each sex with size of inflorescence and plant height, from potted V. thapsus in 1984

Date[a]	C. verbasci sex	No. plants samples	Correlation coefficients[b]			
			C. verbasci		No. C. verbasci vs.	
			No. adults	Males vs. females	Plant height	Inflorescence length
10 July	both sexes	45	639	-	0.73**	0.64**
18 "	females	36	208		0.33**	0.09
	males		177	0.4*	0.12	0.18
17 August	females	36	162		0.22	0.66**
	males		135	0.5**	0.12	0.37*
19 "	females	36	115		0.23	0.57**
	males		129	0.9**	0.14	0.53**

[a]All stages of C. verbasci removed from plants 10 July, 18 July, and 20 July. Plants moved to hay field on 20 July. All stages of C. verbasci were removed following examination on 17 August; 306 females were released into the plot at dusk 17-18 August. Nearest natural sources of C. verbasci were >200 m distant.

[b]Pearson product-moment correlation coefficient, R: *P<0.05, **P<0.01.

This result suggests a strong attraction of males to females and the possible existence of a sex pheromone (Chapter IX), powerful enough to draw males over 300 m within 48 h.

No general relationships between adults and nymphs on plants, or with other arthropods or number of plant wounds were observed. However, feeding by C. verbasci was common and from July onwards, marks were observed on the upper stems of the plants that closely resembled those on tree fruits damaged by C. verbasci. The numbers of other arthropods, particularly weevils, Gymnaetron tetrum (F.), and mullein thrips, Haplothrips verbasci (Osborn), were often correlated with raceme length and, less frequently, with plant length. Larvae of the weevils lived and fed in developing flowers of the racemes; plants with high weevil populations had fewer flowers open, and sometimes lower numbers of C. verbasci adults, than other plants.

Discussion

The distribution of C. verbasci within sites is clearly governed by plant vigour, indexed by height in the spring and raceme length or number of flowers open in summer, as found in other herbivorous insects (Addicott 1978; Thompson 1978; Whitham 1978; Evans 1983; Service 1984; Myers 1985). Vigour is a measure of plant health and herbivorous insects are commonly distributed within a cohort of similar plants according to the quality of food or other resources (Dixon 1967; Chew 1975; Thompson and Price 1977, Thompson 1978; Ives 1978; Bach 1981, 1984; Hill 1982; Evans 1983; Myers 1985).

Simple visual and olfactory cues of plant quality, particularly plant colour and size, have frequently been linked to distribution of herbivorous insects (Mistric and Mitchell 1966; Saxena and Saxena 1974,1975a,b; Ives 1978; Gilbert 1982; Prokopy et al. 1983a,b; Service 1984; Myers 1985). The

results of this study stimulated an investigation of the utility of visual and olfactory traps for monitoring C. verbasci (Chapter IX), because of the striking form and odour of V. thapsus.

In Heteroptera, the reproductive development and fecundity of late nymphs and adults is very dependent upon concentration and quality of nitrogen available (McNeill 1973, McNeill and Southwood 1978, McNeill and Prestidge 1982; Mattson 1980). The occurrence of C. verbasci in the inflorescence of V. thapsus may be due to the greater concentration of several nutrients, including nitrogen and phosphorous, compared with elsewhere in the plant (Abrahamson and Caswell 1982), or because suitable animal prey, particularly the mullein thrips, is found there. The relative extent of feeding by C. verbasci upon the plant or the insects on V. thapsus is not known.

The distribution of herbivorous insects has also been correlated with levels of secondary compounds in a cohort of similar plants (Gupta and Thorsteinson 1960; Rodman and Chew 1980; Berenbaum 1981; Harborne 1982; McNeill and Prestidge 1982; Stanton 1983) and the biological activity of flowers, seeds, and leaves of V. thapsus is well known. Parts of the plant, or those of other closely-related Verbascum spp., are reportedly lethal to insects (McIndoo and Sievers 1924; Hartzell 1944; McIndoo 1945; Heal et al 1950; Srbova and Palaveyeva 1962; Supavarn et al. 1974), fish (Wilhelm 1974; Jankowiak 1976), were used in the 18th century as a rodenticide (Becker 1965), and can also inhibit plant growth (Jameson 1961). V. thapsus is an important medicinal plant and tobacco substitute in parts of Europe and North America (Millspaugh 1974; Wilhelm 1974; Ulubelen et al. 1975; Jankowiak 1976; Gross and Werner 1978; Chandler and Hooper 1979; Huxtable 1980; Osvath et

al. 1982; Hooper and Chandler 1984). The existence in remote areas of several insects specific to Verbascum spp., their success in host finding, and my results suggest that visual and/or olfactory cues, and secondary compounds play an important role in in their distribution.

Some other possible explanations of the aggregation of C. verbasci on specific plants, such as an aggregation pheromone of nymphs, are discounted with the likely exception of a female-produced sex pheromone, known in other Miridae (Scales 1968; Strong et al. 1970; King 1973; Smith 1977; Boivin and Stewart 1982a; Slaymaker and Tugwell 1984) and now shown to occur in C. verbasci (Chapter IX).

2. ASSOCIATION BETWEEN SITES

Introduction

Both increases and decreases in numbers of insects can result from the presence of weeds in different agricultural systems (van Emden 1965a,b, 1973, 1981; Way 1977, 1978; Altieri and Whitcomb 1978, 1979; Zandstra and Motooka 1978; Thresh 1981; William 1981; Norris 1982; Risch et al. 1983; Nordlund et al. 1984). However, a common interaction reported between weeds and insect pests is an early increase in numbers of the insect on weeds in or adjacent to the crop. Plant bugs, Lygus spp., in particular will increase rapidly on alternate host plants early in the spring before attacking many field crops (Stern 1969; Stewart and Khoury 1976; Khattat and Stewart 1980; Anderson and Wuster 1983). Conversely, removal of specific types of weeds in the ground cover, or nearby areas, can reduce the damage and lower the population density of Lygus spp. in apple, peach and pecan orchards of B.C. or elsewhere (Scott and Hodgkiss 1913; Ruhmann 1936; Venables and Waddell 1943; Woodside 1947; Proverbs 1956; Fogle et al. 1974; Fye 1980; Quist 1980; Gruys 1982;

Roberts and Pree 1983; Tedders 1983; Killian and Meyer 1984).

An hypothesis was constructed that sites with V. thapsus would have higher C. verbasci population density, during the summer and overwintering in apple trees during the winter, and greater damage the following year than sites with no V. thapsus. Some type of graded response would occur between the 2 extremes of V. thapsus density.

Materials and Methods

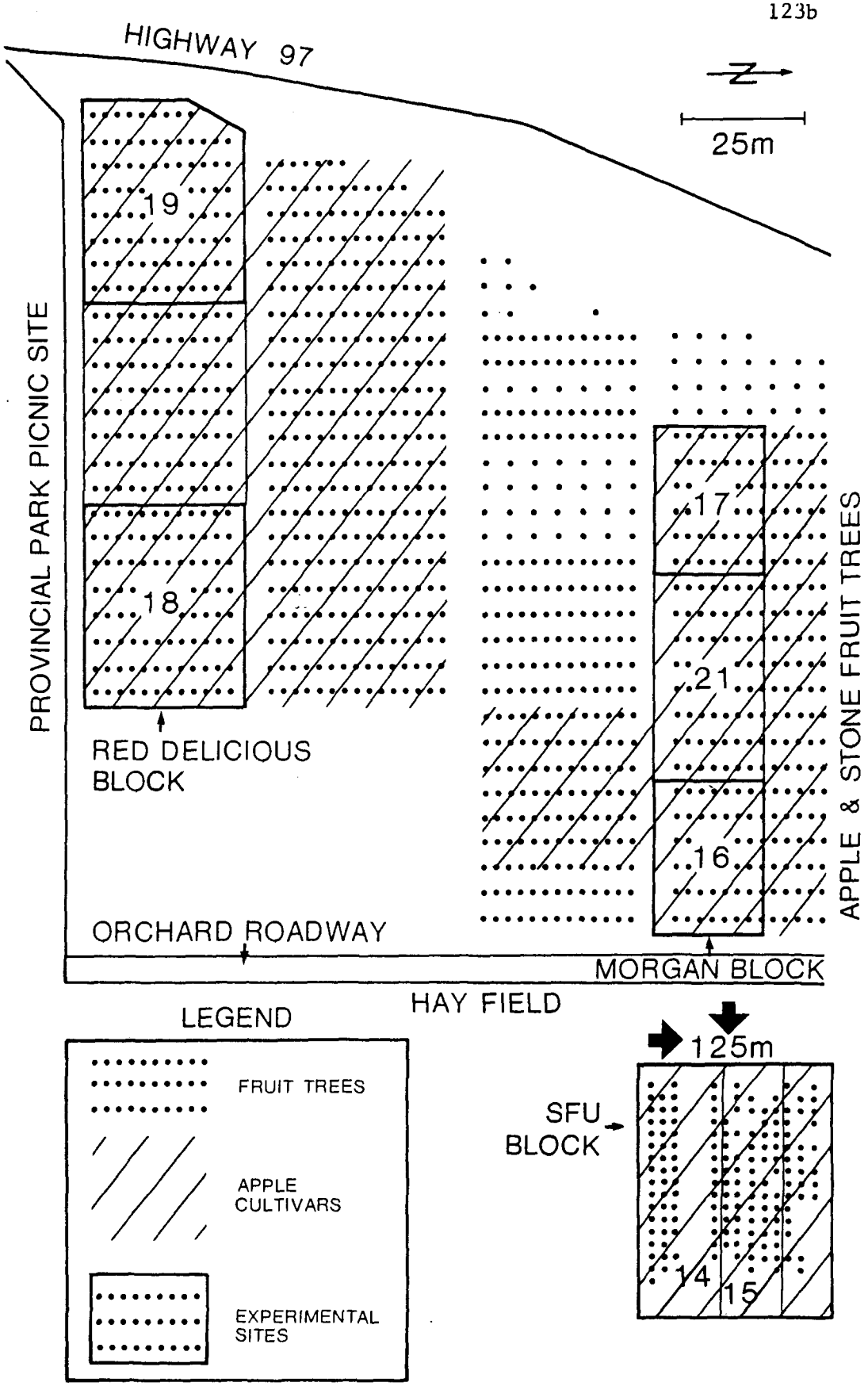
The study area, commercial orchards and experimental sites were briefly described earlier (Fig. 3.1, Table 3.1). The population density of C. verbasci within trees was regularly assessed with the limb-tap method, as part of a study on seasonal abundance (Chapter III), at bi-weekly intervals in the growing seasons of 1982-1984 and weekly intervals throughout the bloom[1] period. Damage to the fruit from C. verbasci was assessed annually in commercial orchards by examination of approximately 500 apples/variety at harvest and in experimental sites by stripping 50% of the trees (Chapter V, Appendix B).

Experimental sites

Experiments were conducted in 3 orchards (sites 14-21, Table 3.1) of the Agriculture Canada Research Station, in Summerland. All trees were on semi-dwarfing rootstocks and the trees within each block had received the same pruning, irrigation and fertilizer treatment for at least the preceding 5 years. None of the blocks was treated with insecticide until the summer of 1984.

The Simon Fraser University (SFU) block (sites 14, 15) consisted of 124 trees arranged in a 3 x 3 m planting (Fig. 8.2) bounded on the east and north sides by tall shade trees, and on the south and west sides by grassy open

Fig. 8.2. Map of part of the Entomology orchards, Agriculture Canada Research Station, Summerland, showing experimental sites 14-21


HIGHWAY 97
N
25m
PROVINCIAL PARK PICNIC SITE
19
18
RED DELICIOUS BLOCK
17
21
16
APPLE & STONE FRUIT TREES
ORCHARD ROADWAY
MORGAN BLOCK
HAY FIELD
LEGEND
FRUIT TREES
APPLE CULTIVARS
EXPERIMENTAL SITES
125m
SFU BLOCK
14
15

areas. The 4 rows of 'McIntosh' variety were designated site 14 and the 60 trees in 5 rows of 'Red Delicious' variety were designated site 15 (Table 3.1).

The Morgan block (sites 16, 17, and 21) consisted of 20 rows of 8 trees of 5 varieties in a 2.4 x 4.3 m planting (Fig. 8.2). The varieties were grouped in sets of 8 trees with 4 replicates of each variety laid out in a completely randomized design. The block was bounded along the 2 sides by apple and pear blocks which were unsprayed during the study period and the ends of the block faced onto open grass pasture (east) and a mixed hedgerow (west). The 6 rows at the east and west ends were designated sites 16 and 17, respectively, and the central portion as site 21.

The Red Delicious block (sites 18 and 19) consisted of 23 rows of 12 trees, and a row of 9 trees (Fig. 8.2). Three 'Red Delicious' trees were planted to each pollenizer of 'McIntosh' or 'Red Rome' variety, which were scattered throughout the 2.4 x 4.3 m planting. The 8 rows at each end were designated as site 18 (east) and site 19 (west).

Association in commercial orchards

During June 1982, 323 V. thapsus plants were studied in the field to develop a sampling method suitable for orchards. The plants were sampled in July 1982 by counting the number of V. thapsus >30 cm high in a strip 10 m wide around the edges of the site, and in every third tree row from the 4 edges to the centre of the orchard. In addition, the number of C. verbasci on the sampled plants was recorded in 1982. In July 1983, I employed a 10 min visual scan of the site as Conn et al. (1982) showed that it is the optimal method for determining the abundance of highly obvious weeds in orchards. All the V. thapsus within vision, including those outside the

site, were counted while walking in an "S" pattern through the orchard. Rosettes >10 cm were also counted.

Collection of data was not possible in sites 7 and 13 after August 1982, and extremely poor weather in 1984 prevented repeated sampling of the orchards for first generation C. verbasci. None of the growers applied a pesticide of known toxicity to C. verbasci during the study periods (Chapter III).

Results were analysed using nonparametric rank correlation methods (Fox 1976; Steel and Torrie 1980; Conover 1980) as the hypothesis did not assume a linear response. The Spearman rank correlation coefficient, Rho, and Kendall's coefficient of concordance, W, were used to test for independence between variables and as an overall measure of the degree of association existing among them.

Experimental alteration of V. thapsus density

In 1983, the hypothesis was tested experimentally, under the constraint of using small plots in unsprayed orchards. It was assumed that the effect of V. thapsus in a site would result in localised changes as no information was available on the flight or dispersal powers of C. verbasci, and because growers complained of damage in particular parts of their orchards. If the null hypothesis is to be rejected, population densities of adults in the Summer and Fall, and of first generation nymphs the following year, should be significantly higher for sites containing V. thapsus than those without.

Experiments were conducted in the Morgan and Red Delicious blocks. Sites 16 and 18 were designated as treatment sites and 17 and 19 as control sites. Controls and buffer areas were included in the routine weed control

program of the Research Station but all Verbascum spp. were removed from the blocks and their surroundings for 500 m, at bi-weekly intervals from May until November 1983. An exception was made for the SFU block, separated from the others by 120 m of hay field, shade trees and stone fruit blocks. Remaining plants within 1 km of the sites were primarily small, grew poorly, and supported few C. verbasci.

Treated sites were prepared by mowing of all vegetation in the tree row during May 1983 as V. thapsus prefers open ground for establishment (Gross 1980). The population density of C. verbasci in each site was assessed on 2 June and 6 June 1983, after which 186 V. thapsus were planted in sites 16 and 18, so that each had similar numbers of different size plants, and by 13 June both sites contained 1.3 plants/apple tree. Before planting, each was carefully checked by 2 individuals who removed the few C. verbasci found on the surface of the plants. The plants were well tended and the number of viable V. thapsus in each site on 18 August, excluding those under 30 cm high, was 1.3 (site 16) and 1.2 (site 18)/apple tree, or 61 and 123, respectively.

Results were analysed using t-tests and analyses of variance (Sokal and Rohlf 1981).

Results

Association in commercial orchards

Orchards with a 'history' of damage from C. verbasci were invariably situated in close proximity to large areas of uncultivated land, particularly hillsides and gullies, with visible populations of V. thapsus. The plant was locally abundant throughout the Okanagan-Kootenay region, in groups of up to several thousand; they frequently grew >2 m high, even in areas with <300 mm

annual precipitation, suggesting the existence of a well-adapted strain as such size and drought tolerance is not reported for V. thapsus elsewhere (Gross and Werner 1978; Reinartz 1984a).

Mullein plants often grew larger than normal along the edges of orchards, where they benefited from the irrigation water meant for trees, and in ditches or along roadsides and railways near orchards. On numerous occasions, dense stands of small plants, or small numbers of large plants (2-3 m), were discovered in these situations, harbouring hundreds of C. verbasci. Inside orchards they grew only in the tree rows where the regular mowing and/or herbicide program often failed to control them, as reported in other situations (Burton 1964; Young and Evans 1984), and they grew well due to the fertilizer programs in the orchards.

Twelve of the 13 commercial orchards had V. thapsus inside or adjacent to their boundaries in 1982-1983 (Tables 8.3, 8.4). The density of V. thapsus was over 100/ha in 7 of 23 samples, or 5 of the 13 commercial orchards. One site (12) contained no V. thapsus in 1982 but large numbers occurred approximately 50 m away, for the length of the orchard, along a railway track. A different sampling method adopted in 1983 included such plants but still had faults; shortly after sampling site 11, >100 plants were discovered that were not included in the 10 min visual scan.

The size of the population of C. verbasci sampled on herbaceous hosts, in commercial orchards in 1982, was directly correlated with the number of V. thapsus bearing the insects (Rho = 0.88, n = 12, P <0.001). As the latter is related to the number of V. thapsus, the population size was correlated with the number of plants in the orchards (Rho = 0.82, n = 12, P<0.01). Site 10 contained fewer infested V. thapsus, and fewer C. verbasci, than expected

Table 8.3. *C. verbasci* and *V. thapsus* plants in commercial orchards (1982-1983) with % damage from *C. verbasci* at harvest

Study site[a]	1982 *V. thapsus*[b]		*C. verbasci*		1983 damage Delicious apples	
	Total no.	with *C. verbasci*	1982 no. on *V. thapsus*[c]	1983 peak of 1st gen. (mean/tap)	Red	Golden
1	145	111	375	1.35	5.8	31.8
2	-	-	-	1.35	0.5	18.0
3	9	1	0	0.7	0.4	0.4
4	0	0	0	0.65	0.6	
5	4	0	0	0.15	0	
6	9	1	32	0.9	0.2	7.6
7	14	1	1			
8	42	9	15	0.25	0.2	5.6
9	77	55	195	3.3		49.4
10	94	8	3	0	0.2	
11	23	16	8	1.2	0.6	5.5
12	0	0	0	21.1	9.7	
13	0	0	0			

[a] Sites 7,13 removed from study, August 1982.

[b] Number >cm high in every 3rd row + 10 m band around periphery.

[c] Sampled 20 July to 8 August 1982.

Table 8.4. *C. verbasci* and *V. thapsus* plants in plants in commercial and experimental orchards (1983-1984) with % damage from *C. verbasci* at harvest

Study site[a]	1983 *V. thapsus*[b]		1984 peak count of 1st gen. ($\bar{x}$ no. *C. verbasci*/tap)[c]	1984 damage to apples[d]	
	No. plants >30 cm	No. of rosettes		Delicious	Mixed varieties
1	70	80	(0.55)		
2	214	75	(0.05)		
3	0	0	(0.15)		
4	14	24	(12.95)	7.0	
5	0	0	-		
6	2	0	-		
8	0	24	(0.35)		
9	162	263	(0.9)		
10	9	11	-		
11	8	0	-		
12	107	-	0.5		
15 T	239	0	1.3	4.4	
16 T	62	0	6.1		4.1
17 C	0	0	3.1		3.0
18 T	124	0	4.4	7.4	
19 C	0	0	3.7	4.7	

[a]Experimental sites (15-19) indicated with T (treated) and C (check).
[b]Number in 10 min visual scan.
[c]Numbers in brackets obtained May 15-18, before poor weather halted sampling, may not be peak values.
[d]No blocks containing Golden Delicious were sampled at harvest in 1984.

which I attribute to frequent use of synthetic pyrethroids (Chapter III).

When site 12 was excluded from the analysis, because of underestimation of V. thapsus, the number of V. thapsus bearing C. verbasci in July 1982 was significantly correlated with population density of C. verbasci in 1983 (Rho = 0.68, $P<0.05$, n = 9), and with its damage (Rho = 0.77, $P<0.02$, n = 9). Total correlation, w, among the number of V. thapsus in a site, C. verbasci population in July, and the 1983 population density was 0.71 ($P<0.01$, n = 9), rising to 0.82 ($P<0.01$) when only the number of infested plants was used in the calculation. Similarly, W using observed damage, rather than nymphal population densities, was always significant ($P<0.05$) for the 2 Delicious apple varieties.

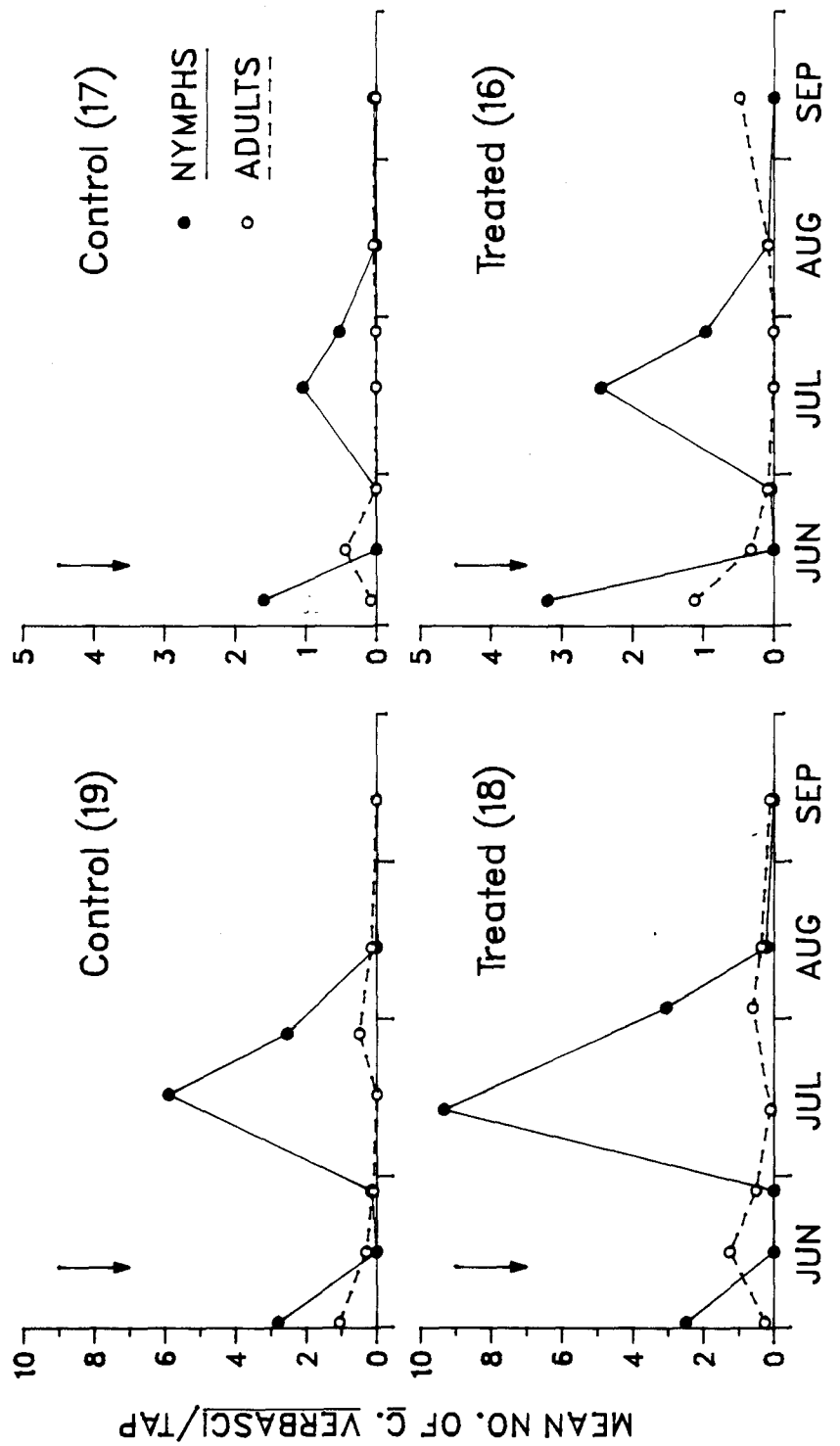
These results are strong evidence that the size of an overwintering population of C. verbasci and resultant damage in the Spring are influenced by the number of V. thapsus plants in the area of the orchard the preceding year.

Experimental alteration of V. thapsus density

In 1983 both sites planted with V. thapsus contained adult C. verbasci in the trees more frequently than control sites. Following the disappearance of first generation adults in late June, one adult was found in the control sites in late July, and 3 on 15 August. However, adults were also found in September in the treated Morgan site, and continuously through July to 13 September in the treated Red Delicious site. More adults were found in August and September in treated sites than in the controls (23 vs 4), and summer generation nymphs were also more abundant in treated sites than controls (Fig. 8.3).

The first generation population density of C. verbasci in 1984 was

Fig. 8.3. Numbers of C. verbasci in treated and control portions of 2 experimental blocks, before and after planting (arrow) of V. thapsus at 1.3 plants/tree, Summerland 1983



higher in treated sites than controls (Table 8.5); significant differences (ANOVA, $P<0.001$) were observed between sites with or without V. thapsus, rejecting the null hypothesis of no effect. Differences were not significant between blocks although they differed in their interactions with the plants (ANOVA, $P<0.025$), and the Morgan block showed the greatest difference in population density between sites ($t = 3.68$, $df = 47$, $P<0.001$). The damage (%) found at harvest was greater in both treated sites (4.1, 7.4) than controls (3.0, 4.7) (Table 8.4) but could not be statistically tested. Moreover, the damage the preceding year was also higher in the treated portion of the Red Delicious block than in the control.

It is difficult to credit the population increase in treated sites simply to differences in V. thapsus density, as an increase in density of C. verbasci also occurred between 1983 and 1984 in control site 17 (Table 8.5). However, the relative change in treated sites was greatest in the Red Delicious block and it is notable that the only decline in density of C. verbasci was observed in the control site of this block (Table 8.5). These results suggest that density of V. thapsus may have an effect on the population of C. verbasci in Red Delicious variety trees, but are not conclusive proof.

Part of the explanation for the unclear results may lie in the great abundance of prey for C. verbasci in all of sites 14-21 in 1983. The experimental sites, unsprayed for several years, supported large populations of pests, predators and parasitic arthropods. No differences were apparent between sites within blocks but the Red Delicious sites (18,19) supported approximately 50% of the arthropods found in the mixed variety Morgan block 16,17,21). Differences in abundance of C. verbasci between sites were

Table 8.5. Populations of C. verbasci in experimental sites with and without V. thapsus 1983-1984

Apple variety	Study site	V. thapsus treatment[a]	Mean no. C. verbasci/tap: 1st gen. peak 1983	1st gen. peak 1984	Change, 1 yr.	Change, 1 yr. %
Mixed	16	1.3 plants/tree	4.3	6.1	+ 1.8	+ 42
Mixed	17	control	1.7	3.1	+ 1.4	+ 86
Red Delicious	18	1.3 plants/tree	2.8	4.4	+ 1.6	+ 59
Red Delicious	19	control	3.9	3.7	- 0.2	- 5

[a]All V. thapsus were removed regularly from the local area for 500 m; remaining plants within 1 km supported few C. verbasci. Between 6-13 June 1983, 186 V. thapsus were planted in sites 16 and 18. On 18 August 1983 the surviving plants numbered 1.3/tree (site 16) and 1.2/tree (site 18).

consistently greater in the Red Delicious block than the Morgan block in 1983.

Discussion

The results from commercial orchards indicate that population density of C. verbasci and its damage can be correlated with V. thapsus density. Although C. verbasci is a significant predator on apple (Kelton 1982; Chapter II) it is also closely associated with V. thapsus; in this respect it appears to behave in the same way as specialized herbivores on their host plants. A considerable literature exists on herbivorous insects in polycultures (for reviews see Perrin 1977; Risch et al. 1983; Stanton 1983). Several studies on the responses of herbivorous insects to plants in varying densities (Root 1973; Ralph 1977a,b; Risch 1980, 1981; Bach 1981, 1984) agree that they are likely to feed and remain in a dense stand of a host plant rather than a sparse one, that specialized herbivores are more effectively trapped this way than others, and that numbers in a stand can be related to stand size. In addition, Waloff and Bakker (1963) found that densities of 4 mirid bugs were inversely related to the distance from large groups of their host plant.

The experimental results are not convincing evidence of a cause and effect relationship, being complicated by the polyphagous feeding of C. verbasci and its dispersal. The occurrence of abundant prey in trees and orchards has been linked to high C. verbasci density (Chapters III, IV) and it is likely the experimental blocks, particularly the Morgan block, had few of the limiting factors usually found in commercial orchards for C. verbasci. Mobile predators commonly aggregate near their prey (Muir 1966; Dixon and Russell 1972; Solomon 1975; Frazer and Gilbert 1976; Parella et al. 1981; Bryan and Wratten 1984: Sholes 1984; Frazer and Raworth 1985). In

an experimental study of beetle diffusion, Wetzler and Risch (1984) found the tenure time of a coccinellid predator of aphids was significantly prolonged in aphid-infested corn in comparison to aphid-free plants and that movement was much faster through corn with low rather than high aphid abundance. The difference in prey population levels might explain the absence of an effect in the Morgan block.

The dispersal power of 129 male C. verbasci was shown in this study to be over 300 m in 48 h, invalidating the small size of the experimental sites. However, the different sizes of the experimental sites, and consequently numbers of V. thapsus, may have had an effect. The Red Delicious sites contained twice as many trees as the Morgan sites, and to preserve a similar V. thapsus/tree ratio the number of V. thapsus planted (125, site 18) was also double that in the Morgan block (60, site 16). Although the density of V. thapsus was similar, the larger number in site 18 may have elicited a different response from the mobile C. verbasci than the number in site 16.

I conclude that in commercial orchards the number of V. thapsus can influence the population density of C. verbasci overwintering in the trees. I found that 2 or more generations of C. verbasci occurred on V. thapsus (Fig. 8.1) at the time that one occurred in the trees (Chapter III), and that large numbers can develop on V. thapsus in or near orchards. The density of V. thapsus in commercial orchards in 1982 was correlated with the number of C. verbasci in the Summer, the population density in the Spring of 1983, and the damage at harvest.

On the other hand, it is clear that the widespread damage from C. verbasci experienced throughout the Okanagan Valley in 1985 (M. Sanders[10],

R.D. McMullen[8], pers. comms.; pers. obs.) cannot be explained simply by the abundance of V. thapsus in 1984. If C. verbasci populations in orchard trees can build up due to insecticide resistance or unusual weather (Chapter III) then the level of V. thapsus is not as critical as at lower population densities, and the value of the plants is likely as reservoirs or refugia for C. verbasci.

In view of these results and the success reported with reduction of weeds for Lygus spp. control (see Introduction), the destruction of V. thapsus populations in and around orchards will likely lead to lower populations of C. verbasci and reduced damage on apple in succeeding years.

IX Visual and olfactory components of an adult monitoring trap for *Campylomma verbasci* in apple orchards.

INTRODUCTION

Damage from *C. verbasci* nymphs to apples is directly related to the level of the overwintering population (MacPhee 1976; Chapter V). Emergence of the nymphs occurs at a critical time for pest management in Canada (MacPhee 1976; Madsen and Procter 1982) and intensive sampling is required for detection near the economic injury level (Chapters IV, VI). Early warning of sites with a dangerously high population would significantly assist pest management programs (MacPhee 1976; Norton 1976; Chapters VI, VII) but overwintering samples taken from orchards in early spring provide unreliable results or are impractical on a large scale (Chapter VII).

Although measurement of the overwintering population itself is infeasible, the number of adult *C. verbasci* in orchards at the time of oviposition may be a useful indicator of the population level of the next generation. If a reliable method of estimating adult number were developed, intensive sampling could be confined to those orchards with high population levels. The simplest method would be to employ an efficient trap, such as a sticky coated trap commonly used in orchards for several insects (Hoyt et al. 1983), as adults are difficult to collect using other methods (Chapters II-IV).

Adult plant bugs, including *C. verbasci*, have been readily collected from traps employing 2 types of stimuli, visual and olfactory. Prokopy et al. (1979) found that adult tarnished plant bugs, *Lygus lineolaris* (Palisot de Beauvois), were more effectively detected in orchards on sticky, non-UV reflecting, white rectangular traps than by 3 other methods: visual counts,

limb-tap samples, or sweepnet samples of ground cover vegetation. Prokopy et al. (1982) related the trap captures to fruit injury levels and developed treatment levels for the tarnished plant bug on apple. Boivin et al. (1982) used this trapping scheme for 2 years to monitor 5 mirid species in a Quebec apple orchard, but caught no C. verbasci on 21 traps, despite finding adults in trees and on ground cover vegetation.

Probably the first report of an olfactory attractant for mirid bugs was Marshall's (1930) observation that traps baited with ethyl propionate, hung in apple trees, had a 'fair' attraction for C. verbasci. Subsequently, the presence of a female sex pheromone, highly effective in attracting males to caged females, was established in 5 mirids: L. lineolaris (Scales 1968; Slaymaker and Tugwell 1984), L. hesperus Knight (Strong et al. 1970), Distantiella theobroma (Dist.) (King 1973), Helopeltis clavifer (Walker) (Smith 1977), and Lygocoris communis (Knight) (Boivin and Stewart 1982a).

Preliminary observations of C. verbasci in 1982 revealed a close association with common mullein, Verbasum thapsus, as well as an aggregated distribution on certain plants (Chapters III, VIII), and suggested that visual and olfactory stimuli could be employed in an attractive trap for C. verbasci. In this study I investigated some possible components of such a trap in and around British Columbia interior apple orchards.

MATERIALS AND METHODS

Experimental sites

Investigations were conducted in commercial orchards (Fig. 3.1, Table 3.1), and in a field (site A) and orchards (sites B, C) of the Agriculture Canada Research Station, Summerland (Chapter III). Site A was, in 1983, an open grassy field, approximately 100 x 200 m, with a few small abandoned

apple trees, and several thousand V. thapsus, bounded on 3 sides by steep gullies. In early 1984, part of site A was planted to apples of many varieties andthe V. thapsus population declined by approximately 60%. Site B contained mature pear trees, primarily cv. Bartlett. Site C held 216 small (2-3 m) apple trees cv. Starkrimson, Red Delicious, and Golden Delicious on M26 rootstock, in 6 rows of a 3 x 4 m planting.

During July 1983 4 rows of 22 stakes, 1.5 m high, were placed in site A in a rectangular lattice pattern 10 x 3 m apart. Because of concern that non-uniform V. thapsus distribution might affect adult movement, on 8 August and 10 September the numbers of healthy V. thapsus >30 cm high within 2 m of a stake were counted, and the distance in cm to the nearest plant was measured at each stake, for use as covariates in data analysis.

Visual traps

Traps were made from white cards (16 x 44 cm) laminated on one side with plastic (Domtar Inc.), normally used as pheromone trap liners. Rectangles were cut and used or painted on the laminated side with 2 coats of paint (General Paint Div., Reed Decorative Products Ltd.): Empress White, Spanish Yellow, Seafoam Green, Supergloss Green, Oxford Blue, Gull Grey, Signal Red, Satellite Yellow, Turf Green or Titan Red (Fig 9.1; the latter 3 colours fluoresce in daylight). The laminated side of each card was coated with Tangletrap (The Tanglefoot Co.), a clear sticky polymer, before use.

All colours except Gull Grey and the unpainted card were used in experiment 1. Pieces 15 x 20 cm were folded into 2 shapes, horizontal rectangles (10 x 15 cm) or vertical cylinders (20 cm x 4.6 cm diameter) and stapled to stakes in site A. Four replicates of the 18 shape x colour combinations were laid out in a split-plot design (Little and Hills 1978;

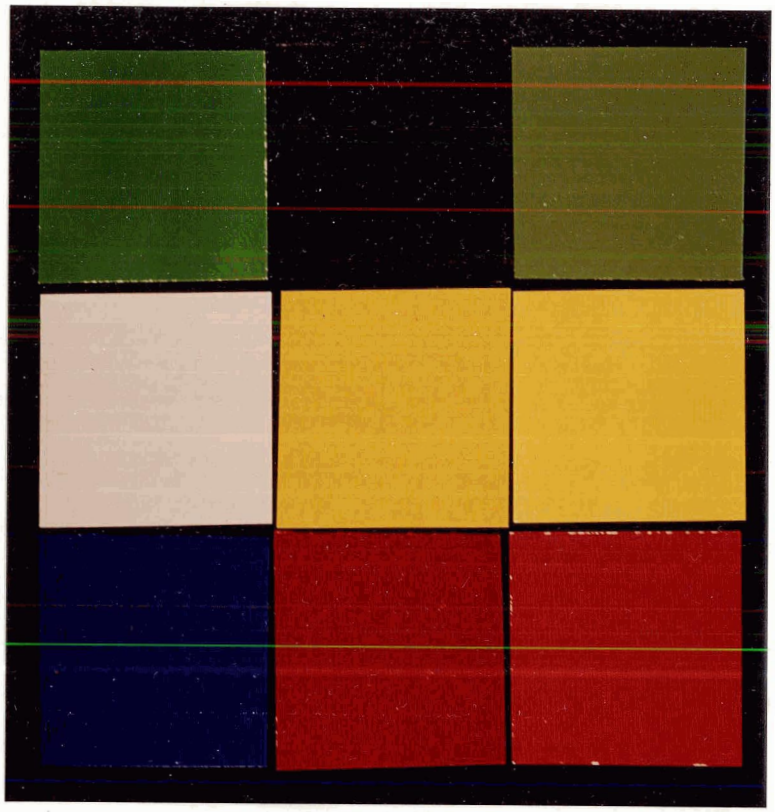


Fig. 9.1. Cards of various hues and shades, used in experiment 1.

Top: Turf Green, Supergloss Green, Seafoam Green

Centre: Empress White, Spanish Yellow, Satellite Yellow

Bottom: Oxford Blue, Signal Red, Titan Red

Snedecor and Cochran 1980) with shape as main plots and colour as subplots, on the western 72 stakes, on 6 August 1983. On 8 August and 12 August, all C. verbasci were removed from the traps, sexed and counted.

Turf Green, Signal Red, Gull Grey, and Empress White colours were compared with unpainted cards (15 x 20 cm) in experiment 2. The cards were stapled in the vertical cylindrical position on the eastern 24 stakes of site A, and deployed in a 4-replicate, randomized block design, on 16 August 1983. They were checked for C. verbasci, rerandomized and replaced on 19 August, and the traps checked and removed on 22 August.

Visible and UV wavelength reflectance of painted and unpainted cards was measured by a Cary 17 recording spectrophotometer with a magnesium oxide standard.

Olfactory traps

In 1982-1983, 7 experiments were conducted using wild-caught or insectary-reared C. verbasci adults and V. thapsus flower parts, in up to 7 treatments simultaneously, as summarized in Table 9.1. The insects were caged with wet dental cotton wicks and filter paper in clear plastic cylinders (3.5 x 10 cm) with gauze across the ends. Between 4-6 adults were placed in each cage, depending on the experiment, together with a sugar-water mixture in glass vials with string wicks. Traps were checked 1-2 times daily and studies were terminated when an average of 1 adult/cage was immobile; in experiments 4 and 5 the treatments were replaced and rerandomized after 4 and 3 days, respectively. Prior to use in the cages, fresh pieces of V. thapsus raceme were cleaned of all C. verbasci and other arthropods except the mullein thrips, Haplothrips verbasci. At the end of each experiment the number of living and dead C. verbasci in each cage was determined.

Table 9.1. Summarized design of 7 experiments with caged *C. verbasci* adults and/or *V. thapsus* inflorescence in sticky-coated traps

Experimental characteristic	Expt. no. 1	2	3	4	5	6	7
Site	Garden	15	16	15	A	18 19	16 17
Duration (days)	5	4	3	8	6	6	5
No. of replicates	8	6	7	4	4	6	12
Treatment							
Control	+	+	+			+	
C. verbasci adult males	+	+	+				
females	+	+	+			+	
both sexes			+			+	
V. thapsus inflorescence	+	+	+	+	+		+
with *C. verbasci* adult males		+	+	+	+		
females	+	+	+	+	+	+	+
both sexes				+	+		

In experiment 1 the cages were clamped to 1 m high stakes spaced 1 m apart in 2 squares of 20 traps each, between 1.5-4 m away from V. thapsus in the experimental garden (Chapter III). Two pieces of white, unpainted card (20 x 20 cm) coated on both sides with Tangletrap, were stapled to the stakes; one vertically facing the plants and the other horizontally mounted above the cage. For experiment 2 the cage was placed through a hole in the centre of a 22 x 22 cm piece of card, coated on both sides with Tangletrap and hung by wire from trees, but in all other studies a cylindrical trap was used.

The cylindrical traps [18.5 cm x 13 cm outside diameter (OD)] were made from white paper ice cream cartons, painted with Exterior Super Varnish (General Paint Div., Reed Decorative Products Ltd.) that dried to a light straw colour. A white pheromone trap liner (44 x 16 cm), described earlier, was coated on the laminated side with Tangletrap and covered the inside of the cylinder. The cage was hung inside the trap in the top centre (Fig. 9.2). Traps were hung in the lower canopy of trees at eye height (1.5 m), or tied to stakes 1-1.5 m high in site A, at least 20 m apart.

Experiments 2-5 were laid out in Latin squares, numbers 1 and 7 in completely randomized blocks, and number 6 in 6 randomized blocks - 4 in rows of Red Delicious trees, one on a fence 50 m away, and one on stakes 100 m into a hayfield. Cut apple foliage and fruit was included as a treatment in experiment 1 and mullein weevils, Gymnaetron tetrum, were caged in experiment 6 but died or became inactive within 36 h.

Insect and plant volatiles

Porapak Q (50-80 mesh, Applied Science Laboratories Inc.) was conditioned by extraction with anhydrous, reagent grade diethyl ether in a

Fig. 9.2. Cylindrical trap used in olfactory experiments, mounted on a stake, showing the trap liner and cage containing plant material and adult C. verbasci

Soxhlet extractor for at least 24 h. Residual solvent was removed by heating the Porapak Q under helium at 60°C for 2 h. Fresh V. thapsus racemes were regularly cut, stripped of all arthropods except mullein thrips, weighed and packed into 3 glass cylinders (30 cm OD x 50 cm) fitted with ground glass joints at top and bottom ends, and across the middle. A glass air scrubber (2.4 cm OD x 12 cm) filled with activated coconut charcoal (50-80 mesh, Fisher) was attached to the top of each cylinder and a glass trap filled with Porapak Q (2.4 cm OD x 20 cm; Vernon et al. 1977) to the bottom. Air was drawn through the systems at approximately 4 L/min by water aspirators. The equipment and air flow rate was checked at least 4 times daily, at 0800, 1200, 1600, and 2100. Room temperature and relative humidity were recorded on a Feuss thermohygrograph.

For capture of insect-produced volatiles, wild-caught or laboratory-reared adult C. verbasci were sexed and placed in the containers on fresh V. thapsus material. Numbers of immobile or dead C. verbasci were counted daily at 0800 and 1600, and when the chambers were opened at intervals of 2-6 days. The concentration of volatiles collected during aeration was expressed quantitatively in terms of bug hours (bh) and gram hours (gh) so that 1 bh = the volatiles from one bug in 1 h, and 1 gh the volatiles from 1 g of V. thapsus (fresh wt.) in 1 h. Targets of 100,000 bh and 1 million gh were set; actual results were, for each treatment: V. thapsus alone, 1.27 million gh (and 500 bh due to some adults that escaped detection); males 1.34 million gh and 97,698 bh; females 1.34 million gh and 95,356 bh.

Volatiles were recovered by extraction of the Porapak Q with 350 ml of pesticide grade hexane (glass distilled, Caledon Laboratories, Ltd.) in a Soxhlet extractor for 24 h. The extractions were concentrated to about 9 ml

under vacuum in a rotary evaporator, transferred to a 10 ml volumetric flask, and the volume brought up to 10 ml. The concentrates were stored in glass vials with Teflon-lined caps in a deep freezer until required.

The concentrates were applied, in volumes of 0.1 and 1 ml, to rubber septa (10 mm; Sigma Chemical Co. Inc.) and left overnight. Seven replicates of each plus a hexane control were prepared. On 12 September 1984 they were placed in traps in 7 locations (sites 9, 15, A, B, C, and 2 other commercial orchards) in trees at least 20 m apart. The traps were checked daily until 21 September.

Insect crushes

Adult C. verbasci were collected in 1984 from V. thapsus, sexed, and held overnight in groups of 10 in darkness at 1-5°C. All solvents were pesticide-grade (glass distilled, Caledon Laboratories Ltd.). The glassware and equipment was washed in acetone, and rinsed in hexane before use and subsequent operations occurred in a cold (1-2°C) room.

Insects were held individually with forceps at the abdomen and prothorax, pulled apart, and the 2 parts placed immediately in separate glass vials containing hexane and resting on solid carbon dioxide. After accumulating sufficient material, normally from 50 insects, the parts were crushed in the vials and the vials sealed and brought to room temperature (approx. 20°C) for 30 min. Solutions in the vials were drawn off, the parts rinsed with hexane, and the solution again drawn off. Collected liquids were stored in sealed vials with Teflon-lined caps in a freezer until required. In total, extracts of 300 male and 420 female C. verbasci were prepared.

Two experiments were made with the materials and the remainder was kept for analysis. In the first, 6 orchards (sites 2,4,9,12,15, B) were checked

with traps containing live female C. verbasci to ensure that a population was present. Six treatments were then placed in a Latin square: blank control, hexane control, male or female head and thoracic sections, and male or female abdominal sections. The material was applied in 10-insect-equivalent amounts to rubber septa (10 mm; Sigma Chemical Co. Inc.) and left overnight for the hexane carrier to evaporate. The septa were placed in the top centre of the standard cylinder traps, described earlier, hung in trees from the edge of the orchards to the centre, at least 10 m apart. The traps were set on 5 September 1984 and checked daily until 10 September.

A second experiment used 30-insect-equivalents of material in 4 replicates of 5 treatments: a hexane control, male or female head and thoracic sections, and male or female abdominal sections. The materials were concentrated under vacuum in a rotary evaporator before application to the septa. They were left overnight and placed in cylindrical traps in 4 orchards (sites A, B, and 2 commercial orchards) and checked daily from 18-24 September.

Data analysis

The studies were analysed by analysis of variance (ANOVA) or covariance (ANCOVA) after transformation by $x = \log_{10}(x+1)$ or $x = \sqrt{(x+0.5)}$ as appropriate. Means were separated by orthogonal contrasts or the Student-Newman-Keul's test (Steel and Torrie 1980). Calculations were performed using MIDAS (Fox 1976) and ANOVAR (Grieg and Osterlin 1978) statistical packages.

RESULTS AND DISCUSSION

Visual responses

A total of 1,323 C. verbasci (804 males and 519 females) were caught on

coloured sticky traps in 1983. The majority were caught in early August, when the number of yellow or white flowers on V. thapsus reaches its annual maximum (Chapter VIII). Later experiments caught fewer C. verbasci, particularly females, than experiment 1 as the females left the area and moved onto perennial overwintering hosts in late August (H. Thistlewood, unpub. results).

Both sexes of C. verbasci were captured in significantly different numbers (ANOVA, $P<0.01$) on 9 colours presented in experiment 1 (Table 9.2). No significant differences ($P = 0.05$) were found among male C. verbasci presented with the 5 colours in experiment 2 (1.3-6.0/trap), when too few females were caught for analysis (0.3-1.3/trap).

The success of fluorescent Turf Green and relative captures of other colours are not explained by the reflectance profiles of the painted cards, nor by comparison with values obtained for V. thapsus leaves (Wuenscher 1970) and flowers (Mulligan and Kevan 1973; Kevan 1983). However, Prokopy and Owens (1978, 1983) and Prokopy et al. (1979) suggest that non-UV-reflecting white is a 'supernormal' bud and blossom mimic of plants and is attractive to 'polyphagous' insects, such as plant bugs, on apple. White would be a suitable colour for a sticky-trap for adult C. verbasci (Table 9.2,) as well as for other plant bugs (Prokopy et al. 1979, 1982; Boivin et al. 1982), provides a highly contrasting background for insect identification, and is easily available owing to widespread use in prefabricated commercial traps.

In experiment 1, cards of the same size were folded in 2 shapes and the vertical cylinders captured significantly more female C. verbasci than the horizontal rectangles (ANOVA, $P<0.02$; Table 9.2). V. thapsus has a striking form, and trap shape, size and orientation can greatly influence capture

Table 9.2. Comparative response of C. verbasci adults to sticky-coated traps of 2 shapes and various hues and shades in experiment 1, 6-12 August 1983

Treatment	Mean no. C. verbasci/trap[a]					
	Males		Females		Adjusted means[b]	
	No.	s.e.	No.	s.e.	Males	Females
Colour (n = 8)						
Turf Green[c]	14.2 a	6.3	12.6 a	4.1	6.2 a	11.5 a
Empress White	11.0 a	2.5	10.1 ab	1.8	7.7 a	10.9 a
Satellite Yellow[c]	8.0 ab	1.9	7.3 abc	1.6	7.8 a	6.9 ab
Seafoam Green	6.4 ab	1.6	6.9 abc	1.5	6.7 a	6.9 ab
Spanish Yellow	5.8 ab	1.2	6.6 abc	1.1	6.5 a	6.3 ab
Oxford Blue	9.4 ab	2.7	6.6 abc	2.0	9.2 a	5.6 ab
Titan Red[c]	7.0 ab	1.5	3.8 bc	1.5	9.6 a	3.6 bc
Supergloss Green	5.5 ab	2.2	3.3 bc	0.7	9.2 a	3.0 bc
Signal Red	1.9 c	0.7	1.0 c	0.3	6.2 a	1.6 c
Shape (n = 36)						
Vertical cylinder	8.6 a	1.0	7.9 a	1.0	7.1 a	6.7 a
Horizontal rectangle	6.7 b	1.6	5.1 b	0.9	8.2 a	5.0 b

[a] Means followed by the same letter are not significantly different at the P=0.05 level (Student-Newman-Keul's test, or planned F-tests, on data transformed to $\sqrt{(x + 0.5)}$).

[b] Adjusted for significant (P<0.01) covariates: males for no. females/trap; females for no. V. thapsus within 2 m of trap.

[c] Fluorescent

rates of visual and pheromone traps (Carde and Elkinton 1984; Levinson and Hoppe 1983; Prokopy and Owens 1983) but in 2 further experiments, using other shapes and orientations, too few females were caught for analysis.

Interpretation of male response was complicated by a very close relationship (ANCOVA and Pearson product-moment correlation, $P<0.01$) with the number of females caught on individual traps. The consistency of this effect in the 4 visual and 7 olfactory experiments (see next section) suggests that it is stronger than a visual preference. Male counts adjusted by the number of females on a trap showed no significant differences (ANCOVA, $P>0.1$) among colours in experiments 1 (Table 9.2) and 2 suggesting that males have little preference for colour. Contrarily, although the number of females captured on a trap was closely related (ANCOVA, $P<0.01$) to *V. thapsus* density (within 2 m of the trap) the adjusted means merely confirmed prior differences (Table 9.2).

These results demonstrate the importance of simultaneous investigation of olfactory and visual components of trap capture, and may be relevant to other insects. Previous investigations of visual responses have often ignored intraspecific sexual differences or interactions (e.g. Owens and Prokopy 1978; Prokopy and Owens 1978; Prokopy et al. 1979, 1982), and lumped both sexes together. In one exception, Boivin and Stewart (1984) noted that significantly more males than females of 4 mirid species were captured on white sticky traps, in ratios of 1.5-4.5 males: 1 female. Although sex ratios of 1:1 or less were consistently found in limb-tap and other orchard samples, Boivin and Stewart (1984) suggested that the different catch ratio was due to greater flight activity by males. My results offer a different explanation by showing that the number of female *C. verbasci* caught on a

coloured sticky trap greatly affects the male catch; aggregation of one or both sexes on traps, resulting from an olfactory signal, can confuse the results. On occasion, large numbers of C. verbasci were found on particular traps (see standard errors, Table 9.2) just as in a cohort of V. thapsus they are more common on certain plants than others (Chapters III, VIII).

The high level of captures of both sexes on white cards caused the visual experiments to be discontinued after 1983.

Olfactory responses

In 1982-1984, 907 male C. verbasci and 92 females were captured in 7 experiments with olfactory traps (Table 9.3). Traps containing caged females captured significantly more males than others ($P<0.05$) in 5 experiments, and addition of V. thapsus to the caged females produced considerable increases ($P<0.05$) in male catch over that of females alone, in 2 experiments (1,6). No differences were identified between treatments for captures of females (Table 9.3).

Trap captures were affected by the number of uncaged adults in the experimental site, and by the continuing attractiveness of captured females on individual traps. In general, twice as many males were attracted to caged females when the females were on V. thapsus than to females caged without the host; conversely, the attraction halved when the females were caged with males (Table 9.3).

The increased attractiveness of females on V. thapsus over females caged alone (with food and water) may be due to the interaction of host plant and insect volatiles or, more likely, to either qualitative or quantitative changes in pheromone production. The release of sex pheromone has been shown to be affected by diet (Hendry 1976), or host plant odours in Lepidoptera

Table 9.3. Capture of adult C. verbasci in sticky-coated traps in 7 experiments using caged insects and plant material alone or in various combinations

Treatment	No. C. verbasci captured in traps															
	Male								Female							
	1	2	3	4	5	6	7	Grand mean[a]	1	2	3	4	5	6	7	Grand mean[a]
Control	2	1	2			0		0.04	0	2	0			0		0.02
C. verbasci adult males	7	0	3					0.12	2	0	2					0.05
females	21	7	0			25		0.44	4	4	1			0		0.07
both sexes			2			8		0.18			0			0		0
V. thapsus inflorescence	1	6	0	1	0		1	0.04	1	4	2	1	3		4	0.08
with C. verbasci adult males		3	0	5	3			0.11		6	2	4	0			0.12
females	49	9	8	8	48	51	118	1.23	3	5	1	5	2	1	6	0.10
both sexes				7	2			0.16				3	0			0.05

[a]Mean catch/trap/day of all experiments

(Labeyrie 1978; van der Pers et al. 1980, van der Pers and King 1982) and Coleoptera (Hummel and Andersen 1982).

The attraction of males to groups of mature females of unknown reproductive history suggests that pheromone production is not confined to virgin or callow females. Many females adopted a characteristic calling position, similar to that drawn by King (1973), in the evening. King (1973) suggested that a loss of attractiveness of females following mating is usual for Hemiptera, with resumption a few days later. The observed decrease in attraction of mature females, when caged with males, agrees with his theory and suggests that multiple mating may occur in C. verbasci, as it does in several mirids (Strong et al. 1970; King 1973; Smith 1977).

The responses of males to extracts of female- and plant-produced volatiles (Table 9.4) and to extracts of females per se (Table 9.5) confirms the existence of a female-produced sex pheromone in C. verbasci. The higher response to traps with 9536 bh of female volatile content than to those with 954 bh content (Table 9.4) indicates a dose-response relationship over the range tested.

The pheromone, or a similar precursor, is apparently located in the head or thorax of the female (Table 9.5) although some activity was associated with the abdominal region. The crude method used to separate the 2 sections of the insect may have resulted in incomplete separation of tissue containing the pheromone, resulting in activity in extracts of both sections.

Chemical analysis (H.D. Pierce, Jr.[14], pers. comm.) revealed that the concentrated volatiles and insect extracts attractive to males contained 2 substances not present in the unattractive fractions. The principal of these, identified as n-butyl butyrate, was not attractive to either sex in

Table 9.4. Capture of C. verbasci in traps containing concentrated solutions in hexane of airborne volatiles collected on Porapak Q polymer

Concentration of volatile extract				
V. thapsus	C. verbasci bh		Total no. C. verbasci in traps	
gh ($\times 10^4$)	Male	Female	Male[a]	Female
0	0	0	3 a	2
1.3	3	3	1 a	1
1.3	977	0	2 a	0
1.3	0	954	43 b	1
12.7	25	25	2 a	1
13.4	9770	0	2 a	1
13.4	0	9536	141 c	0

[a]Totals followed by the same letter are not significantly different at the P=0.05 level (Student-Newman-Keul's test)

Table 9.5. Capture of C. verbasci males in traps containing hexane extract of crushed insect parts from C. verbasci adults

Insect extract (30 insect equivalents/trap)	No. of males captured by day of experiment				Total captured[a]
	1	2	3	4	
Hexane control	0	0	0	0	0 a
♂ Abdomen	1	0	0	0	1 a
♂ Head + thorax	0	0	0	0	0 a
♀ Abdomen	20	4	0	0	24 b
♀ Head + thorax	54	23	1	3	81 c

[a]Totals followed by the same letter are not significantly different at the P = 0.05 level (Student-Newman-Keul's test)

field trials in 1985 (H. Thistlewood, unpub. results). This material has been previously found as a component in metathoracic gland tissue of 3 species of alydid bugs (Aldrich and Yonke 1975).

There is an excellent possibility of utilizing pheromones in monitoring and assessing population levels of C. verbasci. For example, in experiment 7, 118 male and 6 female C. verbasci were captured by the treatment containing females, whereas 50 limb-tap samples taken 7 days before and after the experiment collected 1 and 12 adults, respectively. This comparison illustrates the increase in numbers of sampled insects that is possible with pheromone-baited traps.

On the other hand, visual traps alone were useless for C. verbasci in 2 years in Quebec (Boivin et al. 1982a) or provided confusing results (Boivin and Stewart 1984); likewise, Prokopy and Owens (1978, 1983) found that they are of more limited value for tarnished plant bug than other types of insects. Plant size and vigour (Chapter VIII), trap colour and shape, and olfactory stimuli have significant effects upon C. verbasci adults and the combination of visual and pheromone cues in a trap can be expected to increase capture rates over those of separate stimuli (Childers et al. 1979; Ladd and Klein 1983; Ladd et al. 1984; Carde and Elkinton 1984). Although identification of the sex pheromone components is necessary, the development of a system for forecasting C. verbasci population levels appears possible with the use of an adult monitoring trap.

X Conclusion

This research has shown Campylomma verbasci to be a common pest in apple orchards of the Okanagan Valley. Its overwintering habit is central to this status, due to the predominance of apple and pear as hosts; almost all of the population is found on these trees in the spring. Damage caused by C. verbasci feeding on apple was widespread and often serious.

The strong relationship between the density of the first generation nymphs and feeding damage suggests that the factors governing that density, and methods of estimating or forecasting it, are particularly important for pest management. The limb-tap sample was the most efficient estimator of nymphal population density and was not affected greatly by the spatio-temporal factors investigated. Consequently, I developed sequential plans for estimating population density at a constant precision level, and for decision-making using a small number of limb-taps.

Without a life-table study one can only guess at the relative importance of a particular factor but the overwintering density and mortality of C. verbasci is apparently determined by the population level in August and September, cultural effects such as pesticide applications and pruning prior to spring emergence, and winter weather. No parasites were found in >1200 C. verbasci reared from nymphs taken in many samples (H. Thistlewood, unpub. results) nor did any egg parasites emerge from the branch samples of Chapter VII; parasitism is commonly low in other mirids of commercial orchards (e.g. Glen 1977; Leston 1959, 1961).

Neither the commonly used pesticides, nor unusually low temperatures in winter, restrained the population below damaging levels. Similarly, no correlations were observed between the levels of animal prey suitable for C.

verbasci in an orchard and either the overwintering population density or the degree of damage observed at harvest. The amount of pruning was not quantified in each orchard but my observations do not indicate that typical horticultural practices affect the number of C. verbasci greatly; high populations were found in several sites that were pruned heavily in winter.

On the other hand, I have shown that the density of the overwintering population was correlated with that of the major summer host, common mullein, in study orchards. The proposed introduction of a biological control agent for this plant (Maw 1980, 1984, pers. comm.[12]) offers the possibility of a reduction in numbers outside orchards, although it is not clear whether the mullein shark, Cucullia verbasci L. (Noctuidae), can successfully colonize plants in the intensively sprayed environment of an apple orchard. However, a reduction in the number of common mullein in and around an orchard may be expected to lower the population level of C. verbasci, particularly if the number on the fruit trees can be reduced by a pest management program.

The management of C. verbasci would be greatly improved by the development of a reliable system for forecasting numbers or predicting levels of damage within orchards. Samples taken from orchards during the overwintering period did not provide reliable results, and this method of forecasting is not likely to be suitable for the Okanagan Valley. However, coloured traps and traps baited with extracts of females, or female-produced volatiles, successfully captured large numbers of insects with little effort. Exploitation of these results to develop an adult monitoring trap and correlation of the catches with population density would be of great value.

Identification of the sex pheromone, and of one or more characteristic

substances within the mullein plant that probably act as a kairomone (e.g. Metcalf et al. 1980; Berenbaum 1981) appear to be the most profitable areas of future research. The first identification of a mirid sex pheromone would also be significant because of their world-wide pest status, notwithstanding the importance of Campylomma spp. in North America and Australia (Lloyd 1969; W.G. Thwaite[15], pers. comm.).

A further research subject should be to relate the timing of emergence of the first generation nymphs to the ambient temperature and to develop a predictive model to identify when limb-tap sampling should occur. The accuracy and cost of sampling could be considerably improved if the number of samples required to obtain a peak emergence count were reduced. Such an approach may, however, be constrained by the difficulty of obtaining large numbers of overwintering eggs or of rearing mirids in the laboratory (Collyer 1952; McNeill 1973; pers. obs.), and the significant differences found between air temperature and bud or blossom temperatures (Pearce and Preston 1954; Landsberg et al. 1973; Landsberg et al. 1974), particularly as the eggs are almost buried within the bark.

Finally, in addition to studies aimed at population management, the relationship between C. verbasci and common mullein is worthy of further research. Our knowledge of insect herbivory has advanced considerably with the close attention paid to plants in several groups, notably the Asclepiadaceae, Compositae, and Cruciferae. A considerable literature already exists concerning the phytochemistry of Verbascum spp., used extensively in medicine and the perfume industry, and on the biology and ecology of several species, particularly V. thapsus. The paucity of associated insects other than those using the plant as a source of shelter,

the lack of feeding damage displayed by the majority of these plants, and the restriction of several insects found on the plants to Verbascum spp., suggest that further research into this relationship would be very fruitful.

XI Footnotes

1. Deciduous fruit trees pass through a series of fairly definite growth stages in the spring. The timing of many pesticidal spray treatments are given according to the growth stage, in fruit-growing regions. Unfortunately, no common agreement has been reached on the stages or their names, but many publications now refer to the key growth stages identified by Chapman and Catlin (1976) in their photographic guide. They are, in chronological order for apple: dormant, silver tip, green tip, half-inch green, tight cluster, pink, bloom, petal fall, fruit set. Growth stages falling between the key stages can be qualified by prefixes and adjectives such as prepink, early pink, late pink, full pink, etc. The length of time between the key stages is greatly dependent upon the weather and, to a minor extent, the fruit variety.

2. Vakenti, J.M. and F.E. Peters. 1981. Report on the viability of a private pest management service for southern fruit districts of the Okanagan Valley of B.C., 60 p. and 6 App., unbound, filed in the Entomology Section, Agriculture Canada Research Station, Summerland. Two other useful reports are: 1) Vakenti, J.M. and F. Peters. 1981. Final report on establishment of an orchard pest management service in British Columbia. Agriculture Canada Contract Serial No. OSZ78-00231, DSS File No. 07 SZ.31155-8-0701 40 p., and 2) Vakenti, J.M. and F. Peters. 1980. Interim report on establishment of a pest management service in southern interior B.C., 12 p. and 1 App. Both are filed at the Entomology Section of the Agriculture Canada Research Station in Summerland.

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XIII. Appendix A: plants in the experimental garden

INTRODUCTION

Early in the spring of 1982 and 1983 a clear area (20 x 20 m), adjacent to the S.F.U. Field Laboratory, was treated with herbicide, rototilled, and dug by hand. Seeds and small plants were grown in several plantings, to be full-sized from July onwards, according to recommended practices (Hansen and Stewart 1978).

The garden was divided in 2 halves, horticultural crops and orchard plants, with small plots of other plants in each. At least 3 individual plants or plots of 0.7 m^2 of each cultivar, and up to 4 cultivars/crop were grown in the horticultural section; at least 5 individuals or 1 m^2 plots of each orchard plant were grown. Plants that died were not replaced and not all types were grown in both years. The plants grown in the garden are listed below:

COMMON ORCHARD PLANTS

Apple, Malus, cv. Antonovka, Red Delicious

Wild rose, Rosa spp., collected from 5 sites

Saskatoon berry, Amelanchier cusickii

Field bindweed, Convolvulus arvensis

Climbing nightshade, Solanum dulcamara

Dandelion, Taraxacum officinale

Stinging nettle, Urtica urens

White clover, Trifolium repens

Perennial vetch, Vicia spp.

Buttercup, Ranunculus spp.

Narrow and broad-leaved plantains, Plantago spp.

Field horsetail, Equisetum arvense

Common mallow, Malva neglecta

Common groundsel, Senecio vulgaris

Common mullein, Verbascum thapsus

Lamb's quarters, Chenopodium album

Redroot pigweed, Amaranthus retroflexus

Shepherd's purse, Capsella bursa-pastoris

Common chickweed, Stellaria media

Quackgrass, Agropyron repens

Kentucky blue grass, Poa praetensis

Orchard grass, Dactylis glomerata

Barnyard grass, Echinochloa crus-galli

Annual bluegrass, Poa annua

HORTICULTURAL CROPS

Potato, Solanum tuberosum, cv. Warba, Pontiac, Explorer

Tomato, Lycoperscion esculentum, cv. Starfire, Pik Red, Tiny Tim

Eggplant, Solanum melongea var. esculentum, cv. Imperial, Black Beauty, Satin Beauty, Early Long Purple

Pepper, Capsicum annuum, cv. California Wonder

Corn, Zea mays, cv. Sunnyvee, Tastyvee, Market Beauty, Ornamental (Indian)

Broad Bean, Vicia faba, cv. Windsor

French Bean, Phaseolus vulgaris, cv. Top Crop, Pencil Pod Black Wax

Lima Bean, Phaseolus lunatus, cv. Hendersons Bush

Leek, Allium porrum, cv. Large American Flag

Cucumber, Cucumis sativus, cv. Hybrid Sweet Slice

Radish, Raphanus sativus, cv. Cherry Belle

Lettuce, Lactuca sativa, cv. Great Lakes, Grand Rapids, Buttercrunch

Beet, Beta vulgaris, cv. Detroit Dark Red

Carrot, Daucus carota, cv. Scarlet Nantes, Amsterdam

Onion, Allium cepa, unknown transplants

Spinach, Spinacia oleracea, unknown transplants

Celery, Apium graveolens var. dulce, unknown transplants

Broccoli, Cabbage, Cauliflower, Brassica oleracea, unknown transplants

OTHER PLANTS

Wildflowers of North America, mixed seeds, from Buckerfields Ltd., Vancouver, B.C., and Stecher-Traung-Schmidt of San Francisco, CA.

Verbena spp., "finest mixed hybrids", mixed seeds, Buckerfields Ltd.

Catnip, Nepeta cataria, Buckerfields Ltd.

XIV. Appendix B: peak tap counts and damage at harvest of all varieties and sites, 1982-1984

RED DELICIOUS

Year	Site	Peak count (mean/tap)	No. apples examined	% *C. verbasci* damage	
				>'C' grade	total
1982	2	2.45	200[a]	0.0	0.0
	3	0.15	500	0.0	0.0
	4	9.85	500	0.4	2.4
	11	1.75	400	1.0	2.5
	15	-	651	1.4	-
1983	1	1.35	500	0.6	5.8
	2	1.35	200[a]	0.0	0.5
	3	0.7	500	0.2	0.4
	4	0.65	600[b]	0.3	0.5
	5	0.15	500	0.0	0.0
	6	0.9	500	0.0	0.2
	8	0.25	500	0.0	1.2
	10	0.0	500[b]	0.0	0.2
	11	1.2	500	0.2	0.6
	12	21.1	1000	3.4	9.7
	15	4.9	1000	0.1	0.4
	18	(>2.8)[c]	500	5.6	12.2
	19	(>3.9)[c]	500	2.0	7.0
1984	4	12.95	500[b]	1.2	8.2
	15	1.3	2343	1.7	4.4
	16	6.15	480	2.3	4.6
	17	3.15	587	2.0	4.9
	18	4.4	552	2.7	7.4
	19	3.85	976	1.2	4.7

[a] Few trees of this variety, normal production is 2 bins/yr; sampled 100/bin

[b] Rigorous culling occurred during picking

[c] Estimated from a sample taken on 2 June 1983

GOLDEN DELICIOUS

Year	Site	Peak count (mean/tap)	No. apples examined	% *C. verbasci* damage	
				>'C' grade	total
1982	1	2.4	500	10.8	16.6
	2	2.44	400	6.5	12.8
	3	0.15	1000	3.2	8.2
	5	0.05	500	0.7	3.4
	6	0.3	600	2.3	5.1
	8	0.15	600	0.0	0.1
	9	1.8	1000	3.8	7.1
	11	1.75	600	3.0	4.5
	15	-	1850	2.2	-
1983	1	1.35	500	7.6	31.8
	2	1.35	500	2.8	17.6
	3	0.7	600	0.7	2.9
	6	0.9	500	1.2	7.6
	8	0.25	500	1.4	5.6
	9	3.3	1000	11.2	49.4
	11	1.2	500	0.5	5.5

MCINTOSH

Year	Site	Peak count (mean/tap)	No. apples examined	% *C. verbasci* damage >'C' grade	% *C. verbasci* damage total
1982	10	0.0	500	0.0	0.0
	12	4.5	500	0.4	0.4
	14	-	181[a]	2.8	-
1983	9	3.3	300	0.0	2.0
	10	0.0	500[b]	0.0	0.4
	12	21.1	400	0.0	0.0
1984	14	5.1	519	0.2	0.8
	16	6.15	292	0.3	2.4
	17	3.15	533	0.0	1.1
	21	2.75	347	0.3	1.5

[a] Entire crop

[b] Rigorous culling occurred during picking

SPARTAN

Year	Site	Peak count (mean/tap)	No. apples examined	% *C. verbasci* damage >'C' grade	% *C. verbasci* damage total
1982	5	0.05	500	3.5	4.5
	10	0.0	300[a]	0.4	0.4
1983	1	1.35	300[b]	2.4	18.4
	2	1.35	300[b]	2.0	18.4
1984	11	1.2	600	0.3	0.5
	16	3.15	890	1.0	3.6
	17	6.15	1852	1.3	3.3

[a] Rigorous culling occurred during picking

[b] Few trees of this variety, sampled 100/bin of entire crop

NEWTOWNS AND RED ROME, 1984

Variety	Site	Peak count (mean/tap)	No. apples examined[a]	% *C. verbasci* damage	
				>'C' grade	total
Newtown	16	6.1	481	1.9	8.1
	17	3.1	799	0.3	2.4
Red Rome	16	6.1	97	0.0	1.0
	17	3.1	164	0.6	2.4

[a] 50% of entire crop