

Research Article

The effects of a vegetational corridor on the abundance and dispersal of insect biodiversity within a northern California organic vineyard

Clara I. Nicholls^{1,*}, Michael Parrella² & Miguel A. Altieri³

¹University of California Cooperative Extension, Alameda County, 1131 Harbor Bay Parkway, Suite 131 Alameda CA 94502, USA; ²University of California-Davis, Entomology Department, Davis, USA; ³University of California-Berkeley, Environmental Science Policy and Management Department, Berkeley, CA 94520, USA; *(corresponding author)

Received 26 August 1999; Revised 24 July 2000; Accepted 16 August 2000

Key words: Biological control, landscape ecology, leafhoppers, thrips, vineyards

Abstract

During 1996 and 1997, two adjacent 2.5 ha organic vineyard blocks (A and B) were monitored to assess the distributional and abundance patterns of the Western grape leafhopper *Erythroneura elegantula* Osborn (Homoptera: Cicadellidae) and its parasitoid *Anagrus epos* Girault (Hymenoptera: Mymaridae), Western flower thrips *Frankliniella occidentalis* (Pergande) and generalist predators. The main difference between blocks was that block A was cut across by a corridor composed of 65 flowering plant species which was connected to the surrounding riparian habitat, whereas block B had no plant corridor. In both years, leafhopper adults and nymphs and thrips tended to be more numerous in the middle rows of block A and less abundant in border rows close to the forest and corridor where predators were more abundant. The complex of predators circulating through the corridor moved to the adjacent vine rows and exerted a regulatory impact on herbivores present in such rows. In block B all insects were evenly distributed over the field, no obvious density gradient was detected from the edges into the center of the field. Although it is suspected that *A. epos* depended on food resources of the corridor, it did not display a gradient from this rich flowering area into the middle of the field. Likewise no differences in rates of egg parasitism of leafhoppers could be detected in vines near the corridor or in the vineyard center. The presence of riparian habitats enhanced predator colonization and abundance on adjacent vineyards, although this influence was limited by the distance to which natural enemies dispersed into the vineyard. However, the corridor amplified this influence by enhancing timely circulation and dispersal movement of predators into the center of the field.

Introduction

Typical production agriculture in California, USA has resulted in the simplification of the landscape. The expansion of monocultures has decreased abundance and activity of natural enemies due to the removal of critical food resources and overwintering sites (Corbett and Rosenheim 1996). Many scientists are concerned that, with accelerating rates of habitat removal, the contribution to pest suppression by biocontrol agents using these habitats will decline (Fry 1995; Sotherton 1984). For this reason, many researchers have pro-

posed options to rectify this decline by increasing the vegetational diversity of agricultural landscapes.

One such option is maintenance or planting of vegetation adjacent to crop fields (Thomas et al. 1991; Nentwing et al. 1998). Ideally such areas provide alternative food and refuge for predators and parasitoids, thereby increasing natural enemy abundance and colonization of neighboring crops (Altieri 1994; Corbett and Plant 1993; Coombes and Sotherton 1984). Studies on natural enemy dispersal and colonization from surrounding habitats report that entomophagous insects depend on hedges, windbreaks, forests, etc., adjacent to crop fields for their continual existence in

agricultural areas (Fry 1995; Wratten 1988). Several studies indicate that the abundance and diversity of entomophagous insects within a field is dependent on the plant species composition of the surrounding vegetation, and also on the spatial extent of its influence on natural enemy abundance, which is determined by the distance to which natural enemies disperse into the crop (Lewis 1965; Pollard 1968). Much research has been conducted in California on the role of adjacent vegetation on the *Anagrus epos* Girault-*Erythroneura elegantula* Osborn complex. The classic study by Douth and Nakata (1973) determined the role of riparian habitats and especially of wild blackberry patches near vineyards in enhancing the effectiveness of *A. epos* in parasitizing the grape leafhopper. Later, research by Kido et al. (1984) established that French prunes (*Prunus domestica* L.) adjacent to vineyards could also serve as overwintering sites for *A. epos* and Murphy et al. (1996) detected higher leafhopper parasitism in grape vineyards with adjacent prune tree refuges than in vineyards lacking refuges. Corbett and Rosenheim (1996), however, determined that the effect of prune refuges was limited to few vine rows downwind and *A. epos* exhibited a gradual decline in vineyards with increasing distance from the refuge. This finding poses an important limitation to the use of prune trees, as the colonization of grapes by *A. epos* is limited to field borders leaving the central rows of the vineyard void of biological control protection.

It is in such situations that borrowing from concepts of landscape ecology can prove useful in agricultural pest management. The study described herein explores the importance of changing the spatial structure of a vineyard landscape, particularly through the establishment of a vegetational corridor to enhance movement of beneficials beyond the 'normal area of influence' of adjacent habitats or refuges. Corridors have long been used by conservation biologists for protecting biological diversity as they provide multiple avenues for circulation and dispersal of biodiversity through the environment (Rosenberg et al. 1997).

In Mendocino County located in northern California, many vineyards are interwoven within a matrix of riparian forests, thus providing ample opportunities for the study of arthropod colonization and inter-habitat exchange of arthropods, especially those restricted to the interstices between agricultural and uncultivated land.

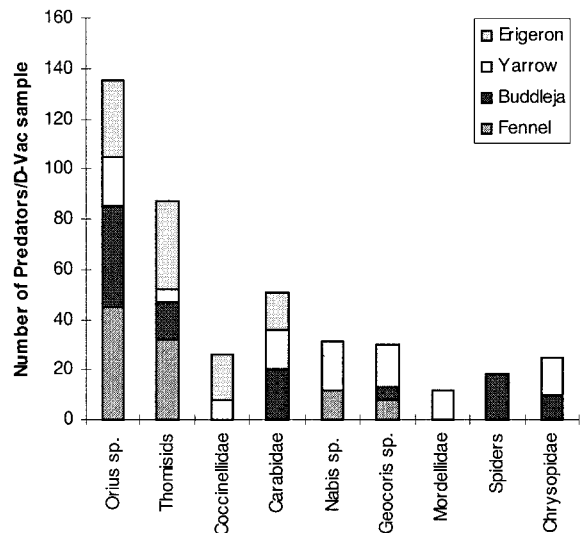


Figure 1. Main predator groups associated with dominant corridor flowering plants (Hopland, California, 1996).

Methods

This study took advantage of an existing vegetational corridor connected to a riparian forest, and that cuts across a monoculture vineyard. This allowed us to test the hypothesis whether such a corridor served as a biological highway for the movement and dispersal of natural enemies into the center of the vineyard. We were interested in evaluating if the corridor acted as a consistent, abundant and well-dispersed source of alternative food and habitat for a diverse community of generalist predators and parasitoids. This can effectively decouple natural enemies from a strict dependence on grape herbivores and allow predator and parasitoid populations to develop in the area of influence of the corridor well in advance of vineyard pest populations, thereby keeping pests below undesirable levels. We also thought that the corridor would serve as a conduit for the dispersion of predators and parasitoids within the vineyard, thus providing protection against insect pests within the area of influence of the corridor by allowing distribution of natural enemies within a certain range of the field.

Study site

This study was conducted in two adjacent identical Chardonnay vineyard blocks (blocks A and B, 2.5 ha each) from April–September, 1996 and 1997, in Hopland, California, a typical wine growing region. For the last four years, both blocks have been under or-

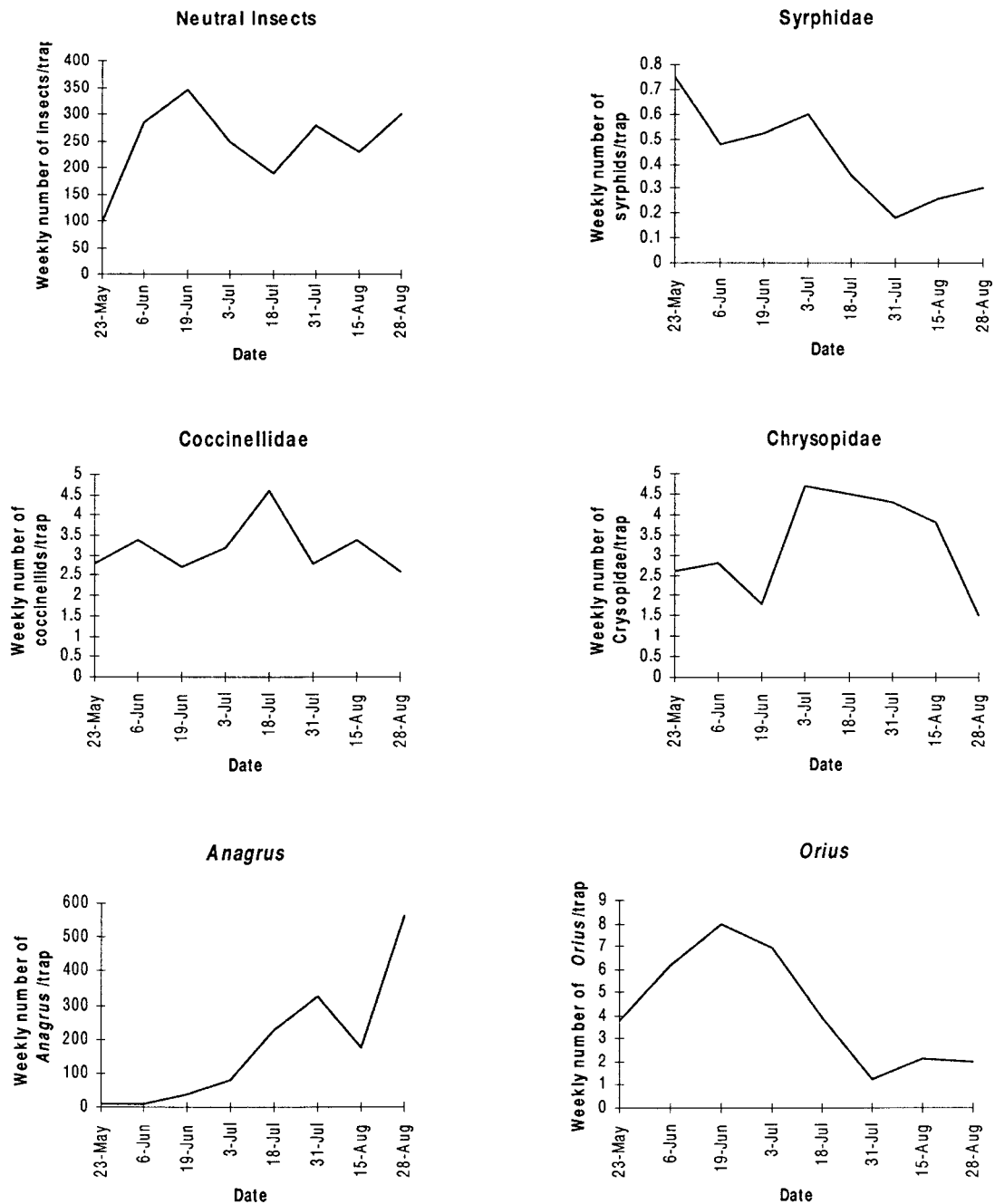


Figure 2. Season-long population levels of neutral insects and associated natural enemies present in the corridor (Hopland, California 1996). Note y-axis scale differences.

ganic management, and planted yearly to winter cover crops (a mixture of barley, *Hordeum vulgare* L. and vetch, *Vicia atropurpurea* L.) and to summer cover crops (buckwheat, *Fagopyrum esculentum* Moench and sunflower, *Helianthus annuus* L.) in an alternating row pattern. The vineyards received an average

of 2 tons of compost per hectare and preventive applications of sulfur against *Botrytis* sp. and *Oidium* sp.

Although both vineyards are surrounded on the north side by riparian forest vegetation, the main difference between the two blocks is that block A is

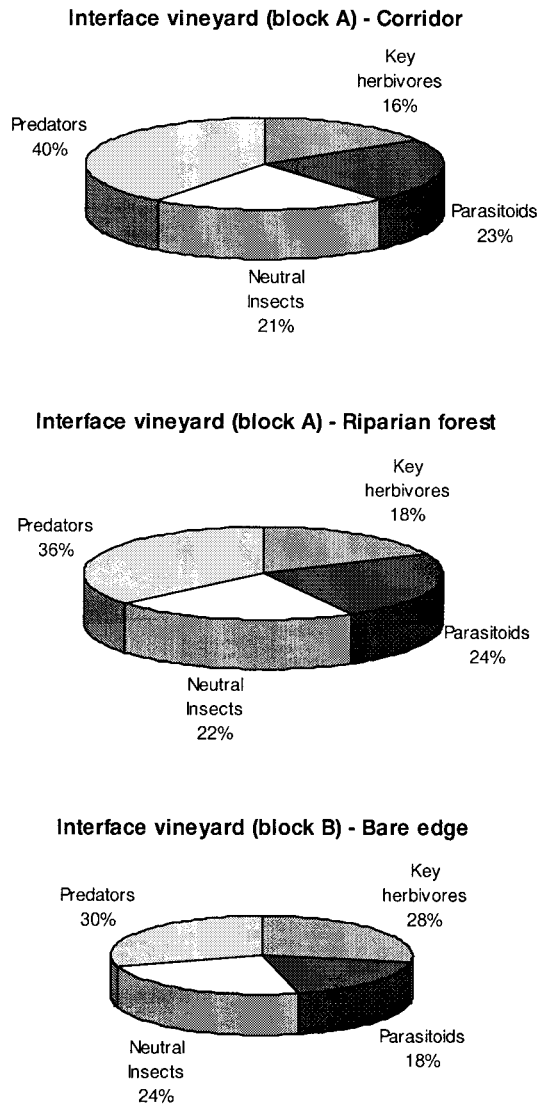


Figure 3. Seasonal proportions (mean of six sampling dates) of major insect guilds caught by Malaise traps at various interfaces during 1996 in Hopland, California.

penetrated and dissected by a five meter wide and three hundred meter long vegetational corridor composed of sixty five different species of flowering plants. Main species include *Erigeron annuus* (L.), *Achillea millefolium* L., *Foeniculum vulgare* Miller, *Buddleja* sp., and *Cistus skanbergii* (L.).

Sampling procedures

In order to determine the species diversity and abundance levels of the arthropod fauna associated with the corridor's shrub and herb layer, insects on the vegeta-

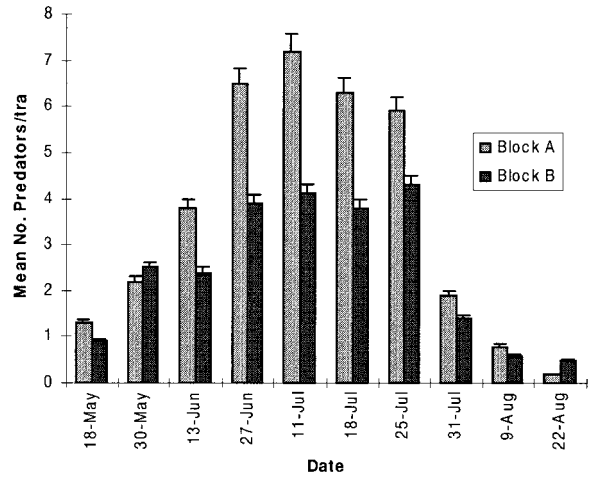


Figure 4. Comparison of abundance of generalist predators (numbers per yellow sticky trap) between block A (with a corridor) and block B (without corridor) ($P < 0.05$, Wilcoxon's signed rank test) (Hopland, California 1996).

tion were sampled two times per month with a D-Vac insect suction machine moved vertically for 1 min from the foliage to the ground surface on specific dominant plant species present in the corridor. Direct observation of adult and immature stages of the beneficial insects associated with flowers on specific corridor plant species was done to detect specific food or refuge resources for key natural enemies. Also, ten yellow and ten blue sticky traps (10 by 17-cm [Seabright Laboratories, Emeryville, CA, USA] coated with tanglefoot) were randomly placed within the corridor, for 7-day periods, and replaced weekly throughout the season to assess presence and abundance of various insect species.

To determine if the corridor influences the species diversity and abundance of entomophagous insects in the adjacent vineyard, two Malaise traps were placed across 'flight paths' between block A and the corridor on the south side and two between the vineyard and the riparian forest on the north side. Two Malaise traps were also placed between block B of the vineyard and the adjacent bare edge. To maximize catches of flying and wind-carried arthropods at the vineyard interfaces, samples were taken from May through September. Each Malaise trap contained a one-quart glass jar filled with ethyl alcohol, which was replaced every two weeks and taken into the laboratory where counting and sorting into families and trophic guilds occurred.

Ten yellow and ten blue sticky traps were placed at different points within the vineyard at increasing distances from the corridor or the bare edge (row

1=1.5 m, row 5=7.5 m, row 15=25 m, row 25=40 m, row 45=70 m, in blocks A and B, respectively) to monitor diversity and abundance of the entomofauna. Yellow sticky traps were used to monitor leafhoppers, the egg parasitoid *A. epos* and various predator species. Blue sticky traps were mainly used to assess thrips and *Orius* sp. populations (Hemiptera: Anthocoridae). Traps were oriented perpendicular to the predominant wind direction and positioned above the vine canopy. Traps were deployed beginning April and replaced weekly throughout 1996–1997 growing seasons. All traps were returned to the laboratory and examined with the dissection microscope to count the number of phytophagous insects and associated natural enemies on the traps. Insect densities (untransformed) at various distances from the corridor were compared using Mann–Whitney U-test. Wilcoxon's signed rank test was used to compare densities in block A as a whole with those observed in block B.

In the same rows where sticky traps were placed, grape leaves were visually examined in the field and the number of *E. elegantula* nymphs recorded. Populations of leafhopper nymphs were weekly estimated on 10 randomly selected leaves in each row. This sampling method allowed one to determine quickly and reliably the proportion of infested leaves, densities of nymphs, and rates of leafhopper egg parasitization by the *A. epos* wasp (Flaherty *et al.* 1992). Egg parasitism in vineyards was determined by examining grape leaves with a dissection microscope for the presence of parasitized or healthy *E. elegantula* eggs (Settle and Wilson 1990).

Results

Diversity of predators in the corridor

Data collected within the corridor during the 1996 and 1997 growing seasons show among the prevalent group of predators, species such as *Chrysoperla carnea* (Neuroptera: Chrysopidae), *Orius* sp. (Hemiptera: Anthocoridae), *Nabis* sp. (Hemiptera: Nabidae), *Geocoris* sp. (Hemiptera: Lygaeidae), and several members of the families Coccinellidae, Syrphidae, Mordellidae and some species of thomisid spiders. These predators were commonly found on the flowers of the dominant corridor plants such as fennel (*Foeniculum vulgare*), yarrow (*Achillea millefolium*), *Erigeron annuus* and *Buddleja* spp. (Figure 1). Certain predator species were continuously found associated

with specific flowering plants as indicated by yellow and blue sticky traps placed within the corridor. The flowering sequence of the various plant species provided a continual source of pollen and nectar, as well as a rich and abundant supply of neutral insects (non-pestiferous herbivores) for the various predator species, thus allowing the permanence and circulation of viable populations of key species within the corridor (Figure 2).

Interception of arthropods with Malaise traps

Considerable exchange of arthropods occurred at the interface of the forest, the corridor and the adjacent block A vineyard. This is illustrated by the substantial number of arthropods intercepted by the Malaise traps placed at the forest-vineyard and corridor-vineyard interfaces.

Of all the number of species of arthropods caught by the Malaise traps during the 1996 season, there was a tendency for more predators and parasitoids to be caught at the interface of the vineyard and the corridor in block A (63%), and also at the interface of the vineyard and the riparian habitat (60%), than in the interface of the vineyard and the vegetation free edge (48%) in block B. More key herbivores were caught at the block B bare edge interface (28%) than in the other block A interfaces (corridor 16% and forest 18%), indicating that in the block without corridor, exchange of herbivores was more prevalent than the exchange of natural enemies (Figure 3). The net effect was that the total number of generalist predators tended to be greater in block A (Figure 4) than in block B which lacked a corridor ($P < 0.05$ Wilcoxon's signed rank test).

Population gradients of leafhoppers and thrips

In both years in block A, adult leafhoppers exhibited a clear density gradient reaching lowest numbers in vine rows near the corridor and forest and increasing in numbers towards the center of the field, away from the adjacent vegetation. The highest concentration of leafhoppers occurred after the first 20–25 rows (30–40 m) downwind from the corridor. Such a gradient was not apparent in block B where the lack of the corridor resulted in a uniform dispersal pattern of leafhoppers (Figures 5a and 5b). Nymphal populations behaved similarly reaching highest numbers in the center rows of block A in both years. The area of influence of the corridor extended to rows 15–20 (25–30 m) whereas the area of influence of the forest on nymphs reached up to 10–15 rows (20–25 m) as

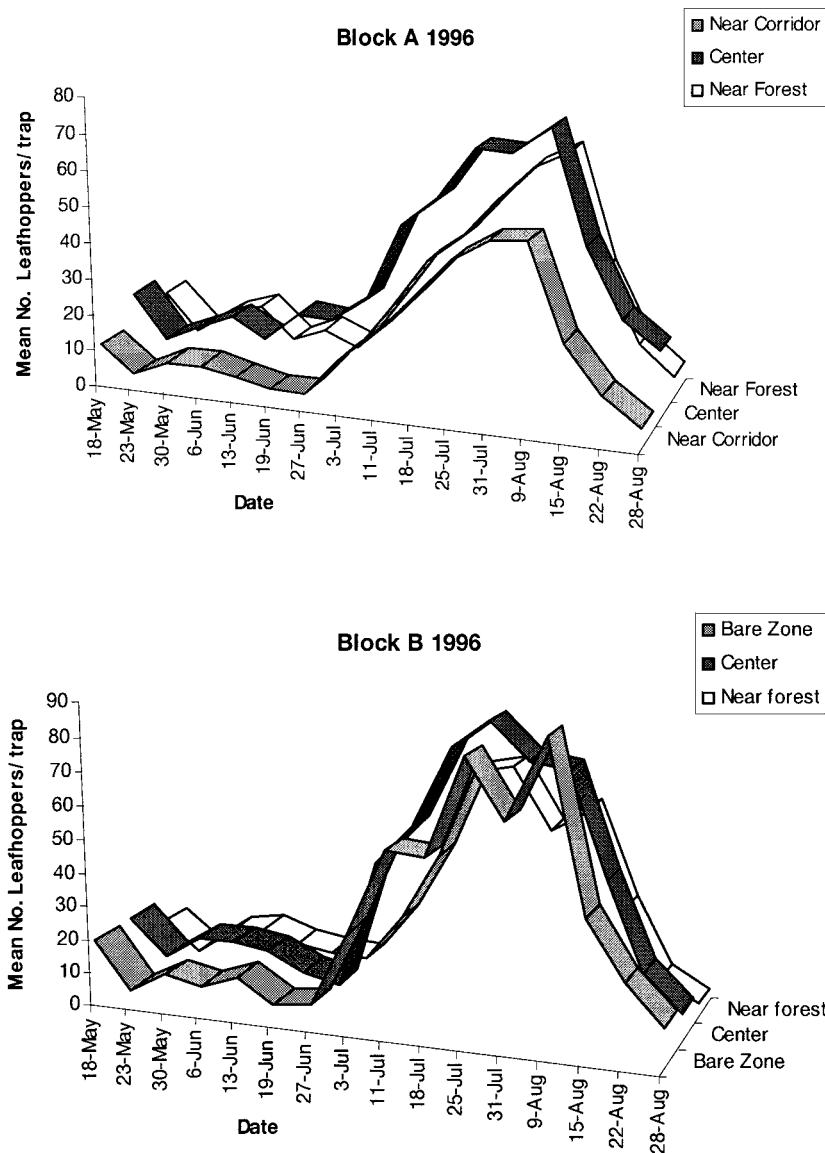


Figure 5a. Seasonal patterns (numbers per yellow sticky trap) of adult leafhopper *E. elegantula* in both vineyard blocks, as influenced by the presence or absence of forest and the corridor ($P < 0.05$; Mann-Whitney U-test) (Hopland, California 1996).

evident from 1997 catches. Nymphs were similarly distributed over the whole block B field.

A similar population and distribution gradient was apparent for thrips (Figures 6a and 6b). In both years catches in block A were substantially higher in the central rows than in rows adjacent to the forest; catches were particularly low in rows near the corridor. In block B there were no apparent differences in catches between the central and bare edge rows, although catches near the forest were lowest especially during 1997.

Natural enemies

Generalist predators in the families Coccinellidae, Chrysopidae, Nabidae and Syrphidae exhibited a density gradient in block A, indicating that the abundance and spatial distribution of these insects was influenced by the presence of the forest and the corridor which channeled dispersal of the insects into adjacent vines (Figures 7a and 7b). Predators were more homogeneously distributed in block B as no differences in spatial pattern in predator catches was observed between bare edge and central rows, although their

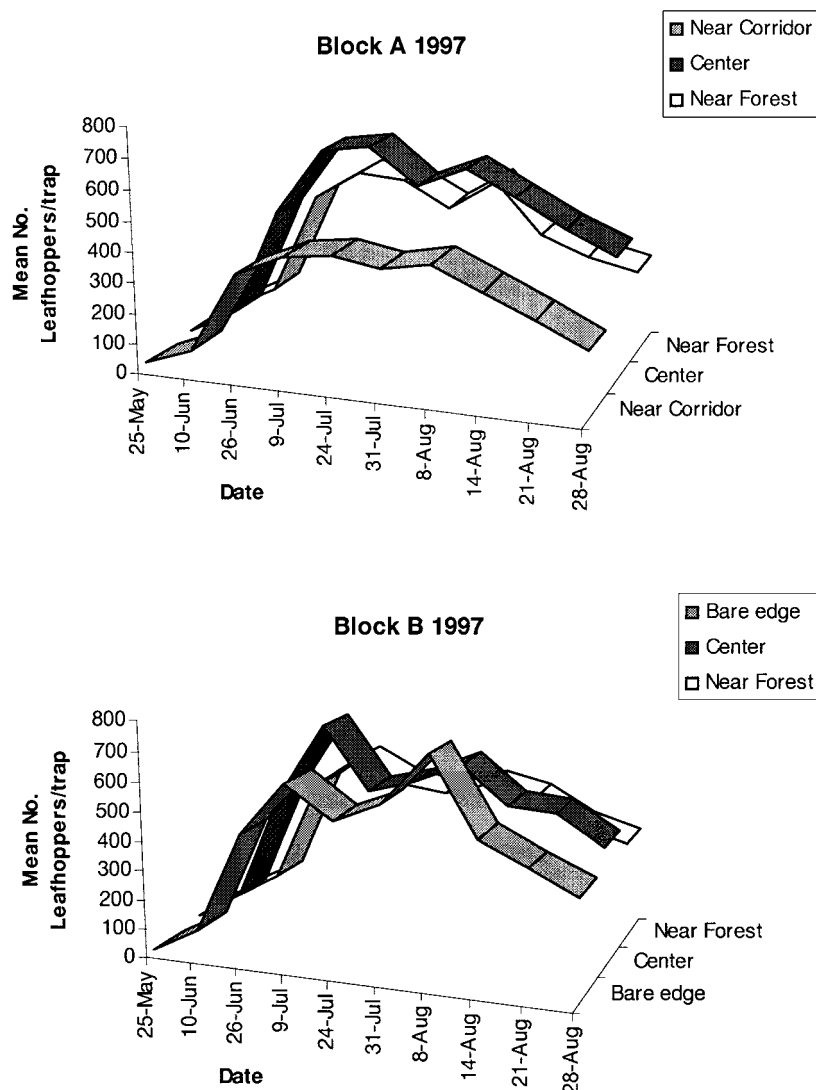


Figure 5b. Seasonal patterns (numbers per yellow sticky trap) of adult leafhopper *E. elegantula* in both vineyard blocks, as influenced by the presence or absence of forest and the corridor ($P < 0.05$; Mann-Whitney U-test) (Hopland, California 1997).

abundance tended to be higher in rows close to the forest (10–15 m).

In block A the distribution of *Orius* sp. was affected by the corridor and forest as higher numbers of *Orius* sp. could be found in vines near the borders (up to 20 m), whereas in Block B no dispersal gradient was apparent (Table 1).

A. epus colonized vineyards from the corridor and forest throughout the sampling area, exhibiting higher densities in late July and throughout August of both years in the central vineyard rows where leafhoppers were most abundant (Figures 8a and 8b). The increasing numbers of *A. epus* captured over time was

noticeable from late-June onward. This indicated that parasitoids began moving into vineyards in early June, a few weeks after *E. elegantula* adults moved into vineyards. The appearance of *A. epus* coincided with the beginning of the oviposition period of leafhopper adults.

Leaf examination revealed high levels of parasitism across leafhopper generations for both 1996 and 1997 in both blocks (Table 2). Eggs in center rows had slightly higher mean parasitization rates than eggs located in rows near the forest or corridor. The proportion of eggs parasitized tended to be uniformly distributed across all rows in both blocks. It is assumed

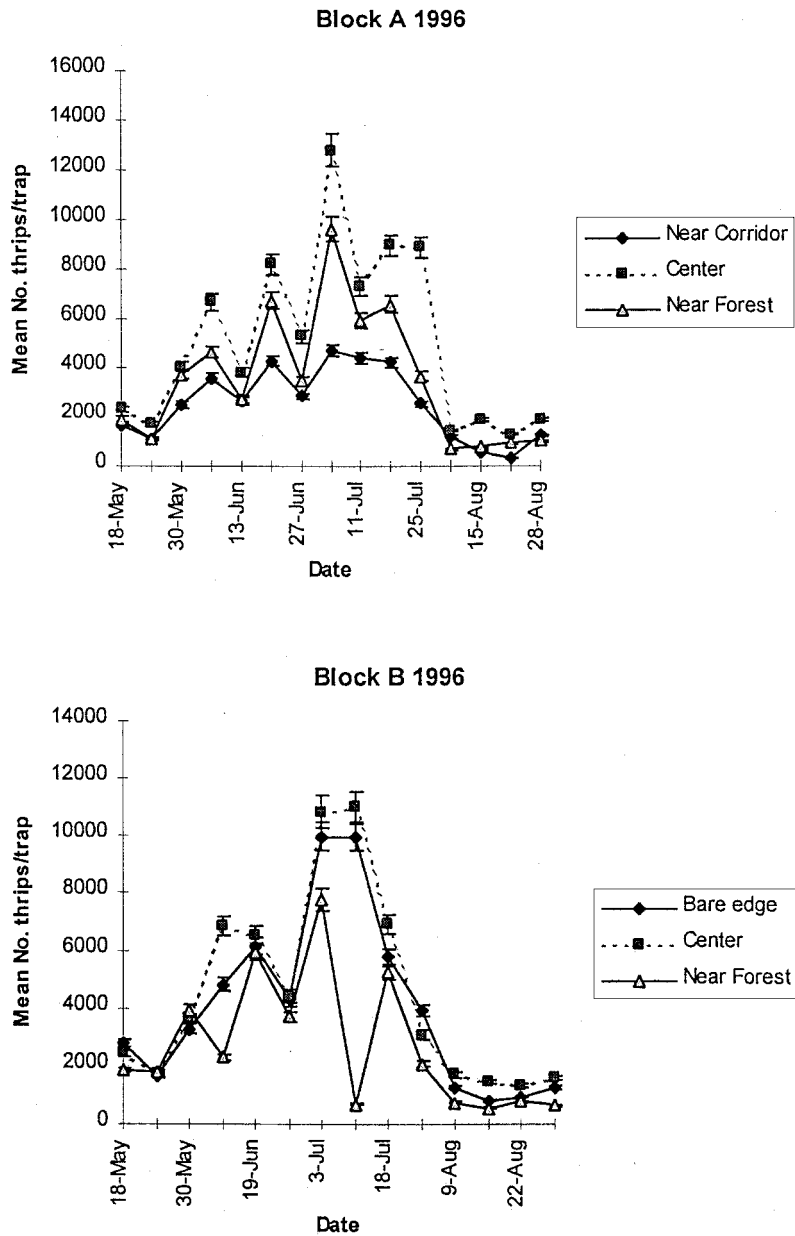


Figure 6a. Seasonal patterns of thrips (numbers per blue sticky trap) in both vineyard blocks, as influenced by the presence or absence of forest edge and the corridor ($P < 0.05$; Mann-Whitney U-test) (Hopland, California 1996).

that the presence of the forest and corridor was associated with the colonization of *A. epos* but this did not result in a net season-long prevalence in *E. elegantula* egg parasitism rates in rows adjacent to such habitats.

Discussion

This research indicates that dispersal and subsequent within vineyard distribution and densities of herbivores and associated natural enemies is influenced by adjacent landscape features such as a forest edge and a corridor. The presence of riparian habitats enhances predator colonization and abundance of adjacent vineyards, although this influence is limited by the distance

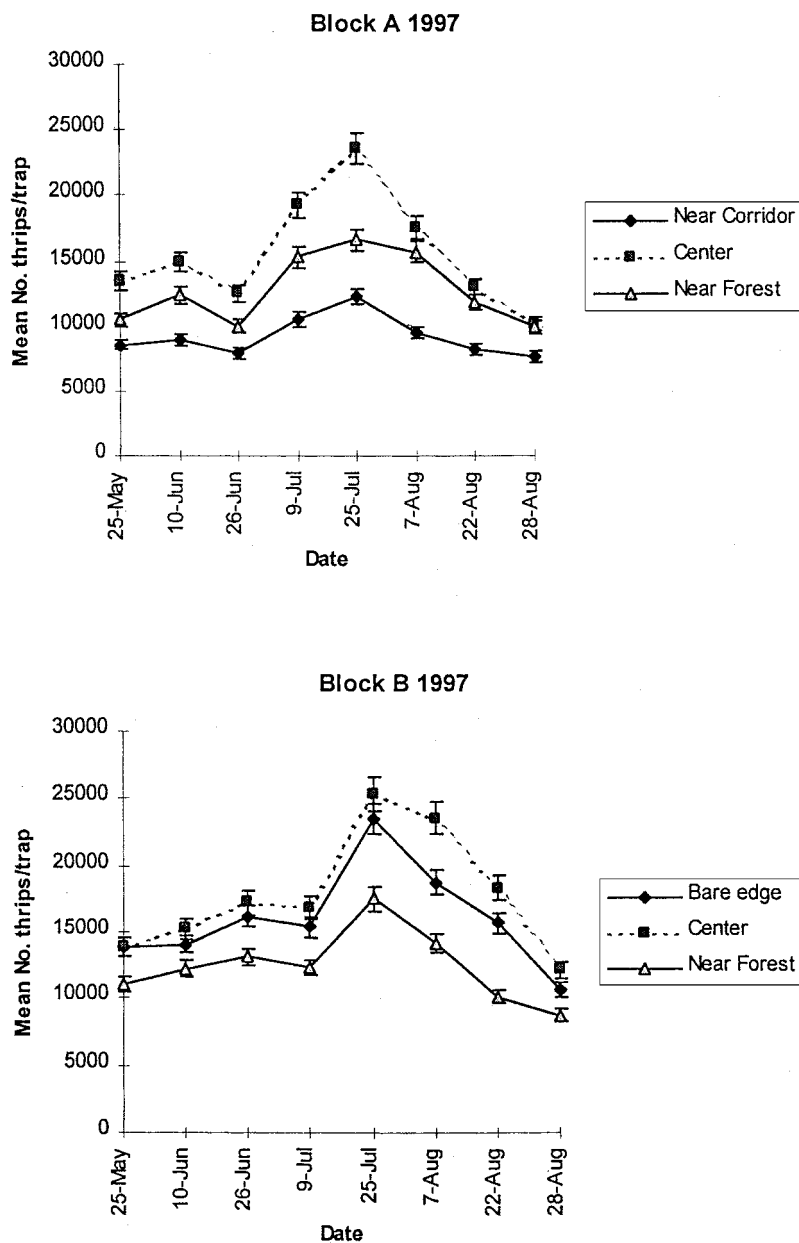


Figure 6b. Seasonal patterns of thrips (numbers per blue sticky trap) in both vineyard blocks, as influenced by the presence or absence of forest edge and the corridor ($P < 0.05$; Mann-Whitney U-test) (Hopland, CA, USA 1997).

Table 1. Mean \pm SE *Orius* sp. densities observed in border and central vineyard rows of blocks A and B, in Hopland, CA, USA (1996).

Vineyard rows	June		July		August	
	A	B	A	B	A	B
Near corridor	1.33 \pm 0.08*	1.20 \pm 0.3	3.75 \pm 0.94	2.54 \pm 0.84	1.53 \pm 0.51	1.85 \pm 0.56
Bare edge/center field	1.16 \pm 0.05	1.36 \pm 0.45	2.11 \pm 0.52	2.96 \pm 0.98	1.20 \pm 0.4	1.70 \pm 0.62
Near Forest	1.90 \pm 0.47	1.40 \pm 0.46	4.52 \pm 1.5	3.01 \pm 0.75	1.42 \pm 0.38	2.03 \pm 0.84

*Monthly means per blue sticky trap (average of 4 sampling dates).

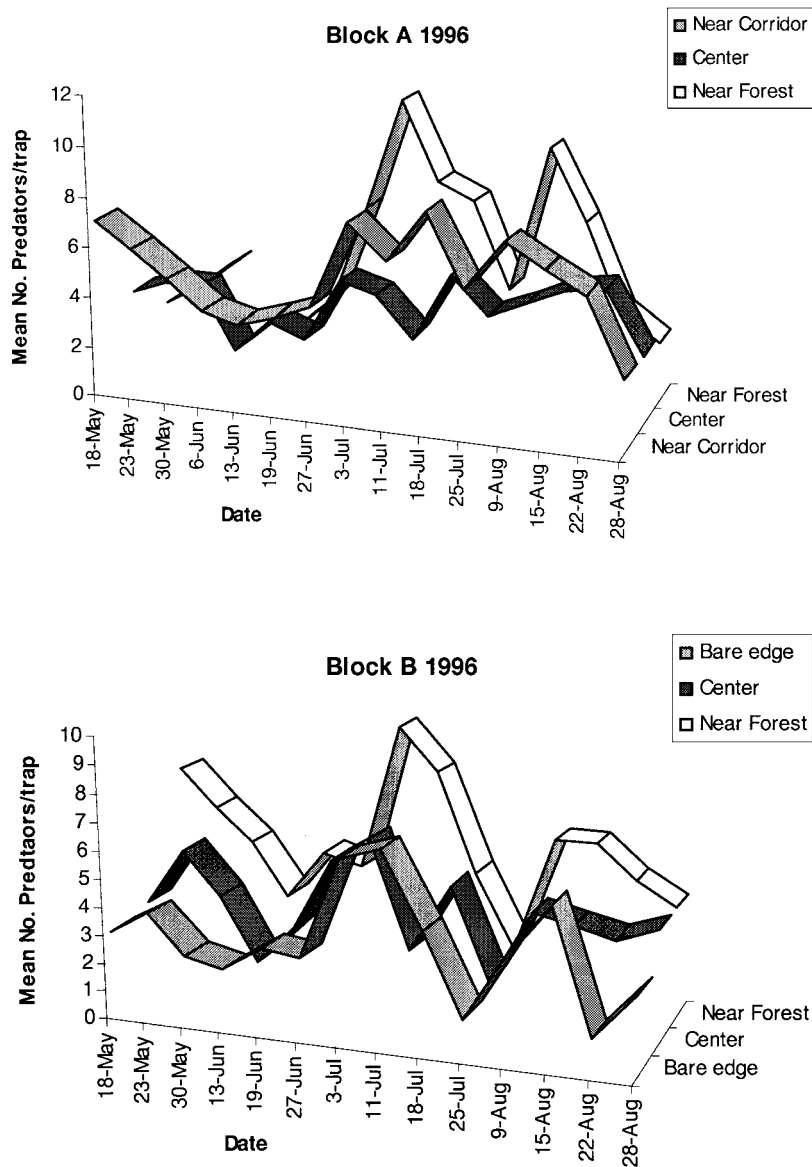


Figure 7a. Seasonal patterns of predator catches (numbers per yellow sticky trap) in both vineyard blocks, as influenced by the presence or absence of forest edge and the corridor ($P < 0.05$; Mann-Whitney U-test) (Hopland, CA, USA 1996).

to which natural enemies disperse into the vineyard (Corbett and Plant 1993). The corridor however amplified this influence by allowing enhanced and timely circulation and dispersal movement of predators into the center of the field. The great availability of pollen and nectar displayed by the various flowers of the corridor as well as the diversity and prevalence of neutral insects (non-pestiferous herbivores) attracted high numbers of generalist predators. Increased abundance of alternative food has often been associated

with a rise in predator abundance either by enhancing their reproduction and/or survival (Lys et al. 1994). In turn, this increases the impact of predators especially in crop rows in close vicinity to habitats providing alternative food (Coombes and Sotherton 1986)

As shown by Malaise trap catches, many of the predator species present in the corridor originated from the riparian forest edge. For some predators' such as Coccinellidae, Chysopidae and Syrphidae, the corridor influenced numbers and dispersal in late

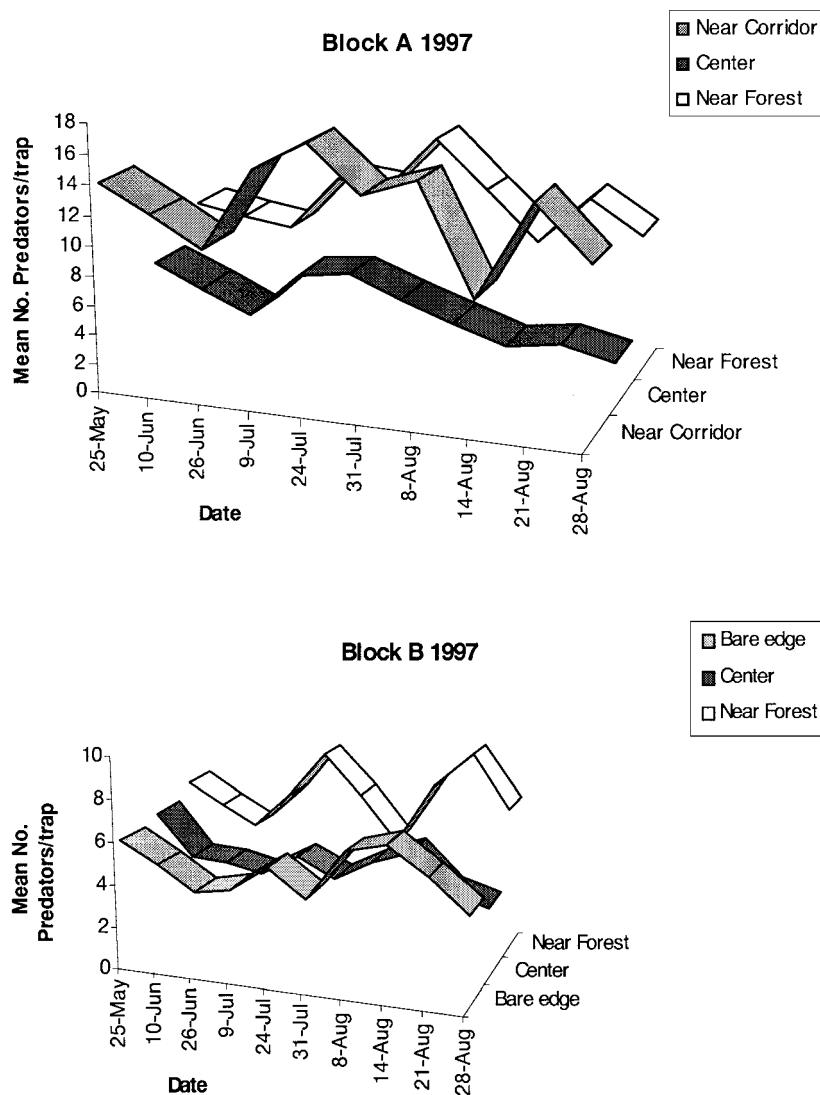


Figure 7b. Seasonal patterns of predator catches (numbers per yellow sticky trap) in both vineyard blocks, as influenced by the presence or absence of forest edge and the corridor ($P < 0.05$; Mann–Whitney U-test) (Hopland, CA, USA 1997).

Table 2. Mean \pm SE leafhopper percent egg parasitism by *Anagrus epos* in border and central rows of both vineyard blocks in Hopland, CA, USA.

Vineyard rows	Block A		Block B	
	1996	1997	1996	1997
Near Corridor	46 \pm 16*	59 \pm 14	62 \pm 21	73 \pm 45
Center Field	61 \pm 23	82 \pm 33	75 \pm 32	80 \pm 37
Near Forest	57 \pm 31	77 \pm 27	74 \pm 43	75 \pm 29

*Seasonal means (average of 12 sampling dates).

spring and early summer, the effect acting through the presence of non-crop aphids and other Homoptera (for Coccinellidae and Chrysopidae), and nectar and pollen (for Syrphidae). Some plant species harbored populations of neutral Homoptera and Hemiptera, which acted as important food reservoir for predatory Anthocoridae and Miridae migrating from the forest and later moving into the vineyard

Various patterns were detected in this study:

- Adult and nymphal leafhopper and thrips populations exhibited density gradients tending to reach highest numbers in the centers of the vineyards.

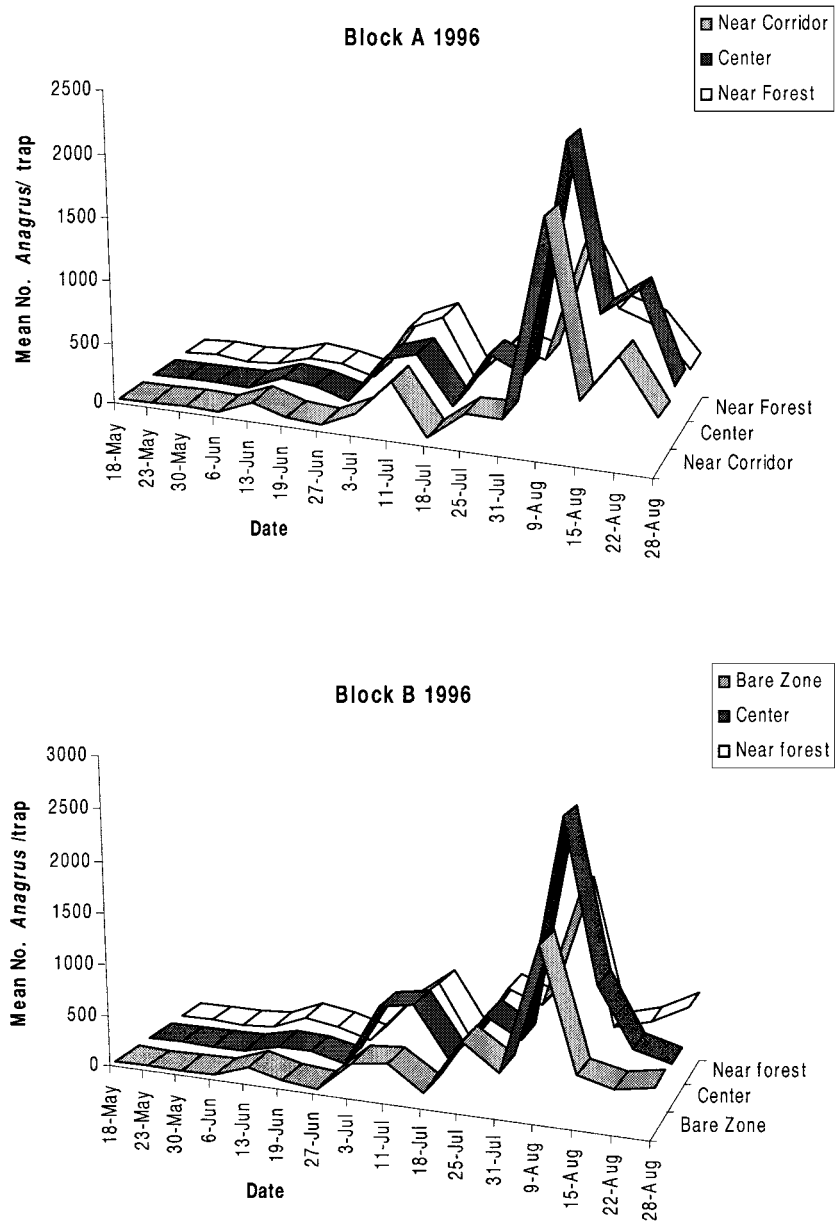


Figure 8a. Seasonal pattern of *Anagrus* catches (numbers per yellow sticky traps) in both vineyard blocks, as influenced by the presence or absence of forest edge and the corridor ($P < 0.05$; Mann-Whitney U-test) (Hopland, CA, USA 1996).

– Although it is shown that *A. epos* colonizes the vines from edges (Corbett and Rosenheim 1996), in this study, the parasitoid followed the abundance patterns of leafhoppers and did not display the distributional response exhibited by predators. Other researchers who have found positive effects of flowers on parasitoid diversity and abundance have also reported the difficulty of showing an ev-

ident gradient of parasitoids from a rich flowering habitat into a crop area (Duelli et al. 1990).
 – Given that *A. epos* dispersed similarly across rows in both blocks, apparently predator enhancement near the vegetational interfaces explained the lower populations of leafhoppers and thrips in the border rows of block A. Such successful impact of predators can be assumed because fewer adults and

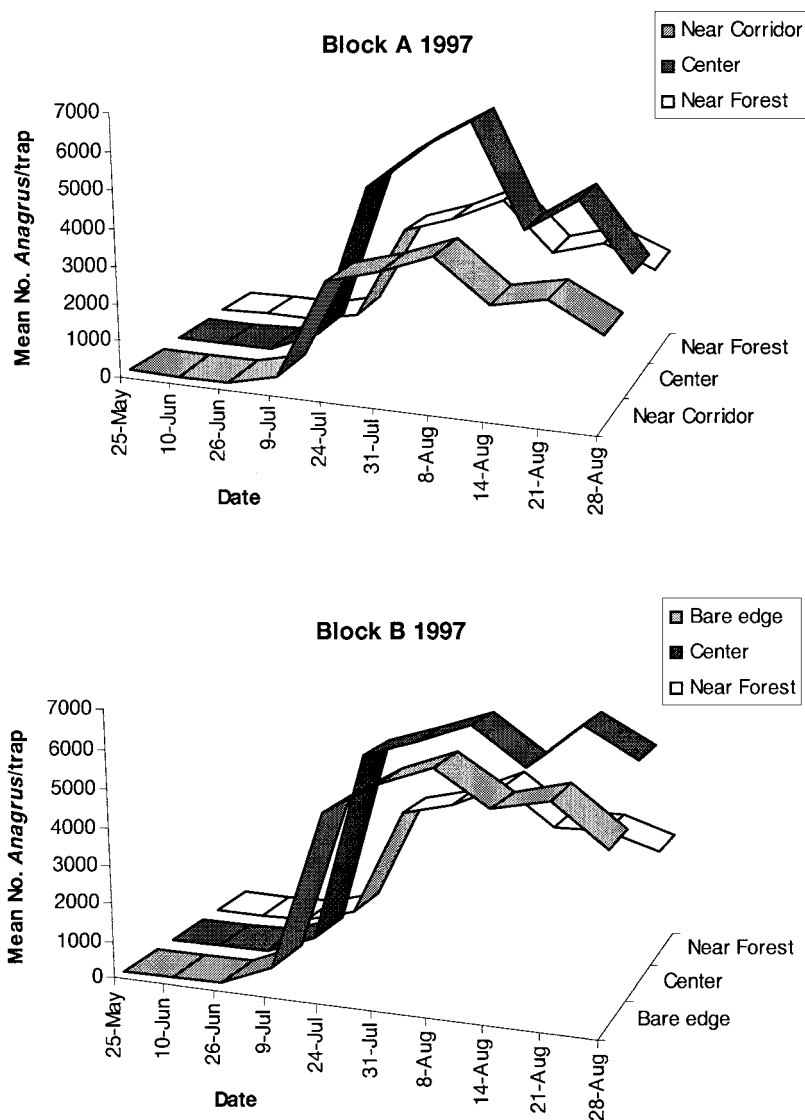


Figure 8b. Seasonal patterns of *Anagrus* catches (number per yellow sticky trap) in both vineyard blocks, as influenced by the presence or absence of forest edge and the corridor ($P < 0.05$; Mann-Whitney U-test) (Hopland, CA, USA 1997).

nymphs of leafhoppers and thrips were caught near the corridor than in the middle of the vineyards.

The corridor provided a constant supply of alternative food for predators effectively decoupling predators from a strict dependence on grape herbivores and avoiding a delayed colonization of the vineyard. This complex of predators continuously circulated into the vineyard interstices establishing a set of trophic interactions leading to lower numbers of leafhoppers and thrips in the border rows of the vineyard.

Findings from this study also suggest that the creation of corridors across vineyards can serve as a

key strategy to allow natural enemies emerging from riparian forests to disperse over large areas of otherwise monoculture systems. Such corridors should be composed of locally adapted plant species exhibiting sequential flowering periods, which attract and harbor an abundant diversity of predators and parasitoids increasing biodiversity. Thus, these corridors or strips, which may link various crop fields and riparian forest remnants, can create a network, which would allow many species of beneficial insects to disperse throughout whole agricultural regions transcending farm boundaries (Baudry 1984).

Acknowledgements

Thanks are due to Dr Harry Kaya and Dr Donald D. Dahlsten for their support and useful guidance. We are grateful for the valuable help in the field and data collection to Rene Montalba, Luz Mercedes Velasquez, Lya Neira, Carlos Pino, Lori Ann Trupp, Ana Maria Altieri, Diego Vasquez, Fabian Banga, Keiko Okano, Ines Estrada, Olga Ortiz, James and Alexander. This research was funded By The Clarence E. Heller Charitable Foundation of San Francisco, California, and the Organic Farming Research Foundation, Santa Cruz, CA, USA.

References

- Altieri, M. A. 1994. Biodiversity and Pest Management in Agroecosystems. Haworth Press, New York, NY, USA.
- Baudry, J. 1984. Effects of landscape structure on biological communities: the case of hedgerows network landscapes, Vol. 1. pp. 55–65. *In: Methodology in Landscape Ecological Research and Planning*. Edited by J. Brandt and P. Agger. Roskilde University Center, Roskilde, Denmark.
- Corbett, A. and Rosenheim, J. A. 1996. Impact of natural enemy overwintering refuge and its interaction with the surrounding landscape. *Ecol Entomol* 21: 155–164.
- Corbett, A. and Plant, R. E. 1993. Role of movement in the response of natural enemies to agroecosystem diversification: a theoretical evaluation. *Environ Entomol* 22: 519–531.
- Coombes, D. S. and Sotherton, N. W. 1986. The dispersal and distribution of polyphagous predatory Coleoptera in cereals. *Ann Appl Biol* 108: 461–474.
- Doutt, R. I and Nakata, J. 1973. The *Rubus* leafhopper and its egg parasitoid: an endemic biotic system useful in grape-pest management. *Environ Entomol* 2: 381–386.
- Duelli, P., Studer, M., Marchand, I. and Jakob, S. 1990. Population movements of arthropods between natural and cultivated areas. *Biol Conserv* 54: 193–207.
- Flaherty, D. L., Christensen, P. T., Lanini, T., Marois, J. and Wilson, L. T. 1992. Grape Pest Management. University of California Division of Agriculture and Natural Resources, Davis, CA, USA.
- Fry, G. 1995. Landscape ecology of insect movement in arable ecosystems. *In Ecology and Integrated Farming Systems*. Edited by D. M. Glen, M. P. Greaves and H. M. Anderson. John Wiley and Sons, Bristol, UK, pp. 177–202.
- Kido, H.; D. L. Flaherty; D. F. Bosch and K. A. Vaero. 1984. French prune trees as overwintering sites for the grape leafhopper egg parasite. *Am J Enol Vitic* 35: 156–160.
- Lewis, T. 1965. The effects of shelter on the distribution of insect pests. *Scientific Horticulture* 17: 74–84.
- Lys, J. A., Zimmermann, M. and Nentwing, W. 1994. Increase in activity density and species number of carabid beetles in cereals as a result of strip-management. *Entomol Exp Appl* 73: 1–9.
- Murphy, B. C., Rosenheim, J. A. and Granett, J. 1996. Habitat diversification for improving biological control: Abundance of *Anagrus epos* (Hymenoptera: Mymaridae) in grape vineyards. *Environ Entomol* 25 (2): 495–504.
- Nentwing, W., Frank, T. and Lethmayer, C. 1998. Sown weed strips: artificial ecological compensation areas an important tool in conservation biological control. *In Conservation Biological Control*. Edited by P. Barbosa. AUTHOR, Publisher please, pp. 133–151.
- Pollard, E. 1968. Hedges IV. A comparison between the carabidae of a hedge and field site and those of a woodland glade. *J Appl Ecol* 5: 649–657.
- Rosenberg, D. K., Noon, B. R. and Meslow, E. C. 1997. Biological corridors: form, function and efficacy. *BioScience* 47 (10): 677–687.
- Settle, W. H. and Wilson, T. 1990. Invasion by the variegated leafhopper and biotic interactions: parasitism, competition, and apparent competition. *Ecology* 71: 1461–1470.
- Sotherton, N. W. 1984. The distribution and abundance of predatory arthropods overwintering on farmland. *Ann. Appl. Biol.* 105: 423–429.
- Thomas, M. B., Wratter, S. D. and Sotherton, N. W. 1991. Creation of 'islands' habitats in farmland to manipulate populations of biological arthropods: predator densities and emigration. *J Appl Ecol* 28: 906–917.
- Wratten, S. D. 1988. The role of field margins as reservoirs of natural enemies. *In Environmental Management in Agriculture*. Edited by A.J. Burn. Belhaven Press, London.