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CONTROL OF THE GRAPE BERRY MOTH, *PARALOBESIA VITEANA*, USING REDUCED-RISK INSECTICIDES, CULTURAL CONTROLS, AND CONSERVATION OF NATURAL ENEMIES

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By

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ABSTRACT

CONTROL OF THE GRAPE BERRY MOTH, *PARALOBESIA VITEANA*, USING REDUCED-RISK INSECTICIDES, CULTURAL CONTROLS, AND CONSERVATION OF NATURAL ENEMIES

By

Paul E. Jenkins

The grape berry moth, *Paralobesia viteana* (Clemens), is the primary insect pest of vineyards in eastern North America. For the development of a reduced-risk integrated pest management program, we conducted experiments in Michigan vineyards testing two alternative methods for control of *P. viteana* and their impact on natural enemies within this system during 2003-2005. Insect control programs based on the reduced-risk insecticides methoxyfenozide and spinosad for control of *P. viteana* and conservation of natural enemies were compared with programs using only conventional insecticides. This multi-year evaluation provides evidence that control of *P. viteana* is achievable using a program that depends on reduced-risk insecticides for control of late-season generations of this pest. Parasitism of *P. viteana* and abundance of natural enemies within vineyards and the surrounding landscape were similar between the two insecticide programs. *Paralobesia viteana* is a monophagous pest and infests both wild and cultivated grape (*Vitis* spp.). To determine the effect of wild grapevines on *P. viteana* infestation and natural enemies in vineyards, wild grapevines were cut up to 60 m deep in woods adjacent to vineyards. No difference in *P. viteana* infestation, parasitism of *P. viteana*, or natural enemy abundance was observed. For the first time, parasitoids and predator insects within Michigan vineyards were described and their community composition documented.

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CHAPTER 1

CONTROL OF THE GRAPE BERRY MOTH, *PARALOBESIA VITEANA*, USING REDUCED-RISK INSECTICIDES, CULTURAL CONTROLS, AND CONSERVATION OF NATURAL ENEMIES.

INTRODUCTION

Grapes are the largest fruit industry in the US, with an annual farm gate value of $2.8 billion (2004). Grapes are grown on approximately 32,400 ha in the eastern US and have a farm gate value of $128 million annually (2004). In Michigan, grapes are grown on approximately 5,600 ha and have an annual farm gate value of 19 million (2004), with most production occurring in the southwest area of the state. The grape industry has historically relied upon broad-spectrum organophosphate, pyrethroid, and carbamate insecticides to control the complex of insect pests that can damage the fruit, leaves, roots, and shoots of this crop. Insect pests are a major challenge to grape production, and grape growers will continue to require effective management programs if they are to manage this crop economically. In a survey of pesticide use in US crops, Gianessi and Marcelli (2000) reported that about one million acres used for grape production received a total of 24 million kilograms of active ingredient per year, making it the sixth highest crop for pesticide application. While not all of this active ingredient was applied for control of insect pests, grapes undoubtedly receive high inputs of insecticides to prevent infestation by the complex of insect pests that can cause reduction in yield and fruit quality, or the rejection of the crop during inspection.

In eastern US viticulture, insect pest management programs are primarily directed at controlling cluster infestation by the grape berry moth, *Paralobesia viteana* (Clemens)[1] (Lepidoptera: Tortricidae), the key insect pest of vineyards east of the Rocky Mountains. If too many clusters are infested at harvest, load rejection may occur. For example, in 2002, approximately 1,000 tons of grapes were rejected at the Welch's processing plant in Michigan, and this loss had an estimated farm gate value of $300,000 (T. Davenport, personal communication). Infestation by *P. viteana* can also reduce yields or force grape growers to leave vineyards unharvested. Prevention of damage and infestation by this pest has been achieved primarily by the use of broad-spectrum insecticides, but increased restrictions on these insecticides, particularly in minor crops, have prompted the need for alternative control methods.

The recent availability of reduced-risk insecticides for use by grape growers against *P. viteana* provides an opportunity for conservation of natural enemies of this pest (Pfeiffer 2000), because these chemicals may be less disruptive to natural enemies. Reduced-risk insecticides are products which reduce risks to human health and the environment when compared to existing alternatives, particularly those which are toxic, persistent, and bioaccumulate in food chains (1998). Within the reduced-risk insecticide category, some chemical classes are broadly active while others are selective to certain taxa. All selective insecticides are considered reduced-risk by the US EPA, but some reduced-risk insecticides have a broad-spectrum of activity, and can have negative effects on pests in different taxa including natural enemies. For the development of an integrated pest management (IPM) program in Michigan vineyards, it will be important to

[1] *Paralobesia viteana* (Clemens) was previously described as *Endopiza viteana* Clemens (Brown 2005, Brown 2006).

determine what natural enemy species are present and whether their abundance could be enhanced if reduced-risk insecticides are used.

Many vineyards in the eastern US are found in close association with deciduous woods, where wild grapevines (*Vitis* spp.) persist. Proximity of vineyards to deciduous woods has been found to be a risk factor for high *P. viteana* infestations (Dennehy et al. 1990, Botero-Garcés and Isaacs 2004a), and wild grapevine cutting, a form of agroecosystem modification, has been used by growers as a cultural control to reduce *P. viteana* pest pressure. However, few studies have examined the effects of cultural control practices on natural enemy species diversity and community composition (Schellhorn et al. 2000) and there is no published report of how removal of this native host near vineyards will affect the pest and natural enemy abundance in adjacent vineyards. It will be important to determine the efficacy of this practice for control of *P. viteana* and its effect on natural enemy populations before such a practice is recommended for grower adoption.

GRAPE INSECT PEST COMPLEX AND MANAGEMENT IN EASTERN NORTH AMERICA

Insect management programs in many eastern North American vineyards are primarily directed at preventing infestation of grape clusters by *P. viteana*. This insect occurs naturally on wild and cultivated *Vitis* spp. and is native to North America. Wild and cultivated grape are its only hosts and commercial viticulture has become widespread in areas throughout the geographic range of wild grape species. After becoming established in vineyards, *P. viteana* became a key pest and is now the primary target of vineyard pest management programs in the eastern US and Canada (Nagarkatti et al. 2002a, Botero-Garcés and Isaacs 2004a). *Paralobesia viteana* overwinter as pupae in leaves and fruit and emerge from May to June. After mating, females oviposit on developing buds, florets, and berries (Clark and Dennehy 1988, Tobin et al. 2003). On average, eggs eclose in 3-4 d (Tobin et al. 2001). There are four larval instars and larvae develop in approximately 10-13 d (Tobin et al. 2001). This species has two or three generations per year with a possible fourth generation in New York (Hoffman and Dennehy 1989) and Pennsylvania (Tobin et al. 2003). In southern regions, such as Virginia and Missouri, a fourth generation is common (Biever and Hostetter 1989, Tobin et al. 2003).

Other economically important grape insect pests include six species of early season Noctuid larvae, *Amathes c-nigrum* L., *Agrotis badinodis* Grote, *Amathes smithii* Snellen, *Rynchagrotis cupida* (Grote), *Euxoa messoria* Harris, and *Spaelotis clandestina* (Harris) (Marmor 1979, Marmor et al. 1981), the grape leafhopper, *Erythroneura comes* (Say), the potato leafhopper, *Empoasca fabae* (Harris) (Martinson et al. 1994, Martinson and Dennehy 1995, Martinson et al. 1997, Williams and Martinson 2000), the rose chafer, *Macrodactylus subspinosus* (Fabricius), and the Japanese beetle, *Popillia japonica* Newman (Mercader and Isaacs 2003a). Noctuid larvae damage developing buds in early spring, which can severely reduce crop yield since larvae chew through an entire bud and prevent development of primary, secondary, and tertiary clusters. Similarly, the rose chafer can damage clusters during bloom, thereby reducing yield. Leafhoppers, rose chafers, and Japanese beetles feed on leaves and may reduce photosynthesis, with subsequent reductions in fruit quality and vine health (Boucher and Pfeiffer 1989, Martinson et al. 1997, Mercader and Isaacs 2003b, Mercader and Isaacs 2004). There are some additional minor pests found in vineyards (Isaacs et al. 2003), but they rarely cause economic injury.

For control of the grape pest complex in the eastern US, growers rely on multiple applications of organophosphate, carbamate, or pyrethroid insecticides, with most applications targeting control of *P. viteana*. Broad-spectrum insecticides generally provide control of both primary and secondary pests. For example, secondary pests such as leafhoppers may be adequately controlled by the use of broad-spectrum insecticides targeting *P. viteana* (Martinson et al. 1994, Martinson et al. 1997, Williams and Martinson 2000). However, passage of the Food Quality Protection Act in 1996 has led to restrictions on the use of effective broad-spectrum insecticides in this industry. In addition, resistance to carbaryl has recently been detected in populations of *P. viteana* in New York and Pennsylvania (Nagarkatti et al. 2002b). Thus, grape growers need new options for effectively controlling primary and secondary insect pests.

In 2003, two new reduced-risk insecticides, methoxyfenozide (Intrepid®) and spinosad (SpinTor®) produced by Dow AgroSciences, Indianapolis, were registered for control of *P. viteana* in Michigan vineyards. These products provide the potential for *P. viteana* control while minimizing the suppression of biological control agents commonly caused by the use of broad-spectrum insecticides (Dhadialla and Jansson 1999, Trisyono et al. 2000, Carlson et al. 2001, Isaacs et al. 2005).

BIOLOGICAL CONTROL IN EASTERN US GRAPE PRODUCTION

The complex of grape insect pests and their biological control agents is different in the eastern US compared to the western US. For example, *P. viteana* only occurs east of the

Rocky Mountains. Compared to other crops, biological control efforts in grape are minimal worldwide and most research in the US has been in California (Flaherty and Wilson 1999). For example, it was discovered that the abundance of the parasitoid *Anagrus epos* (Girault) is greater in grape vineyards located downwind from prune trees (Corbett and Rosenheim 1996, Murphy et al. 1998). Other examples of research in California vineyards include spider composition and abundance (Costello and Daane 1995, Costello and Daane 2003), predation of *Erythroneura variabilis* and *E. elegantula* by lacewings (Daane et al. 1996), parasitism by *Anagyrus pseudococci* of the vine mealybug, *Planococcus ficus* (Daane et al. 2004) and predatory spider mites (Flaherty et al. 1992).

In eastern US viticulture, adoption of biological control strategies is at a very low level, although a number of studies have examined which natural enemies are present in the system, especially those which parasitize *P. viteana*. A survey for natural enemies of *P. viteana* in Pennsylvania revealed that *Trichogramma minutum* Riley was the only native egg parasitoid with potential for controlling *P. viteana*; however, natural parasitism by *T. minutum* was not dependable since it prefers wild *Vitis* spp. in wooded habitats over cultivated grapes (Nagarkatti et al. 2002a). Observations in Michigan vineyards indicate that parasitism of *P. viteana* eggs by *Trichogramma* spp. is at a low level until late in the season (Jenkins, unpublished data). Parasitoids are important natural enemies of many crop pests and many may be keystone species within agricultural ecosystems (LaSalle 1993). Parasitoids belonging to the Superfamilies Ichneumonoidea, Chalcidoidea, and Proctotrupoidea are some of the most abundant natural enemies in fruit cropping systems (Viggiani 2000). Parasitoids that attack *P. viteana* larvae have been described for New York State. In a study by Seaman et al. (1990), three prominent hymenopteran parasitoid species (*Trichogramma pretiosum* Riley, *Glypta mutica* Cushman, and *Apanteles polychrosidis* Viereck) that attack *P. viteana* were collected from three different habitats: wild grapes, organically managed commercial vineyards, and conventionally managed commercial vineyards. In this study, average parasitism by the egg parasitoid *T. pretiosum* was greater than other natural enemies (4.5-20.2%), with the highest parasitism levels occurring in wild habitats. The larval parasitoids *Glypta mutica* and *A. polychrosidis* caused lower levels of mortality (0.01-6.4% and 0-11.5%, respectively) than *T. pretiosum*. Combined, the three species have been observed causing 12-40% mortality of *P. viteana* (Dennehy et al. 1990, Seaman et al. 1990). Research has also been conducted to determine which *Anagrus* spp. are present in New York vineyards for control of leafhoppers (Williams and Martinson 2000) and whether parasitism by *Anagrus* parasitoids can be enhanced by providing cover crops in vineyards (English-Loeb et al. 2003).

METHODS TO ENHANCE BIOLOGICAL CONTROL

Biological control is defined as the use of natural enemies to suppress a pest population, thereby regulating their impact on the environment (Van Driesche and Bellows 1996, Huffaker and Dahlsten 1999). The three main categories of biological control implementation in pest management are: 1) introduction or classical, 2) augmentation, and 3) conservation (Debach and Rosen 1991, Van Driesche and Bellows 1996, Ehler 1998). These methods can be used individually or in combination to control single or multiple pests. Introduction biological control is the process of importing and releasing predators and parasitoids that are known to be effective against the pest. Augmentation biological control uses mass release of natural enemies to increase existing native natural enemy populations. Conservation biological control aims to maintain or preserve predators or parasitoids which occur naturally within the system. Conservation biological control assumes that natural enemies already exist locally and have the potential to effectively suppress the pest (Debach and Rosen 1991, Ehler 1998). Ultimately, for conservation biological control to be effective, natural enemies must be sufficiently abundant at the correct time to attack the pest(s) of interest (Van Driesche and Bellows 1996).

Successful conservation biological control programs seek primarily to identify and manipulate factors restraining natural enemy populations (Debach and Rosen 1991, Ehler 1998). The primary negative influences on natural enemies from agricultural intensification include broad-spectrum pesticide use, lack of overwintering sites, loss of non-crop habitat, and lack of nectar resources (Van Driesche and Bellows 1996, Ehler 1998, Landis and Marino 1999, Burel et al. 2000, Marino and Landis 2000, Viggiani 2000). The specific conditions required by natural enemies within a system can be enhanced by creating and maintaining physical refuge, as well as by providing alternative hosts, carbohydrate sources, and shelter (Letourneau 1998, Marino and Landis 2000). Cover crops can be managed within agricultural systems to increase natural enemy populations by enhancing these conditions (Bugg and Waddington 1994, Costello and Daane 1998, Costello and Daane 2003).

The amount and type of non-crop habitats within agricultural landscapes can also influence natural enemy populations within crops (Gurr et al. 1998, Landis and Marino

1999, Marino and Landis 2000). Specifically, increases in local plant species diversity can enhance the effectiveness and abundance of natural enemies (Corbett and Plant 1993). For example, wild habitats near vineyards significantly increase early season population densities of *Anagrus* spp. parasitoids (Hymenoptera: Mymaridae) at vineyard borders adjacent to woods compared with vineyard interiors (Williams and Martinson 2000). However, most efforts at manipulating habitats within agricultural systems for pest control have been based on anecdotal evidence (Gurr et al. 1998). This is partly due to the fact that many plant, herbivore, and natural enemy interactions are poorly understood (Wratten et al. 1998).

INTEGRATING CHEMICAL AND BIOLOGICAL CONTROL

The use of broad-spectrum insecticides is inimical to natural enemy populations in crop systems (Debach and Rosen 1991, Van Driesche and Bellows 1996). Integrating chemical and biological control can be challenging, but insecticides can be made compatible with conservation of natural enemies if the insecticides' effects on natural enemies are understood (Ruberson et al. 1998). There is generally an inverse relationship between chemical and biological controls: when pests are not controlled by natural enemies, insecticides are one of the few ways to obtain control; conversely, when pests are controlled by natural enemies, insecticide use is decreased or not needed (Greathead 1995). Between these extremes lies the opportunity for IPM to be realized (Ruberson et al. 1998). Adoption of conservation biological control practices by growers is essential for IPM success and one of the easiest ways to do this is by the use of reduced-risk insecticides (Greathead 1995, Ruberson et al. 1998).

Using reduced-risk insecticides can be an effective way of integrating chemical and biological control because they are often highly specific to the target pests (Hull and Beers 1985, Pfeiffer 2000). The greatest benefit of reduced-risk insecticides may be in crops with multiple pests where repeated use of broad-spectrum insecticides targeting a primary pest can promote secondary pest outbreaks by disrupting biological control agents (Ruberson et al. 1998, Johnson and Tabashnik 1999). For example, aphid densities in insecticide-treated blueberry plots began to increase 14 days after treatment, whereas densities in control plots continued to decline due to predation by natural enemies (Whalon and Elsner 1982). However, many reduced-risk insecticides are active only on certain taxa (eg. Lepidoptera), more than one reduced-risk insecticide may be needed to control multiple pests. IPM programs which incorporate reduced-risk insecticides in place of broad-spectrum insecticides may provide greater opportunity for conservation of natural enemy populations resulting in greater biological control of pests.

Insect growth regulators (IGR's) are a class of reduced-risk insecticides that have been developed recently. Ecdysone agonists are one type of IGR used against lepidopteran pests (e.g. Pyralidae, Pieridae, Tortricidae, and Noctuidae). This group includes tebufenozide and methoxyfenozide, which bind to the ecdysone receptor complex in lepidopteran larvae and prematurely activate ecdysis, leading to premature molting and death (Carlson et al. 2001). These insecticides are most effective when ingested; however, there are some topical and ovicidal properties (Banken and Stark 1998, Pfeiffer 2000, Carlson et al. 2001, Isaacs et al. 2005). Spinosad is another reduced-risk insecticide for use against lepidopteran pests. It is an insecticidal macrocyclic lactone, is naturally derived from the soil actinomycete *Saccharopolyspora spinosa* and acts on the insect nervous system, causing hyper-excitation and paralysis (Salgado et al. 1998, Salgado 1998, Pfeiffer 2000). While the activity of methoxyfenozide is specific to Lepidoptera, spinosad is active against many arthropods, including Lepidoptera, Coleoptera, Homoptera, Diptera, and Phytoseiidae (Salgado 1998, Galvan et al. 2005, Pelz et al. 2005, Villanueva and Walgenbach 2005).

Many studies have documented the decreased toxicological effects of some reduced-risk insecticides on biological control agents compared with broad-spectrum insecticides. In laboratory studies, methoxyfenozide did not affect the survival of parasitoids of the obliquebanded leafroller, *Choristoneura rosaceana* (Harris), although imidacloprid and indoxacarb were somewhat toxic (Wilkinson 2002). Methoxyfenozide and indoxacarb are not toxic to *Trichogramma* nr. *brassicae*, a common egg parasitoid of *Helicoverpa* spp., whereas *T. brassicae* are often severely affected by broad-spectrum insecticides (Hewa-Kapuge et al. 2003). Furthermore, emergence of *Trichogramma exiguum* Pinto & Platner from *Helicoverpa zea* (Boddie) host eggs was not affected by exposure to methoxyfenozide and tebufenozide at various stages of development (Suh et al. 2004). Another study showed that field rates of methoxyfenozide and tebufenozide had no effect on the parasitoid *Hyposoter didymator* (Thunberg) which attacks early instars of Lepidoptera (Schneider et al. 2003) and field rates of tebufenozide were harmless against the lacewing *Chrysoperla carnea* (Stephens), a generalist predator (Medina et al. 2003b). In yet another example, methoxyfenozide and tebufenozide were significantly less toxic than carbaryl to eggs and larvae of the lady beetle *Coleomegilla maculata* (De Geer) (Trisyono et al. 2000). In one case of harmful effects, Carton et al. (2003) showed that methoxyfenozide and halofenozide at high rates were toxic to final instar *Harmonia axyridis* Pallas. However, the authors suggested that the toxicological effects of these chemistries could be minimized by selecting a lower concentration which is lethal to the target insect pest but not to *H. axyridis* and concluded that methoxyfenozide and halofenozide have little or no adverse effects on natural enemies or pollinators at normal field rates.

Other control tactics that may be integrated into reduced-risk management programs to improve biological control include the use of semiochemicals for mating disruption. For example, parasitism of the tufted apple bud moth, *Platynota idaeusalis* (Walker), was greater in apple orchards using mating disruption for control of *P. idaeusalis* than in conventional orchards using broad-spectrum insecticides (Biddinger et al. 1994), further suggesting that reducing the toxicity of the management program can increase the effects of natural enemies on the pest. Additionally, more carabid beetles were captured in Washington apple orchards managed using a pheromone-based insect management program compared to a conventional program based on broad-spectrum insecticides (Epstein et al. 2001).

In response to increased regulation of broad-spectrum insecticides for many minor crops in the US, a series of studies are underway to evaluate the effectiveness of pest control programs that incorporate reduced-risk management approaches. Such programs using reduced-risk insecticides with mating disruption and cover crop management in peaches provided equal or improved control of the oriental fruit moth, *Grapholita molesta* (Busck) compared with conventional, broad-spectrum programs (Atanassov et al. 2002, 2003). Part of the control in the reduced-risk programs was achieved by increasing natural enemy abundance when compared with the conventional programs. A similar study using mating disruption in apple proved to be an effective alternative to programs based on organophosphate insecticides for controlling oriental fruit moth, *Grapholita molesta* (Busck) (Kovanci et al. 2005). Replacing organophosphate insecticides with neonicotinyl insecticides in apple provided acceptable control in small plot trials of one of four species of lepidopteran pests (Brunner et al. 2005), but may also increase mite outbreaks (Beers et al. 2005). Reduced-risk insecticides provided greater predator densities and lower pest densities compared to broad-spectrum insecticides in Washington potato fields (Koss et al. 2005). In Michigan blueberry fields, captures of some carabid beetle species increased under reduced-risk insecticide management (O'Neal et al. 2005) and field studies in cotton showed increased conservation of natural enemies using IGR's (Naranjo et al. 2004) compared to conventional management programs. These and other research results confirm that there is a continued need to determine the long-term effects of insecticides on natural enemy populations in order to establish truly sustainable and integrated systems (Ruberson et al. 1998).

CULTURAL PRACTICES AND BIOLOGICAL CONTROL

Cultural control is defined as the purposeful manipulation of agricultural production practices to achieve reduced pest pressure (Schellhorn et al. 2000). Examples include sanitation, tillage, crop rotation, and destruction of alternate habitats and hosts used by the pest. Cultural control practices which alter habitats to create less suitable environments for pests may also indirectly affect natural enemy populations (Debach and Rosen 1991).

There is increasing evidence that natural enemy populations can be enhanced by changing agricultural practices and landscape structure (Gurr et al. 1998, Landis and Menalled 1998, Tscharntke 2000, Landis et al. 2000). Even though there is a positive correlation between parasitoid species richness and plant diversity (Kruess and Tscharntke 1994, Marino and Landis 1996, Thies and Tscharntke 1999), landscape diversity may be critical for providing resources to natural enemies in some, but not all, agroecosystems (Menalled et al. 1999). The simplified structure and limited resources typically found in agricultural landscapes may be less favorable to parasitoid species as compared to noncrop habitats, which generally have greater resources (Landis and Menalled 1998, Thies and Tscharntke 1999). Therefore, cultural management tactics that change the temporal or spatial structure of habitats may alter natural enemy movement, colonization, and conservation (Dennis and Fry 1992, Landis and Menalled 1998, Schellhorn et al. 2000).

Vineyards in the eastern US are found in close association with deciduous woods where wild grapevines (*Vitis* spp.) persist (Botero-Garcés and Isaacs 2004a). Four *Vitis* species (summer grape, *V. aestivalis* Michaux; fox grape, *V. labrusca* L.; river bank grape, *V. riparia* Michaux; and frost grape, *V. vulpine* L.) are found in Michigan (Galet 1979, Voss 1985). Wild grapevines may act as a natural source of pest infestation in vineyards, but they may also be a refuge for natural enemies (Dennehy et al. 1990, Seaman et al. 1990). Cutting wild grapevines has been a cultural method used by growers to reduce *P. viteana* pest pressure, since infestation of grape clusters at vineyard borders near deciduous woods is often higher compared to vineyard interiors (Dennehy et al. 1990, Botero-Garcés and Isaacs 2004a). Other cultural controls used in vineyards, not specific to eastern viticulture, include irrigation management to suppress leafhopper densities (Mills and Daane 2005), the creation of corridors across vineyards, giving natural enemies the opportunity to disperse from natural areas to monoculture systems (Altieri and Nicholls 2004), using cover crops in row middles to increase spider populations (Costello and Daane 1998), and tillage for weed management (Elmore et al. 1992).

INTEGRATED PEST MANAGEMENT IN VITICULTURE

Integrated pest management is the use of several compatible pest management tactics to maintain pest populations below an economic injury level (Debach and Rosen 1991). The original concept of IPM included the combined use of pesticides with natural enemies (Stern et al. 1959) and then was eventually broadened to include cultural controls, host plant resistance, and other biologically based methods (Smith et al. 1976). However, the IPM concept has been evolving over the last forty years and has only been successfully realized a few times in a few cropping systems (Ruberson et al. 1998).

Making crop protection decisions based on an assessment of pest density is a cornerstone of IPM systems (Nyrop et al. 1999). In viticulture, IPM combines insect trapping and scouting to obtain estimates of pest infestation levels (Dennehy et al. 1990). Based on this information, the need for a pesticide application is determined. Pesticides are used judiciously, with the objective of controlling the target pest below an economic threshold. This practice may reduce insecticide inputs and the impact of insecticides on natural enemies compared with calendar-based sprays (Edwards 2000). For IPM in eastern viticulture and other systems, it is important to test chemical, biological, and cultural practices individually before incorporating them into IPM programs.

SUMMARY

To meet quality standards in eastern US grape production, growers currently rely on multiple applications of broad-spectrum insecticides to control a complex of insect pests. However, due to FQPA implementation, effective products have been lost in this industry at a time when they are needed most and additional risk-driven pesticide restrictions in grape production are likely. For example, methyl parathion was banned from use in 1999 and, as of 2004, azinphosmethyl is no longer registered for grape. To make the problem worse, resistance to carbaryl has been detected in *P. viteana* populations. This scenario can lead to increased application rates of insecticides as their efficacy decreases, further exacerbating environmental contamination and insecticide resistance. Clearly, eastern US viticulture would benefit from development of alternative approaches for management of *P. viteana*.

The efficacy of reduced-risk insecticides at vineyard scales for control of *P. viteana* and the consequent effects on vineyard natural enemies are currently unknown. In addition, the effects of agroecosystem modification on *P. viteana* and natural enemies are also unknown. If this information were available, recommendations about these alternative methods for controlling *P. viteana* could be made to the grape industry. Lastly, identification of the natural enemy complex in Michigan vineyards may reveal opportunities for biological control of *P. viteana*. To determine the potential of reduced-risk insecticides and wild host removal for management of *P. viteana*, the research in this

thesis aimed to 1) determine the direct effects of a reduced-risk insect management program for control of *P. viteana* and the indirect effects on conservation of natural enemies compared to conventional insect management programs, 2) determine the effect of cutting wild grapevines in habitats adjacent to vineyards on the control of *P. viteana* and conservation of natural enemies, and 3) characterize the natural enemy complex in Michigan vineyards.

CHAPTER 2

VINEYARD-SCALE EVALUATION OF REDUCED-RISK INSECTICIDES FOR CONTROL OF *PARALOBESIA VITEANA* (LEPIDOPTERA: TORTRICIDAE)

INTRODUCTION

The grape berry moth, *Paralobesia viteana* (Clemens) (Lepidoptera: Tortricidae) is a primary insect pest of eastern North American vineyards, and was recently renamed from *Endopiza viteana* Clemens (Brown 2005). It is a monophagous insect, occurring naturally on wild and cultivated *Vitis* spp. vines, and has become the main target of vineyard pest management programs in the eastern US and Canada (Dennehy et al. 1990, Botero-Garcés and Isaacs 2003). *Paralobesia viteana* is multivoltine, with three or more generations per year (Biever and Hostetter 1989, Hoffman and Dennehy 1989, Tobin et al. 2003). The moths overwinter as pupae and emerge as first generation adults each spring from April to June. Once mated, females oviposit single eggs on developing buds, florets, or berries (Clark and Dennehy 1988, Tobin et al. 2003), requiring management actions throughout the growing season.

Economic losses to *P. viteana* result from fruit contamination at harvest and reduced yield from the combination of insect feeding and associated diseases that opportunistically invade infested berries (Dennehy et al. 1990). Pest pressure varies among years and vineyards, and is also generally greater at vineyard borders adjacent to deciduous woods (Hoffman and Dennehy 1989, Botero-Garcés and Isaacs 2003). Because of this, vineyard scouting is an important component of IPM programs, ensuring that management is targeted at the times and places where pest abundance warrants chemical control.

To control *P. viteana* and other vineyard insect pests in the eastern US, growers currently rely on multiple applications of broad-spectrum insecticides. These insecticides generally provide control of both primary and secondary pests. For example, secondary pests such as leafhoppers may be adequately controlled by early season sprays of organophosphate and carbamate insecticides targeting *P. viteana* (Martinson et al. 1994, Martinson et al. 1997, Williams and Martinson 2000). However, grape growers need alternative control options for effectively managing vineyard insect pests because the Food Quality Protection Act of 1996 has led to restrictions on the use of broad-spectrum insecticides in this industry. Additionally, carbaryl resistance has recently been detected in populations of *P. viteana* (Nagarkatti et al. 2002b).

In response to increased regulation of broad-spectrum insecticides for many food and fiber crops in the US, studies have recently evaluated the effectiveness of insect control programs that incorporate reduced-risk management approaches (Atanassov et al. 2002, Musser and Shelton 2003, Smirle et al. 2003a, Smirle et al. 2003b, Naranjo et al. 2004, Doerr et al. 2004, Pineda et al. 2004, Koss et al. 2005, Brunner et al. 2005, Kovanci et al. 2005). The recent development and registration of reduced-risk insecticides with specificity to Lepidoptera provide an opportunity for *P. viteana* control without using broad-spectrum insecticides. Two products, methoxyfenozide (Intrepid 2F®) and spinosad (SpinTor 2SC®) (Dow AgroSciences, Indianapolis) have recently been registered for use against *P. viteana* in US grape production. Methoxyfenozide is an insect growth regulator (IGR) that binds to the ecdysone receptor complex in lepidopteran larvae and causes premature molting (Carlson et al. 2001). IGRs are most effective when ingested, but also possess some topical and ovicidal properties (Pfeiffer 2000, Carlson et al. 2001, Myers and Hull 2003). Spinosad, an insecticidal macrocyclic lactone, is naturally derived from the soil actinomycete *Saccharopolyspora spinosa* and acts on the insect nervous system, causing hyper-excitation and paralysis (Salgado et al. 1998, Salgado 1998, Pfeiffer 2000). These products offer the potential for *P. viteana* control while minimizing the suppression of biological control agents commonly caused by the use of broad-spectrum insecticides (Dhadialla and Jansson 1999, Legaspi et al. 1999, Trisyono et al. 2000, Medina et al. 2001, Carton et al. 2003, Hewa-Kapuge et al. 2003, Schneider et al. 2004). The recent registration of these insecticides for use in vineyards provides the first opportunity to determine whether adoption of reduced-risk insecticides in commercial vineyards provides effective control of *P. viteana* compared to a program based on broad-spectrum insecticides.

This study aimed to compare control of *P. viteana* with reduced-risk insecticides to that achieved with conventional insecticides over three growing seasons. This project was conducted at commercial grape farms using a combination of approaches to assess whether the two programs differed in their performance, in terms of overall *P. viteana* population size, cluster infestation, berry infestation, and survival of *P. viteana* larvae.

MATERIALS AND METHODS

Study sites

This study was conducted at two mature 1.4 to 4 ha *Vitis labrusca* L. var. 'Concord' grape vineyards at each of four farms in 2003, 2004 and 2005 in Van Buren and Berrien

Counties, Michigan (Appendix 2.1). Vineyards were selected with histories of *P. viteana* infestation and were bordered on at least one side by deciduous woods, where pest pressure has been found to be greatest (Botero-Garcés and Isaacs 2004a). The distance between the vineyard border and the wood border ranged from 6.4 to 20.3 m (Figure 2.1). One farm selected in 2003 was found to have very low pest pressure and the data from this farm were omitted from the analysis. After the 2003 growing season, another farm with higher *P. viteana* pressure was added. Growers made all pesticide applications and other vineyard management actions. Vineyards received standard weed and disease control programs, with both vineyards within each farm receiving the same management inputs.

Insect management

Both vineyards at each farm received a broad-spectrum insecticide immediately after bloom for control of first generation *P. viteana* and leaf-feeding pests. Thereafter, at each farm one vineyard received only broad-spectrum insecticides (conventional program), comprised of organophosphates, carbamates, and pyrethroids (Table 2.1). The other vineyard (reduced-risk program) received an insecticide program containing reduced-risk insecticides for control of the key insect pests (Table 2.1). The conventional vineyard received three or more applications of broad-spectrum insecticides and the reduced-risk vineyard received two or more applications of reduced-risk insecticides for control of second and third generations of *P. viteana* (Table 2.1). Acetamiprid was applied in the reduced-risk vineyards at a rate to control of Japanese beetle (*Popillia japonica*) and grape leafhopper (*Erythroneura comes*) as needed (Table 2.1). Application timing for the

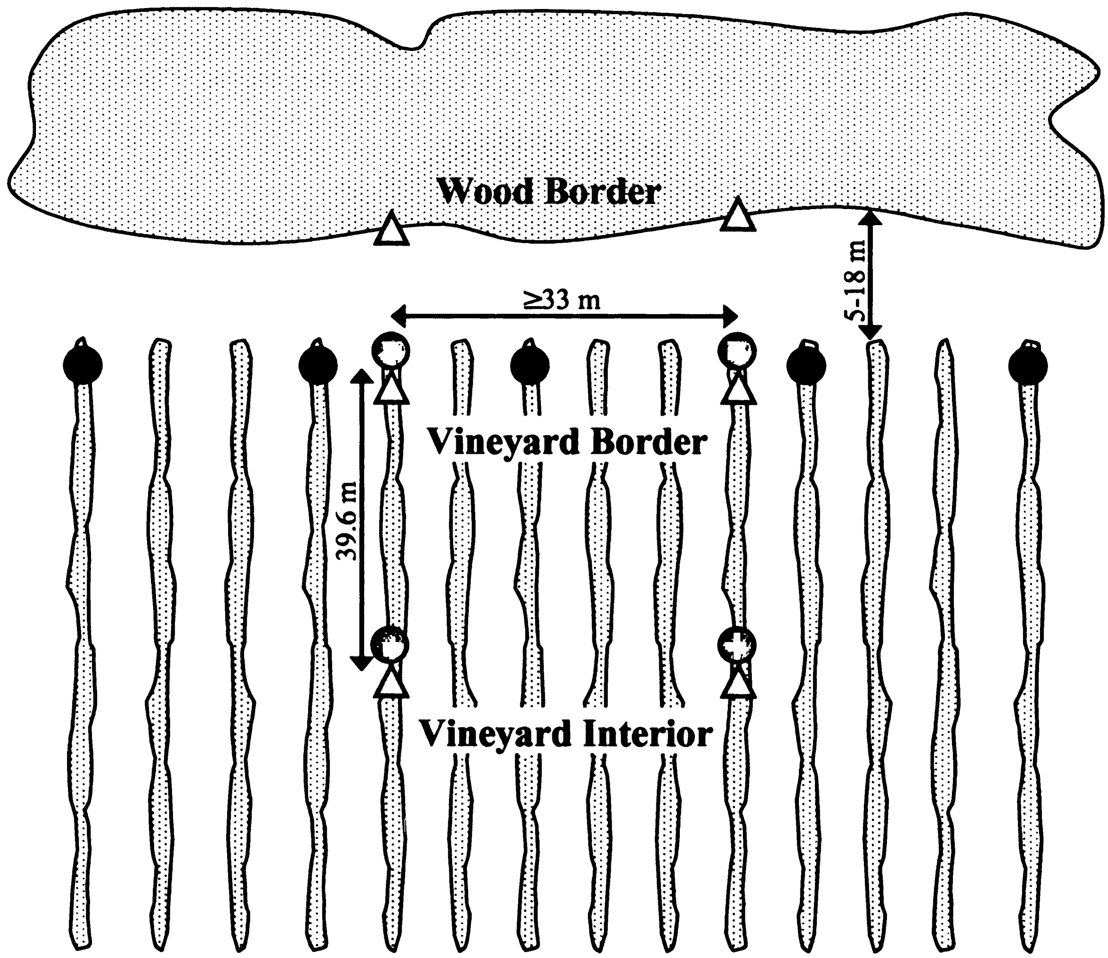


Figure 2.1. Schematic diagram of an experimental vineyard and adjacent wood habitat (not to scale). Triangles represent pheromone trap placement at the vineyard interior, vineyard border, and wood border. Grey circles represent weekly sampling sites for infestation by *P. viteana* eggs and larvae. Black circles represent sampling sites for fruit infested by *P. viteana* larvae.

reduced-risk program was based on weekly scouting of vineyards (see below), while the conventional vineyard was managed according to each grower's standard insect control program. The post-bloom broad-spectrum insecticide applications for control of first generation *P. viteana* in both programs were made using 234 liters of water/ha (25 gallons of water/acre). The applications of methoxyfenozide and spinosad in the reduced-risk program were made using 468 liters of water/ha (50 gallons of water/acre) and the volume of water used for late season conventional applications ranged from 187-468 liters of water/ha (20-50 gallons of water/acre).

***P. viteana* moth captures**

Flights of adult male *P. viteana* were monitored using large plastic delta traps (Suterra LLC, Bend, OR) baited with *P. viteana* sex pheromone (90:10 ratio of (Z)-9-12Ac and (Z)-11-14Ac) (Suterra LLC, Bend, OR). Two traps were placed at a height of 1.5 m at each vineyard border, vineyard interior, and wooded border adjacent to each vineyard. Traps were distributed evenly across the length of the vineyard, at least 33 m apart, and vineyard interior traps were placed 39.6 m from the vineyard border (Figure 2.1). The distance between the vineyard border traps and the wood border traps ranged from 6.4 to 20.3 m (Figure 2.1). Traps were monitored weekly for the number of male *P. viteana* captured, and the moths were removed or traps were replaced with new inserts. Pheromone lures were replaced every four weeks using lures from the same lot in each season. Each year, the total moth captures from each trap were averaged within location and compared between locations and programs using ANOVA (PROC MIXED, SAS

Table 2.1. Insecticides applied to Michigan juice grape vineyards managed using reduced-risk and conventional insecticide programs during 2003-2005. Rates of application of active ingredient are provided in the footnote.

	2003				2004				2005			
Farm	**Date**	**Conventional**	**Date**	**Reduced-Risk**	**Date**	**Conventional**	**Date**	**Reduced-Risk**	**Date**	**Conventional**	**Date**	**Reduced-Risk**
1	6/19	azinphosmethyl (c)	6/30	fenpropathrin (j)	6/17	azinphosmethyl (b)	6/22	fenpropathrin (j)	6/16	fenpropathrin (j)	6/16	fenpropathrin (j)
	6/30	fenpropathrin (j)	7/24	methoxyfenozide (m)	7/1	fenpropathrin (j)	7/16	methoxyfenozide (m)	6/30	phosmet (n)	7/8	methoxyfenozide (m)
	7/15	fenpropathrin (j)	8/18	methoxyfenozide (m)	7/15	azinphosmethyl (b)		+ acetamiprid (a)	7/11	bifenthrin (e)		+ acetamiprid (a)
	7/24	azinphosmethyl (c)	9/8	methoxyfenozide (m)	8/4	fenpropathrin (j)	8/6	methoxyfenozide (m)	7/27	fenpropathrin (j)	8/4	methoxyfenozide (m)
	8/6	azinphosmethyl (c)			8/28	fenpropathrin (j)	9/1	spinosad (p)	8/8	bifenthrin (e)		
	8/26	fenpropathrin (j)							8/27	carbaryl (i)		
	9/9	fenpropathrin (k)										
2	6/29	fenpropathrin (j)	6/28	fenpropathrin (j)	6/25	carbaryl (f)	6/25	carbaryl (f)	6/22	carbaryl (f)	6/22	fenpropathrin (j)
	7/15	carbaryl (f)	7/16	carbaryl (f)	7/12	fenpropathrin (j)	7/14	methoxyfenozide (m)	7/14	bifenthrin (e)	7/14	methoxyfenozide (m)
	7/29	azinphosmethyl (b)	7/28	methoxyfenozide (m)	8/3	azinphosmethyl (b)		+ acetamiprid (a)	8/8	bifenthrin (e)		+ acetamiprid (a)
	8/18	azinphosmethyl (b)	8/14	methoxyfenozide (m)	9/1	carbaryl (g)	8/6	methoxyfenozide (m)			8/8	methoxyfenozide (m)
	9/3	carbaryl (f)		+ acetamiprid (a)				+ acetamiprid (a)				+ acetamiprid (a)
			9/3	methoxyfenozide (m)			9/1	spinosad (p)				
3	6/19	fenpropathrin (j)	6/27	fenpropathrin (j)	6/22	fenpropathrin (j)	6/22	fenpropathrin (j)	6/15	fenpropathrin (j)	6/15	fenpropathrin (j)
	7/8	azinphosmethyl (b)	7/25	methoxyfenozide (m)	7/15	azinphosmethyl (b)	7/15	methoxyfenozide (m)	7/5	carbaryl (f)	7/13	methoxyfenozide (m)
	7/25	carbaryl (f)	8/15	methoxyfenozide (m)	8/10	azinphosmethyl (d)		+ acetamiprid (a)	8/2	bifenthrin (e)		+ acetamiprid (a)
	8/9	azinphosmethyl (b)	9/5	methoxyfenozide (m)	8/31	carbaryl (h)	8/10	methoxyfenozide (m)			8/2	methoxyfenozide (m)
							8/31	spinosad (p)				
4		*Not in program*			6/15	fenpropathrin (j)	6/23	fenpropathrin (j)	6/17	fenpropathrin (j)	6/17	fenpropathrin (j)
					7/9	azinphosmethyl (c)	7/12	methoxyfenozide (m)	7/9	carbaryl (f)	7/9	methoxyfenozide (m)
					8/2	fenpropathrin (j)		+ acetamiprid (a)	8/3	phosmet (n)		+ acetamiprid (a)
					8/30	phosmet (n)	8/6	methoxyfenozide (m)	8/23	phosmet (n)	8/3	methoxyfenozide (m)
					9/10	carbaryl (f)	9/1	spinosad (p)	9/4	carbaryl (f)	9/1	spinosad (p)

Table 2.1 (Continued).

[a] acetamiprid (Assail 70WP) at 54 g/ha; Cerexagri Inc., King of Prussia, PA.

[b] azinphosmethyl (Guthion 50WP) at 841 g/ha; Bayer CropScience LP, Research Triangle Park, NC.

[c] azinphosmethyl (Guthion 50WP) at 560 g/ha; Bayer CropScience LP, Research Triangle Park, NC.

[d] azinphosmethyl (Guthion 50WP) at 785 g/ha; Bayer CropScience LP, Research Triangle Park, NC.

[e] bifenthrin (Capture 2EC) at 56 g/ha; FMC Corp., Philadelphia, PA.

[f] carbaryl (Sevin XLR Plus) at 1681 g/ha; Bayer CropScience LP, Research Triangle Park, NC.

[g] carbaryl (Sevin XLR Plus) at 2242 g/ha; Bayer CropScience LP, Research Triangle Park, NC.

[h] carbaryl (Sevin XLR Plus) at 1793 g/ha; Bayer CropScience LP, Research Triangle Park, NC.

[i] carbaryl (Sevin XLR 80S) at 1345 g/ha; Bayer CropScience LP, Research Triangle Park, NC.

[j] fenpropathrin (Danitol 2.4 EC) at 224 g/ha; Valent USA Corp., Walnut Hills, CA.

[k] fenpropathrin (Danitol 2.4 EC) at 168 g/ha; Valent USA Corp., Walnut Hills, CA.

[m] methoxyfenozide (Intrepid 2F) at 210 g/ha; Dow AgroSciences LLC, Indianapolis, IN.

[n] phosmet (Imidan 70W) at 1177 g/ha; Gowan Co., Yuma, AZ.

[p] spinosad (SpinTor 2SC) at 105 g/ha; Dow AgroSciences LLC, Indianapolis, IN.

Institute 2001). Data were log-transformed (log n+1) to meet normality assumptions prior to analysis and Tukey's test was used to determine differences between means at α=0.05.

P. viteana cluster and berry infestation

Infestation by *P. viteana* was quantified weekly by visually examining 30 clusters (five clusters on three vines spaced ca. 2.7 m apart, at two sampling sites) at the border and interior of the vineyard (Figure 2.1). For each vine, the number of *P. viteana* eggs, *P. viteana* larvae, and clusters with *P. viteana* larvae was recorded and summed within each sampling site for each date. To determine the presence of larvae, berries showing signs of *P. viteana* infestation were scored positive and adjacent berries webbed together were counted as one larva. The total number of eggs found at each farm throughout the season, and for each specific sampling date, were compared between programs and locations using ANOVA (PROC MIXED, SAS Institute 2001). The weekly average of *P. viteana* larvae and clusters infested by *P. viteana* larvae for each farm were compared between programs and locations for each date and across each season using ANOVA (PROC MIXED, SAS Institute 2001). For all ANOVA's, data were log-transformed (log n+1) to meet normality assumptions prior to analysis and Tukey's test was used to determine differences between means at α=0.05.

Survival of *P. viteana* in vineyards

To compare the effects of the two insecticide programs on *P. viteana* survival, 100 berries (five sub-samples of 20 berries) showing signs of *P. viteana* infestation were collected from each vineyard border adjacent to woods (Figure 2.1). Sampling dates were chosen each season to be ca. 10 days after insecticide applications for control of *P. viteana* and when *P. viteana* larvae were susceptible to parasitism. Berry samples were taken on 14 August, 2 September, and 13 September in 2003, on 29 July, 12 August, and 26 August in 2004, and 14 July, 28 July, and 10 August in 2005. In 2003, each sub-sample of 20 berries was placed in a 473 ml polypropylene deli container (Fabri-Kal, Kalamazoo, MI) and brought back to the laboratory where the container was held at 24°C and 16:8 L:D. These methods were changed to improve insect survival in 2004 and 2005; individual berries were placed into separate 37 ml plastic cups (Bioserv Corp, Frenchtown, NJ) with white paper insert lids (Bioserv, Frenchtown, NJ). In all years, small strips of plastic were provided in each container as pupation substrate for *P. viteana*. At the end of five to six weeks, samples were placed at -20°C for 24 h to ensure mortality of specimens. The containers were then opened and the numbers of *P. viteana* adults, pupae, larvae, and parasitoids of *P. viteana* were totaled and recorded. From these values, the proportion of *P. viteana* surviving from each sampling date was calculated. Data were arcsine square root transformed and compared among treatments using the Mann-Whitney U-test (PROC MIXED, SAS Institute 2001). Voucher specimens of *P. viteana* are held in the A.J. Cook Arthropod Collection at Michigan State University (see Appendix 1.1).

RESULTS

P. viteana moth captures

Male moths were trapped from early April until traps were collected at harvest, with the greatest captures in May and June, before and during bloom. Although similar numbers of moths were captured in the reduced-risk program compared to the conventional program in all years (F=2.47; df=1,2; *P*=0.26 in 2003; F=0.03; df=1,3; *P*=0.87 in 2004; F=0.01; df=1,3; *P*=0.93 in 2005), the trend showed consistently fewer moths in the reduced-risk program (Table 2.2). There was no significant interaction between program and location in the total number of male moths captured in any year (F=0.86; df=2,8; *P*=0.46 in 2003; F=2.16; df=2,12; *P*=0.16 in 2004; F=1.81; df=2,12; *P*=0.21 in 2005) (Table 2.2), indicating that pest pressure was similar across vineyards within each farm. Moth captures varied significantly by location within farms; in all years average male moth captures were significantly greater at the vineyard interior compared to the vineyard border (F=29.51; df=1,8; *P*=0.0006 in 2003; F=33.73; df=1,12; *P*<0.0001 in 2004; F=16.53; df=1,12; *P*=0.0016 in 2005). In 2003, moth captures were significantly greater at the wood border compared to the vineyard border (F=23.53; df=1,8; *P*=0.0013), and in 2004 more moths were captured at the vineyard interior compared to the wood border (F=13.67; df=1,12; *P*=0.003).

***P. viteana* cluster and berry infestation**

Comparisons between the two programs indicated that oviposition was generally lower in the reduced-risk program, but with no significant difference between programs across each season (F=0.27; df=1,2; *P*=0.66 in 2003; F=0.24; df=1,3; *P*=0.66 in 2004; F=2.75; df=1,3; *P*=0.20 in 2005) (Table 2.3). On average, the number of eggs detected on 30 cluster samples at the border was approximately seven times greater than the number detected at the interior (Table 2.3). In all years, the number of *P. viteana* eggs detected was significantly greater at the vineyard border compared to the vineyard interior

Table 2.2. Average total captures of male *P. viteana* moths per trap ± S.E. at wood borders and at the borders and interiors of Michigan juice grape vineyards managed using reduced-risk or conventional insecticides during 2003-2005.

Location	Program	2003	2004	2005
Vineyard Interior	Reduced-Risk	86.7 ± 25.0	36.5 ± 10.1	43.4 ± 9.3
	Conventional	126.5 ± 23.0	66.4 ± 22.6	50.8 ± 14.5
Vineyard Border	Reduced-Risk	26.0 ± 1.7	10.7 ± 2.7	12.8 ± 1.6
	Conventional	45.1 ± 11.2	20.8 ± 7.3	21.1 ± 3.5
Wood Border	Reduced-Risk	94.6 ± 23.1	22.6 ± 5.1	36.2 ± 8.4
	Conventional	89.0 ± 8.7	23.9 ± 9.4	33.9 ± 13.4

Table 2.3. Average total number of *P. viteana* eggs per season ± S.E. found on 30 clusters at borders and interiors of Michigan juice grape vineyards managed using reduced-risk or conventional insecticides during 2003-2005.

Location	Program	2003	2004	2005
Vineyard Interior	Reduced-Risk	16.7 ± 4.2	14.8 ± 1.4	9.0 ± 3.3
	Conventional	9.7 ± 3.0	17.3 ± 2.8	9.3 ± 2.3
Vineyard Border	Reduced-Risk	107.7 ± 32.6	74.8 ± 11.4	34.0 ± 9.8
	Conventional	147.3 ± 65.9	78.0 ± 13.9	76.8 ± 16.5

(F=74.19; df=1,4; P=0.001 in 2003; F=172.18; df=1,6; P<0.0001 in 2004; F=33.89; df=1,6; P=0.0011 in 2005), but there was no significant interaction between program and location in any year (F=2.47; df=1,4; P=0.19 in 2003; F=0.2; df=1,6; P=0.67 in 2004; F=1.28; df=1,6; P=0.30 in 2005) (Table 2.3).

Infestation by *P. viteana* larvae was also greatest at the vineyard border throughout this experiment; the number of *P. viteana* larvae was significantly greater at the vineyard border compared to the vineyard interior (F=49.61; df=1,4; P=0.0021 in 2003; F=33.31, df=1,6; P=0.0012 in 2004; F=98.66; df=1,6; P<0.0001 in 2005), but there was no significant interaction between program and location in any year (F=0.46; df=1,4; P=0.54 in 2003; F=0.17; df=1,6; P=0.69 in 2004; F=0.19; df=1,6; P=0.68 in 2005). Comparisons between the two programs indicated that infestation by *P. viteana* larvae was generally lower, but not statistically significant (F=0.13; df=1,2; P=0.76 in 2003; F=0.15; df=1,3; P=0.72 in 2004; F=1.19; df=1,3; P=0.36 in 2005) in the reduced-risk program, particularly later in the growing season (Figure 2.2). Statistical separation between programs was seen on 31 July and 20 August 2003 when there were fewer larvae in the conventional program (F=35.11; df=1,2; P=0.027 and F=18.41; df=1,2; P=0.05, respectively), and on 30 August 2005 (F=10.81; df=1,3; P=0.046) when fewer larvae were found in the reduced-risk program (Figure 2.2).

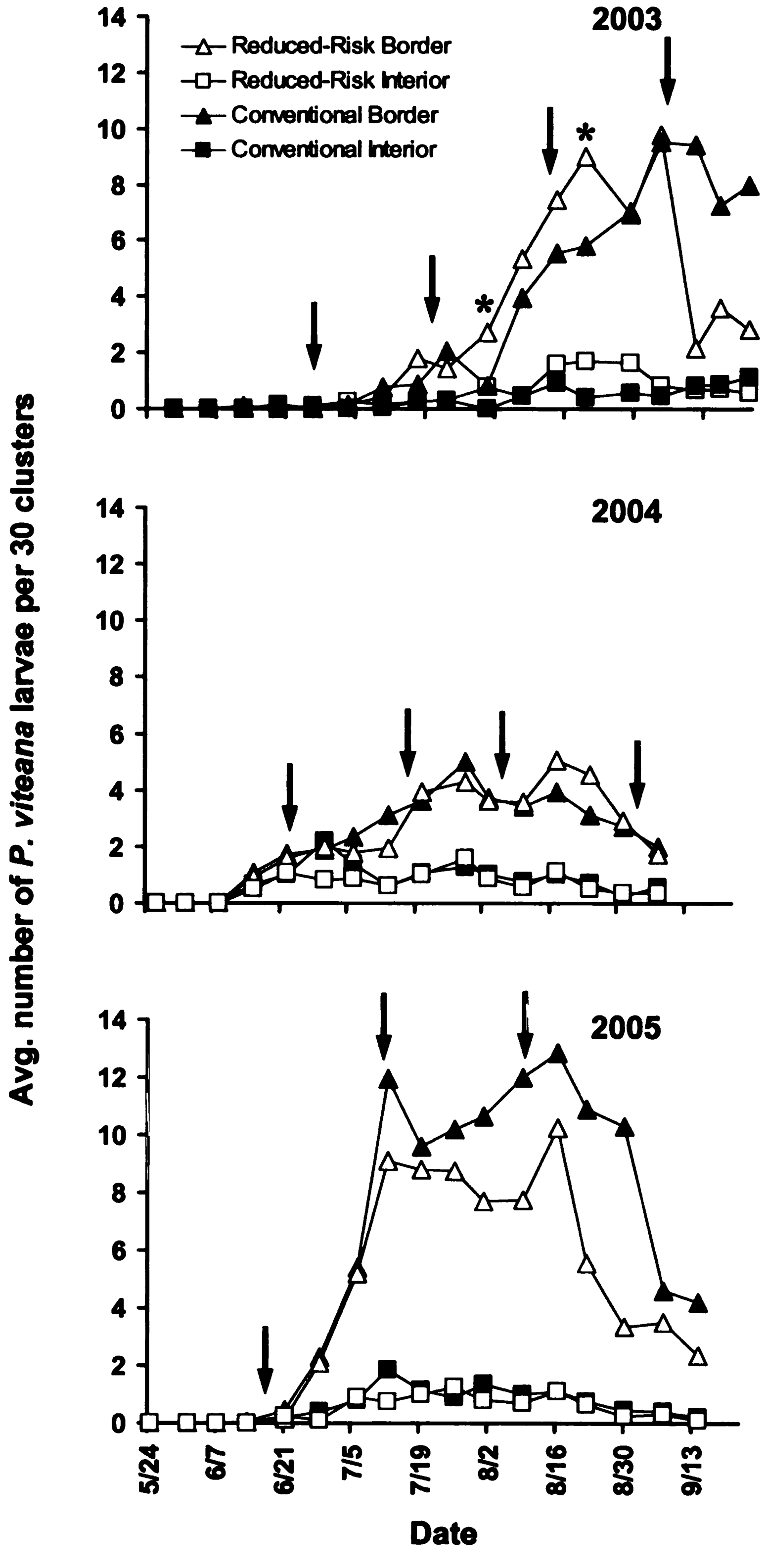
The number of clusters infested by *P. viteana* larvae was significantly greater at the vineyard border compared to the vineyard interior in each year (F=47.12; df=1,4; P=0.0024 in 2003; F=36.27; df=1,6; P=0.0009 in 2004; F=124.84; df=1,6; P<0.0001 in 2005), but there was no significant interaction between program and location (F=0.81; df=1,4; P=0.42 in 2003; F=0.11; df=1,6; P=0.75 in 2004; F=0.05; df=1,6; P=0.84 in

2005). The number of clusters with larvae were not significantly different between programs (F=0.29; df=1,2; P=0.64 in 2003; F=0.23; df=1,3; P=0.66 in 2004; F=0.47; df=1,3; P=0.54 in 2005), except for 31 July 2003, when more clusters with larvae were found in the reduced-risk treatment (F=26.73; df=1,2; P=0.0354).

Survival of *P. viteana* in vineyards

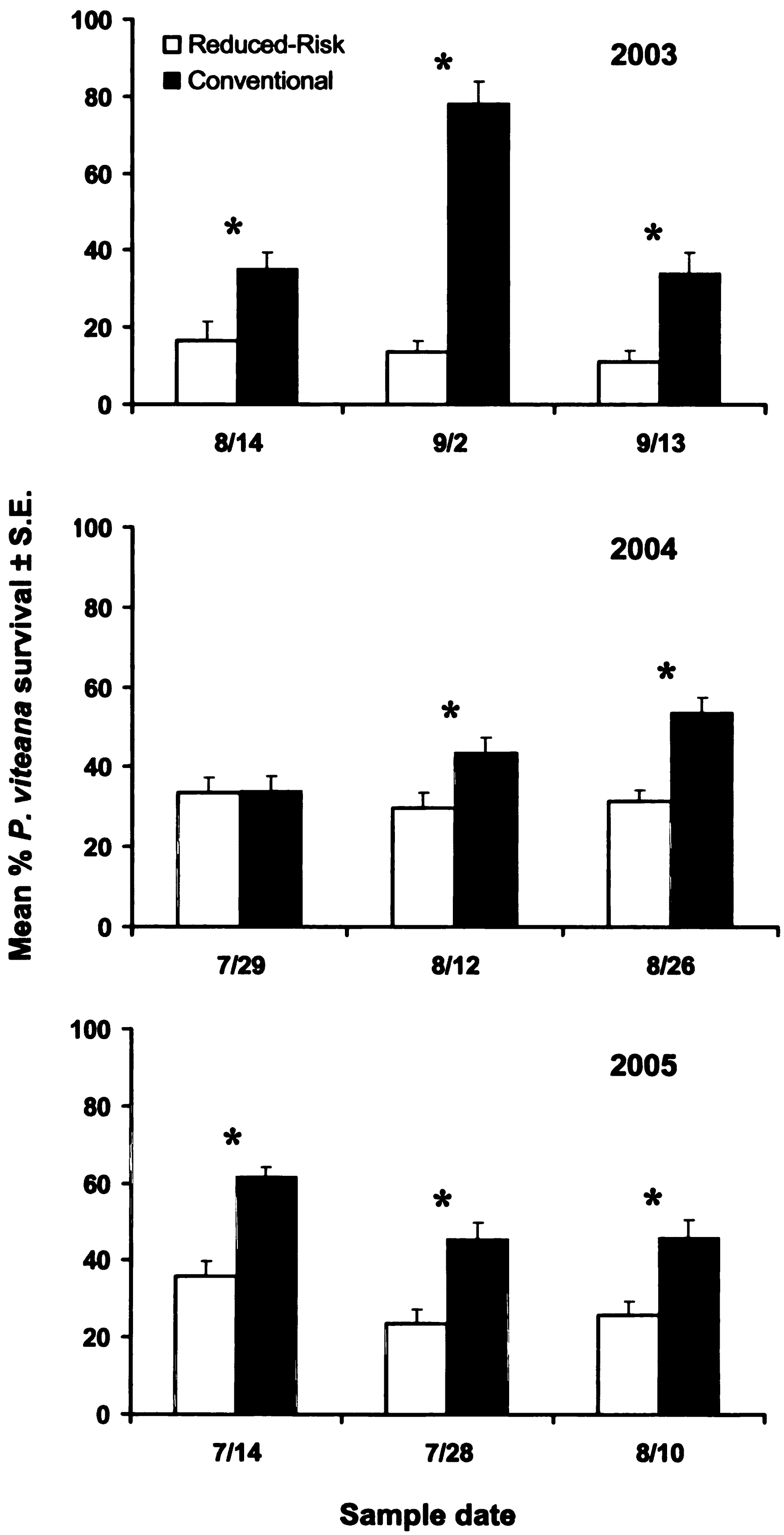
In eight of nine samples of berries infested with *P. viteana* larvae collected from 2003-5, there was more than 23% lower survival of *P. viteana* in the reduced-risk insecticide program compared to the conventional insecticide program ($F>7.5$; df=1,26; $P<0.011$ in 2003; $F>6.5$; df=1,38; $P<0.015$ in 2004; and $F>11.6$; df=1,38; $P<0.0015$ in 2005) (Figure 2.3). The samples taken on 29 July 2004 had similar levels of survival in the two programs (F=0.002; df=1,38; P=0.96).

Figure 2.2. Average number of *P. viteana* larvae at the vineyard border and vineyard interior in juice grape vineyards in Michigan under conventional or reduced-risk insect management programs during 2003-2005. Arrows represent insecticide applications in the reduced-risk program. Vineyard border sample dates with an asterisk are significantly different between programs at P<0.05.



2003
Reduced-Risk Border
Reduced-Risk Interior
Conventional Border
Conventional Interior
2004
2005
Avg. number of P. viteana larvae per 30 clusters
0
2
4
6
8
10
12
14
5/24
6/7
6/21
7/5
7/19
8/2
8/16
8/30
9/13
Date

Figure 2.3. Average percent survival of *P. viteana* larvae ±S.E. from infested berries collected at the border of juice grape vineyards in Michigan under conventional or reduced-risk insect management programs during 2003-2005. Pairs of bars with an asterisk are significantly different between programs at *P*<0.05.



Reduced-Risk
Conventional
2003
2004
2005
Mean % P. viteana survival ± S.E.
100
80
60
40
20
0
*
8/14
9/2
9/13
7/29
8/12
8/26
7/14
7/28
8/10
Sample date

DISCUSSION

This study indicates that grape pest management programs which incorporate reduced-risk insecticides for control of *P. viteana* can obtain similar or greater control of *P. viteana* compared to programs based solely on broad-spectrum insecticides. Similar abundance of *P. viteana* was found in both programs when measured using monitoring traps and cluster sampling. The lower larval survival in vineyards managed using methoxyfenozide for control of late-season generations of *P. viteana* would be expected to have long-term effects on local populations of *P. viteana,* but this was not detected over the three years of this study. The lower larval survival in pre-harvest samples from the reduced-risk vineyards would have reduced the likelihood of inspectors detecting larvae in harvested fruit, reducing the risk for rejection of grape loads by processors.

In response to increased regulation of broad-spectrum insecticides for many minor crops in the US, similar studies have measured control of other key insect pests using reduced-risk management approaches. For example, mating disruption and cover crop management in peaches and apples provided equal or improved control of the oriental fruit moth, *Grapholita molesta* (Busck) compared with broad-spectrum insecticides (Atanassov et al. 2002, 2003, Kovanci et al. 2005), and selective insecticides resulted in lower pest densities and greater predator densities compared to broad-spectrum insecticides in Washington potato fields (Koss et al. 2005). *Bt* sweet corn and spinosad provided equal control of lepidopteran pests and were less toxic to natural enemies in sweet corn compared to the pyrethroid lambda cyhalothrin (Musser and Shelton 2003), and methoxyfenozide and spinosad provided equivalent control of *Lacanobia subjunctata* (Grote and Robinson) in Washington apple orchards (Doerr et al. 2004). Additionally, the fruittree leafroller, *Archips argyrospila* (Walker), the European leafroller *A. rosana* L., the obliquebanded leafroller, *Choristoneura rosaceana* Harris, the three-lined leafroller, *Pandemis limitata* Robinson, and *Spodoptera littoralis* (Boisduval) have all shown high susceptibility to methoxyfenozide and spinosad in the laboratory (Smirle et al. 2003a, Smirle et al. 2003b, Pineda et al. 2004). However, limitations of reduced-risk approaches have also been found. For example, replacing organophosphate insecticides with neonicotinyl insecticides in apple has provided acceptable control of only one of four species of lepidopteran pests in small plot trials (Brunner et al. 2005), and may also increase mite outbreaks (Beers et al. 2005). Although field studies in cotton showed an increase in natural enemy conservation using IGR's compared to conventional insecticides, pest densities were generally higher in the reduced-risk managed program (Naranjo et al. 2004). These and other research results confirm that there is a continued need to evaluate both short- and long-term effects of reduced-risk management approaches on insect communities.

In this study, implementation of a reduced-risk insect management program focused on control of the key insect pest *P. viteana*, and revealed similar abundance of moths, eggs, and larvae of this pest compared to the grower's conventionally managed vineyards. However, lower survival of larvae in the reduced-risk program compared to the conventional program on eight of nine sampling dates over three seasons indicates improved control of *P. viteana* in the reduced-risk program. The improved control may be due to reduced toxicity caused by the insecticides applied and/or increased activity of natural enemies in response to the use of reduced-risk insecticides. The data suggest that increased parasitism is more important than toxicity of the insecticides for reducing the survival of *P. viteana* (see Chapter 4). IPM programs incorporating reduced-risk insecticides in place of broad-spectrum insecticides should provide greater opportunity for conservation of natural enemies and greater biological control of pests, because the compounds have lower toxicity to biological control agents compared with broad-spectrum insecticides (Trisyono et al. 2000, Hewa-Kapuge et al. 2003, Schneider et al. 2003, Medina et al. 2003b, Suh et al. 2004). As the growing season progresses, multiple instars of *P. viteana* larvae are present in vineyards due to overlapping generations (Hoffman and Dennehy 1989, Tobin et al. 2003), providing a broad range of potential hosts for parasitoids.

Both methoxyfenozide and spinosad are highly effective against *P. viteana* eggs and larvae in the laboratory (Jenkins, unpublished data, Isaacs et al. 2005) and have provided equal control compared to broad-spectrum insecticides in multiple-year small-plot trials (Saunders et al. 2003, Wise et al. 2005, Williams et al. 2005). Methoxyfenozide is specific to Lepidoptera and has been shown to be effective against other tortricid pests (Trisyono and Chippendale 1998, Hoelscher and Barrett 2003, Pineda et al. 2004, Borchert et al. 2004a, Borchert et al. 2004b, Irigaray et al. 2005), but is generally safe to natural enemies (Trisyono et al. 2000, Carton et al. 2003, Hewa-Kapuge et al. 2003, Schneider et al. 2003). Spinosad is active against many arthropods, including Lepidoptera, Coleoptera, Homoptera, Diptera, Phytoseiidae, and Hymenoptera, (Salgado 1998, Wilkinson 2002, Galvan et al. 2005, Pelz et al. 2005, Villanueva and Walgenbach 2005) and there are reports on its compatibility (Medina et al. 2001, Williams et al. 2003, Medina et al. 2003a) and non-compatibility (Nowak et al. 2001, Cisneros et al. 2002, Mason et al. 2002, Penagos et al. 2005) with natural enemies. This suggests that methoxyfenozide would be a more suitable alternative to conventional insecticides than spinosad in programs that aim to control *P. viteana* while minimizing the toxicity to natural enemies.

Paralobesia viteana infestation is often greatest at vineyard borders (Biever and Hostetter 1989, Hoffman and Dennehy 1989, Trimble et al. 1991, Botero-Garcés and Isaacs 2004a) and this pattern was also found in our study. Regular pest scouting is an important component of vineyard IPM, and the lower levels of survival by *P. viteana* larvae in the vineyards managed using reduced-risk insecticides may in part be because insecticide applications were timed more appropriately due to weekly scouting information, whereas the conventional vineyards were often sprayed in response to regional recommendations. Since IGR's are most effective when ingested (Carlson et al. 2001), applications of reduced-risk insecticides were targeted at *P. viteana* during peak second and third generation egglaying as a result of direct observations of clusters. In addition to regular scouting, growers were advised to apply these insecticides at a higher volume of water per acre and to spray every row to achieve good cluster coverage. Cluster coverage is critical for control of this pest, particularly late in the season when the leaf canopy makes it difficult to achieve this task.

Paralobesia viteana is the primary insect pest of eastern North American vineyards and, because of multiple generations each year, management actions are required throughout the growing season. This multi-year evaluation of reduced-risk IPM programs in Michigan vineyards provides evidence that control of *P. viteana* is achievable using a program that depends on methoxyfenozide and spinosad for control of late-season generations of this pest. As additional reduced-risk insecticides with high activity against this pest become registered for use in vineyards, a more integrated approach that promotes biologically-based management of *P. viteana* will be possible.

CHAPTER 3

CUTTING WILD GRAPEVINES, A CULTURAL CONTROL STRATEGY FOR *PARALOBESIA VITEANA* IN VINEYARDS

INTRODUCTION

The grape berry moth, *Paralobesia viteana* (Clemens) (Lepidoptera: Tortricidae) is native to North America east of the Rocky Mountains, (Dennehy et al. 1990, Botero-Garcés and Isaacs 2003) and is a primary insect pest of eastern North American vineyards. *Paralobesia viteana* occurs on wild and cultivated *Vitis* spp. and insect management programs in this region are primarily directed at preventing infestation of grape clusters by *P. viteana*. For control of *P. viteana* and other vineyard insect pests, growers in the eastern US rely on multiple applications of broad-spectrum insecticides. However, the Food Quality Protection Act of 1996 has led to restrictions on the use of broad-spectrum insecticides in this industry and grape growers need alternative control options for effectively managing insect pests.

In the geographic range of *P. viteana*, vineyards are often found in close association with deciduous woods where wild grapevines (*Vitis* spp.) persist. Grapevines are an important part of the plant community in deciduous woods. They are often a pioneer species in forest development and their abundance is positively correlated with areas of moderate to high disturbance (Morano and Walker 1995). Four *Vitis* species (*V. aestivalis* Michaux, *V. labrusca* L., *V. riparia* Michaux, and *V. vulpina* L.) are found in Michigan (Galet 1979, Voss 1985, Jenkins, unpublished data). *Vitis riparia* thrives in lowland and upland woods, particularly along borders (Voss 1985), and is one of the most common species found near Michigan and New York vineyards (Dennehy et al. 1990, Jenkins, unpublished data).

Uncultivated land can have a variety of effects on the insect community in agricultural settings (van Emden 1965, Gurr et al. 1998, Wratten et al. 1998). In eastern grape production, woods containing wild grape could provide a habitat for *P. viteana* to escape pest management programs during the growing season (Hoffman and Dennehy 1989, Seaman et al. 1990, Botero-Garcés and Isaacs 2004a), maintaining a pest population outside the area of management that can reinfest vineyards (Dennehy et al. 1990, Seaman et al. 1990). Indeed, infestation of grape clusters at vineyard borders near deciduous woods is often greater than that found at vineyard interiors (Biever and Hostetter 1989, Hoffman and Dennehy 1989, Trimble et al. 1991), and infestation by *P. viteana* has been reported to be positively correlated with wild grape abundance in adjacent habitats (Sanders and DeLong 1921, Dennehy et al. 1990, Botero-Garcés and Isaacs 2004a). Cutting wild grapevines to prevent fruiting has been suggested as a strategy to reduce *P. viteana* pest pressure in adjacent vineyards, thus reducing the need for insecticide treatments. Using a similar approach, insecticide applications were reduced by approximately 75% when compared with conventional orchards after the principal host plants of codling moth, *Cydia pomonella* L, were removed within 200 m of a small commercial apple orchard in Massachusetts (Prokopy 2003). Hosts were removed within 200 m because most female codling moths move less than 100 m (Wildbolz and Baggiolini 1959).

Cultural control practices which alter habitats to create less suitable environments for pests may also indirectly affect natural enemy populations (Debach and Rosen 1991).

Wild grapevines may act as a natural source of pest infestation in vineyards. However, they may also provide a refuge for natural enemies of *P. viteana* outside the region treated with insecticide (Dennehy et al. 1990, Seaman et al. 1990), and so the removal of such hosts may have unintended consequences for natural enemy populations. The effects of cutting wild grape on natural enemies are discussed in Chapter 4 of this thesis.

The average maximum displacement by male *P. viteana* moths has been documented at approximately 105 m between woods and adjacent vineyards and 39 m within vineyards (Botero-Garcés and Isaacs 2004b). This limited flight potential of this species coupled with the close association between *P. viteana* and the distribution of wild and cultivated grapevines, suggests that removing or reducing the availability of its host plant would lead to a reduction in its population. If effective, this could be an important component of an integrated pest management program for management of *P. viteana*. This project aimed to determine whether cutting of this native host near vineyards reduced the abundance of *P. viteana* and the associated fruit infestation in adjacent vineyards.

MATERIALS AND METHODS

Study sites and insect management

This study was conducted at two mature 1.4-4 ha *Vitis labrusca* var. 'Concord' grape vineyards at each of five farms from 2003 to 2005 in Van Buren and Berrien Counties, Michigan (Appendix 2.1). Vineyards were selected with histories of *P. viteana* infestation and bordered on at least one side by deciduous woods containing wild grapevines. At each farm, wild grapevines in the woods adjacent to one of the vineyards (experimental

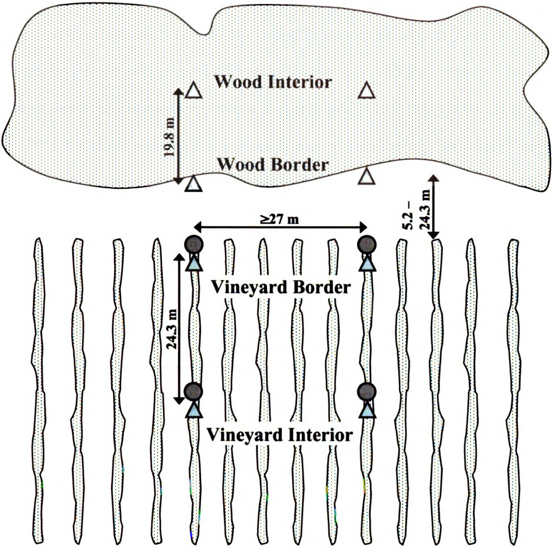


Figure 3.1. Schematic diagram of an experimental vineyard and adjacent wood habitat (not to scale). Triangles represent pheromone trap placement at the vineyard interior, vineyard border, wood border, and wood interior. Grey circles represent monthly sampling sites for infestation by *P. viteana* eggs and larvae.

treatment) were cut, to prevent the vines from fruiting (Figure 3.1). Vines were first cut near ground level between 5-13 May 2003 using 75 cm orchard loppers (Sandvik, Scranton, PA). During the course of this study, regrowth of wild grape was monitored and prevented by re-cutting during each subsequent spring (19-20 May 2004 and 18-19 May 2005). Localized herbicide applications (triclopyr, Pathfinder II, Dow Agrosciences, Indianapolis, IN) were made in 2004 to spot treat problematic areas. Vines were cut to a depth of 60 m from the edge of the woods adjacent to the vineyard or to the end of the woods, whichever came first. The wild vines in the woods adjacent to the comparison vineyard (untreated control) were not cut. Within each farm, both vineyards received the same insecticide and fungicide program which was applied by the grower. In 2004, five leaves were sampled from five randomly chosen wild grapevines in both treatments at each farm and identified to species. Voucher specimens of wild *Vitis* spp. are held in the Michigan State University Herbarium (see Appendix 1.1).

***P. viteana* moth captures**

Flight of adult male *P. viteana* was monitored using large plastic delta traps (Suterra LLC, Bend, OR) baited with *P. viteana* sex pheromone (90:10 ratio of (Z)-9-12Ac and (Z)-11-14Ac) (Suterra LLC, Bend, OR). Traps were placed at a height of 1.5 m at each of the following locations: vineyard interior, vineyard border, wooded edge adjacent to each vineyard, and wood interior. Two traps were placed at each location to account for variability in moth captures and traps were distributed evenly across the width of the vineyard, at least 27 m apart within each location (Figure 3.1). Vineyard interior traps were placed 24.3 m from the vineyard border and wood interior traps were placed 19.8 m from the edge of the woods. The distance between the vineyard border and the wood border ranged from 5.2 to 24.3 m (Figure 3.1). Traps were monitored weekly for the number of male *P. viteana* captured, and the moths were removed or traps were replaced with new inserts. Pheromone lures were replaced every four weeks using lures from the same lot in each season. Each year, the total moth captures from each trap were averaged within location and compared between locations and treatments using ANOVA (PROC MIXED, SAS Institute 2001). Data were log-transformed (log n+1) to meet normality assumptions prior to analysis and Tukey's test was used to determine differences between means at α=0.05.

P. viteana cluster and berry infestation in vineyards

Infestation by *P. viteana* was quantified monthly by visually examining 30 clusters (five clusters on three vines spaced ca. 2.7 m apart, at two sampling sites) at the border and interior of the vineyard (Figure 3.1). For each vine, the number of *P. viteana* eggs, *P. viteana* larvae, and clusters with *P. viteana* larvae was recorded and summed within each sampling site for each date. Berries showing signs of *P. viteana* infestation were scored as being infested and, due to their web-spinning behavior, adjacent berries webbed together were counted as one larva. The total number of eggs found at each farm throughout the season, and for each specific sampling date, was compared between treatments and locations using ANOVA (PROC MIXED, SAS Institute 2001). The weekly average of *P. viteana* clusters infested by *P. viteana* larvae and the number of larvae were compared between treatments and locations for each date and across each season using ANOVA (PROC MIXED, SAS Institute 2001). For all analyses, data were log-transformed (log n+1) to meet normality assumptions prior to analysis and Tukey's test was used to determine differences between means at α=0.05.

RESULTS

Although four *Vitis* spp. are known in Michigan, only *Vitis riparia* was identified in random samples of leaves collected from the wild grapevines at each farm within both treatments in this study.

P. viteana moth captures

Male moths were caught from late April until traps were collected at harvest, with the greatest captures in May and June, before and during bloom. Similar numbers of moths were captured in the experimental and untreated control treatments in 2003, 2004, and 2005 (F=1.1; df=1,4; P=0.35 in 2003; F=1.6; df=1,4; P=0.27 in 2004; F=0.47; df=1,4; P=0.53 in 2005) (Table 3.1). On two dates, 19 July and 7 September 2004, moth captures were significantly greater in the experimental treatment compared to the untreated control (F=7.64; df=1,4; P=0.051 and F=11.28; df=1,4; P=0.028, respectively). There was no significant interaction between treatment and location in the total number of male moths captured in any year (F=1.89; df=3,24; P=0.16 in 2003; F=0.16; df=3,24; P=0.92 in 2004; F=0.43; df=3,24; P=0.73 in 2005) (Table 3.1). Moth abundance was different between locations within farms; in all years male moth captures followed the same trend: captures at the vineyard interior > wood interior > wood border > vineyard border, although not all comparisons were significantly different (Table 3.1). In each year of this study, moth captures were significantly greater at the vineyard interior compared to the

Table 3.1. Average total captures of male *P. viteana* moths per trap ± S.E. by location in Michigan juice grape vineyards where adjacent wild grapevines were cut (experimental) or not cut (untreated control) during 2003-2005.

Location	Wild Grape Program	2003	2004	2005
Vineyard Interior	Experimental	39.8 ± 9.3	34.3 ± 8.4	34.1 ± 4.8
	Untreated Control	29.9 ± 14.5	29.8 ± 11.2	23.8 ± 5.3
Vineyard Border	Experimental	10.9 ± 1.2	11.3 ± 1.7	13.3 ± 4.2
	Untreated Control	14.3 ± 7.2	11.0 ± 5.2	10.4 ± 2.5
Wood Border	Experimental	19.1 ± 4.5	17.2 ± 3.9	15.4 ± 2.5
	Conventional	26.2 ± 10.9	10.8 ± 3.6	16.3 ± 5.2
Wood Interior	Experimental	31.0 ± 7.3	27.7 ± 6.5	25.6 ± 5.0
	Untreated Control	31.0 ± 10.5	20.7 ± 5.2	26.2 ± 6.0

vineyard border (F=12.65; df=1,24; P=0.0016 in 2003; F=17.32; df=1,24; P=0.0004 in 2004; F=19.84; df=1,24; P=0.0002), greater at the wood interior compared to the vineyard border (F=21.88; df=1,24; P<0.0001; F=12.30; df=1,24; P=0.0018; F=15.35; df=1,24; P=0.0006) and greater at the wood interior than the wood border (F=5.76; df=1,24; P=0.0245 in 2003; F=6.96; df=1,24; P=0.0144 in 2004; F=6.12; df=1,24; P=0.0208 in 2005). In 2003, moth captures were significantly greater at the wood border compared to the vineyard border (F=5.18; df=1,24; P=0.032). In 2004 and 2005, moth captures were significantly greater at the vineyard interior compared to the wood border (F=10.84; df=1,24; P=0.0031 and F=9.06; df=1,24; P=0.0061, respectively).

P. viteana cluster and berry infestation in vineyards

Comparisons between the two treatments indicate that egglaying was consistent between both treatments; for all years there was no significant difference in the number of eggs found between treatments for each specific sampling date and across each season (F=0.57; df=1,4; P=0.49 in 2003; F=0.02; df=1,4; P=0.90 in 2004; F=0.82; df=1,4; P=0.42 in 2005). On average, the number of eggs detected on 30 cluster samples at the border was approximately seven times greater than the number detected at the interior (Table 3.2). In all years, the number of *P. viteana* eggs detected was significantly greater at the vineyard border compared to the vineyard interior (F=48.07; df=1,8; P=0.0001 in 2003; F=129.01; df=1,8; P<0.0001 in 2004; F=120.9; df=1,8; P<0.0001 in 2005). There was no significant interaction between program and location in any year (F=0.89; df=1,8; P=0.37 in 2003; F=0.0; df=1,8; P=0.97 in 2004; F=0.22; df=1,8; P=0.65 in 2005) (Table 3.2).

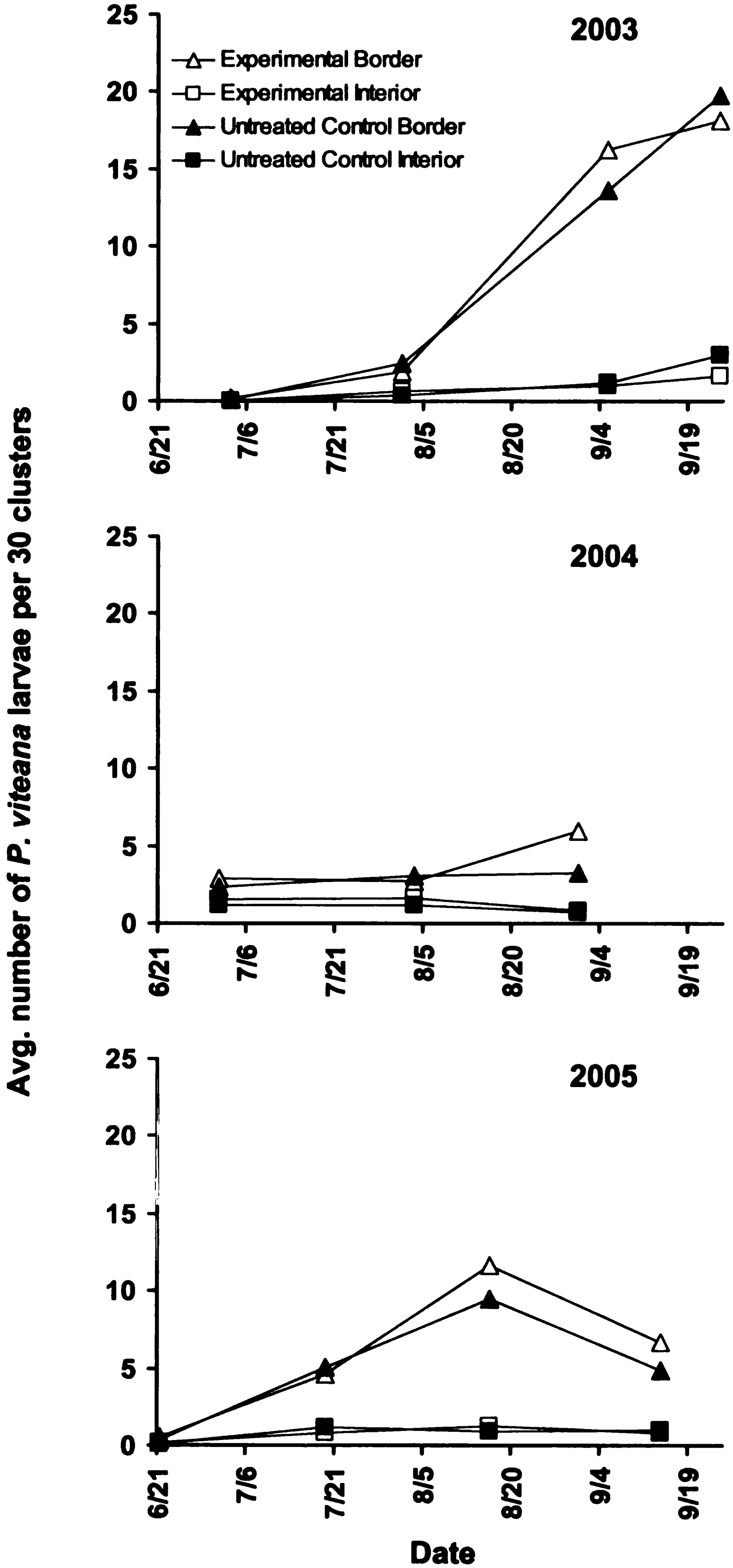
Infestation by *P. viteana* larvae was also greatest at the vineyard border throughout this experiment; the number of *P. viteana* larvae was significantly greater at the vineyard border compared to the vineyard interior (F=92.91; df=1,8; $P<0.0001$ in 2003; F=61.58, df=1,8; $P<0.0001$ in 2004; F=154.16; df=1,8; $P<0.0001$ in 2005). There was no significant interaction between treatment and location in any year (F=0.1; df=1,8; $P=0.75$ in 2003; F=0.4; df=1,8; $P=0.54$ in 2004; F=0.03; df=1,8; $P=0.86$ in 2005). For all years there was no significant difference in the number of larvae found between treatments across each season (F=0.04; df=1,4; $P=0.0.86$ in 2003; F=2.14; df=1,4; $P=0.22$ in 2004; F=0.01; df=1,4; $P=0.93$ in 2005) (Figure 3.2).

Similarly, the number of clusters infested by *P. viteana* larvae was significantly greater at the vineyard border compared to the vineyard interior in each year (F=140.91; df=1,8; $P<0.0001$ in 2003; F=55.14; df=1,8; $P<0.0001$ in 2004; F=148.44; df=1,8; $P<0.0001$ in 2005). There was no significant interaction between program and location in any year (F=0.01; df=1,8; $P=0.92$ in 2003; F=0.13; df=1,8; $P=0.72$ in 2004; F=0.01; df=1,8; $P=0.92$ in 2005). For all years there was no significant difference between treatments in the number of clusters with larvae found across each season (F=0.1; df=1,4; $P=0.77$ in 2003; F=1.92; df=1,4; $P=0.24$ in 2004; F=0.07; df=1,4; $P=0.81$ in 2005).

Table 3.2. Mean number of *P. viteana* eggs per season ± S.E. found on 30 clusters at borders and interiors of Michigan juice grape vineyards where adjacent wild grapevines were cut (experimental) or not cut (untreated control) during 2003-2005.

Location	Wild Grape Program	2003	2004	2005
Vineyard Interior	Experimental	10.6 ± 2.4	5.2 ± 0.6	1.8 ± 0.9
	Untreated Control	7.6 ± 2.9	5.8 ± 1.6	0.6 ± 0.4
Vineyard Border	Experimental	49.8 ± 5.8	41.6 ± 10.6	29.2 ± 19.3
	Untreated Control	51.6 ± 10.7	40.8 ± 9.6	12.0 ± 2.5

Figure 3.2. Average number of *P. viteana* larvae at the vineyard border and vineyard interior in juice grape vineyards in Michigan where adjacent wild grapevines were cut (experimental) or not cut (untreated control) during 2003-2005.


2003
2004
2005
Experimental Border
Experimental Interior
Untreated Control Border
Untreated Control Interior
Avg. number of P. viteana larvae per 30 clusters
0
5
10
15
20
25
6/21
7/6
7/21
8/5
8/20
9/4
9/19
Date

DISCUSSION

This study shows that cutting wild grapevines in woodlots up to 60 m deep for three growing seasons has no effect on infestation of adjacent vineyards by *P. viteana*, the main insect pest in this system. To date, this is the first published report on the effects of vineyard insect pest control from cutting wild grapevines adjacent to vineyards, and in general there are few studies which have documented the effects of wild host removal on insect pest control in perennial crops. Additionally, our understanding of insect movement and dispersal behavior at the landscape level is inferior compared to our understanding at the field level (Barrett 2000, Altieri and Nicholls 2004).

Paralobesia viteana adults move a relatively short distance, with average maximum displacement of 105 m between woods and adjacent vineyards and 39 m within vineyards for male moths (Botero-Garcés and Isaacs 2004b). The greater movement between woods and vineyards than within the vineyard suggests that *P. viteana* will move further when its host is not present. Wild grape removal may be required over a larger spatial scale to minimize immigration of moths into vineyards and to realize a significant effect on vineyard infestation.

The scale at which wild grape was cut in this study was done to simulate what a grower may do on their own property. The assumption taken when cutting wild grapevines in woodlots adjacent to vineyards is that pest pressure by *P. viteana* will be reduced. Although host removal was not effective for reducing pest pressure in this study, host removal has been shown to be an effective component of an IPM program in apples (Prokopy 2003). This suggests that external pest pressure can be minimized if the scale at which alternate hosts are removed is appropriate. Although it may be economically and politically unfeasible, increasing the spatial scale at which wild hosts are removed may make cultural control of *P. viteana* possible.

Cutting wild grapevines and preventing regrowth is a time consuming and labor-intensive process. In this study, the average time taken to cut wild vines and the approximate number of wild vines cut was recorded in 2004 and 2005. In 2004, it took approximately 17 h to cut ca. 1500 vines and in 2005, it took approximately 6.75 h to cut ca. 350 vines at all sites. It should also be noted that sucker growth from vines cut in 2003 was extensive, and up to 35 suckers on one vine were observed (Jenkins, unpublished data), prompting herbicide application in 2004. Coupled with the fact that no additional control of *P. viteana* is achieved, it is recommended that growers do not invest their time and labor resources in cutting wild grapevines in woodlots adjacent to their vineyards, unless this is required for other reasons.

CHAPTER 4

RESPONSE OF NATURAL ENEMIES TO ALTERNATIVE INSECT PEST MANAGEMENT STRATEGIES IN MICHIGAN VINEYARDS

INTRODUCTION

Development of an integrated pest management (IPM) program requires an understanding of how new approaches will affect natural enemies. Current IPM strategies in eastern US grape production provide growers with few resources for effectively controlling the complex of grape insect pests without the use of pesticides, and adoption of conservation biological control in this system is at a very low level. For the continued development of an IPM program in Michigan vineyards, it will be important to determine what natural enemy species are present and whether their abundance could be enhanced if alternative insect pest management strategies are employed. Parasitoids are important natural enemies of many crop pests and may be keystone species within agricultural ecosystems (LaSalle 1993). The super families Ichneumonoidea, Chalcidoidea, and Proctotrupoidea are some of the most abundant natural enemies in fruit crops (Viggiani 2000), and enhancement of their abundance may best be achieved by providing a refuge for natural enemies in adjacent natural habitats while also reducing the toxicity of insect management programs within vineyards.

A number of studies have examined which natural enemies are present in eastern US vineyards, particularly those which parasitize the grape berry moth, *Paralobesia viteana,* a key pest in this region. For example, a survey for natural enemies of *P. viteana* in Pennsylvania revealed that *Trichogramma minutum* Riley was the only native egg parasitoid with potential for controlling *P. viteana*. However, natural parasitism by *T. minutum* was not dependable since it prefers wild *Vitis* spp. in wooded habitats over cultivated grapes (Nagarkatti et al. 2002a). Parasitoids that attack *P. viteana* larvae have been described from New York State. In a study by Seaman et al. (1990), three hymenopteran parasitoid species (*Trichogramma pretiosum* Riley, *Glypta mutica* Cushman, and *Apanteles polychrosidis* Viereck) that attack *P. viteana* were collected from three different habitats: wild grapes, organically managed commercial vineyards, and conventionally managed commercial vineyards. Average parasitism by *T. pretiosum* was greater than other natural enemies (4.5-20.2%), with the highest parasitism levels occurring in wild habitats. *Glypta mutica* and *A. polychrosidis* caused lower levels of mortality (0.01-6.4% and 0-11.5%, respectively) than *T. pretiosum*. Combined, the three species have been observed causing 12-40% mortality of *P. viteana* larvae (Dennehy et al. 1990). Research has also been conducted to determine which *Anagrus* spp. parasitoids are present in New York vineyards for control of leafhoppers (Williams and Martinson 2000) and how parasitism by *Anagrus* parasitoids can be enhanced by providing cover crops in vineyards (English-Loeb et al. 2003).

The typical insecticide program in eastern grape vineyards includes pyrethroids, organophosphates and carbamates, and is therefore expected to limit biological control due to the direct toxicity of these pesticides to most natural enemies (Van Driesche and Bellows 1996, Ruberson et al. 1998, Johnson and Tabashnik 1999). In contrast, the recent development and registration of reduced-risk insecticides with specificity to Lepidoptera provides an opportunity for control of *P. viteana* without using broad-spectrum insecticides. For the potential benefits of reduced-risk insecticide programs to be fully understood, their impact on biological control must be considered. Many studies have recently evaluated the effectiveness of insect control programs that incorporate reduced-risk management approaches, and these generally support the expectation that natural enemy abundance will increase when pesticide toxicity to natural enemies is reduced (Atanassov et al. 2002, Musser and Shelton 2003, Smirle et al. 2003a, Smirle et al. 2003b, Doerr et al. 2004, Pineda et al. 2004, Koss et al. 2005, Brunner et al. 2005, Kovanci et al. 2005). Some of the insect growth regulator insecticides being registered for *P. viteana* control have little effect on survival of egg (Suh et al. 2004) or larval (Brown 1994, Brown 1996) parasitoids of other Lepidoptera. These insects are expected to be more sensitive to pesticides than their hosts (Legaspi et al. 1999).

The most important part of the agricultural landscape, from the perspective of conserving natural enemies, may not be within the crop itself (Ferro and McNeil 1998). Uncultivated land can have a variety of impacts on the agricultural insect community (van Emden 1965, Gurr et al. 1998, Wratten et al. 1998). Cultural control practices which alter habitats to create less suitable environments for pests may also indirectly affect natural enemy populations (Debach and Rosen 1991). Changing the temporal or spatial structure of habitats may alter natural enemy movement, colonization, and conservation thus reducing their regulating effects on pest populations (Dennis and Fry 1992, Marino and Landis 1996, Landis and Menalled 1998, Menalled et al. 1999, Schellhorn et al. 2000, Altieri and Nicholls 2004). For example, predaceous phytoseiid mite abundance was lower in apple orchards that were surrounded by few suitable host plants compared to orchards surrounded by many suitable host plants (Tuovinen 1994). In contrast, a higher abundance of natural enemies was maintained in apple orchards where, as part of an IPM program, unmanaged host trees of *Cydia pomonella* L. and *Argyrotaenia velutinana* (Walker) had been removed within 100 m of the orchard compared to conventional orchards (Prokopy et al. 1990).

Within the geographic range of *P. viteana*, vineyards are often found in close association with deciduous woods where wild grapevines (*Vitis* spp.) persist. In this case, woods containing wild grape could provide a habitat for *P. viteana* to escape pest management programs during the growing season (Hoffman and Dennehy 1989, Botero-Garcés and Isaacs 2004a), providing a pest population outside the area of management that can reinfest vineyards (Dennehy et al. 1990). The close association between *P. viteana* and the distribution of wild and cultivated grapevines, coupled with the limited flight potential of this species (Botero-Garcés and Isaacs 2004b), suggests that removing or reducing the availability of its host plant would lead to a reduction in its population. If effective, wild host removal could be an important component of an integrated pest management program for management of *P. viteana*. However, it may also have negative side-effects on natural enemies by removing alternate host plants for their survival outside treated vineyards.

Wild grapevines may act as a natural source of pest infestation in vineyards, but they may also provide a refuge for natural enemies of *P. viteana* outside the region treated with insecticide (Dennehy et al. 1990, Seaman et al. 1990), and so the removal of such hosts may have unintended consequences for natural enemy populations. As mentioned above, wild grapevines and their surrounding wooded habitat were found to be favored over cultivated grape by *Trichogramma minutum* Riley, an egg parasitoid of *P. viteana* (Nordlund 1994, Nagarkatti et al. 2002a) and parasitism of *P. viteana* by

Trichogramma pretiosum Riley was greater in the wild grape habitat compared to conventional and organic vineyards (Seaman et al. 1990).

The recent registration of selective insecticides for use in vineyards provides a unique opportunity to conduct large-scale tests to determine whether biological control activity is enhanced in reduced-risk insecticide programs. Additionally, there is no published report of how removal of wild grapevines near vineyards will affect natural enemies of *P. viteana*, but it will be important to determine the efficacy of this cultural practice as a component of non-chemical approaches to grape pest management. This three-year study was conducted to determine whether adoption of a reduced-risk insecticide program and cutting of wild grapevines adjacent to commercial vineyards affects the natural enemy community in vineyards.

MATERIALS AND METHODS

Research sites and experimental design

Response to reduced-risk insecticides. This study was conducted at two mature 1.4-4 ha *Vitis labrusca* var. 'Concord' grape vineyards at each of four farms in 2003, 2004 and 2005 in Van Buren and Berrien Counties, Michigan (Appendix 2.1). Vineyards were selected with histories of *P. viteana* infestation and bordered on at least one side by deciduous woods. The distance between the vineyard border and the wood border ranged from 6.4 to 20.3 m (Chapter 2, Figure 2.1). One farm selected in 2003 was found to have very low pest pressure and the data from this farm were omitted from the analysis. At the end of the 2003 growing season it was replaced by another farm for the remainder of the study. Growers made all pesticide applications and other vineyard management actions.

Vineyards received standard weed and disease control programs, with both vineyards within each farm receiving the same management inputs.

At each farm, one vineyard received only broad-spectrum insecticides (conventional program), comprising of organophosphates, carbamates, and pyrethroids (Chapter 2, Table 2.1). The other vineyard (reduced-risk program) received an insecticide program based on using reduced-risk insecticides for control of the key insect pests (Chapter 2, Table 2.1). Both vineyards at each farm received a broad-spectrum insecticide immediately after bloom for control of first generation *P. viteana* and leaf-feeding pests. Thereafter, the conventional vineyard received three or more applications of broad-spectrum insecticides and the reduced-risk vineyard received two or more applications of reduced-risk insecticides for control of second and third generations of *P. viteana* (Chapter 2, Table 2.1). Acetamiprid was applied in the reduced-risk vineyards for control of Japanese beetle, *Popillia japonica*, and grape leafhopper, *Erythroneura comes*, as needed (Chapter 2, Table 2.1). Application timing for the reduced-risk program was based on weekly scouting of vineyards, while the conventional vineyard was managed according to each grower's standard insect control program. All immediate post-bloom insecticide applications for control of first generation *P. viteana* were made using 234 liters/ha (25 gallons of water per acre), while the later applications of methoxyfenozide and spinosad in the reduced-risk program were made using 468 liters/ha (50 gallons of water per acre).

Response to wild grape cutting. This study was conducted at two mature 1.4-4 ha *Vitis labrusca* var. 'Concord' grape vineyards at each of five farms from 2003 to 2005 in Van

Buren and Berrien Counties, Michigan (Appendix 2.1). Vineyards were selected with histories of *P. viteana* infestation and bordered on at least one side by deciduous woods containing wild grapevines. The distance between the vineyard border and the wood border ranged from 5.2 to 24.3 m (Chapter 3, Figure 3.1).At each farm, wild grapevines in the woods adjacent to one of the vineyards (experimental vineyard) were cut, to prevent the vines from fruiting (Chapter 3, Figure 3.1). Vines were first cut at ground level in May of 2003 using 75 cm orchard loppers (Sandvik, Scranton, PA). During the course of this study, regrowth of wild grape was monitored and prevented by recutting during each subsequent spring. Localized herbicide applications (triclopyr, Pathfinder II, Dow Agrosciences, Indianapolis, IN) were made in 2004 to spot treat problematic areas. Vines were cut to a depth of 60 m from the edge of the woods adjacent to the vineyard or to the end of the woods, whichever came first. The wild vines in the woods adjacent to the comparison vineyard (conventional vineyard) received no cutting. Within each farm, both vineyards received the same conventional insecticide and fungicide program, and all applications were made by the growers.

Parasitism and survival of *P. viteana*

In both experiments, *P. viteana* parasitism and survival were measured by collecting 100 berries (5 sub-samples of 20 berries) showing signs of *P. viteana* infestation from each vineyard border adjacent to woods. Sampling dates for berries infested with *P. viteana* larvae were chosen each season to best correspond with insecticide application timings and the availability *P. viteana* for parasitism. In the reduced-risk insecticide study, berry samples were taken on 14 August, 2 September, and 13 September in 2003, on 29 July, 12 August, and 26 August in 2004, and 14 July, 28 July, and 10 August in 2005. In the cultural control study, berry samples were taken on 19 August, 9 September, and 30 September in 2003, on 29 July, 12 August, and 26 August in 2004, and 14 July, 28 July, and 10 August in 2005. In 2003, each sub-sample of 20 berries was placed into a 473 ml polypropylene deli container (Fabri-Kal, Kalamazoo, MI) and brought back to the laboratory where the container was held at 24°C and 16:8 L:D. These methods were changed to improve insect survival in 2004 and 2005; individual berries were placed into separate 37 ml plastic cups (Bioserv Corp, Frenchtown, NJ) with white paper insert lids (Bioserv, Frenchtown, NJ). In all years, small pieces of plastic were provided in each container as pupation substrate for *P. viteana*. At the end of five to six weeks, samples were placed at -20°C for 24 h to ensure mortality of specimens. The containers were then opened and the number of *P. viteana* adults, pupae, larvae, and parasitoids of *P. viteana* was recorded and totaled. From these values, the proportion of *P. viteana* surviving and the proportion of parasitized *P. viteana* from each sampling date were calculated. *Paralobesia viteana* survival and parasitism data were compared among treatments for each sample date using the Mann-Whitney U-test (PROC NPAR1WAY, SAS Institute 2001). All parasitoids were identified by specialists to genus or species. Voucher specimens of *P. viteana* and parasitoids are held in the A.J. Cook Arthropod Collection at Michigan State University (see Appendix 1.1).

Natural enemies on yellow sticky traps

In both experiments, natural enemies were monitored each season in vineyards and adjacent habitats using unbaited yellow sticky traps (Great Lakes IPM, Vestaburg, MI).

In the reduced-risk insecticide study, traps were deployed at three locations (vineyard interior, vineyard border, and wood border) from 16 May to 20 September 2003, 17 April to 17 September 2004, and 16 April to 17 September 2005. In the cultural control study, traps were deployed at four locations (vineyard interior, vineyard border, wood border, and wood interior) from 24 April to 20 September 2003, 17 April to 16 September 2004, and 16 April to 17 September 2005. In 2003, two traps per location were deployed in both experiments. Power analyses (Analyst Application, SAS Institute 2001) on data collected in 2003 indicated that greater sample size was required, and so the sample size was increased to six traps per location in 2004 and 2005. All traps in all years for both experiments were collected and replaced with new traps approximately every 14 days. Upon return to the laboratory, all traps were placed at -20°C until assessed. For all years, traps were assessed for the number of natural enemies in the following dominant groups: green lacewings (Neuroptera: Chrysopidae), brown lacewings (Neuroptera: Hemerobiidae), ladybird beetles (Coleoptera: Coccinellidae), parasitoid wasps (Hymenoptera: Ichneumonidae, Braconidae), and syrphid flies (Diptera: Syrphidae). Each year, the total number of natural enemies from each trap were compared between treatments and locations using ANOVA (PROC MIXED, SAS Institute 2001). Additionally, the response of each individual natural enemy group to changes in insecticide program and wild grape cutting was analyzed separately using ANOVA (PROC MIXED, SAS Institute 2001). All data were log-transformed (log n+1) to meet normality assumptions prior to analysis and Tukey's test was used to determine differences between means at α=0.05.

Parasitoid community composition

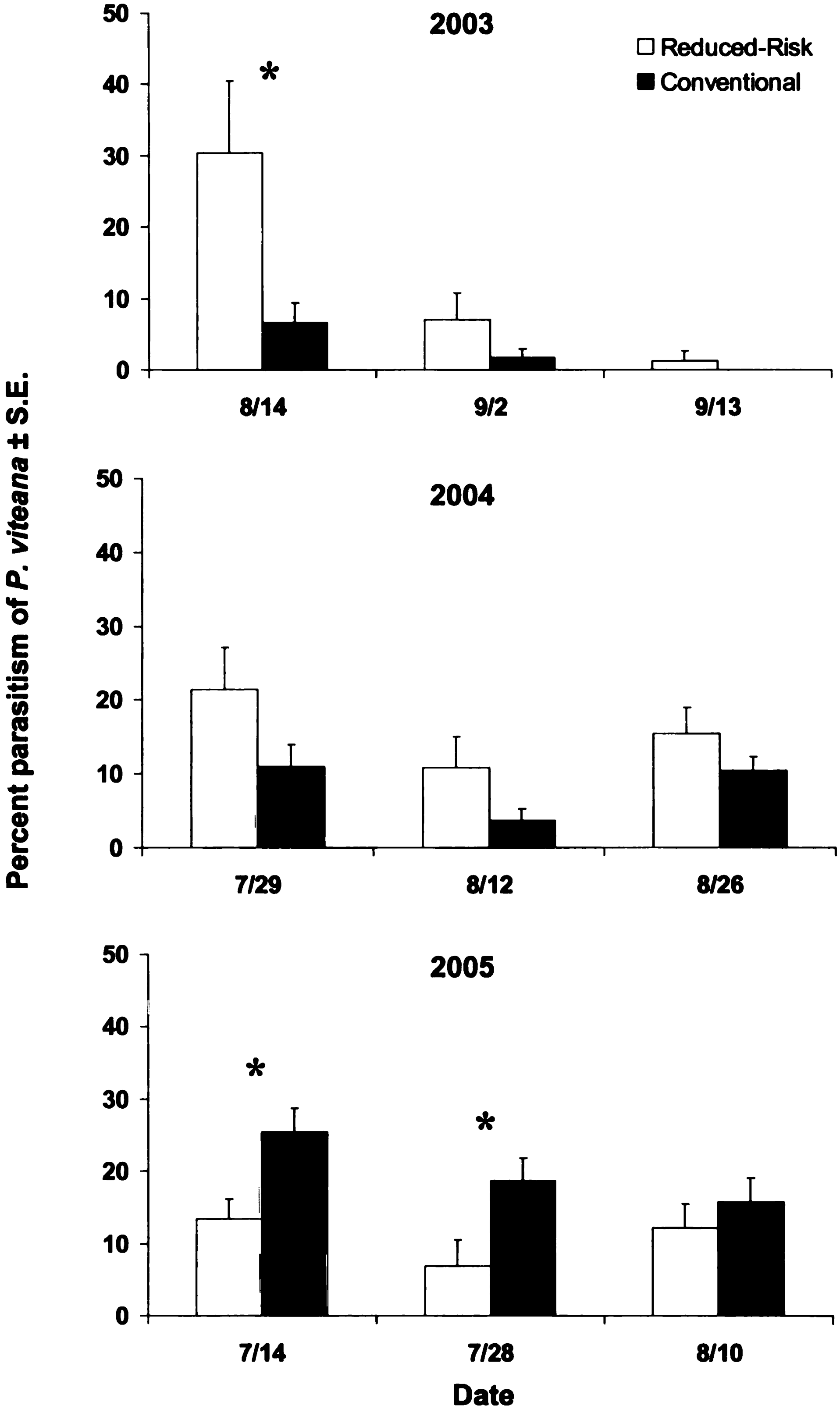
Parasitoids from samples collected to measure parasitism and survival of *P. viteana* were used to determine the relative abundance of the identified parasitoid community in Michigan vineyards. The percent of the total was calculated for each species within each treatment for all years. Statistical analyses were not performed on these data.

RESULTS

Parasitism and survival of *P. viteana*

In 2003 and 2004, parasitism of *P. viteana* was numerically greater in the reduced-risk insecticide program compared to the conventional insecticide program for all sampling dates, but was significantly different only on 14 August 2003 (F=5.8; df=1,26; *P*=0.023) (Figure 4.1). In 2005, parasitism of *P. viteana* was numerically greater in the conventional insecticide program compared to the reduced-risk insecticide program, and significantly greater in the conventional program on 14 July and 28 July (F>5.85; df=1,38; *P*<0.021) (Figure 4.1). Survival of *P. viteana* in the reduced-risk insecticide study was described in Chapter 2. In summary, significantly fewer *P. viteana* survived in the reduced-risk insecticide program compared to the conventional insecticide program in eight of the nine sample dates (F>7.5; df=1,26; *P*<0.011 in 2003; F>6.5; df=1,38; *P*<0.015 in 2004; and F>11.6; df=1,38; *P*<0.0015 in 2005) (Chapter 2, Figure 2.3). In all years of the cultural study, no change or trend in the level of parasitism of *P. viteana* was detected in response to cutting wild grapevines in surrounding habitats (F<1.3; df=1,48; *P*>0.26) (Figure 4.2). Significantly fewer *P. viteana* survived in the untreated vineyards compared to the vineyards where wild grapes were cut on 19 August 2003 (F=4.75;

Figure 4.1. Percent parasitism of *P. viteana* ±S.E. in juice grape vineyards in Michigan under conventional and reduced-risk insecticide management programs during 2003-2005. Pairs of bars with an asterisk are significantly different between programs at P<0.05.


Percent parasitism of P. viteana ± S.E.
2003
Reduced-Risk
Conventional
50
40
30
20
10
0
*
8/14
9/2
9/13
2004
7/29
8/12
8/26
2005
*
*
7/14
7/28
8/10
Date

df=1,48; *P*=0.034), but for all other dates, there was no significant difference in survival of *P. viteana* between treatments (F<2.7; df=1,48; *P*>0.11) (Figure 4.3).

Natural enemies on yellow sticky traps

In both studies, there was some fluctuation in the seasonal occurrence of natural enemies collected on yellow sticky traps, but the five main natural enemy groups were generally found throughout the entire season. In the reduced-risk insecticide study, total natural enemy abundance was similar between programs for all three years (F=1.73; df=1,2; *P*=0.3187 in 2003; F=0.17; df=1,3; *P*=0.71 in 2004; F=2.83; df=1,3; *P*=0.19 in 2005) (Figure 4.4). In all years, the number of natural enemies was significantly greater at the wood border compared to the vineyard border (F=118.24; df=1,8; *P*<0.0001 in 2003; F=45.68; df=1,12; *P*<0.0001 in 2004; F=158.82; df=1,12; *P*<0.0001 in 2005), at the vineyard border compared to the vineyard interior (F=12.13; df=1,8; *P*=0.0083 in 2003; F=7.87; df=1,12; *P*=0.016 in 2004; F=33.5; df=1,12; *P*<0.0001 in 2005), and at the wood border compared to the vineyard border (F=54.64; df=1,8; *P*<0.0001 in 2003; F=15.63; df=1,12; *P*=0.0019 in 2004; F=46.43; df=1,12; *P*<0.0001 in 2005). However, there was no significant interaction between program and location in any year (F=0.27; df=2,8; *P*=0.77 in 2003; F=0.38; df=2,12; *P*=0.69 in 2004; F=2.88; df=2,12; *P*=0.095 in 2005), indicating that natural enemy abundance was similar across vineyards within each farm.

In the cultural control study, total natural enemy abundance was similar between grape cutting treatments for all three years (F=0.12; df=1,4; *P*=0.75 in 2003; F=0.05; df=1,4; *P*=0.83 in 2004; F=0.11; df=1,4; *P*=0.76 in 2005) (Figure 4.5). Similar to the reduced-risk insecticide study, natural enemy abundance also varied significantly

Figure 4.2. Average percent parasitism of *P. viteana* ±S.E. in juice grape vineyards in Michigan where adjacent wild grapevines were cut (experimental) or not cut (untreated control) during 2003-2005.

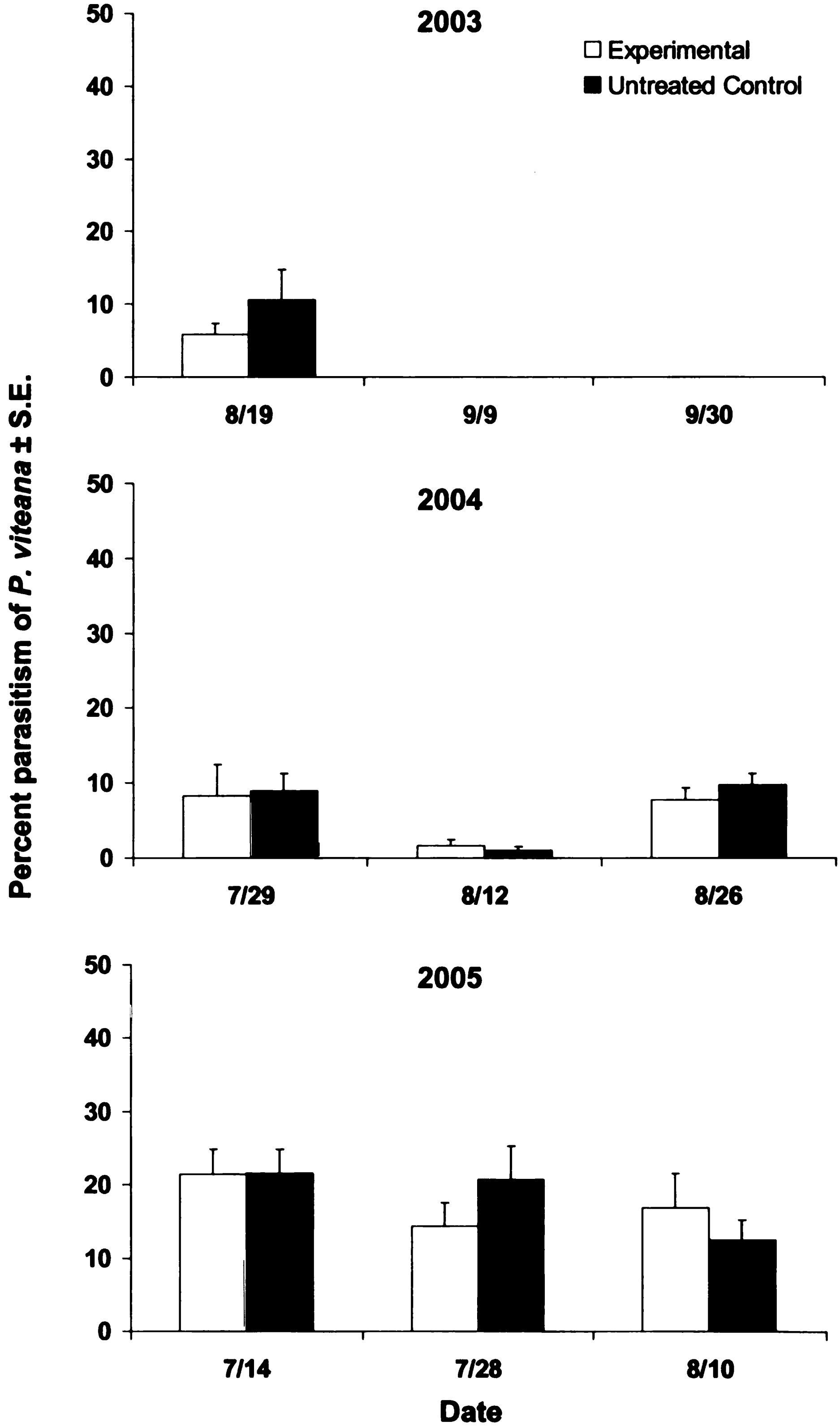

2003
Experimental
Untreated Control
50
40
30
20
10
0
8/19
9/9
9/30
2004
50
40
30
20
10
0
7/29
8/12
8/26
2005
50
40
30
20
10
0
7/14
7/28
8/10
Date
Percent parasitism of P. viteana ± S.E.

Figure 4.3. Average percent survival of *P. viteana* ±S.E. in juice grape vineyards in Michigan where adjacent wild grapevines were cut (experimental) or not cut (untreated control) during 2003-2005. Pairs of bars with an asterisk are significantly different between programs at P<0.05.

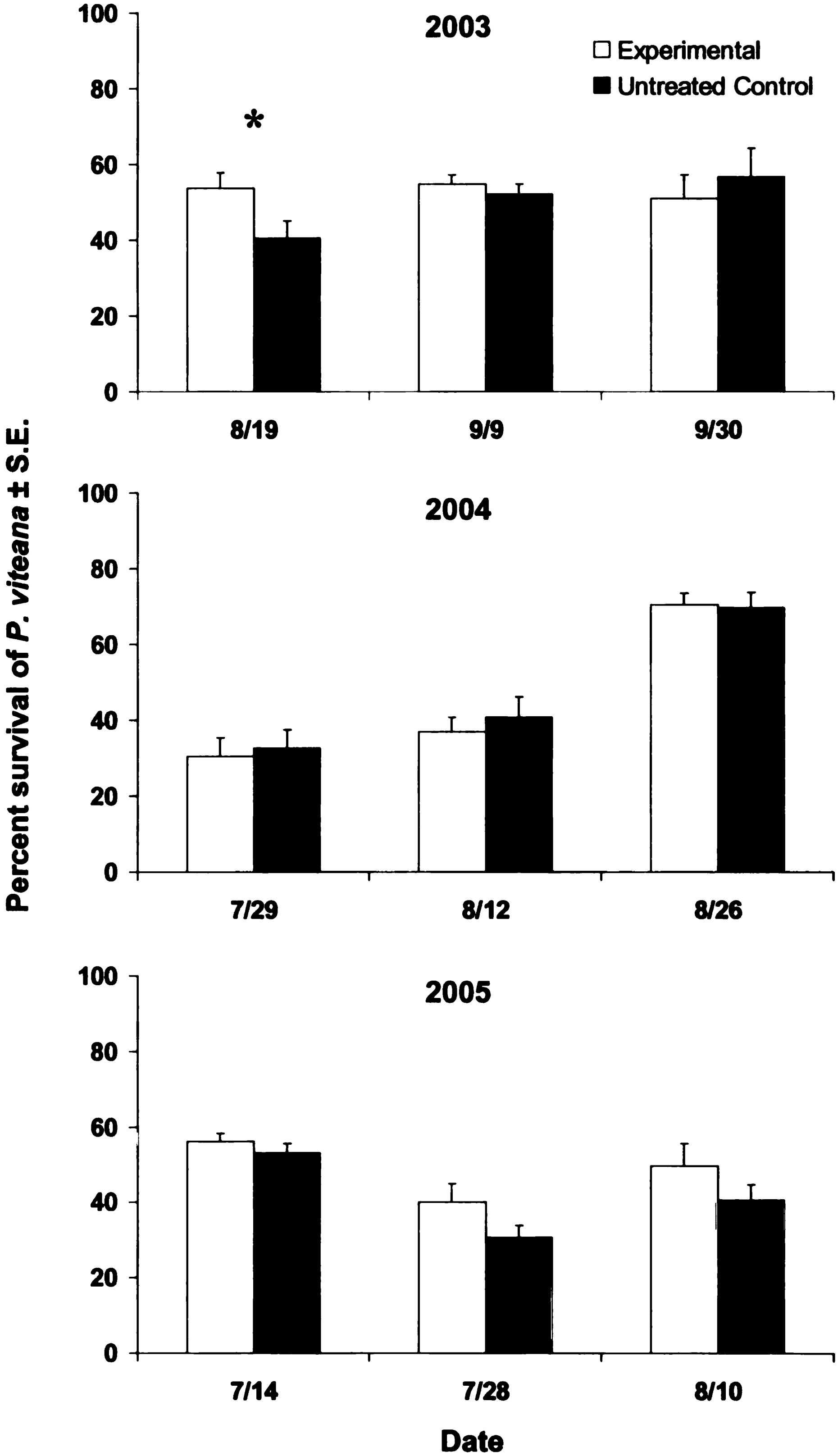
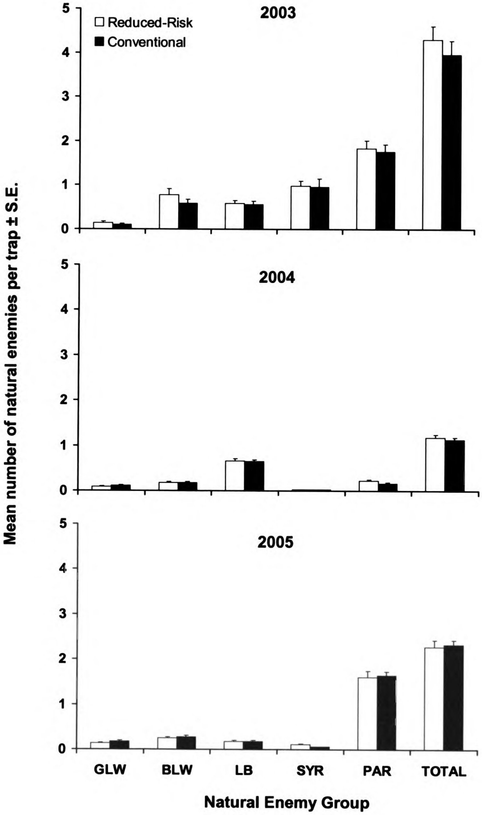
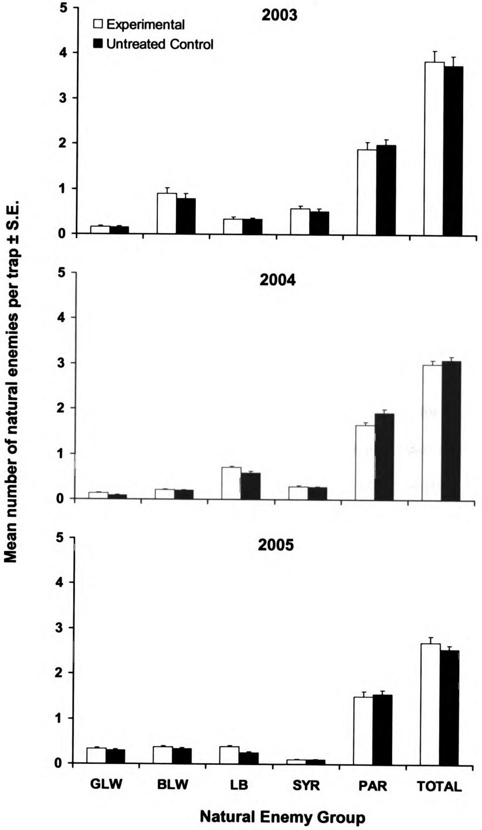

Percent survival of P. viteana ± S.E.
2003
Experimental
Untreated Control
*
100
80
60
40
20
0
8/19
9/9
9/30
2004
100
80
60
40
20
0
7/29
8/12
8/26
2005
100
80
60
40
20
0
7/14
7/28
8/10
Date

Figure 4.4. Average number of natural enemies from yellow sticky traps ±S.E. in adjacent habitats and vineyards in Michigan under conventional and reduced-risk insecticide management programs during 2003-2005. GLW=green lacewings; BLW=brown lacewings; LB=ladybird beetles; SYR=Syrphid flies; PAR=parasitic wasps.



Mean number of natural enemies per trap ± S.E.
2003
Reduced-Risk
Conventional
2004
2005
0
1
2
3
4
5
GLW
BLW
LB
SYR
PAR
TOTAL
Natural Enemy Group

Figure 4.5. Average number of natural enemies from yellow sticky traps ±S.E. in vineyards and adjacent wooded habitats in Michigan where adjacent wild grapevines were cut (experimental) or not cut (untreated control) during 2003-2005. GLW=green lacewings; BLW=brown lacewings; LB=ladybird beetles; SYR=Syrphid flies; PAR=parasitic wasps.



2003
2004
2005
Experimental
Untreated Control
Mean number of natural enemies per trap ± S.E.
0
1
2
3
4
5
GLW
BLW
LB
SYR
PAR
TOTAL
Natural Enemy Group

between locations. Captures were significantly greater at the wood border compared to the wood interior (F=17.72; df=1,24; P=0.0003 in 2003; F=24.40; df=1,24; P<0.0001 in 2004; F=20.24; df=1,24; P=0.0001 in 2005), and at the wood border compared to the vineyard border (F=36.34; df=1,24; P<0.0001 in 2003; F=20.49; df=1,24; P=0.0001 in 2004; F=64.42; df=1,24; P<0.0001 in 2005). The only exception to this trend was in 2004 when vineyard border captures were greater than wood border captures. Natural enemy abundance was significantly greater at the vineyard border compared to the vineyard interior in 2003 and 2005 (F=6.43; df=1,24; P=0.018 and F=13.53; df=1,24; P=0.0012, respectively), and was greater but not significantly different in 2004 (F=3.97; df=1,24; P=0.058). In 2003, there was a significant interaction between grape cutting treatments and location in the abundance of natural enemies (F=3.18; df=3,24; P=0.042), but not in 2004 and 2005 (F<1.71; df=3,24; P>0.19).

In all years, natural enemy species composition was similar for both insecticide programs and grape cutting treatments. In the reduced-risk insecticide study, there were no differences observed in the response of green lacewings (F=0.34; df=1,2; P=0.62 in 2003; F=0.24; df=1,3; P=0.66 in 2004; F=0.4; df=1,3; P=0.57 in 2005), brown lacewings (F=2.39; df=1,2; P=0.26 in 2003; F=0.17; df=1,3; P=0.7 in 2004; F=0.09; df=1,3; P=0.78 in 2005), ladybird beetles (F=0.09; df=1,2; P=0.8 in 2003; F=0.17; df=1,3; P=0.71 in 2004; F=0.0; df=1,3; P=0.98 in 2005), parasitoid wasps (F=0.1; df=1,2; P=0.78 in 2003; F=1.09; df=1,3; P=0.37 in 2004; F=1.86; df=1,3; P=0.27 in 2005), or syrphid flies (F=1.06; df=1,2; P=0.41 in 2003; F=0.45; df=1,3; P=0.55 in 2004; F=5.27; df=1,3; P=0.11 in 2005) to insecticide programs (Figure 4.4). Similarly, no differences were observed in the response of green lacewings (F=0.0; df=1,4; P=0.99 in 2003; F=1.63;

df=1,4; *P*=0.27 in 2004; F=1.33; df=1,4; *P*=0.31 in 2005), brown lacewings (F=1.18; df=1,4; *P*=0.34 in 2003; F=0.01; df=1,4; *P*=0.93 in 2004; F=0.41; df=1,4; *P*=0.56 in 2005), ladybird beetles (F=0.0; df=1,4; *P*=0.96 in 2003; F=3.59; df=1,4; *P*=0.13 in 2004; F=7.29; df=1,4; *P*=0.054 in 2005), parasitoid wasps (F=1.37; df=1,4; *P*=0.31 in 2003; F=0.73; df=1,4; *P*=0.44 in 2004; F=2.99; df=1,4; *P*=0.16 in 2005), and syrphid flies (F=0.1; df=1,4; *P*=0.77 in 2003; F=0.2; df=1,4; *P*=0.68 in 2004; F=0.0; df=1,4; *P*=0.95 in 2005) to wild grape cutting (Figure 4.5).

Parasitoid community composition

During 2003-2005, a total of 649 parasitoids comprised of 12 species were reared from berry samples infested with *P. viteana* in both experiments (N=55 in 2003; N=196 in 2004; and N=398 in 2005). *Sinophorus* sp. was the most common parasitoid reared and accounted for ca. 11-76% of all specimens within each treatment. There was little difference in the parasitoid community between the two studies and the same dominant species were found in both experiments. In the reduced-risk insecticide study, eight parasitoid species belonging to four families were identified (*Enytus obliteratus* (Cresson); *Glypta mutica* Cushman; *Sinophorus* sp.; *Xorides (Xorides) calidus* (Provancher); prob. *Euderus cushmani* (Crawford); *Bracon variabilis* Provancher; *Bassus annulipes* (Cresson); *Apanteles polychrosidis* Viereck; and *Goniozus foveolatus* Ashmead) (Table 4.1). In the cultural control study, ten parasitoid species belonging to three families and one subfamily were identified (*Enytus obliteratus* (Cresson); *Glypta mutica* Cushman; *Sinophorus* sp.; *Scambus brevicornis* (Gravenhorst); *Scambus*

(Scambus) hispae (Harris); *Bracon variabilis* Provancher; *Bassus annulipes* (Cresson); *Apanteles polychrosidis* Viereck; *Goniozus foveolatus* Ashmead); and Microgasterinae sp. (Table 4.2).

Table 4.1. Composition of parasitoid community reared from *P. viteana* collected from borders of Michigan juice grape vineyards under reduced-risk and conventional insecticide management programs during 2003-2005.

	2003		2004		2005	
Species	**Reduced-Risk**	**Conventional**	**Reduced-Risk**	**Conventional**	**Reduced-Risk**	**Conventional**
	N=13	N=10	N=50	N=45	N=43	N=133
Enytus obliteratus	0.0	0.0	20.0	13.3	23.3	27.8
Glypta mutica	7.7	0.0	22.0	11.1	32.6	4.5
Sinophorus sp.	23.1	20.0	26.0	62.2	27.9	45.9
Xorides calidus	0.00	0.00	2.00	0.00	0.00	0.00
prob. Euderus cushmani	0.0	0.0	0.0	0.0	0.0	4.5
Bracon variabilis	23.1	0.0	2.0	0.0	4.7	1.5
Bassus annulipes	0.0	0.0	0.0	0.0	0.0	2.3
Apanteles polychrosidus	7.7	10.0	8.0	8.9	11.6	11.3
Goniozus foveolatus	0.0	0.0	4.0	0.0	0.0	0.8
Unknown	38.5	70.0	16.0	4.4	0.0	1.5
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.2. Composition of parasitoid community reared from *P. viteana* collected from borders of Michigan juice grape vineyards where adjacent wild grapevines were cut (experimental) or not cut (untreated control) during 2003-2005.

	2003		2004		2005	
Species	**Experimental**	**Untreated Control**	**Experimental**	**Untreated Control**	**Experimental**	**Untreated Control**
	N=18	N=14	N=42	N=59	N=115	N=107
Enytus obliteratus	0.0	0.0	2.4	3.4	16.5	24.3
Glypta mutica	11.1	7.1	14.3	28.8	11.3	13.1
Sinophorus sp.	33.3	14.3	76.2	66.1	27.0	27.1
Scambus brevicornis	0.0	0.0	0.0	0.0	0.0	0.9
Scambus hispae	0.0	0.0	0.0	0.0	0.9	0.0
Bracon variabilis	11.1	14.3	0.0	0.0	0.9	4.7
Bassus annulipes	0.0	0.0	0.0	0.0	0.9	2.8
Apanteles polychrosidus	0.0	0.0	0.0	1.7	41.7	26.2
Goniozus foveolatus	0.0	0.0	0.0	0.0	0.9	0.9
Microgasterinae sp.	5.6	0.0	0.0	0.0	0.0	0.0
Unknown	38.9	64.3	7.1	0.0	0.0	0.0
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0

DISCUSSION

When integrating alternatives into insect control programs of crop pests, the impact on natural enemies must be considered. In general, this study shows that using reduced-risk insecticides and cutting wild grapevines for control *P. viteana* has minimal effect on the community of natural enemies in vineyards. After three years, the response of *P. viteana* parasitism to reduced-risk insecticides and wild grape cutting was not largely affected. The abundance of natural enemies captured on yellow sticky traps was similar throughout three growing seasons in both of these experiments.

Reduced-risk insecticides offer a good opportunity for integrating chemical and biological control because the mode of action of many such insecticides is selective (Hull and Beers 1985, Pfeiffer 2000). As discussed in Chapter 2, many studies have recently evaluated the effectiveness of insect control programs that incorporate reduced-risk management approaches (Atanassov et al. 2002, Musser and Shelton 2003, Smirle et al. 2003a, Smirle et al. 2003b, Doerr et al. 2004, Pineda et al. 2004, Koss et al. 2005, Brunner et al. 2005, Kovanci et al. 2005). In general, these studies support the expectation that natural enemy abundance will increase as conventional insecticide use is reduced. Additionally, as discussed in Chapter 1, the decreased toxicological effect of some reduced-risk insecticides on natural enemies, compared with broad-spectrum insecticides, has been well documented (Trisyono et al. 2000, Wilkinson 2002, Hewa-Kapuge et al. 2003, Schneider et al. 2003, Medina et al. 2003b, Suh et al. 2004). However, biological control of pests is not equal across all agricultural systems. Conservation biological control aims to maintain or preserve predators or parasitoids which occur naturally within the system. It assumes that natural enemies already exist locally and are abundant at the correct time to effectively suppress the pest(s) of interest (Debach and Rosen 1991, Van Driesche and Bellows 1996, Ehler 1998). Thus, merely reducing chemical toxicity may not increase the effect of biological control agents.

Observations in Michigan vineyards indicate that parasitism levels are typically low until later in the season (Jenkins, unpublished data). In 2003 and 2004, there was no significant difference in percent parasitism of *E. viteana* between programs in the reduced-risk insecticide study. However, the trend showed numerically greater parasitism in the reduced-risk insecticide program for all collections in both years. In 2005, percent parasitism of *E. viteana* was significantly greater in the conventional insecticide program for two of the three sampling dates. There are three potential reasons for why this occurred. First, in 2003 and 2004, azinphosmethyl was used in ca 40% of the conventional program sprays (Chapter 2, Table 1) and, after 2004, it was no longer produced with a label for applications in vineyards. Since azinphosmethyl was no longer being applied in the conventional program during 2005, greater parasitoid survival and hence greater parasitism of *P. viteana* may have been possible in the conventional program. Secondly, in 2004 vineyards in the reduced-risk program needed protection from late season *P. viteana* infestation. Since methoxyfenozide has a 30 d pre-harvest interval, spinosad was applied in the reduced-risk vineyards. Although spinosad is considered a reduced-risk insecticide, recent literature has shown that it can have sublethal effects on natural enemies (Galvan et al. 2005, Wang et al. 2005). This suggests that local parasitoid populations within the reduced-risk vineyards may have been affected by this late-season spinosad spray in 2004, leading to a reduction in parasitism in 2005. Lastly, parasitism in this system may be host-density dependent. The lower larval survival in vineyards managed using reduced-risk insecticides for control of late-season generations of *P. viteana* would be expected to have long-term effects on local populations of *P. viteana*. Although this was not detected over the three years of this study (see Chapter 2), reduced survival of *P. viteana* in the reduced-risk program may have provided fewer larvae for parasitism.

Parasitism and survival of *P. viteana* were similar in vineyards where wild grapevines were cut and not cut in the adjacent habitat. Prior to this study, the effect of cutting or removing wild grapevines in habitats adjacent to vineyards was not well documented. In general, there are few studies which have documented the effects of wild host removal on insect pest control in perennial crops. Wild grape may provide a habitat for *P. viteana* to escape pest management programs during the growing season (Hoffman and Dennehy 1989, Seaman et al. 1990, Botero-Garcés and Isaacs 2004a), and could maintain a pest population outside the area of management for reinfesting vineyards (Dennehy et al. 1990, Seaman et al. 1990). While wild grapevines may act as a natural source of pest infestation in vineyards, they may also provide a refuge for natural enemies of *P. viteana* outside the region treated with insecticide (Dennehy et al. 1990, Seaman et al. 1990), and so the removal of such hosts may have unintended consequences for natural enemy populations. For example, *Acer saccharum* Marshall, *Robinia pseudo-acacia* L., *Rosa multiflora* Thunberg, *Salix nigra* L., *Vitis riparia* Michaux, and *Zanthoxylum americanum* Miller were determined to be important plant species for overwintering sites of *Anagrus* spp. parasitoids near vineyards (Williams and Martinson 2000) and, in western US grape production, vineyards bordered by *Rubus* spp. and French prune trees, *Prunus domestica* L., effectively increased biological control of leafhoppers by *Anagrus epos* Girault (Pickett et al. 1990, Corbett and Rosenheim 1996, Murphy et al. 1998).

Similar captures of green lacewings, brown lacewings, ladybird beetles, parasitic hymenoptera, and syrphid flies on yellow sticky traps throughout three growing seasons in both of these experiments suggest that the natural enemies in this system are highly mobile and are likely operating on a larger spatial scale. The natural enemies captured on yellow sticky traps in this study are common in many agricultural systems and may be moving over larger areas than measured in these experiments. Furthermore, although green lacewings (*Chrysoperla carnea* Stephens) will feed on *P. viteana* under no-choice laboratory conditions (Jenkins, unpublished data), the effect of predation on *P. viteana* by these natural enemies in vineyards has not been documented. Further research to assess predation of *P. viteana* by generalist insect predators in vineyards is needed. Although yellow sticky cards are useful for measuring the abundance of natural enemies within a system, alternative methods for assessing predation, such as deployment of sentinel prey, should be considered.

Until now, the parasitoids attacking *P. viteana* in Michigan have not been reported. Unlike Pennsylvania and New York State, *Trichogramma* sp. were not observed in samples collected from any year in either experiment. However, the two common larval parasitoids of *P. viteana* described in New York (*G. mutica* and *A. polychrosidis*) were also found to be dominant in Michigan. Additionally, *G. mutica* and *B. annulipes* were previously reared from *P. viteana* in Delaware (Dozier et al. 1932). As mentioned above, *Sinophorus* sp. (Hymenoptera: Ichneumonidae) was the most common parasitoid reared, although this has not been reported from other regions on *P. viteana*.

This multi-year evaluation of alternative approaches for control of *P. viteana* provides evidence that reduced-risk insecticides and wild grape cutting do not directly and consistently enhance the conservation of natural enemy abundance or affect parasitism of *P. viteana*. The results from this study confirm that there is a need to evaluate both short- and long-term effects of alternative pest management approaches on insect communities.

CHAPTER 5

CONCLUSIONS AND FUTURE RESEARCH

Since the 1950's, the grape industry in Michigan has historically relied upon broad-spectrum organophosphate, pyrethroid, and carbamate insecticides to control the complex of insect pests that can damage this crop. Insect pests are a major challenge to grape production, and grape growers will continue to require effective management programs if they are to manage this crop economically. Current IPM strategies in eastern US grape production provide growers with few resources for effectively controlling the complex of grape insect pests without the use of pesticides and adoption of biological control in this system is at a very low level. Prevention of damage and infestation by *Paralobesia viteana* has been achieved primarily by the use of broad-spectrum insecticides, but increased restrictions on these insecticides have prompted the need for alternative control methods. In 2003, the availability of two reduced-risk insecticides for use by grape growers against *P. viteana* provided an opportunity for conservation of natural enemies of this pest. Additionally, the efficacy of wild grape cutting as a cultural control for *P. viteana* was undocumented. In response to the needs of the eastern US grape industry, control of *P. viteana* using reduced-risk insecticides, cultural controls, and conservation of natural enemies was studied.

Prior to this study, the efficacy of cutting wild grapevines in habitats near vineyards for control of grape berry moth was unknown. Various recommendations have been made regarding this practice over time in the Extension literature (Slingerland 1904, Johnson and Hammar 1912, Weigle 2004). However, most efforts at manipulating habitats within agricultural systems for pest control have been based on anecdotal evidence (Gurr et al. 1998). This is partly due to the fact that many plant, herbivore, and natural enemy interactions are poorly understood (Wratten et al. 1998). Without question, *P. viteana* pressure is typically greater near woods where wild grapevines persist (Dennehy et al. 1990, Botero-Garcés and Isaacs 2004a). However, after a three-year evaluation of cutting wild grapevines up to 60 m into the woods, it is recommended that growers do not invest their time and labor resources in cutting wild grapevines in woodlots adjacent to their vineyards for control of *P. viteana*. Since wild grape cutting was ineffective at reducing *P. viteana* infestation in adjacent vineyards, it would be interesting to increase the spatial scale of this work. For example, removing wild grapevines across a farm may result in pest reduction. However, this also may have unintended consequences on other species that use wild grape, such as birds and other wildlife.

This three-year evaluation of reduced-risk IPM programs in Michigan vineyards provides evidence that control of *P. viteana* is achievable using a program that depends on reduced-risk insecticides for control of late-season generations of this pest. However, adoption of reduced-risk insecticides by growers may be challenging. First, control of *P. viteana* using methoxyfenozide and spinosad requires very good cluster coverage, requiring the applicator to increase gallonage, spray every row, and drive slowly. Secondly, most reduced-risk insecticides, including methoxyfenozide and spinosad, are selective in their mode of action. This may require more than one insecticide for control of multiple pests compared to the action of broad-spectrum insecticides. Third, as discovered by this research, the potential of reduced-risk insecticides to conserve natural enemies and thus increase the effects of biological control may not be immediately observable. Lastly, reduced-risk insecticides are more expensive and may not be practical in an economically-challenged industry. As additional reduced-risk insecticides become registered for use in vineyards, a more integrated approach that promotes biologically-based management of *P. viteana* may be possible.

As mentioned in Chapter 1, conservation biological control aims to maintain or preserve predators or parasitoids which occur naturally within the system. For conservation biological control to be effective, natural enemies must already exist locally and have the potential to effectively suppress the pest (Debach and Rosen 1991, Ehler 1998). Additionally, they must be sufficiently abundant at the correct time to attack the pest(s) of interest (Van Driesche and Bellows 1996). In addition to reducing broad-spectrum insecticide use, other negative influences on natural enemies from agricultural intensification include lack of overwintering sites, loss of non-crop habitat, and lack of nectar resources (Van Driesche and Bellows 1996, Ehler 1998, Landis and Marino 1999, Burel et al. 2000, Marino and Landis 2000, Viggiani 2000). Each of these resources may need to be addressed before natural enemy abundance will increase consistently in vineyards.

The research on conserving natural enemies in this thesis is only the first step to understanding the potential of biological control in this system. Now that the parasitoid complex has been identified, it will be important to understand the life history, behavior, and potential of these parasitoids to limit *P. viteana* population development. For generalist predators, especially the dominant species, it will be important to determine their purpose for inhabiting vineyards. Likewise, information on their life history, behavior, and predatory habits within vineyards will be important to understand if we are to fully realize the potential of biological control in vineyard ecosystems.

Appendix 1.1

Record of Deposition of Voucher Specimens*

The specimens listed on the following sheet(s) have been deposited in the named museum(s) as samples of those species or other taxa, which were used in this research. Voucher recognition labels bearing the Voucher No. have been attached or included in fluid-preserved specimens.

Voucher No.: 2006-02

Title of thesis or dissertation (or other research projects):

Control of the grape berry moth, *Paralobesia viteana*, using reduced-risk insecticides, cultural controls, and conservation of natural enemies.

Museum(s) where deposited and abbreviations for table on following sheets:

Entomology Museum, Michigan State University (MSU)

Other Museums (*Vitis riparia* leaf specimens):
Michigan State University Herbarium, Accession No. 389126 - 389150

Investigator's Name(s) (typed)
Paul E. Jenkins

Date 10 May 2006

*Reference: Yoshimoto, C. M. 1978. Voucher Specimens for Entomology in North America.
Bull. Entomol. Soc. Amer. 24: 141-42.

Deposit as follows:
Original: Include as Appendix 1 in ribbon copy of thesis or dissertation.

Copies: Include as Appendix 1 in copies of thesis or dissertation.
Museum(s) files.
Research project files.

This form is available from and the Voucher No. is assigned by the Curator, Michigan State University Entomology Museum.

Appendix 1.2

Voucher Specimen Data

Page 1 of 13 Pages

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Scambus (Scambus) hispae (Harris)	Michigan; Van Buren Co.; Lawton, 72nd St. nr. CR 354; 28-Jul-2005 Brown 72 WG Cut D					1			MSU
Scambus brevicornis (Gravenhorst)	Michigan, Van Buren Co.; Lawton; M-40 nr. CR 669; 10-Aug-2005 Brown M-40 GS H							1	MSU
Goniozus foveolatus Ashmead	Michigan; Van Buren Co.; Lawton M-40 nr. CR 669; 10-Aug-2005 Brown M-40 WG Cut B							1	MSU
	Michigan, Van Buren Co.; Lawton; 28th St. nr. CR 358; 10-Aug-2005 Brown Lewis GS H							1	MSU

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Paul E. Jenkins

Date 10-May-2006

Voucher No. 2006-02

Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

Curator Date 5/11/2006

Appendix 1.2

Voucher Specimen Data

Page 2 of 13 Pages

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Goniozus foveolatus Ashmead	Michigan; Van Buren Co.; Lawton CR 358 nr. 28th St.; 10-Aug-2005 VanVleck Medskar GS J							1	MSU
Apanteles polychrosidis Viereck	Michigan; Van Buren Co.; Lawton M-40 nr. CR 669; 28-Jul-2005 Brown M-40 GS F							1	MSU
	Michigan; Van Buren Co.; Lawton 72nd St. nr CR 354; 14-Jul-2005 Brown 72 GS J							1	MSU
	Michigan; Van Buren Co.; Lawton M-40 nr. CR 669; 14-Jul-2005 Brown M-40 WG Cut D							1	MSU

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

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Date 10-May-2006

Voucher No. 2006-02

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Appendix 1.2

Voucher Specimen Data

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Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Apanteles polychrosidis Viereck	Michigan; Van Buren Co.; Lawton M-40 nr. CR 669; 10-Aug-2005 Brown M-40 WG Cut B							1	MSU
	Michigan; Van Buren Co.; Lawton CR 358 nr. 28th St.; 10-Aug-2005 Oxley GS F							1	MSU
	Michigan; Van Buren Co.; Lawton CR 358 nr. 28th St.; 14-Jul-2005 Cronenwett GS F							1	MSU
	Michigan; Berrien Co.; Watervliet Napier Ave. nr. Bainbridge Ctr.; 10-Aug-2005 Hinkelman WG Cut A, E							4	MSU

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Paul E. Jenkins

Date 10-May-2006

Voucher No. 2006-02

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Curator Date

Appendix 1.2

Voucher Specimen Data

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Species or other taxon	Label data for specimens collected or used and deposited	Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
		Number of:							
prob. *Euderus cushmani* (Crawford)	Michigan; Van Buren Co.; Lawton CR 358 nr. 28th St.; 28-Jul-2005 Oxley GS J							6	MSU
Glypta Mutica Cushman	Michigan; Berrien Co.; Berrien Springs Hinchman nr. Scottdale Rd.; 28-Jul-2005 Pagel Lausman GS H					1			MSU
	Michigan; Berrien Co.; Berrien Springs Hinchman nr. Scottdale Rd.; 10-Aug-2005 Pagel Lausman WG Cut B					1			MSU
	Michigan; Berrien Co.; Berrien Springs Hinchman nr. Scottdale Rd.; 28-Jul-2005 Pagel Lausman RR O					1		1	MSU

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Paul E. Jenkins

Date 10-May-2006

Voucher No. 2006-02

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Appendix 1.2

Voucher Specimen Data

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Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Glypta mutica Cushman	Michigan; Berrien Co.; Watervliet Napier Ave. nr. Bainbridge Ctr.; 10-Aug-2005 Hinkelman GS G, I					2			MSU
	Michigan, Van Buren Co.; Lawton M-40 nr. CR 669; 26-Aug-2004 Brown M-40 GS H					2			MSU
	Michigan; Van Buren Co.; Lawton M-40 nr. CR 669; 10-Aug-2005 Brown M-40 WG Cut B							1	MSU
	Michigan; Van Buren Co.; Lawton 72nd St. nr. CR 354; 10-Aug-2005 Brown 72 WG Cut C					1			MSU

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Paul E. Jenkins

Date 10-May-2006

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Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Xorides (Xorides) calidus Provancher	Michigan; Berrien Co.; Berrien Springs Hinchman nr. Scottdale Rd.; 29-Jul-2004 Pagel Lausman RR L							1	MSU
Microgasterinae	Michigan; Van Buren Co.; Lawton M-40 nr. CR 669; 19-Aug-2003 Brown M-40 WG Cut B							1	MSU
Bassus annulipes (Cresson)	Michigan; Berrien Co. Watervliet Napier Ave. nr. Bainbridge Ctr.; 10-Aug-2005 Hinkelman WG Cut B							2	MSU
	Michigan; Berrien Co.; Berrien Springs Hinchman nr. Scottdale Rd.; 10-Aug-2005 Pagel Lausman GS I, J					3			MSU

(Use additional sheets if necessary)

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Voucher Specimen Data

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Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Enytus obliteratus (Cresson)	Michigan; Van Buren Co.; Lawton 28th St. nr. CR 358; 14-Jul-2005 Brown Lewis WG Cut A					1			MSU
	Michigan; Van Buren Co.; Lawton M-40 nr. CR 669; 14-Jul-2005 Brown M-40 GS F							1	MSU
	Michigan; Van Buren Co.; Lawton CR 358 nr. 28th St.; 14-Jul-2005 Cronenwett GS G, J					2			MSU
	Michigan; Van Buren Co.; Lawton CR 358 nr. 28th St.; 14-Jul-2005 VanVleck GS J					1			MSU

(Use additional sheets if necessary)

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Voucher Specimen Data

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Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Enytus obliteratus (Cresson)	Michigan; Berrien Co.; Watervliet Napier Ave. nr. Bainbridge Ctr.; 14-Jul-2005 Hinkelman GS I, J					1		1	MSU
	Michigan; Berrien Co.; Berrien Springs Hinchman nr. Scottdale Rd.; 14-Jul-2005 Pagel Lausman GS I, J					1		1	MSU
	Michigan; Berrien Co.; Berrien Springs Hinchman nr. Scottdale Rd.; 14-Jul-2005 Pagel Lausman RR N					1			MSU

(Use additional sheets if necessary)

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Voucher Specimen Data

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Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Bracon variabilis (Provancher)	Michigan; Van Buren Co.; Lawton CR 358 nr. 28th St.; 10-Aug-2005 VanVleck Medskar GS H							1	MSU
	Michigan; Van Buren Co.; Lawton CR 652 nr. Huzzy Lake; 10-Aug-2005 Oxley RR E							2	MSU
	Michigan; Van Buren Co.; Lawton 28th St. nr. CR 358; 28-Jul-2005 Brown Lewis GS I							1	MSU
Sinophorus sp.	Michigan; Van Buren Co.; Lawton CR 358 nr. 28th St.; 28-Jul-2005 Oxley GS G, I					1		2	MSU

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

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Voucher Specimen Data

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Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Sinophorus sp.	Michigan; Van Buren Co.; Lawton CR 358 nr. 28th St.; 28-Jul-2005 VanVleck Medskar GS F, I					1		1	MSU
	Michigan; Van Buren Co.; Lawton 72nd St. nr. CR 354; 14-Jul-2005 Brown 72 WG Cut D					1			MSU
	Michigan; Berrien Co.; Berrien Springs Hinchman nr. Scottdale Rd.; 14-Jul-2005 Pagel Lausman WG Cut A					1			MSU
	Michigan; Berrien Co.; Berrien Springs Hinchman nr. Scottdale Rd.; 28-Jul-2005 Pagel Lausman WG Cut A, D							2	MSU

(Use additional sheets if necessary)

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Voucher Specimen Data

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Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Sinophorus sp.	Michigan; Berrien Co.; Berrien Springs Hinchman nr. Scottdale Rd.; 10-Aug-2005 Pagel Lausman WG Cut A							1	MSU
Paralobesia viteana (Clemens)	Michigan; Van Buren Co.; Lawton 72nd St. nr. CR 354; 11-Aug-2004 Brown 72					1	1		MSU
	Michigan; Van Buren Co.; Lawton CR 358 nr. 28th St.; 11-Aug-2004 VanVleck Medskar					2			MSU
	Michigan; Berrien Co.; Berrien Springs Hinchman nr. Scottdale Rd.; 13-Aug-2004 Pagel Lausman					1	1		MSU

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Paul E. Jenkins

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Voucher No. 2006-02

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Curator Date

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Voucher Specimen Data

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Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Paralobesia viteana (Clemens)	Michigan; Van Buren Co.; Lawton CR 652 nr. Huzzy Lake; 11-Aug-2004 Oxley Huzzy Lake					1	1		MSU
	Michigan; Berrien Co.; Watervliet Napier Ave. nr. Bainbridge Ctr.; 27-Aug-2004 Hinkelman					1	1		MSU
	Michigan; Van Buren Co.; Lawton CR 358 nr. 28th St.; 11-Aug-2004 Cronenwett					1	1		MSU
	Michigan; Van Buren Co.; Lawton M-40 nr. CR 669; 11-Aug-2004 Brown M-40					1	2		MSU

(Use additional sheets if necessary)

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Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Paralobesia viteana (Clemens)	Michigan; Van Buren Co.; Lawton 28th St. nr. CR 358; 26-Aug-2004 Brown Lewis					2	1		MSU
	Michigan; Van Buren Co.; Lawton CR 358 nr. 28th St.; 11-Aug-2004 Oxley Home						2		MSU

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Paul E. Jenkins

Date 10-May-2006

Voucher No. 2006-02

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Curator Date

Appendix 2.1

Farm location information for reduced-risk insecticide study

Farm Number	Program	Farm Name	Grower	Location
1	Reduced-Risk	Abbott	Bryan Cronenwett	Michigan, Van Buren Co., Lawton, CR358 nr. 28th St.
	Conventional	Abbott	Bryan Cronenwett	Michigan, Van Buren Co., Lawton, CR358 nr. 28th St.
2	Reduced-Risk	Huzzy Lake	Ed Oxley	Michigan, Van Buren Co., Lawton, CR652 nr. Huzzy Lake
	Conventional	Home	Ed Oxley	Michigan, Van Buren Co., Lawton, CR358 nr. 28th St.
3	Reduced-Risk	Medskar	Bob Van Vleck	Michigan, Van Buren Co., Lawton, CR358 nr. 28th St.
	Conventional	Medskar	Bob Van Vleck	Michigan, Van Buren Co., Lawton, CR358 nr. 28th St.
4	Reduced-Risk	Lausman	Bob Pagel	Michigan, Berrien Co., Berrien Springs, Hinchman nr. Scottdale Rd.
	Conventional	Lausman	Bob Pagel	Michigan, Berrien Co., Berrien Springs, Hinchman nr. Scottdale Rd.

Farm location information for cultural control study

Farm Number	Program	Farm Name	Grower	Location
1	Wild Grape Cut	Bass	Jon Hinkelman	Michigan, Berrien Co., Watervliet, Napier Ave. nr. Bainbridge Ctr.
	Untreated Control	Bass	Jon Hinkelman	Michigan, Berrien Co., Watervliet, Napier Ave. nr. Bainbridge Ctr.
2	Wild Grape Cut	Lausman	Bob Pagel	Michigan, Berrien Co., Berrien Springs, Hinchman nr. Scottdale Rd.
	Untreated Control	Lausman	Bob Pagel	Michigan, Berrien Co., Berrien Springs, Hinchman nr. Scottdale Rd.
3	Wild Grape Cut	M-40	Rick Brown	Michigan, Van Buren Co., Lawton, M-40 nr. CR669
	Untreated Control	M-40	Rick Brown	Michigan, Van Buren Co., Lawton, M-40 nr. CR669
4	Wild Grape Cut	Home	Rick Brown	Michigan, Van Buren Co., Lawton, 72nd St. nr. CR354
	Untreated Control	Home	Rick Brown	Michigan, Van Buren Co., Lawton, 72nd St. nr. CR354
5	Wild Grape Cut	Lewis	Rick Brown	Michigan, Van Buren Co., Lawton, 28th St. nr. CR358
	Untreated Control	Lewis	Rick Brown	Michigan, Van Buren Co., Lawton, 28th St. nr. CR358

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