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Relative captures of grape root borer, *Vitacea polistiformis* (Lepidoptera: Sesiidae) in pheromone traps within vineyards and adjacent woodlands

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A B S T R A C T

The grape root borer (GRB), *Vitacea polistiformis* (Harris), is a significant pest of grapes (*Vitis* spp.) throughout parts of the eastern United States. Early detection and implementation of management tactics can prevent economic losses and vine death. The establishment of an effective monitoring program requires the deployment of pheromone baited traps in vineyards and native wild grapes. An understanding of the spatial distribution of GRB infestations is critical for the development of sampling plans and for implementing management decisions. Wing traps baited with synthetic GRB sex pheromones (99:1 blend of (E,Z)-2,13-ODDA and Z,Z-3,13-ODDA) were deployed in commercial vineyards and surrounding woodlands in wild grapes to monitor GRB abundance and distribution. In addition, pheromone-baited wing traps were placed at low, medium, and high positions (0.5 m–2 m above the ground) on the grapevine trellis in commercial vineyards to evaluate the effect of trap height on the number of GRB captured. Traps placed in the cultivated vineyard had consistently higher counts of GRB compared with traps along the vineyard edge and in the wild grapes in the woodland. The pheromone-baited traps placed on the highest trellis wire caught more GRB adults than traps placed at the lowest position on the bottom trellis wire. Therefore, we recommend to place traps at approximately 2 m in the upper grapevine canopy early in the season before flight of GRB moth begins in order to aid in the timing and implementation of management tactics.

1. Introduction

The grape root borer (GRB), *Vitacea polistiformis* (Harris) (Lepidoptera: Sesiidae), is a significant pest of grapes (*Vitis* spp.) throughout the eastern United States (All et al., 1987) and has been reported from Michigan to Florida and west to Missouri and Arkansas (Snow et al., 1991). It is an oligophagous species on plants in the family Vitaceae, and consequently is common in commercial vineyards (Bergh et al., 2005; Weihman and Liburd, 2007) and wild grapes (Snow et al., 1991; Bergh, 2006). Flight activity of the GRB moth throughout the eastern United States begins mid-June or early July and continues through October (Snow et al., 1991; Webb et al., 1992), therefore, cultivated grapes are most susceptible to GRB damage in the summer months.

Grape root borer larvae feed on grape roots, causing extensive root damage which can restrict nutrient and water transportation from roots to the rest of the plant, reducing vine vigor (Clark and Enns, 1964; Dutcher and All, 1976; All et al., 1987). In addition, vines become more susceptible to freeze damage, drought, and pathogens due to the injured roots (Pearson and Meyer, 1996). A single larva can reduce the yield of a grape vine by 50% (All et al., 1982), and two to three larvae are capable of killing an entire vine (Dutcher and All, 1979). Therefore, control measures should be used as soon as GRB is detected in the vineyard.

The period that GRB larvae are vulnerable is relatively narrow (Roubos and Liburd, 2008) from when they hatch on grape foliage to entry into the soil. First-instar larvae immediately burrow into the soil in search of grape roots and once larvae enter the roots, they are sheltered from insecticides, predators, and other mortality factors (Harris et al., 1994). Vine infestations can be dependent on the success of GRB larvae to survive once they have entered the soil. Grape root borer infestations are also dependent on neonates finding and establishing on grape roots, and grape root volatiles can play an important role in larval food-finding (Rijal et al., 2013). Several studies have indicated an effect of abiotic and biotic factors, including rainfall (Clark and Enns, 1964), soil properties (Sarai, 1972; Rijal et al., 2014a) and proximity of wild hosts (Hoffman and Dennehy, 1989; Bergh, 2006), on infestation rates of grape pests among vineyards.

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Fig. 1. Site map of pheromone traps placed at four different locations: 1) 10 m into the woodlands, 2) along the edge of the woodlands, 3) along the edge of the vineyard, and 4) in the vineyard at the University of Florida Suwannee Valley Agricultural Extension Center (SVAEC) in Live Oak, FL. The letters (A–D) indicate the replicate for each treatment.

Larval infestations may go unnoticed for 5–10 years after the initial infestation at which time the vines usually begin to show symptoms (All et al., 1987). Therefore, it is important to monitor adult GRB populations as they enter the field to allow growers to better time their sprays when first instar larvae are crawling into the soil (Roubos and Liburd, 2008). The traditional method of counting pupal exuviae collected at the base of the vines (Weihman and Liburd, 2005) is considered the most accurate method to assess the presence of larvae on individual vines (Bergh, 2012). However, the use of pheromone-baited traps is a less time-consuming and labor intensive alternative for detecting GRB adult activity in grapes. Optimizing trap deployment within vines will further improve GRB monitoring programs and allow for a more sustainable management of GRB populations. By determining ideal trap placement in the vineyard, a reduction in the usage of broad spectrum pesticides that may kill beneficial insects can be achieved as traps can indicate when GRB populations are high and thus limit pesticide applications only under pest outbreak conditions (Weihman and Liburd, 2005).

Disruption of pheromone-mediated communication used in mating by GRB was first reported by Johnson et al. (1981). The primary component of the GRB pheromone was identified by Schwarz et al. (1983) [(E,Z)-2,13-octadecadienyl acetate (ODDA)] and the addition of 1% (Z,Z)-3,13-ODDA by Snow et al. (1987) greatly increased attractiveness. Sanders et al. (2011) used wax-based specialized pheromone and lure application technology (SPLAT) to test mating disruption, and found that dispensers dosed with 5 mg of GRB pheromone and applied at a rate of 150 dispensers per ha achieved 95% disruption during a 7-wk trapping period in Florida.

Captures of male GRB in pheromone traps can accurately reflect the presence and seasonal phenology of adults (Snow et al., 1991; Bergh et al., 2005; Weihman and Liburd, 2007). However, the temporal and spatial distribution of GRB infestations needs further investigation in order to improve monitoring and management decisions. It is hypothesized that GRB infestations in commercial vineyards are preceded by early season abundance in wild grape vines found in surrounding woodlands (Johnson et al., 1988; Snow et al., 1991; Bergh, 2006). Understanding the moth pressure from native hosts is important for evaluating the risk to both new and established plantings.

Bergh (2006) evaluated pheromone-baited traps in apple orchards and vineyards, as well as in surrounding habitats, in northern Virginia and found more GRB moths captured in traps within the crop than in adjacent woodlands. In the Bergh (2006) study, the traps were placed at a constant height of 1.5 m. In this study, trap height is considered as a potential factor affecting the evaluation of insect distribution and abundance, particularly when there is considerable difference in canopy height between habitats in which the insect is distributed (Derrick et al., 1992; Humphrey et al., 1999; Boiteau et al., 2000). As virgin GRB females prepare to call to potential mates, they climb up several inches above the soil surface onto the grape vine or surrounding vegetation, and mating that follows will occur less than 1 m above the soil (Wylie, 1974; Dutcher and All, 1978). Therefore, it is important to evaluate trap height within grapevines in order to maximize trap catches.

The purpose of this study was to evaluate GRB abundance and distribution in commercial vineyards and in woodlands with native wild grape hosts (*Vitis* spp.). The specific objectives were to 1) assess the abundance and distribution of GRB inside commercial vineyards and in surrounding woodlands with wild grapes, and 2) determine the effect of trap height on the number of GRB that are captured in commercial vineyards.

2. Material and methods

2.1. Abundance and distribution of GRB in vineyards and adjacent woodlands

The study was conducted during the summer/fall 2013 and 2014 to determine whether GRB male moths immigrate into vineyards from the nearby wooded habitats containing wild grapes. The experiment was established on a 15 year old vineyard located at the University of Florida, Suwannee Valley Agricultural Extension Center (SVAEC), Live Oak, FL (30°18′02.2″N 82°54′00.0″W) (Fig. 1). The total area of the vineyard was approximately 0.3 ha with 16 rows each 54 m long spaced 3 m apart. This vineyard was chosen because it was one of the few unsprayed vineyards that was available for research. The vineyard rows were approximately 10–18 m away from a woodland that was populated with wild grapes (*Vitis* spp.), pine trees (*Pinus* spp.), and fully grown oak trees (*Quercus* spp.), among other common shrubs. The area between the vineyard and the woodland consisted of a well-maintained grass field that was mowed regularly.

Experimental design was a stratified random sampling design, such that sampling was separated into distinct habitats (i.e., woodland, woodland edge, vineyard, vineyard edge). Moth abundance was measured using pheromone traps (IPM wing trap, Great Lakes IPM, Inc., Vestaburg, MI) each baited with a rubber septa lure containing synthetic sex pheromone of GRB [99:1 blend of (E,Z)-2,13-octadecadienyl acetate (ODDA) and Z,Z-3,13-ODDA] (Schwarz et al., 1983; Snow et al., 1987; Weihman and Liburd, 2007). In 2013, there were four treatments that included pheromone trap placements: 1) 10 m into the woodlands, 2) along the edge of the woodlands, 3) along the edge of the vineyard, and 4) 20–25 m in the vineyard (Fig. 1). Based on the results of 2013, traps were not deployed on the edge of the vineyard or woodlands; therefore, in 2014, two treatments were evaluated that included pheromone trap placements: 1) 10 m into the woodlands and 2) 20–25 m in the vineyard. Traps were hung in the canopy of cultivated and wild grapevines, or approximately 1–2 m from the ground (depending on height of the vines). In both 2013 and 2014, 4 replicates were used for each treatment and spaced approximately 20 m apart. Traps were serviced regularly by replacing the sticky bottom of traps every two weeks and pheromone lures at 4-week intervals. Sampling was conducted for approximately two months from 12 Aug 2013 to 3 Oct 2013 and 16 July 2014 to 17 Sept 2014. The slight change in dates is reflective of GRB flight activity during those respective years. Trap bottoms were brought to the Small Fruit and Vegetable IPM Laboratory at the University of Florida Gainesville, FL and the number of GRB males was recorded.

2.2. Trap height in vineyards

Research was conducted during the summer/fall 2012 and 2013 to investigate trap placement within the grapevines. The experiment was established in a 20 year old vineyard located at the University of Florida campus in Gainesville, FL in 2012 and 2013 (29°38′13.8″N 82°21′47.9″W). The total area of the vineyard was approximately 0.3 ha with 12 rows each 67 m long spaced 3 m apart. Experimental design consisted of three trap placements (high, medium, and low) replicated four times in a randomized complete block design. Low and high traps were hung from the lower (approximately 0.5 m above the ground) and upper (approximately 2 m above the ground) trellis wires, respectively. Medium traps were hung from the grape vine at a position halfway between the trellis wires (approximately halfway between 0.5 m–2 m above the ground). IPM wing traps (Great Lakes IPM, Inc., Vestaburg, MI) were used; and each trap was baited with a rubber septum containing the GRB sex pheromone as described earlier. Traps were spaced approximately 10 m within a block (replicate) with an additional 6 m buffer between the blocks. Traps were replaced weekly and pheromone lures were replaced after three weeks. Sampling was conducted for six weeks from 19 July 2012 to 30 August 2012 and 30 July 2013 to 3 Sept 2013. Traps were brought to the Small Fruit and Vegetable IPM Laboratory at the University of Florida Gainesville, FL and the number of GRB males was recorded.

2.3. Data analysis

Data were analyzed using repeated measure analysis of variance (ANOVA; PROC MIXED, SAS Institute, 2009) with trap placement and time as fixed factors and trap placement × time interactions. Sample date was the repeated measure. Treatment means were separated by least significant differences (LSD) test (SAS Institute, 2009) where ANOVA indicated a significant difference between treatments ($p \le 0.05$).

3. Results

3.1. Abundance and distribution of GRB in vineyards and adjacent woodlands

In 2013, the number of male GRB moth captures were different by trap location ($F = 25.60$; df = 3, 69; $P \le 0.0001$) and time ($F = 35.24$; df = 5, 69; $P \le 0.0001$), and there was an interaction effect ($F = 2.58$; df = 15, 69; $P = 0.0041$). Treatments were significantly different from each other until the fourth sampling period in mid-September when GRB populations started to decrease. Throughout the sampling period, there were significantly more GRB males captured 20–25 m within the vineyard (average 20 males/trap) than along the edge of the vineyard (average 14 males/trap), edge of the woodland (average 10 males/trap) and within the woodlands (average 6 males/trap). Grape root borer male trap captures were 2X greater in the vineyards (average of 31 males/trap) compared with captures in the woodlands (average of 16 males/trap) at the end of August (Fig. 2).

In 2014, the number of male moth captures were different by trap location ($F = 59.64$; df = 1, 57; $P \le 0.0001$), time ($F = 15.50$; df = 9, 57; $P \le 0.0001$), and there was an interaction effect ($F = 5.59$; df = 9, 57; $P \le 0.0001$). Treatments were not different until the fourth week of sampling at the beginning of August, when GRB populations began to significantly increase in the vineyard. There were more GRB males captured within the vineyard (average 18 males/trap) than in the woodland (average 8 males/trap). Similar to the findings from 2013, GRB trap captures were approximately 2X greater in the vineyard (average of 31 males/trap) compared with captures in the woodland (average of 15 males/trap) by the end of August (Fig. 3).

3.2. Trap height in vineyards

In 2012 at the Gainesville site, the number of male moth captures were different by trap height ($F = 24.27$; df = 2, 60; $P \le 0.0001$), time ($F = 32.44$; df = 6, 60; $P \le 0.0001$), and there was an interaction effect ($F = 2.29$; df = 12, 60; $P = 0.0179$). There were treatment

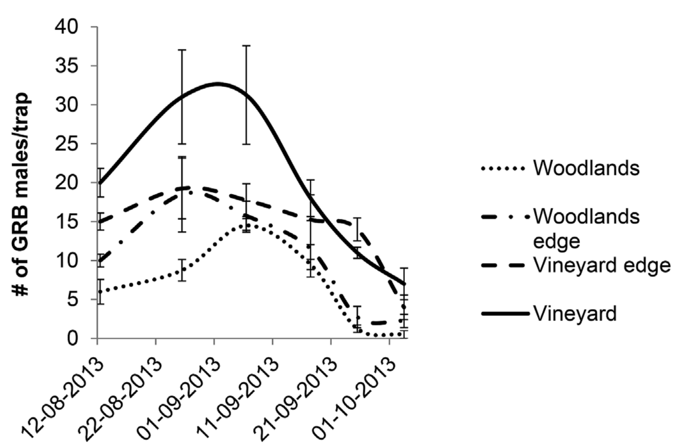

Fig. 2. Mean (± SE) number of adult male GRB per trap captured over two months for the GRB distribution study in 2013 collected from traps placed in four locations: woodlands, edge of woodlands, edge of vineyard, and in the vineyard.

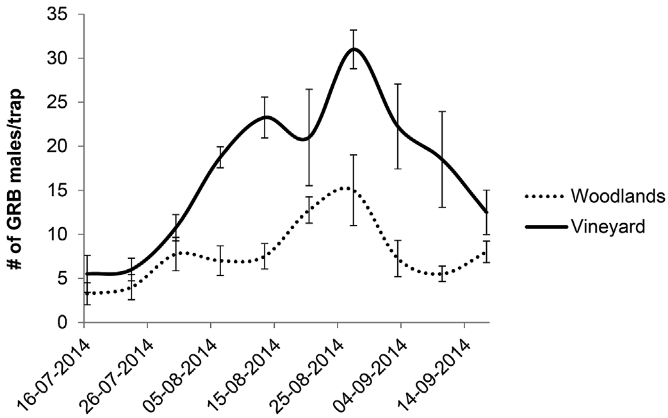

Fig. 3. Mean (± SE) number of adult male GRB per trap captured over two months for the GRB distribution study in 2014 collected from traps placed in two locations: woodlands and in the vineyard.

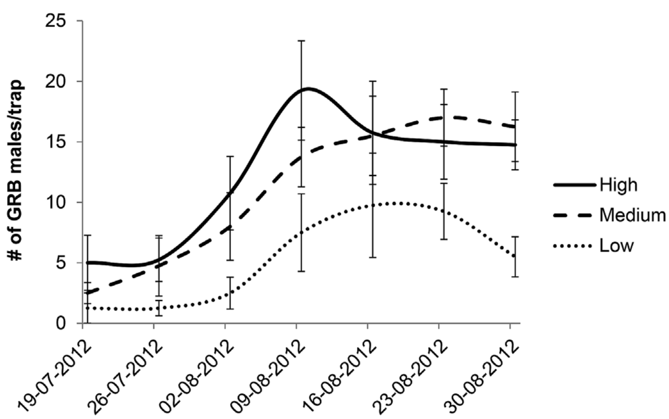

Fig. 4. Mean (± SE) number of adult male GRB per trap captured over six weeks for the GRB trap position study in 2012 collected from traps placed at three heights on grapevine canopy: high, medium, and low.

differences for all sampling periods except the first week in mid-July, when GRB populations were relatively absent from the field, and the fifth week in mid-August, when GRB populations had peaked. Traps placed on the lower trellis caught significantly fewer male GRB moths (average 5 males/trap) than those placed on the high trellis wire (average 12 males/trap) or at the medium height (average 11 males/trap) (Fig. 4). There was no significant difference in the number of GRB caught when the traps were placed at the high position compared with the medium position (Fig. 4).

In 2013, the number of male moth captures were different by trap height ($F = 8.41$; df = 2, 51; $P = 0.0007$), time ($F = 19.71$; df = 5, 51; $P \leq 0.0001$), but there was no interaction effect ($F = 0.85$; df = 10, 51; $P = 0.5834$). Traps placed on the high trellis caught significantly more male GRB moths (average 10 males/trap) than those placed on the low trellis wire or at the medium height (average 5 males/trap) (Fig. 5). There was no significant difference in the number of GRB caught when the traps were placed in the low position compared with the medium position (Fig. 5).

4. Discussion

Traps placed in the vineyard caught consistently higher numbers of male moths compared with traps placed at the vineyard edge or adjacent woodland throughout the sampling period for both years we evaluated GRB habitat distribution. Low densities of male GRB moths were present in traps along the edge of the vineyard and in the wild grapes in the woodland. Bergh (2006) also reported significantly more

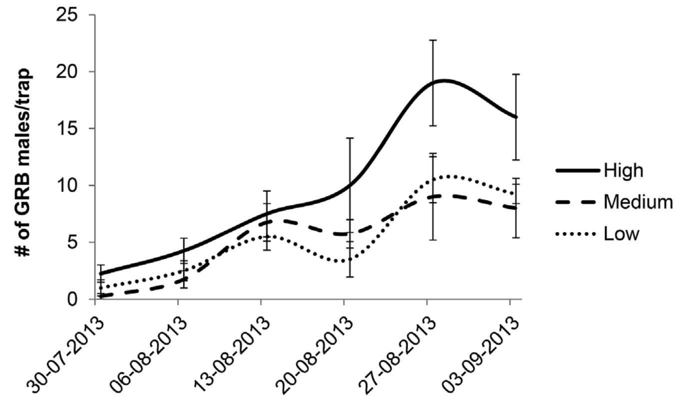

Fig. 5. Mean (± SE) number of adult male GRB per trap captured over six weeks for the GRB trap position study in 2013 collected from traps placed at three heights on grapevine canopy: high, medium, and low.

GRB moths captured in traps within vineyards and apple orchards than in traps placed at the forest edge and in the forest. The reasons for the observed differences in trap catches are not fully understood and need further research. However, several hypotheses may explain these results. For instance, it is possible that there is a higher density of GRB within the vineyard due to the higher density of borer infested vines within the vineyard than in adjacent woodland. Male catches in traps will be higher when more females emerge within the vineyard and call males for mating. Secondly, wild grapes may be a less preferred host to GRB than cultivated grapes and may be exhibiting some form of resistance towards GRB. For instance, in tests using container-grown plants, Webb and Mortensen (1990) demonstrated that rootstocks derived from the Florida leatherleaf grape, *Vitis shuttleworthii* House showed some level of resistance to larval GRB establishment. Firoozabady and Olmo (1982) demonstrated that hybrid plantings of *Vitis rupestris*, a native species of grape in the US, showed resistance to grape phylloxera, *Phylloxera vitifoliae* Fitch, another destructive pest of grapevines.

There may also be a relationship between adult distributions and the spatial distribution patterns of immature insects (Toepfer et al., 2007). Grape root borer larval location is primarily influenced by adult emergence, oviposition, and proximity to a host where the larvae can establish on roots. After moth emergence from the soil, the females will walk up a nearby grape trunk, begin calling and mate (Dutcher and All, 1978). Females are likely to begin oviposition at the mating site, especially where larval resources are abundant and perennially available (Greenfield, 1981). Therefore, the higher number of adult captures within the vineyard would be expected due to higher larval numbers in the vineyard than in adjacent woods.

At the start of the sampling period for this experiment at the beginning of August 2013, which occurred after moth flight began, the number of male moth captures was significantly higher in traps located in the vineyard compared to any other location. However, at the start of the earlier sampling period in mid-July in 2014, the number of male moth captures in traps was not significantly different between the wild grapes in the woodland and the cultivated grapes in the vineyard. This may indicate that moth emergence begins earlier in July (Snow et al., 1991) when some moths disperse from wild grapes in adjacent habitat and accumulate in cultivated grapes. Previous research has indicated that initial GRB infestations in commercial vineyards likely originated from endemic populations in nearby woodlands. As the vineyard aged, it acquired a higher density of GRB larvae per area than in adjacent woods that typically would have a lower number of wild grapes per area. Therefore, early monitoring for GRB should include traps along the vineyard edge, and the grower could remove alternative hosts such as wild grapes before cultivated grapes matured to lessen future GRB moth dispersal and infestation of the commercial vineyard. Dutcher and

All (1979) demonstrated the economic injury level of *V. polistiformis* to be extremely low (0.07 larvae per vine), and the use of insecticidal treatments should be applied immediately after detection. The existence of a low economic injury level further highlights the importance of detecting male GRB moths early before it mates and females begin ovipositing in the cultivated grapes.

While the deployment of pheromone-baited traps has been useful to detect the presence and abundance of moths, the relationship between trap catches and infestation rates in vineyards is unclear. Based on our findings of higher trap catches within the vineyard where infestations are likely to be higher compared to the woodland, we would expect a positive relationship between trap catches and infestation rates within the vineyard. Rijal et al. (2014b) found a relationship between pupal exuviae counts and the initial emergence of adult GRB. Over a period of five years, they collected the majority of pupal exuviae between the third week of July and the first week of August. In the mid-Atlantic region, the peak emergence of adult GRB has been reported to range from the first to the last week in August (Pearson and Meyer, 1996). Furthermore, they reported that although the total numbers of pupal exuviae collected per vine often exceeded the recommended threshold, most vines showed no apparent effects, and the threshold recommendation of 0.074 larvae per grapevine by Dutcher and All (1979) may be a conservative estimate for GRB on *V. vinifera* produced in the mid-Atlantic region (Bergh, 2012). While pupal exuviae counts may be a good indicator of when to establish traps in the field, it is best to set out and monitor pheromone traps before the earliest historical trap catch. The first trap catch of adult GRB can aid timing and placement of mating disruption dispensers (Johnson et al., 2013) or insecticide sprays (Horton, 1988) when GRB are at their most vulnerable stage to reduce further infestations.

In this study, we used a baited Delta-wing trap that is effective when the GRB population is relatively low and traps are serviced weekly. The delta-wing trap is the trap of choice in GRB mating disruption programs (Sanders et al., 2011). Another available monitoring tool is the pheromone-baited bucket trap. These traps may be more useful in long-term monitoring operations where the GRB male population is high and traps are serviced irregularly (once or twice per month) (Weihman and Liburd, 2007).

For both years, the pheromone-baited traps placed on the highest trellis wire (approximately 2 m above the ground) caught more male moths compared with traps placed on the lowest trellis wire (approximately 0.5 m above the ground). This suggests that the pheromone is more readily detected and found by the males when released from a trap position high above the ground since males are predominately searching for females that call on the grapevine trunk just below the canopy (Dutcher and All, 1978). In apple orchards, Peterson (1926) found that captures of the oriental fruit moth, *Cydia molesta*, increased with trap height. Weissling and Knight (1995) also found that trap monitoring for codling moth and placement of mating disruption ties was most effective in the upper canopy of apple trees.

In 2012, the number of male moths captured in traps placed in the medium position were higher compared to traps placed in the lowest position, but were not different from traps placed at the highest position. However, in 2013, the number of male moths captured in traps placed in the medium position was lower compared with traps placed in the highest position, but was not different from traps placed at the lowest position. It is hypothesized that the variation between years in male moth captures in traps hung in the medium position was because the traps placed in this position were not hung on a trellis wire but were placed on the grapevine itself. Therefore, the height of traps in the medium position may have been more variable and position placement was limited by the structure of the grapevine. Based on our findings, a trap placed lower on the grapevine could result in fewer GRB adult males captured in the trap.

Traps placed within the vineyard had consistently higher numbers of male moths compared to traps along the edge of woodlands and edge of vineyard as well as in the woodland. Based on our findings and previous observations of GRB flight activity (e.g., Snow et al., 1991; Webb et al., 1992), it appears that deploying 2–4 traps per hectare on a vineyard by mid-June on the top trellis-wire (prior to the start of the GRB flight) will optimize the monitoring efficiency for GRB from first to last male flight. This recommendation would apply to areas that have a similar climate and seasonality to northern Florida, and may differ from recommendations made in northeastern US climates that would be based on GRB emergence and flight activity. Furthermore, traps should be positioned high in the canopy to maximize the accuracy of GRB detection in the vineyard. In summary, a pheromone-monitoring program utilizing traps placed within the grapevine canopy early in the season before harvest would be a valuable tool to monitor for GRB activity and determine when management tactics should be implemented.

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