Influence of Uncultivated Habitats and Native Host Plants on Cluster Infestation by Grape Berry Moth, *Endopiza viteana* Clemens (Lepidoptera: Tortricidae), in Michigan Vineyards

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ABSTRACT *Vitis* grapevines are the native host of the grape berry moth, *Endopiza viteana* Clemens (Lepidoptera: Tortricidae), and are found in uncultivated habitats throughout eastern North America. Levels of infestation by grape berry moth larvae at vineyard borders and interiors were compared among vineyards adjacent to four types of uncultivated habitats: deciduous woods, coniferous woods, a single row of trees, and grasses. Adult male moths were monitored at these same positions and inside uncultivated habitats using sex pheromone-baited traps. Wild grapevines were surveyed at each site for their presence or absence, abundance, and whether they bore fruit. Infestation of grape clusters at vineyard borders was greater when adjacent to deciduous woods than grasses, but infestation near grasses was not significantly different from infestation near coniferous woods. Captures of moths inside vineyards were similar irrespective of nearby uncultivated habitat type. In uncultivated habitats, significantly fewer moths were trapped in grasses than in habitats with trees. Depending on habitat type, wild grapevines were found in 71–100% of the adjacent habitat sites, and although vine presence did not vary with habitat type, the proportion fruiting was significantly greater in deciduous woods than the other habitats. Significant, but weak positive correlations were found between larval infestation in vineyards and the abundance of wild grapevines and occurrence of fruit in adjacent uncultivated habitats. Results indicate that the presence of wild hosts within adjacent habitats and their likelihood of fruiting are important determinants of risk from grape berry moth infestation in a vineyard. The implications of these findings for cultural approaches to management of grape berry moth are discussed.

Resumé Les vignes *Vitis* (Vitaceae) sont les hôtes originaires de la tordeuse de la vigne, *Endopiza viteana* Clemens (Lepidoptera: Tortricidae), et se trouvent dans les habitats non-cultivés de l'Amérique du Nord. Nous avons comparé les niveaux d'infestation par larves à l'intérieur et au bord de vignobles commerciaux côtoyés par quatre genres d'habitats non-cultivés: bois de décidées, bois de conifères, une seule ligne d'arbres parallèle au vignoble, et des herbes. Les mâles adultes ont été échantillonnés à l'aide de pièges à phéromone placés à ces mêmes positions et aussi dedans les habitats non-cultivés. À chaque endroit étudié nous avons fait le levé de la présence de vignes sauvages, de la présence de grappes de raisins sur celles-ci, et de l'abondance de vignes. L'infestation par larves de *E. viteana* était plus intense aux bords des vignobles quand ils étaient côtoyés par des bois de décidées que par des herbes; seulement, les niveaux d'infestation dans les vignobles côtoyant des herbes n'étaient pas différents de ceux présents près des bois de conifères. L'abondance de mâles dans les vignobles était similaire, sans importer quel genre d'habitat les côtoyait. Dedans les habitats non-cultivés, nous avons attrapé significativement moins de mâles dans les herbes que dans les habitats possédant des arbres. Il y avait des vignes sauvages dans le 71–100% des habitats non-cultivés, mais la possibilité de trouver des grappes de raisins sauvages était majeure dans les bois de décidées où les vignes étaient plus abondantes. Des corrélations significatives entre les niveaux d'infestation par larves de ces vignobles et l'abondance de vignes sauvages dans l'habitat contigu, et aussi de l'occurrence de grappes sauvages étaient positives mais faibles. Ces résultats indiquent que l'abondance de *Vitis* spp. (et de grappes) dans les habitats contigus est une donnée importante pour le risque d'infestation par *E. viteana* dans un vignoble. Les implications de ces résultats sur comment manager la tordeuse de la vigne sont discutées.

KEY WORDS wild grape, risk, natural habitats, vineyards

INSECTS REQUIRE VARIED RESOURCES, such as food, water, oviposition substrate, shelter, and overwintering hosts, and these may not be available within a single habitat (Toepfer et al. 2002). Habitat heterogeneity is not only important for resource availability and consequently insect conservation (Welch 1990, Woiwod

and Stewart 1990), but it may also contribute to keeping insect pest populations below economic thresholds within agricultural landscapes (Altieri 1983, Macdonald and Smith 1990, Welch 1990, Banks 2000, Ekbom 2000) by increasing the effectiveness of natural enemies (Wratten and Thomas 1990, Williams and Martinson 2000). However, wild hosts in uncultivated habitats may also harbor insect pests and diseases (Barrett 2000, Jeanneret 2000). Thus, pest management strategies that consider the entire habitat mosaic may be more effective than those designed solely for the agricultural setting.

The grape berry moth, *Endopiza viteana* Clemens (or *Paralobesia viteana* (Clemens) (J. Smith, personal communication) (Lepidoptera: Tortricidae), is the primary insect pest of cultivated grapes across eastern North America (Jubb and Danko 1982, Alm et al. 1989, Nagarkatti et al. 2002). It is an obligate specialist on vines in the genus *Vitis* (Vitaceae) (Johnson and Hammar 1912, Fergusson-Kolmes and Dennehy 1993), and is abundant throughout natural and uncultivated habitats across its geographic range (Morano and Walker 1995, Downie and Granett 2000). In Michigan, adult moths first emerge in late April-early May, and females lay eggs individually on young flower clusters of *Vitis* spp. that larvae then feed on, sometimes causing extensive damage on flowers and young berries. Subsequent generations lay eggs on berries, which the young larvae penetrate before feeding internally (Slingerland 1904, Johnson and Hammar 1912). There may be two or more generations per year (Hoffman et al. 1992, Tobin et al. 2002), the last of which overwinters as pupae in leaf litter (Johnson and Hammar 1912). The proportion of clusters damaged by grape berry moth has exceeded 50% in some vineyards in New York, Pennsylvania, and Michigan, where unprecedented load rejections have occurred recently. In Michigan, during 2002, the rejection of >1,000 tons of grapes because of direct grape berry moth damage or associated decay was valued at $300,000 (T. Davenport, personal communication).

Studies on *E. viteana* have used pheromone traps as a tool to understand pest distribution and phenology. Comparisons of relative male moth captures at different positions within vineyards have been reported by several researchers (Taschenberg et al. 1974, Biever and Hostetter 1989), who pointed out that more *E. viteana* males are typically caught at borders versus interiors of vineyards. Hoffman and Dennehy (1989) used 15 traps to sample male moths in two vineyards, two woodlots, and one alfalfa field, and found more male moths were captured in the woods at the beginning of the season, a situation that was reversed by mid-June, when numbers in the vineyard had increased. In contrast, few moths were caught in the nearby alfalfa fields. This study also noted that infestation of grapes by *E. viteana* larvae was greater at vineyard edges than interiors, as reported elsewhere by Biever and Hostetter (1989) and Trimble et al. (1991). Taschenberg et al. (1974) suggested this could be because of immigration of gravid females from wild areas, thus proposing a link between managed and

uncultivated habitats. Dennehy et al. (1990a) later developed a risk assessment program for New York state vineyards, in which risk from *E. viteana* was based partly on the proximity to woods.

Vineyards across eastern North America are surrounded by a range of different uncultivated habitats. Most of them are suitable for wild grapevines, including grassy fields, trees, and mature woodlots, yet the effect of these habitats on vineyard cluster infestation by *E. viteana* larvae has not been reported previously. There is also little information on how abundance of wild grape varies with uncultivated habitat type, and the relationship between these wild grapevines and vineyard infestation by grape berry moth. The goal of the current study was to determine the relationship between the type of adjacent uncultivated habitat and vineyard infestation by *E. viteana*, focusing on the role of wild grapevines. Specific objectives were to compare the relative abundance of male grape berry moths across vineyards and habitat types and its relationship with vineyard infestation, to determine the effect of habitat type on abundance of wild grape, and to determine whether vineyard infestation by this insect is predicted by the presence, density, or fruiting of wild grapevines in adjacent habitats.

Materials and Methods

This study was conducted in commercial juice grape (*Vitis labrusca*, variety Concord and Niagara) vineyards in Van Buren County, Michigan, during 2001 and 2002. All vineyards were ≈1.6 ha in size, with at least one side bordered by an uncultivated habitat of one of the following four types: deciduous woods, coniferous woods, a single row of mixed trees (a tree row) 8–12 m wide, or grasses. All uncultivated habitats sampled, except for the grasses, consisted of mostly mature trees established at least 20 yr earlier. The number of replicated sites (vineyard with adjacent uncultivated habitat) ranged from four to eight in 2001 and from seven to nine in 2002. Growers managed all 26 vineyards studied in 2001 and the 30 vineyards studied in 2002 using conventional management practices (Wise et al. 2003).

Cluster Infestation in Vineyards. Infestation by grape berry moth was assessed nondestructively by visual inspection of grape clusters once per month during July, August, and September of 2001 and 2002. A cluster was considered infested if one or more grapes were observed with symptoms (entrance hole, frass, webbing, larvae) of grape berry moth. Percentage of cluster infestation was determined by examining 20 clusters per vine on 5 vines at the vineyard border (100 clusters) and 5 vines at the interior (another 100 clusters), for a total of 200 clusters per site (Martinson et al. 1991). This procedure was conducted only in vineyards and not in the adjacent uncultivated habitats.

Moth Abundance. At each site, relative moth abundance was measured using four large plastic delta traps (Suterra LLC, Bend, OR) lined with sticky inserts. Traps were baited with a rubber septum containing
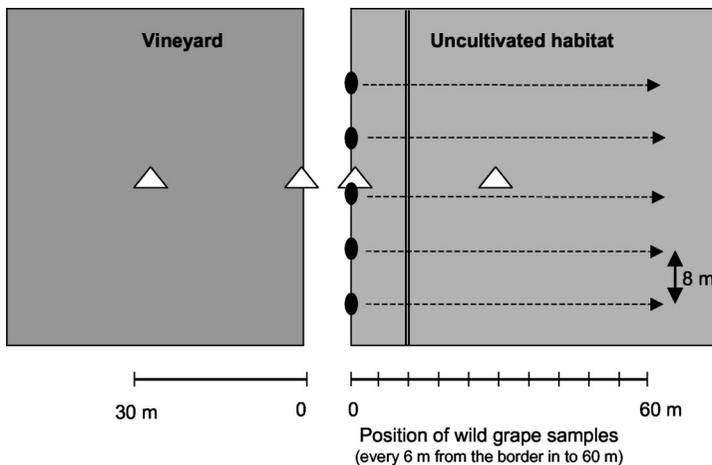
Fig. 1. Schematic representation of an experimental site (not to scale), with pheromone traps (triangles) at four positions across the vineyard-uncultivated habitat transect. The vertical double line indicates the extent of the tree row habitat. The distance between vineyards and uncultivated habitats ranged from 5 to 10 m depending on the vineyard. Wild grape surveys were done by five observers (filled ovals) following a 60-m transect (horizontal dotted lines). Counts of wild grape were recorded every 6 m along these transects.

synthetic grape berry moth sex pheromone (Suterra LLC, Bend, OR). At each site, a trap was placed 30 m inside the vineyard, at the vineyard border, at the border of the uncultivated habitat, and 30 m inside it (Fig. 1). Because tree row habitats were long and narrow (8–12 m width), only one trap was deployed in this habitat, and it was considered a border position. Trap inserts were replaced as needed and pheromone lures were changed monthly using the same batch of lures for all traps. Traps were deployed before the first grape berry moth flight and checked weekly for the number of male moths caught until vineyards were harvested in September. The cumulative total capture of male *E. viteana* was determined for each trap at each date that infestation was assessed.

Wild Grape Survey. During 2001 and 2002, the presence or absence of wild grapevines and wild grape clusters within the uncultivated habitat was determined by examining the vegetation in an area 38 m wide × 63 m deep in woods and grasses (2,394 m^2), and 15 m deep in tree row habitats (570 m^2). In 2002, a more extensive survey was carried out to measure the relative abundance of wild grapevines within the uncultivated habitats studied, adapting methods of Matteucci and Colma (1982) for vegetation sampling. At each site, five trained observers were spaced 8 m apart along the edge of the uncultivated habitat, so that the middle observer was standing next to the pheromone trap placed at the border (Fig. 1). Each observer recorded wild grape presence (1) or absence (0) by looking in three directions (samples): to their left, in front of them, and to their right, including the tree canopy, within a 3-m radius. Measurements were taken every 6 m (a station) until observers reached 60 m inside the uncultivated habitat, for a total of 165 samples (11 stations × 3 samples per observer × 5 observers). In the case of the tree row habitat, the maximum depth sampled was 18 m, to ensure that both

sides of each row were inspected. A wild grape index was calculated by adding numbers recorded at each station (minimum 0 and maximum 3 per station) to provide a measure of the number of times wild grape was observed in each uncultivated habitat site. This extensive sampling was done only in 2002 because wild grapes are perennial and their presence was unlikely to change in consecutive years.

Data Analysis. One-way analysis of variance (ANOVA) was used to test the effect of uncultivated habitat type on cluster infestation by *E. viteana* and the cumulative number of male moths trapped at each position on each sampling date, using PROC GLM (SAS, version 8.0). Moth counts were log (n + 1) transformed, and values of percent cluster infestation were arcsine transformed to homogenize variance among treatments. Wild grape indices were compared among habitat types with the GLM procedure (SAS, version 8.0). For all significant factors, Tukey's test was used to determine differences between means at the 5% probability level. Habitats were compared for frequency of wild grapevine presence and for presence of fruit using the Kruskal-Wallis nonparametric one-way procedure (SAS, version 8.0). Correlations between vineyard infestation levels and presence of wild grape and wild grape clusters were also analyzed using the Kruskal-Wallis test (SAS, version 8.0). Regressions between vineyard cluster infestation and cumulative moth captures in vineyards or habitats adjacent to them, and between cluster infestation and wild grape indices were obtained with the REG procedure (model 1) (SAS, version 8.0). All analyses were performed with the SAS program (SAS Institute 1996).

Results

Cluster Infestation by *E. viteana* in Vineyards. In 2001, levels of infestation by grape berry moth larvae

Table 1. Infestation of grape clusters by *E. viteana* larvae at border and interior positions of vineyards adjacent to four types of uncultivated habitats

Adjacent to:	n	Mean (± SEM) cluster infestation (%) in vineyards					
		July		August		September	
		Border	Interior	Border	Interior	Border	Interior
2001							
Deciduous woods	8	26.0 ± 6.9a	10.8 ± 2.6a	46.2 ± 4.5a	23.6 ± 5.3a	78.2 ± 6.3a	37.2 ± 9.5a
Coniferous woods	7	12.1 ± 1.4ab	6.3 ± 2.3a	28.9 ± 4.3ab	15.0 ± 6.0a	60.0 ± 7.2ab	26.1 ± 6.9a
Tree row	4	8.5 ± 0.7ab	8.0 ± 2.1a	33.2 ± 11.6ab	12.5 ± 2.9a	71.2 ± 11.3ab	40.7 ± 9.9a
Grasses	7	8.4 ± 2.6b	4.7 ± 0.7a	18.4 ± 3.3b	9.4 ± 1.6a	41.9 ± 7.3b	21.1 ± 6.6a
2002							
Deciduous woods	8	72.4 ± 5.1a	39.5 ± 5.4a	79.4 ± 11.3a	62.7 ± 7.8a	99.2 ± 0.6a	78.6 ± 4.3a
Coniferous woods	6	30.5 ± 2.8b	13.0 ± 2.8b	86.8 ± 2.4a	55.2 ± 6.6a	92.3 ± 5.1ab	65.1 ± 10.0a
Tree row	7	34.6 ± 8.4b	20.6 ± 6.2ab	75.3 ± 8.5a	56.9 ± 7.3a	93.9 ± 1.8ab	71.9 ± 8.0a
Grasses	9	29.2 ± 4.9b	21.8 ± 5.4ab	61.3 ± 9.8a	40.1 ± 8.7a	78.3 ± 9.1b	56.2 ± 11.1a

For each year, means within a column followed by the same letter are not significantly different (Tukey $\alpha = 0.05$).

at vineyard borders varied significantly depending on the type of neighboring uncultivated habitat in July ($F = 3.71$; df = 3, 22; $P = 0.03$), August ($F = 5.69$; df = 3, 22; $P = 0.005$), and September ($F = 4.46$; df = 3, 22; $P = 0.01$) (Table 1). Percentage of larval infestation was significantly greater in vineyards near deciduous woods than near grasses ($P = 0.02$, $P = 0.003$, and $P = 0.01$, for each month, respectively). Vineyard interior infestation levels showed similar trends (Table 1), but with no significant difference among habitats ($F = 1.43$; df = 3, 22; $P = 0.26$ for July; $F = 1.43$; df = 3, 22; $P = 0.26$ for August; $F = 1.24$; df = 3, 22; $P = 0.32$ for September).

In July 2002, larval infestation at vineyard borders was significantly affected by the type of neighboring habitat ($F = 10.24$; df = 3, 26; $P < 0.0001$) as in the previous year (Table 1). In addition, larval infestation at vineyard interiors varied with type of adjacent habitat ($F = 4.05$; df = 3, 26; $P = 0.02$) (Table 1). Vineyard borders near deciduous woods had a greater proportion of infested grape clusters than vineyards near grasses ($P = 0.0003$), tree rows ($P = 0.001$), or coniferous woods ($P = 0.001$). The interior levels of infestation were also different between vineyards bordered by the two types of woods ($P = 0.02$). In August, uncultivated habitats had no significant effect on either border ($F = 1.33$; df = 3, 26; $P = 0.28$) or interior ($F = 1.83$; df = 3, 26; $P = 0.17$) vineyard infestation. In September, as in the previous year, vineyard borders had significantly greater infestation near deciduous woods than near grasses ($F = 3.20$; df = 3, 26; $P = 0.04$), but this effect was not found at vineyard interiors ($F = 1.11$; df = 3, 26; $P = 0.36$).

Abundance of Male *E. viteana* in Vineyards. The number of male moths captured was similar in all vineyards regardless of the type of uncultivated habitat adjacent to it. This was consistent throughout the study for both borders ($F = 0.30$; df = 3, 22; $P = 0.83$ in 2001; $F = 0.96$; df = 3, 26; $P = 0.43$ in 2002) and interiors ($F = 0.84$; df = 3, 22; $P = 0.54$ in 2001; $F = 0.24$; df = 3, 26; $P = 0.87$ in 2002) (Fig. 2a). Male moth abundance was greatest in 2002, and more moths were trapped inside vineyards than at vineyard borders. When mean infestation of vineyard clusters (average

of border and interior levels) was regressed against male moth captures in vineyards, the correlation was always weak and negative, except in July 2001, when there was no correlation (Table 2a).

Abundance of Male *E. viteana* in Uncultivated Habitats. When male moths were sampled within uncultivated habitats adjacent to vineyards, there were significant differences among the different types of habitats (Fig. 2b). In July 2001, captures of males at the border ($F = 3.63$; df = 3, 22; $P = 0.03$) and interior ($F = 5.06$; df = 2, 22; $P = 0.02$) of uncultivated habitats were significantly different according to habitat type, as in August ($F = 3.83$; df = 3, 22; $P = 0.02$; $F = 5.14$; df = 2, 22; $P = 0.02$, respectively) and September ($F = 3.28$; df = 3, 22; $P = 0.04$; $F = 5.02$; df = 2, 22; $P = 0.02$). Fewer moths were caught in borders of grasses near vineyards than in borders of coniferous woods ($P = 0.04$ in July, $P = 0.03$ in August) (Fig. 2b). Similarly, in 2002, moth captures at borders and interiors of uncultivated habitats varied significantly among habitat types (borders, $F = 27.59$ for July, $F = 26.03$ for August, $F = 26.86$ for September with df = 3, 26 and $P < 0.0001$ for all; interiors, $F = 43.09$, $F = 41.88$, $F = 40.31$, respectively, df = 2, 26 and $P < 0.0001$ for all). The lowest male moth abundance was in grasses compared with the other uncultivated habitats ($P < 0.0001$ for each comparison in July, August, and September) (Fig. 2b). A regression analysis between the cumulative captures of male moths in uncultivated habitats and mean vineyard infestation (average of border and interior levels) showed a positive, but weak relationship in September 2001 and August and September 2002, but not in July of either year (Table 2b).

Survey of Wild Grape. The probability of wild grapevines being present was similar among the different uncultivated habitats (Table 3) (Kruskal-Wallis $\chi^2 = 1.78$, df = 3, $P = 0.65$ for 2001; $\chi^2 = 4.11$, df = 3, $P = 0.25$ for 2002). However, the frequency with which wild grapevines bore clusters in these uncultivated habitats varied with habitat type (Table 3) ($\chi^2 = 14.0$, df = 3, $P = 0.003$ for 2001; $\chi^2 = 10.07$, df = 3, $P = 0.02$ for 2002). As measured by Wilcoxon rankings,
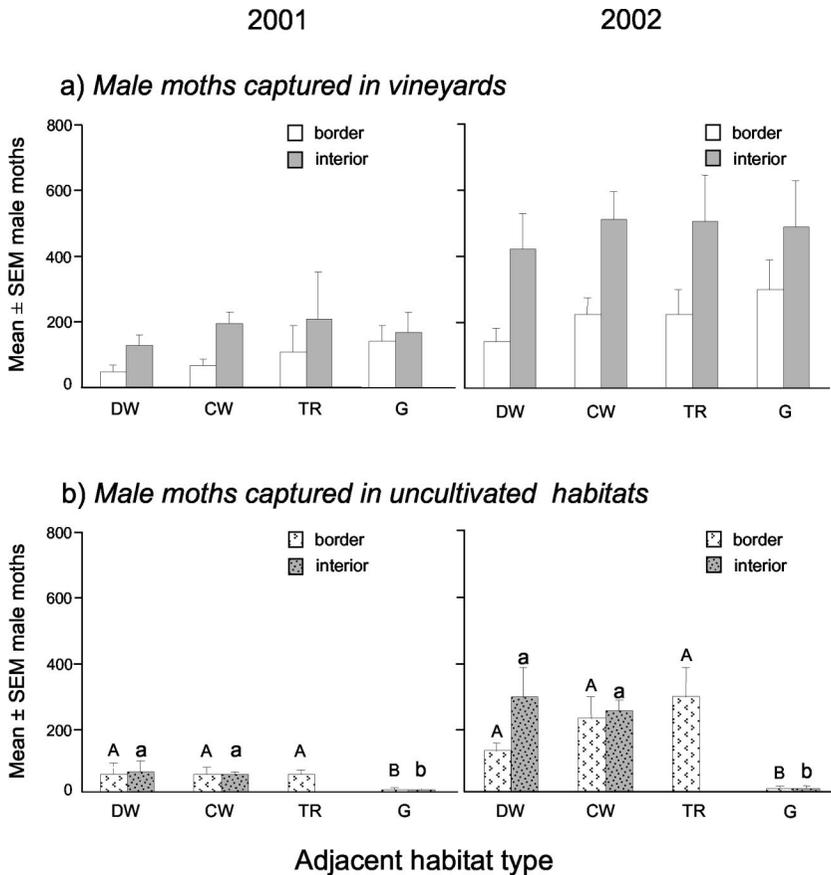
Fig. 2. Cumulative captures of male *E. viteana* adults until July 2001 and 2002 at border and interior positions of (a) vineyards bordered by four types of uncultivated habitats, and (b) within these adjacent uncultivated habitats. For either borders (capitals) or interiors (small capitals), significant differences among adjacent habitat types are denoted by different letters (Tukey $\alpha = 0.05$).

wild grapevines with fruit clusters were more frequently found in deciduous woods, followed by tree rows, then coniferous woods (where no fruit clusters were found in 2001). Wild grapevines in grasses were never observed with fruit clusters.

Wild grape index (WGI) values varied significantly among habitats ($F = 7.81$; df = 3, 22; $P = 0.001$ in 2001; and $F = 7.21$; df = 3, 26; $P = 0.001$ in 2002) (Table 3). There were more wild grapevines in deciduous woods compared with tree rows ($P = 0.007$ in 2001, $P = 0.001$ in 2002) and grasses ($P = 0.001$ in 2001, $P = 0.006$ in 2002). WGI values were not significantly different between the two types of woods ($P = 0.10$ in 2001, and $P = 0.34$ in 2002), although WGI values were greater in deciduous woods (Table 3).

Relationship Between Wild Grape and Grape Berry Moth Infestation. The presence or absence of wild grapevines in uncultivated habitats was not predictive of vineyard infestation during any of the sampling times in this study, neither at vineyard borders (Kruskal-Wallis df = 1, $P > 0.21$ in 2001; df = 1, $P > 0.36$ in 2002) nor vineyard interiors (df = 1, $P > 0.33$ in 2001; df = 1, $P > 0.08$ in 2002). However, the

presence of fruit clusters on wild grapevines in uncultivated habitats was related to cluster infestation by grape berry moth larvae in vineyards during some of the sampling times of both years (Table 4; Fig. 3).

In 2001, cluster infestation in vineyard borders was not correlated with WGI of the adjacent uncultivated habitat (df = 1, 24; $F = 4.14$; $P = 0.05$ for July; $F = 3.50$, $P = 0.07$ for August; $F = 1.30$, $P = 0.27$ for September) nor in vineyard interiors (df = 1, 24; $F = 0.93$; $P = 0.34$ for July; $F = 1.60$, $P = 0.22$ for August; $F = 0$, $P = 0.95$ for September). In contrast, in July 2002, infestation levels at vineyard borders were greater when the adjacent uncultivated habitat had greater WGI (df = 1, 28; $F = 7.93$; $P = 0.009$) (Fig. 4), but not for the following months (df = 1, 28; $F = 2.29$; $P = 0.14$ for August; $F = 3.10$, $P = 0.09$ for September). That same year, no significant relationship was observed between WGI of uncultivated habitat and vineyard interior levels of infestation, either in July (df = 1, 28; $F = 1.38$; $P = 0.25$) (Fig. 4) or the other sampling times (df = 1, 28; $F = 0.02$; $P = 0.89$ for August; $F = 0.38$, $P = 0.54$ for September).

Table 2.   Values obtained for regression analysis of mean cluster infestation in vineyards and cumulative number of male *E. viteana* adults captured in a) vineyards and b) uncultivated habitats

a) Year	df	F	P	r^2	Slope
2001					
July	1, 50	3.27	0.08	0.06	−0.06
August	1, 50	5.53	**0.02**	**0.10**	−0.11
September	1, 50	8.85	**0.004**	**0.15**	−0.22
2002					
July	1, 58	23.14	**0.0001**	**0.28**	−0.32
August	1, 58	4.84	**0.03**	**0.08**	−0.23
September	1, 58	8.36	**0.005**	**0.13**	−0.30

b) Year	df	F	P	r^2	Slope
2001					
July	1, 46	0.73	0.39	0.02	−0.03
August	1, 46	1.42	0.24	0.03	0.05
September	1, 46	14.91	**0.0004**	**0.24**	0.20
2002					
July	1, 51	2.91	0.09	0.05	0.07
August	1, 51	14.14	**0.0004**	**0.22**	0.15
September	1, 51	10.93	**0.002**	**0.18**	0.14

Significant regressions are displayed in bold.

Discussion

This study shows that uncultivated habitats adjacent to vineyards in Michigan influence cluster infestation by grape berry moth larvae, and that the effect is most evident at vineyard borders (Table 1). Greater larval infestation by *E. viteana* at vineyard borders than interiors has been reported previously in other eastern United States grape production regions (Biever and Hostetter 1989, Hoffman and Dennehy 1989, Trimble et al. 1991). The greater infestation at borders could be caused by improved overwintering survival of pupae at borders as opposed to interiors (Trimble et al. 1991), immigration by gravid females from woods (Trimble et al. 1991, Trimble 1993), *E. viteana* possibly favoring woods in which it has evolved over cultivated vineyards (Nagarkatti et al. 2002), or because borders provide a restricted area for movement by females to lay eggs in comparison with vineyard interiors, making egg deposition more likely at borders.

Comparisons between vineyards with different neighboring habitats revealed that the greatest infestation was observed in vineyards near deciduous woods, whereas the lowest infestation was observed in vineyards near grasses (Table 1). Woods were previously reported to pose a greater risk of grape berry moth larval infestation in vineyards (Hoffman and Dennehy 1989). Potential explanations included the observation that wild grapes were usually (although not always) present in wooded habitats, or that *E. viteana* could be responding to structural characteristics of wooded edges (Hoffman and Dennehy 1989, Martinson et al. 1991). The study reported in this work separated woods into two types according to their primary vegetation, and separated uncultivated habitats into three different structure types: woods, a single row of trees, and grasses. The results show that deciduous vegetation in woods presents a greater risk than coniferous vegetation (Table 1), and that trees,

Table 3.   Parameters measured in the 2002 survey of *Vitis* spp. wild grapevines within four types of uncultivated habitats adjacent to vineyards

Type of uncultivated habitat	n	Wild grape presence (%)	Wild grape cluster presence (%)	Wild grape index (WGI)
Deciduous woods	8	100	75	45.0a
Coniferous woods	6	100	33	29.0ab
Tree row	7	71	43	7.1b
Grasses	9	89	0	14.0b

For WGI, means within a column followed by the same letter are not significantly different (Tukey $\alpha = 0.05$).

whether as part of a forest or in a single row, are sufficient to provide greater risk of infestation than habitats without trees.

Although larval infestation of grape clusters varied according to the type of habitat adjacent to them, the abundance of male grape berry moths in vineyards did not vary in a similar pattern. No positive relationship between the level of cluster infestation by larvae and male moth captures was detected, and rather, the relationship was often negative (Table 2a). This corroborates earlier studies on *E. viteana* (Dennehy et al. 1990b) and on the European grape berry moth *Lobesia botrana* (Karg and Sauer 1995). We caution that low captures of male moths in vineyards cannot be taken as a reliable indicator of high risk of oviposition by *E. viteana*, because this could also be caused by low populations of moths. While abundance of male moths in vineyards did not vary significantly in relation to the type of adjacent uncultivated habitat, there was an effect on abundance of moths within these uncultivated habitats (Fig. 2). Male moth abundance in uncultivated habitats was positively correlated with mean vineyard infestation in August 2002 and September of both years (Table 2b). The greatest infestations were found in vineyards near deciduous woods that contained the greatest numbers of male moths. Lowest levels of vineyard infestation occurred near grassy habitats in which the fewest males were captured. Sciarretta et al. (2001) similarly showed that in the plum fruit moth, *Cydia funebrana*, catches of males were insignificant in landscapes other than orchards in

Table 4.   Correlation between vineyard percentage of cluster infestation by *E. viteana* larvae at vineyard borders and interiors, and the incidence of wild grapevines bearing fruit clusters in the uncultivated habitat adjacent to the vineyard

Year	df	Vineyard border		Vineyard interior	
		χ^2	P	χ^2	P
2001					
July	1	3.02	0.08	**4.03**	**0.04**
August	1	3.32	0.07	0.30	0.58
September	1	1.08	0.30	0.66	0.42
2002					
July	1	4.18	**0.04**	0.47	0.49
August	1	2.49	0.11	0.15	0.70
September	1	0.70	0.40	0.05	0.83

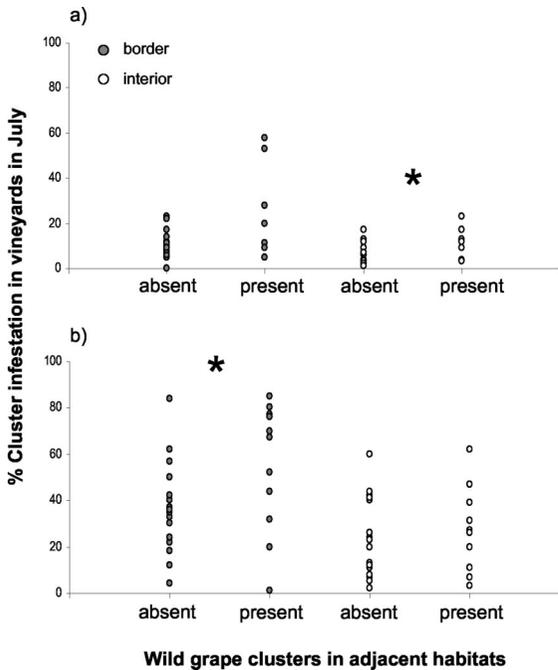Significant Kruskal-Wallis test χ^2 values are in bold.

Fig. 3. Infestation levels of *E. viteana* larvae in vineyard borders (filled) and interiors (open) adjacent to habitats in which wild grape clusters were present or not. (a) July 2001, (b) July 2002. The asterisk indicates a significant difference between sites with wild grape clusters absent or present.

which their food substrate was present, and in their studies of *E. viteana* Hoffman and Dennehy (1989) demonstrated that this species was more abundant in woods and vineyards containing grapes than in neighboring alfalfa fields.

The variation in abundance of adult male *E. viteana* among different habitats suggests that the suitability of these habitats for this pest is not identical. This study focused on variation in the host plant within these habitats as a potential explanation for the difference in captures of *E. viteana* males. When wild grapevines were sampled, the plants were equally likely to be present in each adjacent habitat (Table 3). This is in agreement with observations that appropriate habitats for wild grapevines, particularly *V. riparia* and *V. rupestris*, are relatively continuous across eastern North America (Morano and Walker 1995, Downie and Granett 2000). The habitats did, however, differ in the likelihood of the wild vines having clusters. These were most commonly observed in the deciduous wood sites, but were never observed in grasses, which could be because wild grapes are poor competitors of weeds and shrubs when they lack structural support, but also because grapevines are likely to be mowed with the grass. In addition, Mullins et al. (1992) report that horizontally trained shoots are less fruitful than vertically trained ones.

The presence of woods per se did not create equal risk of pest infestation, because the two types of woods differed significantly in their impact on vineyard in-

festation, male moth abundance, and likelihood of containing grape clusters. Indeed, wild grapevines were in 75% of deciduous wood sites and only 33% of coniferous wood sites studied. The lower fruit production of grapevines in coniferous woods has not been documented previously, but increased soil acidity (pH < 6.5) can sometimes limit commercial grape production. Pine needles on the ground affect soil acidity, inhibit germination of new grapevines, and decrease the number of flowers available for cross pollination, which is necessary to the primarily dioecious wild grapes (Mullins et al. 1992). The most important factor affecting the suitability of this habitat for vines is that coniferous woods have dense canopies throughout the year, reducing light penetration to the forest floor and creating less favorable mesoclimatic conditions than those found in deciduous woods (Mullins et al. 1992). We are not aware of other studies that describe wild grape fruiting distribution or abundance in any geographical range, but unpublished data of wild grapevines indicate that inside deciduous woods, the majority of fruiting typically occurs higher than 12 m within the woods canopy, while at the edges of woods and along tree rows, fruit clusters are found from low near the ground to high into tree canopies (N.B-G., unpublished data).

Fruiting frequency and WGI of uncultivated habitats were both related to vineyard infestation by grape berry moth larvae. Fruiting in uncultivated habitats was significantly correlated with greater cluster infestation in vineyard interiors (July 2001) and borders (July 2002) (Table 4; Fig. 3), probably because the presence of wild fruit clusters in the uncultivated habitat improved the quality of the overall landscape for *E. viteana*. Border infestation tended to be greater when the adjacent uncultivated habitat carried greater WGI values, as suggested by the positive correlation in July 2002 (Fig. 4). The low predictive power of wild grape parameters might be because *E. viteana* do not only depend on the presence or abundance of wild grapevines for development, but on the presence and abundance of wild grape berries. This result is in accordance with the "ideal free distribution" prediction in which herbivores distribute themselves so that they use resources optimally (Milinski and Parker 1991, Williams et al. 2001). Indeed, Nagarkatti et al. (2002) postulated that females of *E. viteana* preferred wild grapes over cultivated ones and were better adapted to densely wooded habitats with varied vegetation. A recent study in vineyards and neighboring deciduous woods (Botero-Garcés and Isaacs 2003) suggested that the distribution of *E. viteana* throughout this agrolandscape was tightly correlated to the vertical and horizontal distribution of *Vitis* spp. host plants, because even though male moths were rarely caught above the height of the vineyard, in deciduous woods >76% of them were captured at and above 9 m in the tree canopy. Moths may be very attracted to wild grape clusters, but if the population cannot be supported, females unable to lay eggs in wild grapes may disperse to locate new hosts in the nearby vineyards.
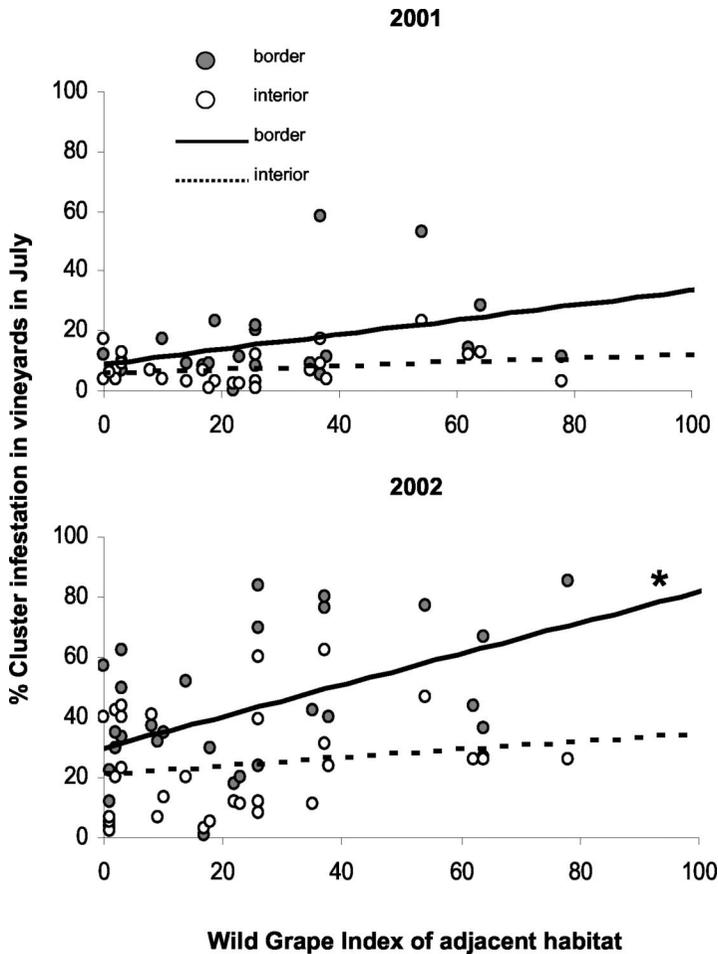
Fig. 4.   Percentage of cluster infestation by *E. viteana* larvae in vineyards in July 2001 and 2002, and wild grape index values of the adjacent habitats. Cluster infestation at the borders is shown by filled circles and solid lines, and infestation at the interiors is shown by open circles and dashed lines. The asterisk indicates the correlation is significant.

This study highlights the importance of landscape structure for crop pest population dynamics. Typically, descriptions of the influence of adjacent habitats on crops have addressed whether the effect is negative because of pest immigration or positive because of movement of natural enemies (Seaman et al. 1990, Dorn et al. 1999) and the availability of alternate insect hosts for pest parasitoids (Dennehy et al. 1990a). The grape berry moth, a specialist pest species that dwells in native habitats next to cultivated grapes, may be able to cross the area between habitats to colonize vineyards, much like codling moth, *Cydia pomonella* (Dorn et al. 1999). Nagarkatti et al. (2002) argue that interhabitat movement by *E. viteana* may occur only within the immediate vicinity, because of the insect's lack of flight vigor. Future studies should address potential dispersal capacity of this species and factors affecting interhabitat movement.

Integrated pest management programs may be more effective against grape berry moth by accounting for the wild grape abundance and fruiting in neighboring habitats. Future trapping strategies should evaluate the use of female baits like the one developed for *C. pomonella* (Light et al. 2001) in uncultivated habitats, because these appear to be influential to grape berry moth populations. The removal of wild grapevines in habitats neighboring vineyards, especially deciduous woodlots, may reduce the impact of this pest by decreasing the amount of larval food substrate available for *E. viteana.* This removal should be done during the winter months to aid in vine detection and to ensure overwintering moths are deprived of an oviposition resource in the spring. However, the immediate effects of removing wild hosts may be an increase in pest pressure, because it is not unusual for a portion of a resident population to migrate in response to environmental cues and selection pressure (Hughes and Dorn 2002). Further studies should address the effect of wild host removal on grape berry moth and associated populations of parasitoids. In a study in which egg parasitoids accounted for the greatest *E. viteana* mortality, Dennehy et al. (1990a) indicated that wild hosts were a "source and refuge for natural enemy populations." Wild hosts in

conjunction with more diverse vegetation than vineyards offer a habitat that is favored by parasitoids, as discussed by Nagarkatti et al. (2002). Because Williams and Martinson (2000) have shown that leafhopper parasitoids are better able to successfully colonize New York vineyards when alternate hosts are present within uncultivated (wooded) habitats, parasitoids of *E. viteana* may also require these resources adjacent to vineyards. The benefits of maintaining a complex landscape (preserving woods and riparian vegetation) or simplifying it (removal of woods and wild grapevines) should be further studied in this system before any management plans are implemented, because controversy exists on the effect of habitat complexity on parasitoid communities (Menalled et al. 1999, Thies and Tscharntke 1999).

Acknowledgments

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