MONITORING AND CONTROL TACTICS FOR GRAPE ROOT BORER *Vitacea polistiformis* HARRIS (LEPIDOPTERA: SESIIDAE) IN FLORIDA VINEYARDS

By

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This document is dedicated to my parents, Robert and Ceil Weihman

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Sixteen vineyards from four grape-growing regions across Florida were evaluated for presence and severity of grape root borer (GRB), *Vitacea polistiformis* Harris (Lepidoptera:Sessidae), during 2003 and 2004. Grape root borer males were caught in all vineyards, with heavier concentrations in the northern and southern counties. Grape root borer began emerging in late June and early July in the Panhandle and southern regions. In the north central region, emergence occurred in late July and in the central region, mid-August. Weekly trap catches indicated that peak GRB flights occurred during mid to late August for the Panhandle region and the second and third week of September for the north central, central, and southern regions. Wing-style sticky traps were compared with Universal Moth Traps (Unitraps) in order to determine which trap was more effective for monitoring GRB activities. The Unitrap caught significantly ($P < 0.05$) more GRB than the wing trap. Farmers were surveyed to determine if there was a correlation between cultural control practices, chemical usage, and environmental conditions and total GRB trap catch, and the results indicated a strong correlation between a combination of these factors and the total trap catch in 2003. The results from the 2004 survey showed a weaker correlation compared with 2003. Mating disruption and attract-and-kill (A&K) gels were evaluated for control of GRB in Florida vineyards. For mating disruption, pheromone twist-ties with leopard moth, *Zeuzera pyrina* L. (Lepidoptera:Cossidae), pheromone were placed in vines at a rate of 254 per acre. Attract-and-kill gels containing the GRB pheromone and a pyrethrin were applied to vine trunks at a rate of 45 grams per acre. These treatments were compared with chlorpyrifos (Lorsban) and an untreated control in a randomized complete block design. Two wing traps with GRB pheromone were placed in each treatment to monitor male moth activity and determine levels of trap shutdown. Complete trap shutdown occurred in the twist-tie section for both 2003 and 2004 suggesting disruption of mating. Both A&K and the twist-tie sections caught significantly fewer GRB than the Lorsban treatments in 2003. In 2004, significantly fewer moths were caught in the twist-tie and Lorsban treatments than the A&K and untreated controls. Both A&K and mating disruption with the leopard moth pheromone show promise as reduced-risk control strategies for GRB and warrant further study.

CHAPTER 1
INTRODUCTION

There are over 1,000 acres (405 ha) of grapes planted in Florida and this number is steadily increasing. The grapes are used for fresh fruit, U-pick, jam, juice, and wine. Florida has 13 registered wineries, producing over $8,000,000 in wine sales (WineAmerica, 2003). In comparison with other crops, grapes are a relatively small crop in Florida but have a strong potential for growth. Florida is the third highest wine consuming state in the nation, and most vineyards have to import grape juice from other states and countries to keep up with the demand. The Viticulture Advisory Council was established in 1978 to help develop the viticulture industry in Florida, and annually gives grants to farmers for increased grape acreage.

The primary grape grown in Florida is the muscadine (*Vitis rotundifolia* Michx.), which is native to the southeastern U.S. It is well adapted to Florida conditions and does not succumb to many diseases or pests. The American bunch grape (*Vitis labrusca* L) is also native to the southeastern U. S. It is very susceptible to Pierce's disease and other pathogens, so disease-resistant hybrids were developed (*Euvitis spp*.) which are now widely planted in Florida. *Euvitis* is the second-most planted grape, and is used mostly for traditional wines. The European bunch grapes (*Vitis vinifera*), such as Pinot Noir and Chardonnay, have not been successfully grown in Florida, due primarily to Pierce's disease.

The most important insect pest of grapes in Florida is the grape root borer, *Vitacea polistiformis* (Harris), (Lepidoptera: Sesiidae). Grape root borers (GRB) have been damaging vineyards in the southeastern U. S. for over 150 years (Mitchell, 1854). In the last 40 years they have received more attention and research due to the increase in grape acreage in many Atlantic states. The grape root borer (GRB) does not occur in California, the principal grape-producing state in the U.S., therefore not much attention has been afforded it. GRB infestations cause loss of vigor in grapes, serious decreases in yields, and high vine mortality. Entire vineyards have been destroyed in Missouri (Clark and Enns, 1964), Arkansas (Attwood and Wylie, 1963), Virginia (Virginia Tech, 2003), South Carolina (Pollet, 1975), and Florida. In Georgia, damage and control costs totaled $81,000 in 1997, more than any other insect pest of grapes (University of Georgia Department of Entomology, 1997). It has been declared the most destructive insect pest of grapes in Georgia (All et al., 1989), North Carolina (McGiffen and Neunzig, 1985), Florida (Liburd et al., 2004) and other states.

The GRB is a difficult pest to detect and control because it spends the majority of its lifecycle underground. It is sequestered inside grape roots, and its damage is not readily apparent. The exposed roots of an infested vine will show tunnels just under the cambium filled with a reddish frass and trunk girdling. The adult stage is active for only about a week (Clark and Enns, 1964) and it is not obvious because of its resemblance to a paper wasp of the genus *Polistes* (which is prevalent in summer vineyards). Damage to a vine may not be apparent for several years. Symptoms include yellowing of leaves, smaller leaves and berries, reduced shoot growth, dieback of portions of the vine, and reduced yields. These symptoms occur gradually and may also be the result of other factors. The most prominent sign of infestation is the accumulation of pupal casings that persist at the base of vines.

Many strategies for control have been investigated, including mounding, covering the base of vines with ground cloth, chemical control with Lorsban 4E®, and mating disruption (Olien et al., 1993). Mounding is a technique by which a layer of soil is ridged over the base of the grape plant and under the trellis in order to prevent the adults from emerging. Wylie (1972) showed that mounding significantly reduced GRB numbers in an Arkansas vineyard. Mounding would not be a very effective technique to manage GRB in muscadine grapes in Florida vineyards because the roots are easily damaged and the vines are shallowly rooted and would quickly grow roots into the ridge. Also, Florida has a long GRB season with bimodal emergence peaks. Subsequently, mounding would control only a small portion of the population. To control GRB effectively using the mounding technique, vineyards would have to be mounded several times a season and this would be very labor intensive.

Applying ground cloth under the base of vines is another strategy used to prevent GRB from emerging from the soil, as well as entering the root zone. This cultural control method may also not be practical for Florida conditions. Most of the soil in Florida is primarily loose sand, and mowers would probably dislodge and destroy the ground cloth. Workers may also damage the ground cloth while pruning and harvesting. Similarly, harvesting machines could also do damage when picking grapes. It may be effective in reducing GRB numbers, and may be the best option for organic growers, but it is too expensive, high maintenance and impractical for the average grape grower.

The conventional method of GRB control involves the use of Lorsban 4E (chlorpyrifos), although this is not available to the hobbiest, or the unlicensed farmer. This compound is an organophosphate, which is a class of insecticide targeted by the

Food Quality Protection Act (FQPA) of 1996 to be among the riskiest chemicals used in agricultural systems (FQPA, 1996). Subsequently, the future use of this compound is not guaranteed. Also, with the increase in consumer concern over pesticide usage in their food crops, it is essential that effective IPM strategies be developed to manage GRB with limited chemical usage. Several studies have shown Lorsban to be ineffective in control of GRB (Wylie and Johnson, 1978; Adlerz, 1984). Lorsban can only be used once per season and 35 days pre-harvest, which is well before the peak emergence period, and after harvest. Since GRB emerge over a long period in Florida, and Lorsban is effective for roughly four weeks (All et al., 1985), it cannot effectively control GRB population. The main goal of my research was to find an effective, reduced-risk strategy for controlling grape root borer in Florida vineyards.

Before initiating control studies, I surveyed the prevalence of GRB in Florida vineyards to determine if farmers' cultural practices promoted or suppressed GRB populations. Traps were placed in vineyards from different grape growing regions of Florida and checked weekly to determine the degree of infestation and to ascertain the time of peak emergence. Previous research by Webb et al. (1992) and Snow et al. (1991) demonstrated peak emergence for certain areas of Florida, with longer emergences in the more southern regions. I wanted to increase the scope of the study and reexamine the seasonal distribution for the present era. A questionnaire was developed in order to correlate vineyard management practices, chemical usage, local terrain, and age of vineyards with GRB infestation levels.

In order to monitor the pest populations most efficiently, I chose to compare pheromone-baited bucket traps with pheromone-baited wing traps. Researchers have used both traps, but their effectiveness for catching GRB has never been compared.

In order to develop an effective control tactic for GRB in Florida, I compared the standard, Lorsban 4E (chlorpyrifos), with the new attract-and-kill technology and with traditional mating disruption. Mating disruption has proven to be effective in controlling other sesiid moths, the peachtree borer (*Synanthedon exitosa* Say) and the lesser peachtree borer (*Synanthedon pictipes* Grote and Robinson) (Yonce, 1981). It has also shown promise for the grape root borer (Johnson and Mayes, 1980; Johnson et al., 1981; Johnson et al., 1986; Johnson et al., 1991; Webb, 1991; Pearson and Meyer, 1996) and warrants further investigation.

Attract-and-kill is a relatively new technology whereby insects are lured to a matrix that contains an attractant (pheromone) and a pesticide, and subsequently killed. This technology is selective to a target pest and safe for humans and the environment since it involves significantly less pesticide than traditional chemical treatments (10 g of pyrethrins per ha for GRB). Attract-and-kill has been effective in controlling codling moth, *Cydia pomonella* L. (Ebbinghaus et al., 2001) as well as several other lepidopteran pests. An attract-and-kill product for grape root borers was developed by IPM Tech (Portland, OR) called Last Call-GRB. It contains 9% pyrethrins and 0.16% GRB pheromone.

Grape farmers in Florida presently only have Lorsban to combat GRB damage to their vineyards. Most of them are not licensed to apply this chemical, which is only partially effective. The goal of my study is to survey and research the severity of GRB infestations in vineyards in Florida, delineate the emergence periods, and to investigate alternative control strategies to Lorsban. This research will show farmers the peak for GRB emergence so that they will be better able to time their control efforts. I will also discuss some vineyard management techniques that may help reduce infestation levels, and give them some alternative reduced-risk strategies for controlling GRB.

CHAPTER 2
LITERATURE REVIEW

Lifecycle

The grape root borer (GRB) *Vitacea polistiformis* (Harris), (Lepidoptera: Sesiidae) is a day flying sesiid clearwing moth with brown scales on the forewing, and a brown abdomen with orange or yellow bands. Its flight behavior, buzzing sound, and appearance resemble the paper wasp (*Polistes spp*.), with long legs hanging well below the body. The males are smaller than the heavier females with four tufts of scales extending beyond the abdomen. Most studies have reported a 2-year life cycle, although Sarai (1972) suggests a 3-year cycle. Webb and Mortensen (1990) reported a one-year life cycle in containerized, screen house grape plants in Florida. J.R. Meyer (North Carloina State University, pers. comm.) also reports a predominantly one-year life cycle in the southern end of its range. The GRB is native to the eastern United States, ranges from Vermont across to Minnesota and east of the Mississippi River states, and occurs in most of Florida from the Panhandle to Miami (All et al., 1987; Snow et al., 1991). They have not been recorded in some of the major wine growing areas such as the Finger Lakes region of New York or the southern shores of Lake Erie in New York, Ohio, and Pennsylvania (Jubb, 1982). Their life cycle is dependent on grapes of the species *Vitis*, both wild and cultivated.

The GRB is holometabolous and goes through egg, possibly six larval instars, a pupal stage, and adult. The adults can emerge over a six-month period in Florida, compared with < 2 months in northern states. In the southeastern U.S., GRB generally begin flying in June or early July and continue to emerge until the weather becomes cooler (<16°C) (Snow et al., 1991). In the Florida Panhandle, emergence continues until October, and in south Florida they can emerge until January (Webb et al., 1992). The period of emergence may be longer in wet, cool years and shorter in hot dry years (Clark and Enns, 1964). The grape root borer emergence is characterized by single peaks in the northern states and variable bimodal peaks in the South (Snow et al., 1991). Prior to peak emergence, males predominate, but the percentage of females emerging after the peak is higher. Overall, the sex ratio over the season is about equal (Townsend and Micinski, 1981).

Adult GRB live for about eight days (Dutcher and All, 1978a). During this time they do not feed but spend their time reproducing. The male can mate several times and the females usually mate once. After the female emerges from her pupal case, she will alight on a leaf or branch [weeds seem to be the favorite spot for copulation (Sarai, 1972)] and begin calling within about 30 minutes (Dutcher and All, 1978a). The virgin female calls by lifting her abdomen and extending her pheromone gland/ovipositor, releasing the pheromone complex (Pearson and Meyer, 1996). Males downwind are quickly able to locate the female by this distinct chemical signal. With initial contact, the male will touch the female with his antennae and continue to hover around her. While hovering parallel to her and in the same direction, the male will bend his abdomen 180 degrees and insert his genitalia, thus joining at the tips of the abdomen. The male then alights on the substrate facing the opposite direction of the female. Copulation often lasts for about four hours and usually takes place between 1:00 and 6:00 in the afternoon (Dutcher and All, 1978a).

The female lays her eggs within 24 hours after mating (Dutcher and All, 1978a). During daylight hours, the gravid female lays her eggs one at a time, often a few cm apart, on soil, the trunk, and low grape leaves and branches, but mostly on weeds near the trunk. These eggs are then shaken down to the soil surface by wind and rain. Initially, being heavily weighted down, GRB female lays the majority of her eggs around the nearest trunk. She loosely attaches them with a weak adhesive secretion, and they fall to the ground shortly thereafter. As she lightens her load, she flies to other vines to spread her progeny. The female GRB lays an average of 354 eggs, ranging from 122-707 (Dutcher and All, 1979a). The eggs are small (1.0 mm) reddish-brown ovals with one side convex and the other with a longitudinal groove (Bambara and Neunzig, 1977). In the field, the eggs incubate for roughly 18.2 days. Egg survivability is 70-85% under laboratory conditions, but undoubtedly much lower in the field (Clark and Enns, 1964).

As the first instar hatches, it immediately enters the soil in search of grape roots. Moisture is extremely important at this stage because desiccation of the first larval instars is a major mortality factor, and therefore dry months often result in smaller infestations (Sarai, 1972). Abiotic factors, such as soil moisture and depth of roots, affect first-instar mortality. Only 1.5 to 2.7% of the larvae that emerge survive to infest the roots of grape vines (Dutcher and All, 1978b). The young GRB start feeding on the smaller roots, but migrate towards the larger roots and crown as they grow. The first-instar is whitish and only measures between 1.7 and 2.7 mm (Bambara and Neunzig, 1977).

The young larvae continue feeding for the rest of the season and may go through an obligate diapause during the winter in the colder areas of its range. All et al. (1987) indicate that in Georgia GRB are quiescent during the winter but may become active if the soil becomes sufficiently warm. Further research is required to determine its over wintering mechanisms in Florida.

As the larvae mature they become cream white with brown heads that are retractable. Larvae have 3 pairs of true legs and 5 pairs of abdominal prolegs. Their bodies are about 3-4 cm long and are sparsely covered with coarse hairs. They burrow into the cambium layer of the root system and make tunnels, depositing a reddish-brown frass behind them, and move in the direction of the crown (Dutcher and All, 1978c). The more mature larvae are generally found in the larger roots and in the crown. Large gouge-like wounds are indicative of GRB feeding.

In the early summer of their second year, after 22 months of development, the mature larvae burrow their way to the top 5 cm of soil and begin spinning their cocoons (3-4 cm long) of silk, frass, and soil. The cocoons are often attached to a root. The pupal stage lasts between 26 to 45 days (Sarai, 1972). Grape root borers complete their development after 1100 degree days, base 10º C (Johnson et al., 1981). The pupa is 1.5 to 2.5 cm in diameter. When the adult is fully developed, the pupa will wiggle ¾ of the way out of the cocoon by spiraling its body with the use of abdominal spikes, and emerge vertically half way above the soil. The pupal case then splits in half and the adult emerges and climbs onto the nearest substrate to dry its wings.

The vast majority (92%) of the cocoons are found within 35 cm of the trunk (Townsend, 1980). Small larvae are found evenly throughout the root structure and medium and large larvae are more abundant toward the trunk and larger roots. Most larvae are found within 5 and 20 cm of the soil surface, but they have also been discovered as deep as 80 cm (Dutcher and All, 1978c).

The mechanisms that initiate emergence have been a subject of debate. Dutcher and All (1978d) suggest that it is based on degree-days and the accumulation of berry sugar (for Concord grapes). The percentage of berry sugar (>5%) correlates to the development of pupae and percentage of adult emergence. This may be true for Georgia and other states, but research by Webb et al. (1992) suggests that in Florida, emergence may relate more to soil temperature and type, rainfall, and timing of changes in nutritional quality of grape roots.

Damage

Grapes root borers attack cultivated muscadine grapes, *Vitis rotundifolia* Michx., American bunch grapes, *V. labrusca* L., European bunch grapes, *V. vinifera* L., and hybrid bunch grapes, *Euvitis* spp. They also live on wild grapes and spread from these into new vineyards. If an old infested vineyard is nearby, moths populate the new vineyard starting from the rows nearest to the old vineyard. In one study, the average yield per vine increased on vine rows progressively farther from the old vineyard (Townsend, 1980).

Grape root borers damage vines by girdling the roots, cutting off nutrients and water transfer from the roots to the rest of the plant. Extensive damage may be done before symptoms appear. The first symptom of GRB damage is often yellowing and wilting of the leaves, which may also result from other factors. This is followed by reduced shoot growth, smaller leaves and berries, loss of vigor, susceptibility to freeze damage and drought, susceptibility to pathogens, and reduced yields. In some cases, canes will start to die off and eventually the whole plant succumbs. This may take several seasons to become obvious. The traditional method of monitoring GRB activity, besides digging up the vines and inspecting for larvae, is to count the pupal casings under the vines. Monitoring male GRB with pheromone traps is another method for estimating GRB populations.

Studies by Dutcher and All, (1979b) show that one GRB larva feeding at the crown can cause as much as 47% decrease in yield in a single vine, and 6 larvae can cause a 100% decrease. Although an economic threshold of 73 larvae per hectare has been established by Dutcher and All, (1979b), a vine can withstand a high GRB population with minimum yield loss if GRB are feeding on the lateral roots. Olien et al. (1993) suggest that a healthy, vigorous vine should be able to grow new roots faster than GRB can consume them. It is the destruction of the crown that causes severe yield loss and eventual death. Harris et al. (1994), reported that older vineyards are more severely infested and younger vines suffer less damage.

Monitoring

The standard trap used for monitoring GRB populations in pheromone and mating disruption experiments has traditionally been wing-style sticky traps (Johnson et al., 1986; Johnson et al., 1991; Snow et al., 1987; Snow et al., 1991; Webb, 1991; Webb et al., 1992). Scientists working on other lepidopteran pests have investigated the performance of wing traps against Universal Moth Traps (Unitraps) (Great Lakes IPM, Vestaburg, MI). Shaver et al., (1991) compared Unitraps with 13 other trap types for monitoring Mexican rice borer (*Eoreuma loftini* Dyar). In all tests, the Unitrap caught significantly more moths than the 13 other traps including the wing trap. Schmidt and Roland (2003) compared Unitraps with wing traps for monitoring populations of forest tent caterpillars (*Malacosoma disstria* Hubner). At endemic population levels, the Unitrap caught twice as many moths as the wing trap. At high population levels, the wing trap became completely filled with moths and debris and became unusable after a saturation point of about 20 moths per trap.

Management History

The grape root borer has been an elusive pest to control. Traditional control methods in the early 20th century included scalding the cocoons with hot water, and hoeing of cocoons to expose them to environmental conditions. It was not until the 1960s that scientists began looking at more effective strategies.

Resistant Varieties

Resistant varieties have been reported and negated since the early 1900s. It was first thought that muscadines were resistant to GRB but that was proven to be erroneous. Later, it was suggested that the Scuppernong variety of muscadines was also resistant to GRB, but that was proven to be untrue (Wylie, 1972). However, it appears that a few varieties of muscadines may show a higher degree of resistance. Harris et al. (1994) found ‘Doreen’ to be highly resistant to GRB perhaps due the fact that its main roots are smaller and more numerous, enabling it to tolerate more damage. Earlier, Wylie (1972) investigated resistance and discovered 10 rootstocks that showed promise. Webb et al. (1990) concluded that none of the grape rootstocks in their trial were totally resistant but some varieties were more tolerant. They found that rootstocks that had the Florida leatherleaf grape, *V. shuttleworthii*, in their parentage were significantly less damaged by GRB. Furthermore, they concluded that the roots of muscadines were often more damaged by GRB than those of the hybrid bunch grapes, perhaps due to the fact that muscadines are more shallowly rooted and thus more accessible to the GRB larvae.

Weed Control

Weeds, in general, are important to the grape root borer's lifecycle. They provide substrate upon which to lay eggs, and are the preferred mating sites for the adults (Sarai, 1972). They also provide cover to the newly emerged adults and create a humid environment and protection for first larval instars. The egg and first larval instars are the most vulnerable stages of the GRB lifecycle. Research has shown that over 95% of eggs and first larval instars are killed before they reach the roots (All et al., 1987). The mortality of the eggs and first larval instars is due primarily to predation, environmental extremes, pathogens, and parasites. After they have reached the roots, mortality is under 1%.

Mounding

Mounding is a technique by which a layer of soil is built over the base of the grape plant and under the trellis. This is done to prevent the adults from emerging. Grape root borer cocoons are generally found at 3 cm under the soil surface. Sarai (1969) tested different depths of soil to determine the depth from which the majority of GRB would not be able to emerge. He found that 100% mortality was achieved at a depth of 7.5 inches. However, any new larvae making their way to the surface after the soil ridge is placed at the base of the plant would simply burrow to the top of the ridge. Timing is important during mounding. The ridge must be placed right before the peak emergence, and since the majority of GRB emerge within 35 cm from the trunk, the ridges should extend out about 50 cm from the trellis wire (Dutcher and All, 1979a). In field experiments, Wylie (1972) found 0 and14 GRB pupal cases in two mounded test vineyards versus 71 and 134, respectively, in the controls. Later, All et al. (1985) reported 83% control of GRB by using the mounding technique. Further work showed that, in addition to preventing adults from emerging, mounding also created a higher rate of juvenile mortality, since the first larval instars might starve before locating the roots (All et al., 1987). Other research has shown that mounding not only helps with GRB, but also limits the amount of herbicide used (Kennedy et al., 1979).

Physical Barriers

The implementation of a synthetic sheet (as a mulch) may prevent first-instar larvae from reaching the soil, allowing them to die of desiccation. The use of a soil barrier would also prevent adults from emerging from the soil.

Yonce (1995) used physical barriers in field studies as a means to control GRB over a three-year period. In his studies, three different ground cloths (Weed Barrier®, an experimental polypropylene (BASF Corp., Parsippany, NJ), and the standard black polyethylene) were compared with the control (no barrier) in a randomized block design. No significant differences were recorded between his barrier treatments. However, overall, infestations in the barrier treated plots showed 20-81% reduction in larval numbers compared with the control plots. Larvae were still able to penetrate the fabric, but it slowed down their progress, increasing the time they were exposed to the air. In lab experiments, larvae died when exposed to air for 4-5 hours without supplemental moisture (Townsend, 1980).

Yonce (1995) conducted similar experiments using potted grapes in the greenhouse. Weed Barrier (a spun fabric) proved to be the most effective ground cloth, compared with black polyethylene and an experimental polypropylene. This reduced first larval instar penetration by 42%. In another study, Attwood and Wylie (1963) suggest that black polyethylene will control adults from emerging by 90% for a 60 cm wide strip and 100% for a 120 cm wide strip. But for this to be effective, the barrier has to be installed properly and well maintained. It also has the added benefit of weed prevention, and thus reduction of herbicide use.

Biocontrol

There are a number of organisms that prey on grape root borers. Birds such as barn swallows, *Hirundo rustica erythrogaster* Boddaert, mocking birds, *Mimus polyglottus* L., and the great crested flycatcher, *Myiarchus crinitus* L., have been observed eating GRB adults (Clark and Enns, 1964). Arthropods such as firefly larvae, *Photuris pennsylvanica* De Geer, and soldier beetle larvae, *Chauliognathus pennsylvanicus* De Geer, also feed on root borers. In a study to determine the types of predators that prey on GRB eggs, Dutcher and All (1978b) recorded tiger beetles, *Cicindella punctulata* (Olivier); ground beetles, *Calosoma sayi* (DeJean), *Harpalus pennsylvanicus* (De Geer), and *Calathus sp*., shore flies, *Notiophilus sp*., and a staphylinid beetle feeding on GRB eggs. Other natural enemies include a parasitic braconid wasp, *Bracon caulicola* (Gaham), which parasitizes mature GRB larvae within the top 5 cm of soil (Dutcher and All, 1978b). Also, Clark and Enns (1964) found chalky white GRB specimens in the field, and lab results showed that the mortality was caused by the insect pathogenic white muscardine fungus, *Beauveria bassiana* Balsamo, and green muscardine fungus, *Metarrhizium anisopliae* Metchnikoff. These fungi killed GRB both in the field and in the lab (Sarai, 1972). In one vineyard in Georgia, *M. anisopliae* killed seven of 12 GRB pupae in one vine (Dutcher and All, 1978b). Two other organisms that attack the pupal stage are *Aspergillus flavus* Link ex Fr., a fungal pathogen, and *C. pennsylvanicus*, a lightning bug (Dutcher and All, 1978b). The application of predatory nematodes of the genera *Heterorhabditis* and *Steinernema* have also shown some promising results against GRB larvae (Williams et al., 2002).

Dutcher and All (1978b) compared two vineyards, one with regular pesticide treatments of carbaryl (Sevin) and methyl parathion and an untreated (control) vineyard to determine the effects of pesticides on naturally occurring biocontrol agents. They found that egg predation by natural predators and egg hatchability were 11.6% and 25.3% respectively in the treated vineyard, suggesting that the chemicals may have had an ovicidal effect. Alternately, egg predation and hatchability were 61.7% and 76.38% respectively in the vineyard that was not treated with insecticides. The total egg mortality for the chemical site was 77.45%, compared with 66% in the untreated vineyard, suggesting that pesticides may have an ovicidal effect. No significant differences were found with the underground life stages. In the chemical-free vineyard, survival for each stage was egg 22.6%, first larval instar 2.7%, root established larvae 95.8%, and pupae 92.5%, suggesting that the most vulnerable stages are egg and first larval instar.

Entomopathogenic Nematodes

Entomopathogenic nematodes are roundworms that parasitize and infect insects and arthropods. The nematode enters the insect through a body cavity or in some cases directly through the body wall and enters the haemocoel. The insect dies as a result of septicemia induced by *Xenorhabdus* bacteria, which has a mutualistic relationship with the nematode, and kills the insect within 24-48 hours (Grewal et al., 1994). A single GRB host can produce 300,000 to 400,000 nematodes. The infective stage is the third stage juvenile, the only free living stage of growth, which locates the host and initiates the parasitism.

The idea of using entomopathogenic nematodes to control an insect species was being discussed as early as 1969 (McGuire and Wylie, 1969). They recognized the relationship of *Neoaplectana carpocapse* (Weiser) (presently *Steinernema*) with grape root borer. The first use of this nematode was against peach tree borer. Schmidt and All (1978) found that the nematode dauer larvae locate their host by sensing excrement and a chemical gradient around the host through the use of chemoreceptors.

All et al. (1981) made the first attempt at using *Steinernema carpocapse* to control GRB. They discovered a strain of *Steinernema carpocapse* in several Concord grape vineyards in Georgia but also noted that GRB larvae and pupae mortality was low. All et al. (1981) reported that naturally occurring populations would not be large enough for proper control and that introduction of high levels would be needed for effective control. In laboratory tests, the introduction of 10,000 dauer larvae resulted in 80% mortality of eclosed larvae, 76.9% mortality for one-year-old larvae, and 80% mortality for two-year-old larvae. Nematodes began emerging from infested one and two-year-old larvae within 7-18 days at 21°C. The high mortality rates were promising. The disadvantage of this tactic is that high levels of nematodes are necessary and that GRB larvae had to be placed near the nematodes for infection to take place. Saunders and All (1985) found that *Steinernema carpocapse* was effective in killing first larval instars as they burrowed down to their primary feeding sites, and that there was an inverse relationship between GRB density and nematode densities. *Steinernema carpocapse* nematodes were found to be the most effective in suppressing GRB activity at 29°C and their survival was directly correlated to soil temperatures (30°C) and soil moisture (>79.5% R.H.) at which infective juveniles lived for 1.5 to 2 years (Gray and Johnson, 1983).

Williams et al. (2002) did laboratory and greenhouse bioassays to determine which species of nematodes would be most effective against GRB. Their conclusion was that

Heterorhabditis zealandica Poinar (strain XI) showed the most promise in all of the tests. In the laboratory, *H. zealandica* produced an 86% infection rate, and in the greenhouse, it produced a 53% infection rate. At a rate of 60,000 nematodes per plant, 95% mortality was achieved. *H. zealandica* can also locate GRB in root pieces, and in one study caused 96% mortality. In the field, when 5 billion *H. zealandica* per hectare were applied, it achieved 70% control (Pollock, 2002).

Control of GRB using entomopathogenic nematodes shows great promise and should be investigated for Florida soils.

Mating Disruption

To initiate mating, a female grape root borer will emit a pheromone, which is specific to her species. This is referred to as ‘calling’, and the male downwind will sense it and be able to locate her. Mating disruption occurs when an area becomes saturated with the female sex pheromone. The male, confused, is unable to locate the female and mating does not take place. Over time, populations will decline. This has successfully been used to reduce populations of other sesiid moths, for example, the peach tree borer, *Synanthedon exitosa* (Say) and the lesser peachtree borer *Synanthedon pictipes* (Grote and Robinson) in peach orchards (Yonce, 1981).

The first pheromone used for GRB was the one developed for the peachtree borer, and the lesser peachtree borer, (Z,Z)-3,13 octadecadienyl acetate (Z,Z-ODDA). Johnson and Mayes (1980) tested this pheromone and found it to be attractive to GRB. Later, Johnson and Mayes (1981) evaluated it and found it to be an ineffective monitoring device, but showing some potential in mating disruption. In further mating disruption experiments, GRB densities declined twofold faster in plots treated with Z,Z-ODDA using Hercon laminated dispensers than the check plots (Johnson et al., 1986). In another experiment, Johnson et al. (1986) caged calling females in a pheromone-saturated vineyard and also in a non-pheromone saturated vineyard (control). The former attracted 14 males while the latter attracted 127.

Schwartz et al. (1983) analyzed samples of pheromones from female GRB ovipositor extracts and identified (E,Z)-2,13-ODDA to be the GRB pheromone. They also acknowledged that there were probably other minor components. Snow et al. (1987) added 1% (Z, Z)-3,13 octadecadienyl to the pheromone and found that it increased the capture of GRB males by 3 to 7 times more than by using the major component by itself. Johnson et al. (1991) applied the new pheromone blend using saturated Shin-Etzu ropes (Mitsubishi Corporation, Tokyo, Japan) (254 ropes per hectare) in one vineyard and compared it to an untreated vineyard (control). By counting the pupal skins, they noted a reduction of 92.7% over a two-year period, whereas the check plot had an increase of 17.2% over the same period.

Webb (1991) compared a pheromone-saturated vineyard with an untreated vineyard in Florida. The pheromone-treated vineyard produced significantly fewer pupal skins than the control as well as trap shutdown. Also, 70% of the females caught in the control plot had mated, whereas, in the pheromone-saturated vineyard, only 11.6% had mated. In a more recent study, Pearson and Meyer (1996) showed that Shin-Etzu ropes were more effective than using rubber septa in mating disruption experiments because the chemical is dispensed over a longer period from the twist ties. Further analysis of the data showed that in the treated vineyard with a high GRB population, the percent of females mated was 54%, while in another treated vineyard with a low population density, it was 0%.

They concluded that mating disruption of GRB may only work when the population is moderate to low.

Attract-and-Kill

Attract-and-kill (A&K) is a promising new technique for pest control. This method employs an attractant and a toxicant. The attractant is a semiochemical, such as a sex pheromone or a kairomone. The insect is attracted to the pheromone and is killed by the toxicant. The pesticide in the droplet adheres to the insect cuticle, or is ingested and the insect dies shortly thereafter, depending on the dosage and the length of exposure. One of the benefits of using this technique is that it targets the desired insect pests and has less detrimental effects on beneficial insects. Also, there is no spray drift with attract-and-kill systems and no pesticide residues are left on the fruit. It is easy to apply and lesser amounts of pesticides will be used per hectare.

Attract-and-kill treatments have been used successfully to suppress populations of several lepidopteran pests in different crops: *Spodoptera littoralis* Boisduval in cotton (De Souza et al., 1992), *Epiphyas postvittana* Walker in apples (Brockerhoff and Suckling, 1999), (Suckling and Brockerhoff, 1999), *Cydia pomonella* L. in apples (Ebbinghaus et al., 2001), (Ioiratti and Angeli, 2002), *Amyelois transitella* Walker in almonds (Phelan and Baker, 1987), *Pectinophora gossypiella* Saunders in cotton, (Haynes et al., 1986), and *Plodia interpunctella* Hubner in stored foods (Nansen and Phillips, 2003). Liburd et al. (1999) showed considerable success using a similar attract-and-kill technique for control of a dipteran pest *Rhagoletis sp*. in blueberries. Recently, IPM Technologies, Inc. (Portland, OR) has developed a product called Last Call, which combines a sex pheromone with a pesticide into a gel matrix for controlling codling moth

C. pomonella. IPM Tech reported that Last Call® CM was 2-3 times more effective for controlling codling moth than a regular spraying program (IPM Tech, 2002).

The primary goal of attract-and-kill is to kill insects before it can mate or cause damage. However, death is not necessary for attract-and-kill formulations to be effective. Sublethal effects such as hyperactivity, convulsions, autotomy, and paralysis will result in the inability of the insect to fly, perceive a mate, or carry out regular behavioral mating responses and would effectively prevent an individual from procreating (Krupke et al., 2001). This would, of course, depend on the amount of pesticide encountered and the length of exposure. Nansen and Phillips (2003) found that >6% permethrin concentrations killed males within a 24-hour period, which may be sufficient time to find and court a female. However, in toxicity tests, males encountering the attracticide containing at least 3% permethrin were visibly affected and unable to perform normal courtship behavior and copulation. Haynes et al. (1986) showed that pink bollworm males who survived pesticide exposure for 24 hours were significantly less likely to locate a pheromone source than unexposed males. In a study by Brockerhoff and Suckling (1999), male *E. postvittana* exposed to attracticide were caged with virgin females; mortality was 100% and no females were impregnated.

In addition to knockdown, impaired mating performance, and death, another mechanism by which attract-and-kill controls pests may be traditional mating disruption. Suckling and Brockerhoff (1999) compared treatments of no pheromone, A&K and caged A&K droplets for *E. postvittana*. Trap catches in the A&K treatment were reduced by 95% compared to the control. In the caged attracticide treatment, trap catches were reduced by 63% compared with the control, indicating that the A&K droplets may have a mating disruption effect. When Krupke et al. (2001) compared treatments of attracticide in different dosages (50, 100, 200, and 500 drops per ha.) for *C. pomonella*, they found a dramatic reduction in the trap-catch in the treatments of 500 drops per ha compared with other treatments, which may be the direct result of more point sources of pheromone per area.

Attract-and-kill may be more attractive to male GRB than the calling females. Krupke et al., 2001 found this to be true for codling moths with Last Call CM. Brockerhoff and Suckling (1999) also found that attracticide droplets could be more attractive than calling females when the percentage of pheromones in the gel matrix is higher than that of the female moth. On the other hand, it has been suggested that the pesticide in the attract-and-kill formulation may hinder its attractiveness to male moths. Studies of several moths indicate that there is no significant repellency in the attracticide where pesticide is added to the matrix (De Souza et al., 1992), (Haynes et al., 1986), (Phelan and Baker, 1987), (Suckling and Brockerhoff, 1999). Pyrethroids have a low vapor pressure and may not be detectable until after contact.

These studies indicate that the attract-and-kill technology can perform equally or better than chemical control. However, like mating disruption, attracticides suffer some of the same setbacks: high pest selectivity, inverse density dependence, and immigration of gravid females.

Chemical

All and Dutcher (1977) tested 25 pesticides (contact, systemic and fumigant) using several rates and application methods and found that only soil injection of fumigants near the trunk base and under the trellis wire were effective in suppressing populations of

GRB. The chemicals that caused the highest mortality were ethylene dibromide (EDB) and ethylene dichloride (EDC) when used with a pressure flow injection device.

The most vulnerable stage of the GRB was found to be first larval instar, as they begin to burrow into the soil in search of grape roots. All et al. (1982) proposed the use of Lorsban 4E® (chlorpyrifos) (Dow Chemical U.S.A., Midland, MI) as a residual barrier to intercept and kill the young GRB larvae as they enter the soil. This treatment provided a 100% mortality rate to first instars for 21 days. Gas Liquid Chromatography (GLC) analysis of soils treated with Lorsban showed that over 90% of chlorpyrifos was retained in the 0-3 cm layer of the soil and that Lorsban maintains its toxicity in the soil for four weeks (half life=3 weeks) (All et al., 1985).

Adlerz (1984) compared the use of fumigating with EDC and using chlorpyrifos (Lorsban) as a soil drench. These treatments were found to be effective for muscadine grapes but Lorsban was not effective for bunch grapes. Muscadines are shallow rooting vines and a drench of Lorsban will reach many roots and the GRB living in them. Research since then has focused on Lorsban since EDC and EDB are no longer registered for use.

The use of Lorsban as a soil drench is not only effective on the first larval instars, but it also reduces egg hatchability. However, Lorsban had no effect on the pupae or the emerging adults (Wylie, 1972), though lab experiments proved it to be toxic to adult male moths. Several contact insecticides have also been tested and proved to be lethal to adult root borers, but the use of contact insecticides in vineyards would probably have little effect on the overall population (All et al., 1985).

Currently, Lorsban 4E is recommended at 1.06 L to 378 L of water to treat 200 vines (All et al., 1987). For best results, treatments should be concentrated around the base of the vine and under the trellis, and the area to be treated should be weed-free. One of the problems with Lorsban is that it can only be used once per growing season and it has a 35-day pre-harvest interval. Lorsban cannot control a heavy infestation, but it can be used to prevent a large population from establishing. All et al. (1989) suggests monitoring the vineyard for pupal casings. When 5 or more pupal cases are found per 100 vines, then Lorsban should be used the following year. This should be repeated until pupal cases are at the 2% level.

It is difficult to manage GRB in Florida with Lorsban since adults fly 4 to 6 months with two major peak emergence times. The recommended application can only kill a small percentage of the total population. Another problem is that peak emergence coincides with harvest in many parts of Florida; subsequently, Lorsban cannot be applied at that time (Webb et al., 1992).

Chlorpyrifos may be taken off the market soon due to regulations resulting from the 1996 Food Quality Protection Act (FQPA, 1996). With the increased grape acreage in Florida, increased public interest in organic foods, and the fact that Florida is the third highest wine drinking state, there is great potential for increased grape production. However, before growers increase their production, effective tactics must be developed to manage GRB. Since the future for Lorsban is threatened and growers are reluctant to use pesticides, special efforts must be made to develop an integrated approach for control of GRB. In Georgia, our nearest neighbor, GRB accounted for 80% of all control cost and damage losses due to arthropod pests in grapes in 1997 (University of Georgia

Department of Entomology, 1997). Certainly, effective reduced-risk strategies are needed as an alternative to chemical treatment with Lorsban.

CHAPTER 3
STATEWIDE SEASONAL DISTRIBUTION OF GRAPE ROOT BORER (GRB) IN FLORIDA; AND THE RELATIONSHIP BETWEEN ENVIRONMENTAL FACTORS AND CULTURAL CONTROL TECHNIQUES AND GRB DENSITY

Grape growing is a small but increasingly important part of the Florida economy and grape acreage has increased significantly over the past several years. Florida is the third highest wine consuming state in the United States, and visiting wineries for wine tasting is an increasingly popular tourist activity. The largest insect deterrent to grape (*Vitis* sp.) growing in the southeastern United States is the grape root borer (GRB), *Vitacea polistiformis* (Harris); (Lepidoptera: Sesiidae). It has devastated vineyards in several states (Olien et al., 1993) including Florida (S.Webb, University of Florida, pers. comm.). Large infestations can also weaken plants and reduce yields. The only feasible control method currently being used is soil drenching with chlorpyrifos (Lorsban 4E). In order for this insecticide to be effective, it must be applied during the peak emergence period of GRB. Unfortunately, the peak emergence for GRB coincides with the period of grape ripening for muscadines and pre-harvest interval regulations forbid Lorsban application at these times. Although Lorsban is not highly effective in Florida, it is the only chemical listed for control (Adlerz, 1984). Therefore, research must be done to develop alternative methods of control for GRB. Understanding the seasonal distribution patterns of GRB as well as the environmental factors regulating populations will be important when developing management programs.

Snow et al. (1991) investigated the seasonal distribution of GRB and found that, in Florida, GRB generally begin to emerge in June. Emergence continues throughout the season until the onset of colder temperatures. Peak emergence was generally bimodal, and sometimes had several modes. Later work by Webb et al. (1992) explored the seasonal distribution of GRB in Florida on a larger scale, with nine vineyards, instead of four, and corroborated the earlier findings.

In order to detect any changes that may have occurred in GRB flight patterns over a 10-year period (1993-2004), populations of GRB were monitored in the major grape-growing regions of Florida during 2003 and 2004. In addition, a survey was conducted to examine the relationships between population densities of GRB, environmental factors, and cultural management techniques to determine if there are any correlations among these factors. To do this, a survey was compiled that included age and size of vineyard, proximity to wild grape populations, soil characteristics, as well as irrigation techniques, weed maintenance, and chemical usage. Information was obtained on rainfall and temperatures for the areas monitored.

Specific objectives for this research were to monitor vineyards for GRB in four distinct regions of Florida for two years. Weekly trap catches would reveal seasonal distribution patterns and peak emergence for GRB. Total trap catch would indicate vineyards or regions with severe infestations. Another objective was to correlate GRB trap catches with environmental factors and cultural control techniques in order to ascertain if there was a relationship between certain factors or sets of factors and GRB levels.

Materials and Methods

Monitoring

Pheromone monitoring of GRB was carried out in 16 vineyards in 2003 and 18 vineyards in 2004, representing four distinct regions of Florida. During 2003, sixteen privately owned vineyards were chosen in four areas: the Panhandle (including 1 vineyard each in Washington, Calhoun, Leon, and Jefferson counties), north-central Florida (1 vineyard in Alachua County and 3 vineyards in Putnam County), mid-Florida (4 vineyards in Lake County), and south Florida (including 1 vineyard in Hillsborough County, 2 in Manatee County, and 1 in Highlands County) for 2003. During 2004, two additional vineyards in north-central Florida, one in Putnam and one in Alachua counties, were added to the study. Vineyards were chosen based on the diversity of environmental conditions, age, and cultural practices, and included abandoned plantings, organic farms, mechanized modern farms and U-pick vineyards. Another important criterion in choosing vineyards was to find farmers who were willing to cooperate with research efforts.

Four green Universal Moth Traps (Great Lakes IPM, Vestaburg, MI) baited with female GRB pheromone (99% (E,Z)- 2,13 octadecadienyl acetate, 1% (Z,Z)- 3,13 octadecadienyl acetate) (1 mg of pheromone per septa) (Great Lakes IPM, Vestaburg, MI) were placed in each vineyard. Traps were distributed evenly throughout each vineyard, at least 30 m apart. A rubber septum with the female GRB pheromone was deposited into each cage and attached at the top of each trap. Pheromone lures were changed once per season, at the midpoint of the GRB emergence period for the specific region (approximately 2 months). A Vaportape (Hercon Environmental, Emigsville, PA) treated with 2,2-dichlorovinyl dimethyl phosphate was affixed to the bottom of each trap within the bucket to kill the GRB as they became entrapped. Traps were hung from the trellis wire about 1 to 1.5 m above the ground near a vine.

Monitoring began in June each year because Webb et al. (1992) demonstrated that the first emergence of GRB in the regions in which we were trapping began in June or later. Trap contents were collected weekly into labeled plastic resealable bags. Specimens were brought back to the lab for analysis. The number of GRB, along with other insects collected in each trap, was recorded each week. Traps were continuously monitored until no more borers were caught. Average weekly trap catch for each vineyard was plotted on a graph in order to display the emergence pattern for the season.

Survey

A list of questions was asked of each grape grower participating in the survey. Questions included biological information, environmental conditions, and management strategies, as well as general information. These questions (Table 3-1) were designed to ascertain which conditions or cultural techniques might influence population densities of GRB. Growers were interviewed at the end of the growing season for 2003 and 2004, respectively. Other information obtained included weekly precipitation, average ground temperature, and average solar radiation. This information was obtained from weather stations closest to each vineyard from the Florida Automated Weather Network.

From these questions, certain factors were chosen to be further studied based on whether they might favor the development of GRB or hinder its survival, based on previous literature. The answers to these questions were then awarded numerical values or points. Factors that favored GRB were given a positive rating, factors that had no effect were rated neutral (0), and factors that hindered development or led to death were given negative ratings. The ratings for each factor differed depending on the degree to which the factor can potentially affect the GRB life cycle.

Previous literature has suggested conditions in which GRB thrive and rankings were determined based on this (All et al., 1982; All et al., 1985; All et al., 1987; Clark and Enns, 1964; Dutcher and All, 1978b; Dutcher and All, 1979a; Harris et al., 1994;

Sarai, 1972; Townsend, 1980). Older vineyards often have higher GRB populations (All et al., 1987) and points were awarded on a scale of 0 - 5 (based on age) as follows: 2 years and under (0 points), 3 - 4 (1 point), 5 - 6 (2 points), 7 - 8 (3 points), 9 - 14 (4 points), and 15 and higher (5 points).

Larger vineyards can support higher populations and points for size were awarded on a scale of 1 - 5 as follows: less than 1.2 ha (1 point), 1.3 - 3.1 ha (2 points), 3.2 - 6.0 ha (3 points), 6.1 - 8.4 ha (4 points), and 8.5 ha and over (5 points). GRB also feed and over winter in wild grapes which are prevalent in forested areas in Florida; therefore scores were assigned from 0 to 5 based on the distance of the vineyard to forests containing wild grapes: 5 points if the vineyard was surrounded by forests and bordered at a 10 m distance, 4 points if forests were within 100 m, 3 points if large forested areas were within 500 m, 2 points if some forests occurred at least 1 km away, 1 point if forests were within a 5 km radius, and 0 points if there were not any forests in the area.

It was beyond the scope of this study to analyze the soil of each vineyard so I judged the soil characteristic and rated it on a scale of -3 to 3 based on tilth: coarse dry sand (-3), very dry sand (-2), dry sand (-1), sand (0), sandy loam (1), loam (2), and wet loam (3).

Environmental factors

Hot dry situations can cause mortality in newly emerged larvae as they enter the soil to find roots (All et al., 1987; Dutcher and All, 1978b; Harris et al., 1994; Sarai, 1972). Thus, soil characteristics such as low moisture retention, as well as high ground surface temperature, high solar radiation, and low precipitation do not favor GRB development, and received negative ratings. Wet, cool conditions in moisture retentive soil favor GRB and were positively rated. Weather data were obtained from the Florida

Automated Weather Network (University of Florida IFAS Extension Florida Automated Weather Network, 2004). For the average weekly precipitation: < 3.28 cm (-3 points), 3.29 - 3.80 cm (-2 points), 3.81 - 4.31 cm (-1 points), 4.32 - 4.81 cm (0 points), 4.82 - 5.32 cm (1 point), 5.33 - 5.83 cm (2 points), and > 5.84 cm (3 points). For average ground temperature (AGT) points were awarded as follows: <26.5°C (3 points), 26.6 - 27.1°C (2 points), 27.2 - 27.7°C (1 point), 27.8 - 28.3°C (0 points), 28.4 - 28.9°C (-1 point), 29.0 - 29.5°C (-2 points), and > 29.6°C (-3 points). Average solar radiation (ASR) (w/m2) was rated as follows: < 159 w/m2 (3 points) 160 - 169 w/m2 (2 points), 170 - 179 w/m2 (1 point), 180 - 189 w/m2 (0 points), 190 - 199 w/m2 (-1 point), 200 - 209 w/m2 (-2 points), and > 210 w/m2 (-3 points).

Cultural conditions

Cultural conditions can also affect GRB populations. There are several methods for irrigating vineyards in Florida: drip irrigation, maxi-jets, overhead sprinklers and no irrigation system. Drip irrigation was given 5 points because it maintains the soil moisture near the base of the vines and favors GRB, mixed use of drip and maxi-jet irrigation was given 4 points, and maxi-jets alone 3 points. Overhead sprinklers that wet the soil for shorter periods of time than the other systems was awarded 2 points. No irrigation system was given -5 points.

Previous research by Harris et al. (1994) suggests that weed control is one of the main cultural practices that farmers can implement to reduce GRB numbers in their vineyards. Weedy conditions offer first instar larvae cooler, more humid environments that favor survival. In addition, weeds provide oviposition sites for female GRB and protection for eggs. Taking a visual survey of the vineyards throughout the season, I rated the vineyards from -5 to 5 based on the percentage of weed coverage: 5 (100%), 4

(85%), 3 (70%), 2 (55%), 1 (40%), 0 (25%), -1 (20%), -2 (15%), -3 (10%), -4 (5%), -5 (0%).

The effect that mass-trapping has on GRB is unknown. However, if many males are taken out of the breeding pool, it will have an effect on subsequent generations. Negative numbers were awarded to vineyards that had trapped males the previous year and -5 points were given for having trapped the entire season. Some vineyards began trapping late in the season and these were awarded partial points based on the duration of trapping during GRB flight period.

Chemical

Since Lorsban is the only chemical listed for control of GRB, -5 points were awarded for its use, and 0 for no use. Partial credit was given if farmers applied the Lorsban to portions of their vineyards. The effects of other chemicals such as herbicides, other insecticides, and fungicides on GRB abundance have not been studied. Since most of the GRB life cycle occurs underground, and since the adults live for only seven days, my assumption is that these other chemicals have little direct effect on GRB abundance. However, it is possible that predators in the system could be killed by wide scale applications of these pesticides, so I rated their overall effect as positive, favoring the GRB. Chemical points were awarded per application as follows: insecticides (2 points), herbicides (1 point) and fungicides (1point). These points were then added together for all applications and rated on a scale of 0 - 5: no chemicals used (0 points), 1 - 3 chemical points (1 point), 4 - 5 chemical points (2 points), 6 - 9 chemical points (3 points), 10 - 14 chemical points (4 points), and 15+ chemical points (5 points).

Statistical Analysis

These ratings were added together to achieve a cumulative score called the sum of factors, representing the effects of these factors working together. Correlation coefficients were calculated between the logarithm of total trap catch and the sum of factors as well as each individual factor. A linear regression was conducted on the sum of factors (SAS Institute, 2004).

Results

Monitor

Total grape root borer trap catch per week for the two years of study, 2003 and 2004, is represented in Figures 3-1 (Florida Panhandle), 3-2 (north-central Florida), 3-3 (central Florida), and 3-4 (southern Florida). The timing of the peaks of emergence generally coincided for vineyards within the same region. Table 3-2 shows the first emergence and peak emergence of GRB for each vineyard for the entire season for the years 2003 and 2004. Figure 3-5 shows the total GRB trap catches for all 16 vineyards for 2003 and 2004. Activity began the earliest, late June - early July, in the northernmost area of Florida and the southern region. GRB emerged in the north-central region in mid to late July, and in mid-August for the mid-Florida region. GRB peak flight occurred in the Panhandle in mid to late August for both 2003 and 2004, except for two vineyards whose peaks occurred in early September in 2004 (Figure 3-1). For the north-central region of Florida, peak flight occurred in the second week of September in 2003 and the beginning of October in 2004 (Figure 3-2). In the mid-Florida region (Lake County), peak flight mostly occurred in the third week of September (Figure 3-3). In the southern region, GRB emergence peaked in the second and third week of September at the vineyards nearer to the coast and on the first week of October at the inland vineyard

(vineyard BH). For 2004, the peaks occurred from late August to mid-September, with the inland peak slightly later than the coastal peaks (vineyards BH, OM, RF) on the third week of September (Figure 3-4). When data from the 4 vineyards in each region were pooled into one graph for both 2003 and 2004, some interesting regional trends were apparent (Figure 3-6). Adult GRB activity lasted for about 3 ½ months in the Panhandle region, 4 months in North-central Florida, 3-3.5 months in mid-Florida, and 5-5.5 months in the southern region.

Trap catches varied among vineyards and were relatively high for certain vineyards, and quite small for others (Table 3-2). However, there was large variation in characteristics among vineyards, including differences in size and age, and thus it is difficult to compare totals. Lower numbers of GRB were caught in 2004 compared with 2003, but this reduction was not significantly different.

Survey

Results of the survey are shown in Table 3-3 (2003) and Table 3-4 (2004). Tables 3-5 (2003) and 3-6 (2004) represent the graded points for the answers to the survey and the weather information for the year.

Correlations were performed between trap counts and each of the individual factors for 2003 and 2004 (Table 3-7). During 2003, the sum of all factors had the highest r (r = 0.774) and was the most significant variable for the 2003 survey ($P < 0.01$). The regression equation is $\log(\mathit{total\ GRB\ trap\ catch}) = 1.049 + 0.0903 \times (\mathit{sum\ of\ factors})$. The SEM for the intercept is 0.25 and the SEM for the slope is 0.02. The regression line for the linear regression between the sum of factor points and the log of the total season's trap catch is shown in Figure 3-7. Trap catch also showed a significant ($P < 0.05$) correlation with vineyard age.

In 2004, trap catch showed the strongest correlation with age (r = 0.539; $P < 0.05$). Again, the sum of factors showed a significant correlation (r = 0.510; $P < 0.05$). Trap catch also showed significant correlation with soil type (r = 0.458; $P < 0.05$). The linear equation for the correlation for the sum of factors and the total GRB trap catch in 2004 is $\log(\mathit{total\,GRB\,trap\,catch}) = 1.736 + 0.0483 \times (\mathit{sum\,of\ \ factors})$. The SEM for the intercept is 0.22 and the SEM for the slope is 0.02. Figure 3-8 shows the regression line for the linear regression between the sum of factors and the square root of the total trap catch for 2004.

Discussion

The results of the monitoring experiments indicate that GRB were present in all of the vineyards studied. Variations in climate, size, age, and cultural practices made it difficult to draw overall conclusions. However, the results were useful in showing the general emergence patterns and peak flight activities for GRB in these four regions of Florida. Overall, the results show that GRB begin emerging in late June/early July in the Panhandle and southern region of the state, but emergence is later for the north-central and central regions. The peak flights occur in late August in the Panhandle and generally occur around mid to late September for the rest of the state. Previous research suggested that GRB peaks were bimodal in the southern end of the GRB range (Snow et al., 1991). Most of the peaks from this study have been single, however, a few bimodal peaks occurred. This could be attributed to weather conditions as opposed to a true ‘two-phase’ emergence. The differences between my study and earlier published information may be due to the use of bucket traps for monitoring currently versus the wing traps used in previous work. I often had weekly trap catch numbers from 40 to 70 per trap with highs in the 150-170 range during peak emergence. Wing traps are incapable of capturing this volume of moths.

The Panhandle had the highest GRB trap catch during the two years of the study. This may be due to a richer, more moisture-retentive soil than that found lower in the peninsula (based on information from this study). There was a slight reduction in regional total trap catches from 2003 to 2004 as well as total GRB trap catch from 6185 in 2003 to 4781 in 2004. The number of GRB decreased in 11 of the 17 vineyards monitored. However, vineyards would have to be monitored over a longer period of time to show definite trends over multiple years.

The results of my trapping study will help farmers to learn the emergence time for GRB in their region, and as a result, to optimize the timing of their Lorsban application, and any subsequent chemicals that may be listed for the control of GRB in grapes. This study also gives the relative emergence dates and emergence periods, so that farmers will know when to begin monitoring, and for how long. In the Panhandle, the GRB peak coincides with the grape harvest around the third and fourth week of August. If farmers were to apply Lorsban 35 days pre-harvest, they would only be able to affect a small percentage of the GRB population. This study shows that it would be best to apply Lorsban directly after harvest in order to maximize the potential number of GRB to be killed, and affect subsequent generations. This is also true for the three more southern regions. Peaks mostly occur 1 to 2 weeks after grape harvest, also around the third and fourth weeks of August, so Lorsban applications would be best timed after harvest.

Bunch grapes are ready for harvest at the end of June and throughout July, depending on the region. The application of Lorsban will be best timed after harvest and slightly after the peak GRB emergence for that area.

Certain factors and conditions, when combined, can favor the development of GRB and result in high potential GRB populations. Previous work has explored the life cycle of the GRB and has postulated that the implementation of certain cultural control techniques can affect the GRB population. Some of the factors are uncontrollable such as rainfall, solar radiation, and temperature, as well as age and size of vineyard. Other factors need to be considered before choosing the vineyard site such as soil conditions and proximity to forests where wild grapes occur. The survey results show that an integrated approach incorporating various control strategies may be able to lower GRB densities.

Cultural control practices such as irrigation, weed management, and chemical usage can be adjusted. The most common and probably most effective method of irrigating vineyards is by drip irrigation. Drip irrigation favors GRB more than other methods since it maintains moist conditions near the root zones, for longer periods of time than other systems. This is a reasonable assumption, although the effect that drip systems have compared with other irrigation systems on GRB development has not been explored. Drip irrigation is probably the most efficient system for grape production and it is unlikely that farmers would choose a different system.

Keeping the areas under the vine clean, especially following peak GRB activity is the primary cultural control technique over which farmers have direct control. Most farmers control weeds with regular, scheduled applications of Round-Up (glyphosate). With a weed-free soil surface at the base of vines, first larval instars are exposed to predation and or desiccation from environmental extremes (Townsend, 1980). It also exposes recently emerged adults and limits the hidden areas in which to lay eggs.

The effects of chemical usage in vineyards are unclear. There is a great body of research that demonstrates the importance of natural enemies in controlling and stabilizing pest species (Price, 1997). In this study, it was assumed that a high degree of chemical usage would negatively impact the natural enemy population and favor GRB. Also, predators are present in each vineyard ecosystem that feed on GRB (Clark and Enns, 1964; Dutcher and All, 1978b). Based on these assumptions, the conclusion is that heavy use of pesticides favor GRB. Unlike bunch grapes, muscadine grapes are native to this area and thus are well adapted to many of the insects, fungi, and other pathogens that occur in Florida. Chemical inputs are not entirely necessary, and muscadine farmers could probably reduce or eliminate their chemical usage without harming their yields. Growers of bunch grapes are more reliant on fungicides and other chemicals than are farmers who grow muscadines. In a thoroughly integrated IPM system for bunch grapes, fungicide use could probably be reduced and alternative, reduced-risk pesticides incorporated.

Lorsban (chlorpyrifos) is currently the only chemical listed for use against GRB in grapes in Florida. When applied, Lorsban has a half-life of 3 weeks, and thus can only kill GRB for 3 weeks of the 3-5 month GRB emergence period. Although Lorsban, by itself, is an ineffective control strategy for GRB, it can be a part of a successful IPM program to reduce GRB populations, especially when its use is appropriately timed.

The survey shows that many factors working together can contribute to the success or detriment of GRB. The correlation analyses showed a high correlation between the sum of factors and the total GRB trap catch. This indicates that there is predictability in the degree of GRB infestation and this knowledge can help farmers to realize what size infestations to expect, and some of the control measures they can implement to help reduce GRB damage. In addition, the age of the vineyard as well as the soil type could individually have a significant effect on GRB populations.

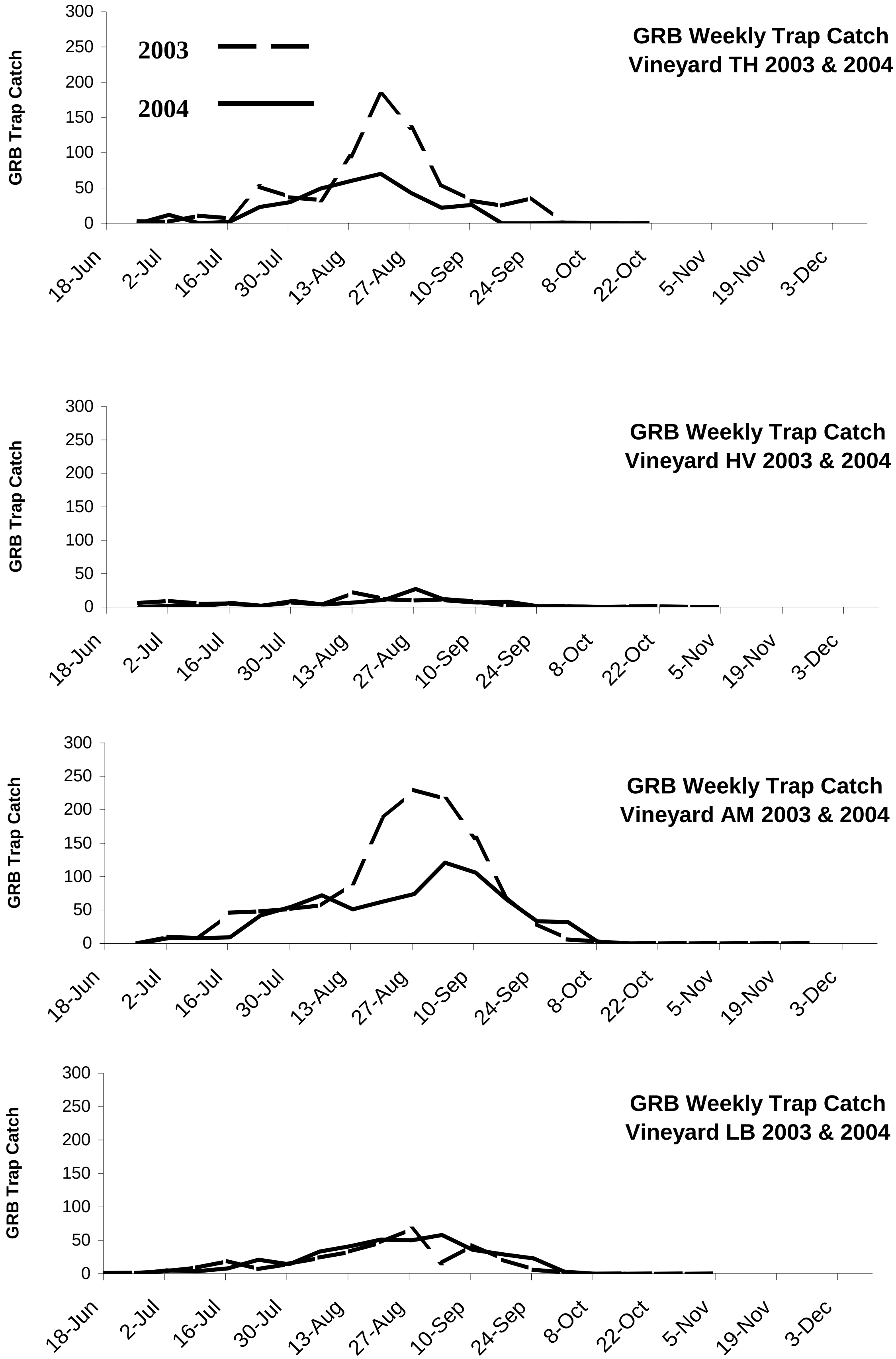

Figure 3-1. Weekly GRB trap catch for years 2003 and 2004 for four Florida Panhandle vineyards.

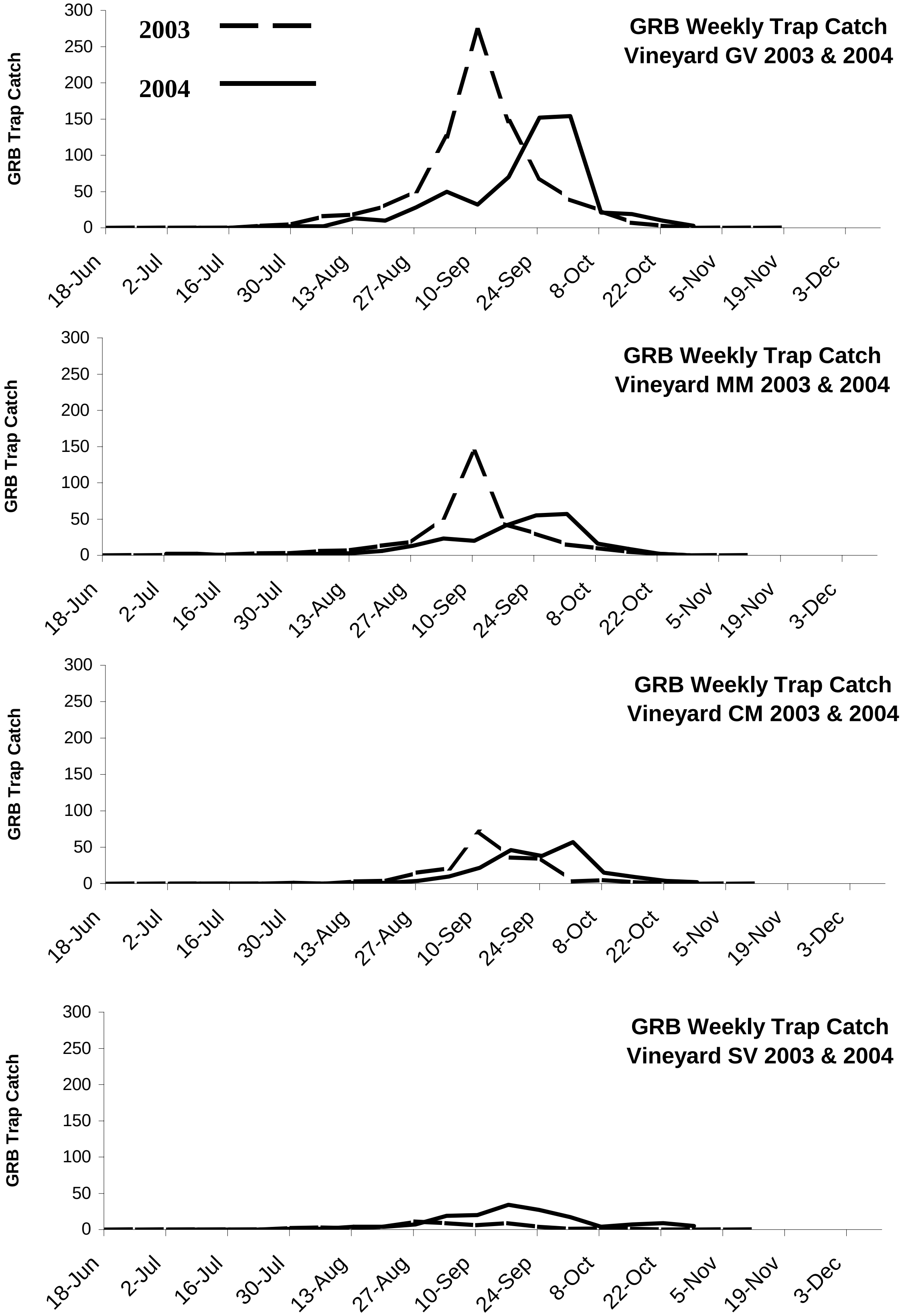

Figure 3-2. Weekly GRB trap catch for years 2003 and 2004 for four North-Central Florida vineyards.

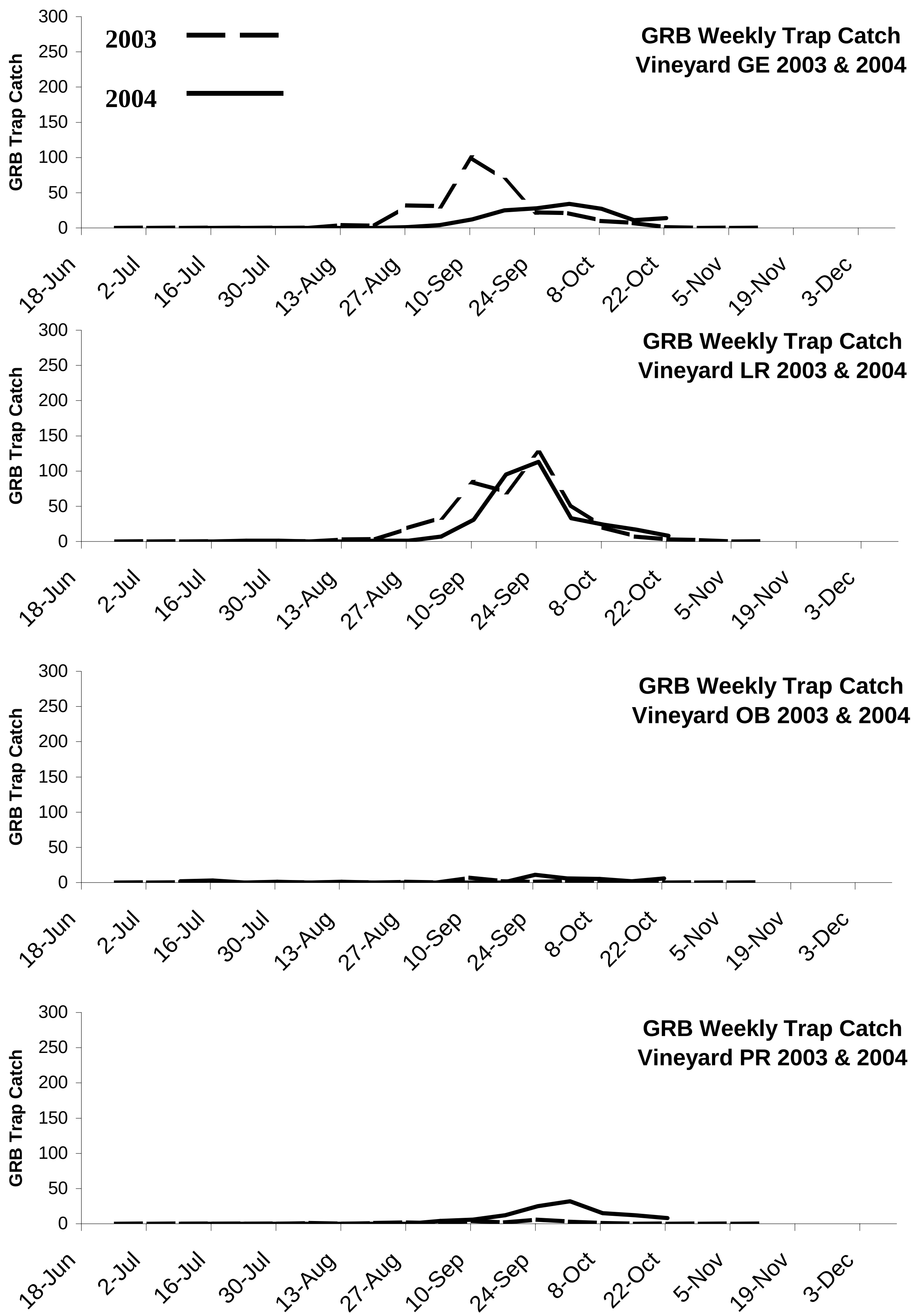

Figure 3-3. Weekly GRB trap catch for years 2003 and 2004 for four Mid-Florida vineyards.

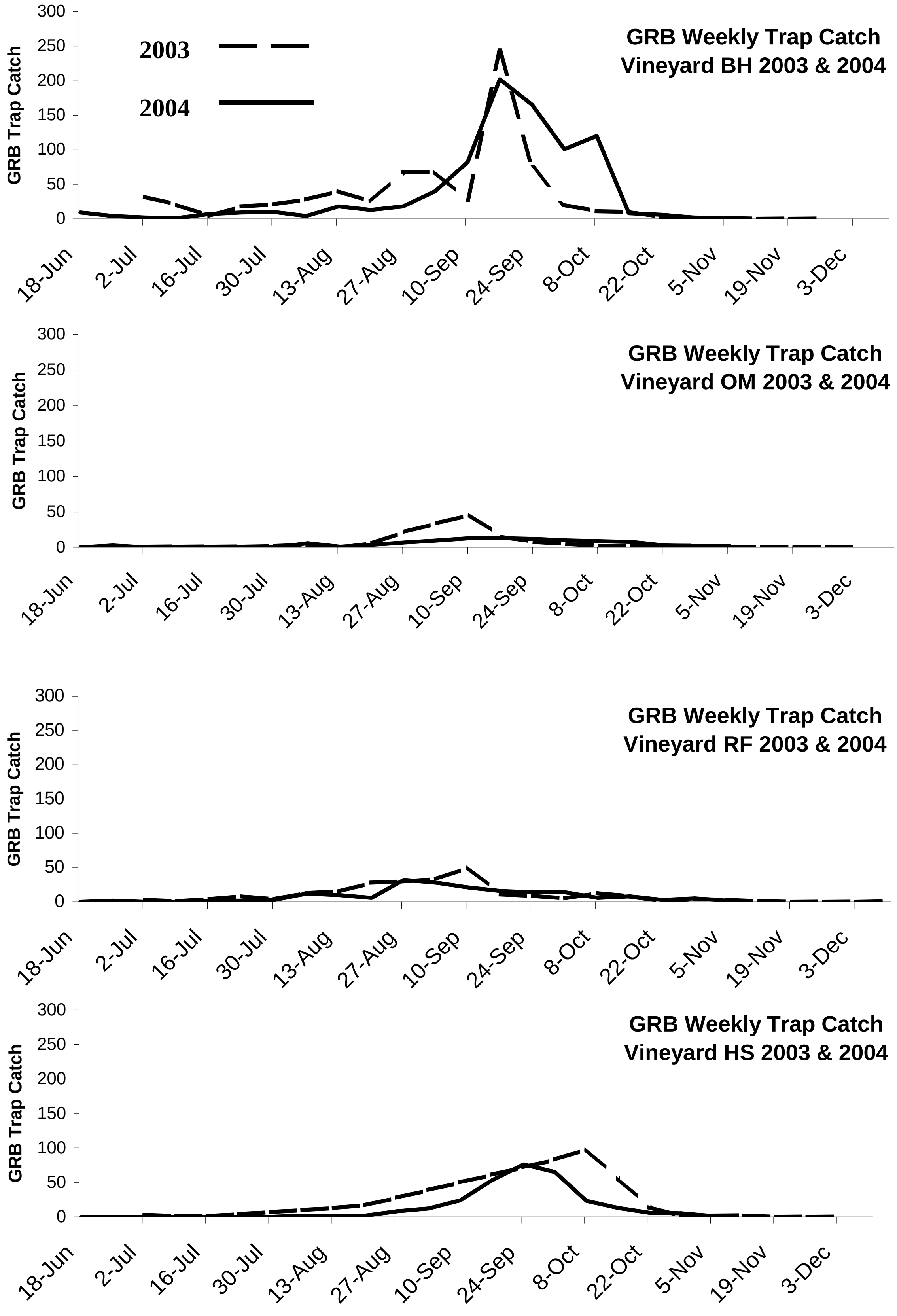

Figure 3-4. Weekly GRB trap catch for years 2003 and 2004 for four South Florida vineyards.

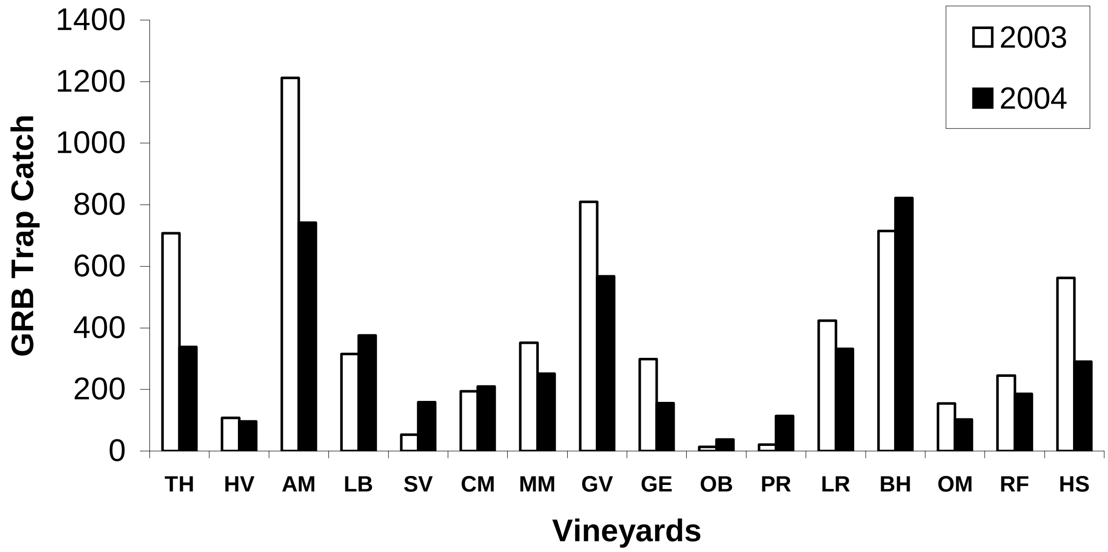

Figure 3-5. Total GRB Trap Catch for 16 Florida Vineyards for the years 2003 & 2004

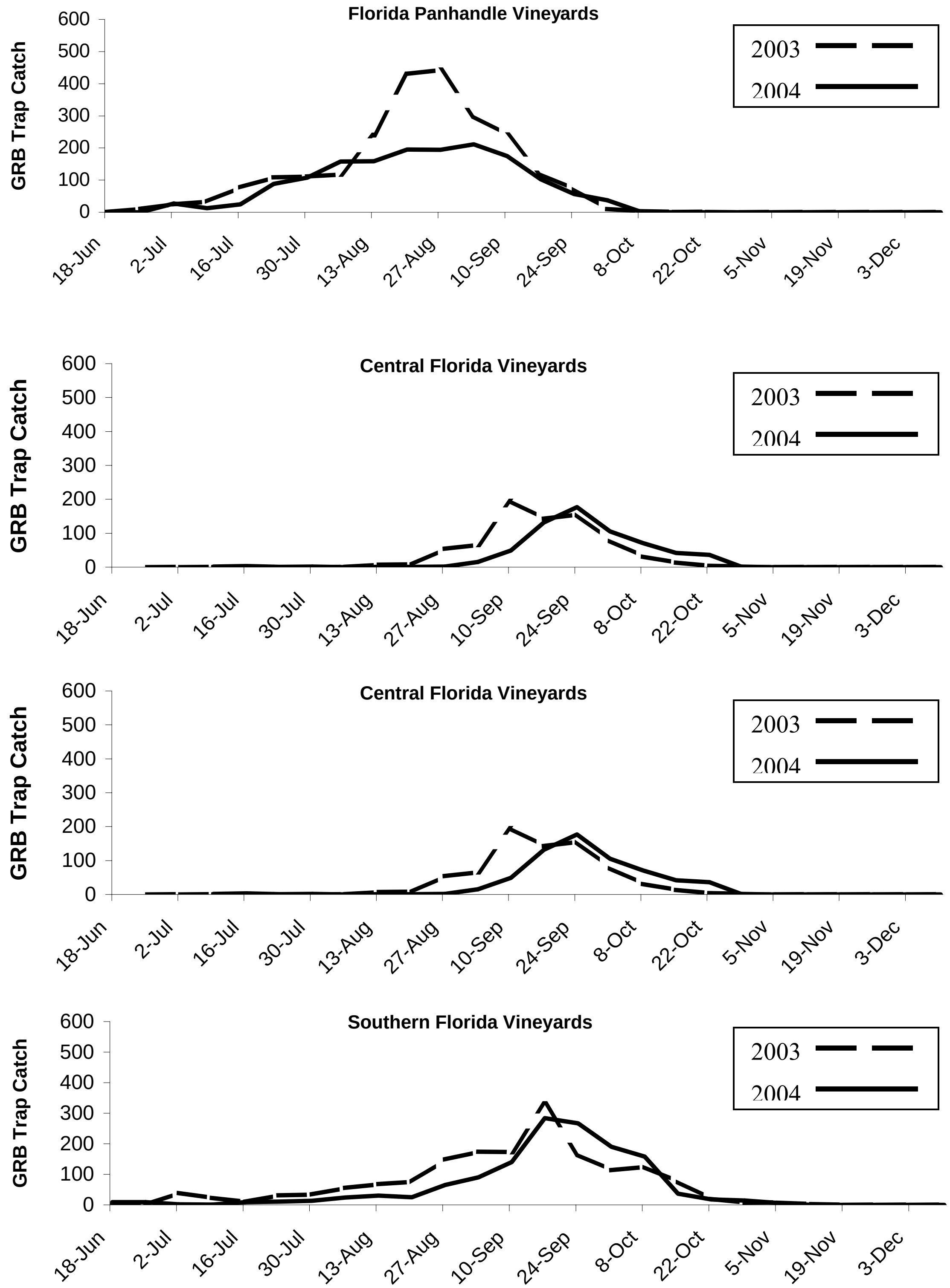

Figure 3-6. Seasonal distribution of GRB in four regions of Florida, with the data from four vineyards within each region pooled into one graph for the years 2003 and 2004.

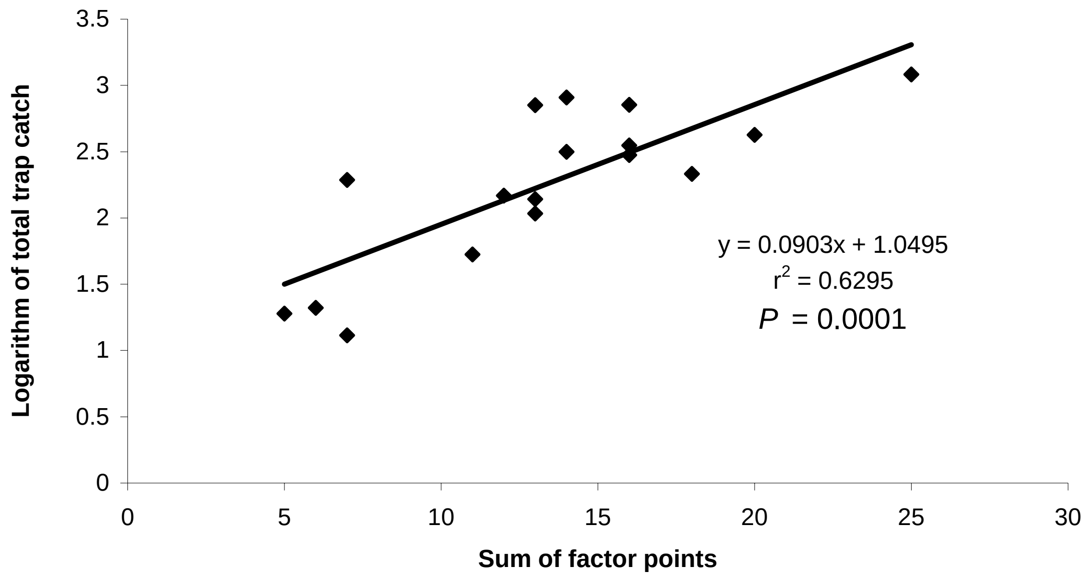

Figure 3-7. Relationship between log of total trap catch (y) and sum of factor points (x) for 2003 season.

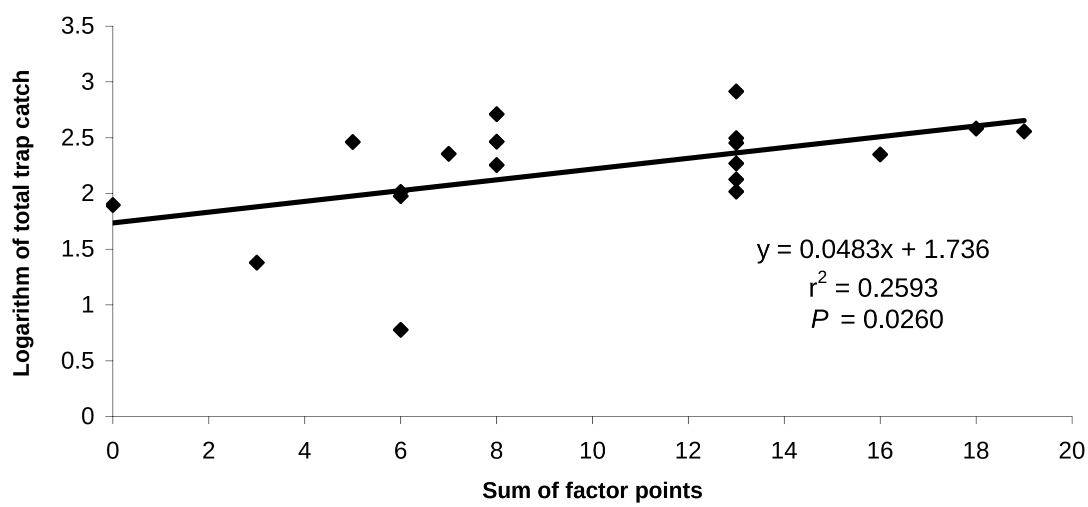

Figure 3-8. Relationship between log of total trap catch (y) and sum of factor points (x) for 2004 season.

Table 3-1. Survey questions

1.	How many acres of grapes?
2.	What varieties are planted? What percentage of muscadine vs. bunch grapes are grown?
3.	How old is the vineyard?
4.	How many vines were replaced (or died) this year?
5.	What were the yields this year?
6.	What chemicals were used (application rates and times)? Pesticides? Herbicides? Fungicides? Fertilizers?
7.	What types of irrigation systems are used?
8.	How are the weeds maintained?
9.	How is the proximate land being used?
10.	What other crops are grown?
11.	Do you monitor for pests? By what method?
12.	What grape pests have you seen? What ones do you consider a problem?
13.	Do you use any cultural pest control techniques?
14.	Soil type and pH?
15.	When did you harvest?
16.	Grape use (wine, u-pick, grape products, table)?

Table 3-2. First emergence, and peak emergence for 16 Florida vineyards for 2003 and 2004 by region

Region	**Vineyard**	**First emergence 2003**	**First emergence 2004**	**Peak emergence 2003**	**Peak emergence 2004**
Panhandle	TH	Jun 25	Jul 2	Aug 20	Aug 20
	HV	Jun 25	Jul 2	Aug 13	Aug 27
	AM	Jul 2	Jul 2	Aug 27	Sep 3
	LB	Jun 18	Jul 2	Aug 27	Sep 3
North-central	GV	Jul 23	Jul 23	Sep10	Oct 1
	MM	Jul 16	Jul 2	Sep 10	Oct 1
	CM	Aug 13	Jul 30	Sep 10	Oct 1
	SV	Jul 30	Jul 30	Aug 27	Sep 10
Central	GE	Aug 13	Aug 27	Sep 10	Oct 1
	OB	Aug 27	Jul 9	Sep 10	Sep 24
	PR	Aug 6	Sep 4	Sep 24	Sep 24
	LR	Aug 13	Jul 1	Sep 24	Sep 24
South	BH	< Jul 2	< Jun 18	Sep 17	Sep 17
	OM	Jul 2	Jun 25	Sep 10	Sep 14
	RF	Jul 2	Jun 25	Sep 10	Aug 27
	HS	Jul 2	Aug 6	Oct 8	Sep 24

(<) indicates that GRB were caught the first week of monitoring and may have emerged sooner than data indicates.

Table 3-3. 2003 Grape survey results for 17 vineyards*

Vineyard	Size (ha)	Age	# of varie-ties	% bunch grapes	% musca-dine grapes	Distance to wild grapes	Soil types	Average Weekly Rainfall	AGT	ASR	Irrigation	Weed coverage	Lorsban used	Chemical usage	GRB trap catch
TH	3.2	11	12	50%	50%	100m	Loam	3.05	27.74	184	M, D	20%	Y	10	708
HV	2.0	10	10	0%	100%	500m	Sandy loam	3.05	27.74	184	D	0%	N	16	108
AM	8.1	19	100	80%	20%	500m	Loam	4.17	26.26	188	D	20%	N	16	1212
LB	4.0	11	16	0%	100%	500m	Loam	4.17	26.26	188	M, D	5%	N	0	315
GV	1.6	18	4	0%	100%	100m	Sand	4.70	26.52	183	O	5%	N	5	810
MM	1.4	22	15	1%	99%	10m	Dry sand	3.30	28.74	155	M	100%	N	0	352
CM	3.6	25	13	0%	100%	10m	Very dry sand	3.30	28.74	155	N	70%	N	0	194
SV	1.1	8	15	0%	100%	100m	Dry sand	3.30	28.74	155	M, D	25%	N	4	53
LC	2.0	4	10	0%	100%	500m	Dry sand	4.17	26.70	191	D	10%	Y (1/4)	3	19
GE	1.4	16	15	5%	95%	100m	Very dry sand	3.00	27.70	184	D	85%	N	0	299
OB	4.0	6	2	0%	100%	5km	Very dry sand	3.96	28.02	204	D	25%	N	3	13
PR	.1	13	1	0%	100%	100m	Sand	3.96	28.02	204	N	100%	N	0	21
LR	26.7	18	10	32%	68%	1km	Dry sand	3.96	28.02	204	D	55%	N	20	423
BH	4.0	6	4	0%	100%	100m	Loam	5.56	27.56	206	D	15%	N	3	715
OM	1.0	4	2	0%	100%	100m	Sand	5.56	27.56	206	D	15%	N	4	147
RF	4.0	13	10	60%	40%	1km	Wet loam	5.56	27.56	206	M	15%	N	10	215
HS	4.2	6	20	0%	100%	500m	Sand	4.37	29.49	193	D	15%	N	16	139

* Average weekly rainfall is in cm. AGT is average ground temperature (°C). ASR is average solar radiation (w/m^2). The methods of irrigation used are M= microjets, D= drip, O= Overhead sprinklers, and N=none. Lorsban was either used that year (Y) or not (N) and fractions are awarded for partial coverage. Chemical usage (see text) is a set of points awarded for each variety of pesticides used in that specific vineyard per treatment. GRB trap catch is the total number of GRB caught per vineyard per season

Table 3-4. 2004 Grape survey results for 19 vineyards*

Vine-yard	Size (ha)	Age	# of varie-ties	% bunch grapes	% musca-dine grapes	Distance to wild grapes	Soil types	Weekly Rainfall Average	AGT	ASR	Irrigation	% Weed coverage	Lorsban used	Chemical usage	GRB trap catch
TH	3.2	12	12	50%	50%	100m	Loam	3.45	28.58	193	M, D	20%	Y	10	289
HV	2.0	11	10	0%	100%	500m	Sandy loam	3.45	28.58	193	D	0%	N	16	95
AM	8.1	20	100	80%	20%	500m	Loam	4.55	26.67	202	D	20%	N	16	382
LB	4.0	12	16	0%	100%	500m	Loam	4.55	26.67	202	M, D	5%	N	0	227
GV	1.6	19	4	0%	100%	100m	Sand	4.70	27.1	189	O	5%	N	5	515
MM	1.4	23	15	1%	99%	10m	Dry sand	5.59	28.35	174	M	100%	N	0	224
CM	3.6	26	13	0%	100%	10m	Very dry sand	5.59	28.35	174	N	70%	N	0	180
SV	1.1	9	15	0%	100%	100m	Dry sand	5.59	28.35	174	M, D	25%	N	4	134
LC	2.0	5	10	0%	100%	500m	Dry sand	5.21	26.94	193	D	10%	Y (1/4)	3	6
GE	1.4	17	15	5%	95%	100m	Very dry sand	5.00	28.27	192	D	85%	N	0	104
OB	4.0	7	2	0%	100%	5km	Very dry sand	4.11	28.5	214	D	25%	N	3	24
PR	.1	14	1	0%	100%	10m	Sand	4.11	28.5	214	N	100%	N	0	79
LR	26.7	19	10	32%	68%	1km	Dry sand	4.11	28.5	214	D	55%	N	20	283
BH	4.0	7	4	0%	100%	100m	Loam	5.92	27.33	216	D	15%	N	3	822
OM	1.0	5	2	0%	100%	100m	Sand	5.92	27.33	216	D	15%	N	4	103
RF	4.0	14	10	60%	40%	1km	Wet loam	5.92	27.33	216	M	15%	N	10	186
HS	4.2	7	20	0%	100%	500m	Sand	5.28	29.73	192	D	15%	N	16	291
FV	.4	22	14	90%	10%	500m	Sand	5.59	28.35	174	D	20%	N	4	359
LV	1.2	32	4	0%	100%	500m	Sandy loam	5.59	28.35	174	O	10%	N	3	313

*Average weekly rainfall is in cm. AGT is average ground temperature (°C). ASR is average solar radiation (w/m^2). The methods of irrigation used are M= microjets, D= drip, O= Overhead sprinklers, and N=none. Lorsban was either used that year (Y) or not (N), and fractions are awarded for partial coverage. Chemical usage (see text) is a set of points awarded for each variety of pesticides used in that specific vineyard per treatment. GRB trap catch is the total number of GRB caught per vineyard per season.

Table 3-5. Point scores for factors influencing GRB infestation severity, 2003*

Vineyards	Age 0-5	Size 1-5	distance to wild grapes 0-5	Soil type -3-+3	Weekly Rainfall average -3-+3	AGT -3-+3	ASR -3-+3	Irrigation -3-+3	Weed coverage -5-+5	Lorsban used -5-0	Chemical usage 0-5	Trapped previous year -5-0	Sum of factors	GRB trap catch	Sqrt GRB trap catch
TH	4	3	4	2	-3	1	0	4	-1	-5	4	0	13	708	26.61
HV	4	2	3	1	-3	1	0	5	-5	0	5	0	13	108	10.39
AM	5	4	3	2	-1	3	0	5	-1	0	5	0	25	1212	34.81
LB	4	3	3	2	-1	3	0	4	-4	0	0	0	14	315	17.75
GV	5	2	4	0	0	3	0	2	-4	0	2	0	14	810	28.46
MM	5	1	5	-1	-2	-1	3	3	5	0	0	-2	16	352	18.76
CM	5	3	5	-2	-2	-1	3	-5	3	0	0	-2	7	194	13.93
SV	3	1	4	-1	-2	-1	3	4	0	0	2	-2	11	53	7.28
LC	1	2	3	-1	-1	2	-1	5	-3	-1	1	-2	5	19	4.36
GE	5	2	4	-2	-3	1	0	5	4	0	0	0	16	299	17.29
OB	2	3	1	-2	-1	0	-2	5	0	0	1	0	7	13	3.61
PR	4	1	4	0	-1	0	-2	-5	5	0	0	0	6	21	4.58
LR	5	5	2	-1	-1	0	-2	5	2	0	5	0	20	423	20.57
BH	2	3	4	2	2	1	-2	5	-2	0	1	0	16	715	26.74
OM	1	1	4	0	2	1	-2	5	-2	0	2	0	12	147	12.12
RF	4	3	2	3	2	1	-2	3	-2	0	4	0	18	215	14.66
HS	2	3	3	0	0	-2	-1	5	-2	0	5	0	13	139	11.79

*Each of 17 vineyards was rated for each factor category (from Table 3-1) using the scale ranges shown below the category title. The sum of factors is the total score for each vineyard of all factor points added together. GRB trap catch is the total number of GRB caught per vineyard in 2003 and Sqrt GRB trap catch is the square root of the total GRB trap catch.

Table 3-6. Point scores for factors influencing GRB infestation severity, 2004*

Vineyards	Age 0-5	Size 1-5	distance to wild grapes 0-5	Soil type -3-+3	Weekly Rainfall average -3-+3	AGT -3-+3	ASR -3-+3	Irrigation -5-+5	Weed coverage -5-+5	Lorsban used -5-0	Chemical usage 0-5	Trapped previous year -5-0	Sum of factors	GRB trap catch	Sqrt GRB trap catch
TH	4	3	4	2	-2	-1	-1	4	-1	-5	3	-5	5	289	17.00
HV	4	2	3	1	-2	-1	-1	5	-5	0	5	-5	6	95	9.75
AM	5	4	3	2	0	2	-2	5	-1	0	5	-5	18	382	19.54
LB	4	3	3	2	0	2	-2	4	-4	0	0	-5	7	227	15.07
GV	5	2	4	0	0	2	0	2	-4	0	2	-5	8	515	22.69
MM	5	1	5	-1	2	0	1	3	5	0	0	-5	16	224	14.97
CM	5	3	5	-2	2	0	1	-5	3	0	1	-5	8	180	13.42
SV	4	1	4	-1	2	0	1	4	0	0	3	-5	13	134	11.58
LC	2	2	3	-1	1	2	-1	5	-3	-1	2	-5	6	6	2.45
GE	5	2	4	-2	1	0	-1	5	4	0	0	-5	13	104	10.20
OB	3	3	1	-2	-1	-1	-3	5	0	0	3	-5	3	24	4.90
PR	4	1	5	0	-1	-1	-3	-5	5	0	0	-5	0	79	8.89
LR	5	5	2	-1	-1	-1	-3	5	2	0	5	-5	13	283	16.82
BH	3	3	4	2	3	1	-3	5	-2	0	2	-5	13	822	28.67
OM	2	1	4	0	3	1	-3	5	-2	0	0	-5	6	103	10.15
RF	4	3	2	3	3	1	-3	3	-2	0	4	-5	13	186	13.64
HS	3	3	3	0	1	-3	-1	5	-2	0	4	-5	8	291	17.06
FV	5	1	3	0	2	0	1	5	-1	0	3	0	19	359	18.95
LV	5	1	3	1	2	0	1	2	-3	0	1	0	13	313	17.69

*Each of 19 vineyards was rated for each factor category (from Table 3-2) using the scale ranges shown below the category title. The sum of factors is the total score for each vineyard of all factor points added together. GRB trap catch is the total number of GRB caught per vineyard in 2004 and Sqrt GRB trap catch is the square root of the total GRB trap catch.

Table 3-7. Correlation coefficients (r) for vineyard factors against log of total GRB trap catch.

Factors	2003			2004		
	r	*P*-value	Significance ** $P < 0.01$ * $P < 0.05$ n.s. = not significant	r	*P*-value	Significance ** $P < 0.01$ * $P < 0.05$ n.s. = not significant
Age	0.533	.0276	*	0.539	.0172	*
Size	0.409	.1033	n.s.	0.187	.4438	n.s.
Distance to wild grapes	0.300	.2415	n.s.	0.219	.3678	n.s.
Soil type	0.467	.5860	n.s.	0.463	.0459	*
Weekly rainfall average	0.085	.7453	n.s.	0.179	.4623	n.s.
AGT	0.346	.1736	n.s.	0.014	.9596	n.s.
ASR	0.157	.5483	n.s.	0.151	.5385	n.s.
Irrigation	0.190	.4647	n.s.	0.010	.9657	n.s.
Weed coverage	0.115	.6611	n.s.	0.059	.8107	n.s.
Lorsban used	0.175	.5019	n.s.	0.020	.9637	n.s.
Chemical usage	0.298	.2457	n.s.	0.121	.6214	n.s.
Trapped previous year	0.280	.2769	n.s.	0.225	.3545	n.s.
Sum of factors	0.794	.0001	**	0.509	.0260	*

CHAPTER 4
COMPARISON OF TWO TRAPS FOR MONITORING GRAPE ROOT BORER POPULATIONS

The grape root borer (GRB) *Vitacea polistiformis* (Harris), (Lepidoptera: Sesiidae) is the most important pest of grapes (*Vitis* sp.) in Florida (Liburd et al., 2004). Grape root borers were first noticed as pests of cultivated grapes in the southeastern U.S. in 1854 (Mitchell, 1854). The larvae bore into the roots of grapevines and eventually cut off the flow of the phloem and xylem. One to three larvae can seriously weaken the vine and cause lowered yields. Six larvae can kill the vine, especially if they are feeding in the crown (Dutcher and All, 1979b). Entire vineyards have been wiped out in many Southeastern states (Olien, 1993), including Florida (S.Webb, University of Florida, pers. comm.). The overall effects of their continued feeding on vines is not well understood, but the weakening of the plant makes it more susceptible to freeze damage, drought, and pathogens.

Several studies have focused their efforts on understanding the GRB lifecycle and explored the potential for non-chemical control tactics. Trapping with pheromone-baited traps has been an important tool in these studies. The discovery of sesiid sex pheromone and more specifically GRB pheromone in the 1980s has helped advance our knowledge of GRB greatly (Snow et al., 1987). The seasonal distribution of GRB has been widely studied using pheromone-baited traps. The traditional trap has been the wing-style sticky trap. This trap has been used for monitoring in all the previous pheromone and mating disruption studies of GRB (Johnson et al., 1986; Johnson et al., 1991; Snow et al., 1987; Snow et al., 1991; Webb, 1991; Webb et al., 1992).

The problem with wing-style sticky traps is that they become inundated with insects and debris and need to be replaced on a regular basis in order for them to be effective. Researchers working with other lepidopteran pests have found great success with Universal Moth Traps (Unitraps) (Great Lakes IPM, Vestaburg, MI). These two trap styles have been compared in studies with other lepidopteran pests, and in each study, the Unitrap caught significantly more moths (Shaver et al., 1991; Schmidt and Roland, 2003).

The purpose of this study was to compare the effectiveness of wing-style sticky traps with Unitraps for monitoring GRB populations in order to find the most practical use by farmers..

Materials and Methods

This study was carried out in three sites in 2003 and expanded to five sites in 2004. In 2003, traps were placed in three vineyards representing different area of Florida: the Panhandle (vineyard HV) (Calhoun County), mid-Florida (vineyard OB) (Lake County), and the south Florida (vineyard BH) (Hillsborough County). For 2004, two vineyards in the north-central region in Putnam County (vineyard LV) and Alachua County (vineyard FV) were added to the original three locations.

The two traps compared for this experiment were Unitraps (Figure 4-1) and wing-style sticky traps (Figure 4-2). Both traps were baited with GRB pheromone, 99% (E,Z)-2,13 octadecadienyl acetate and 1% (Z, Z)-3,13 octadecadienyl acetate (Great Lakes IPM, Vestaburg, MI). Pheromone lures were changed once per season, after 8 weeks.

A Unitrap, or Universal Moth Trap, (Great Lakes IPM, Vestaburg, MI) is a plastic bucket trap (all green) with a central lure cage containing the pheromone septa hanging at the top, and a slippery tunnel that guides the captured moth into a lower chamber (Figure 4-1). The moth is trapped within and killed by a Vaportape (Hercon Environmental, Emigsville, PA) treated with 2,2-dichlorovinyl dimethyl phosphate. Wing-style sticky traps (IPM Tech, Portland, OR) are waxed paper traps with a sticky lower board (Figure 4-2). A rubber pheromone septum was placed in the center of the sticky board. Boards were changed at six-week intervals. Both traps were hung from the trellis wires at roughly 1.5 m above the ground, and spaced at least 30 m apart. Traps were set out at the beginning of the GRB emergence period for each region, late June for the Panhandle and south and early July for central regions.

In order to compare traps, 2 Unitraps and 2 wing-style traps were placed in each vineyard in a randomized complete block design with three vineyards in 2003 and five vineyards in 2004. Trap catches were counted and recorded weekly for the entire emergence periods. For 2003, each of 3 vineyards had two treatments (two traps each) with 18 weekly samples. For 2004, each of 5 vineyards had two treatments (two traps each) with 16 weekly samples. Total number of GRB weekly captures was analyzed using analysis of variance (ANOVA) and differences were evaluated by using a paired t-test ($\alpha = 0.05$) (SAS Institute, 2004).

Results

For the 2003 emergence GRB period, the total trap catch was 553 (84%) for the bucket trap and 104 GRB (16%) for wing traps (Table 4-1). Bucket traps caught significantly more GRB ($P < 0.05$), five times as many, than the wing trap on a weekly basis ($df = 1, 106$; $t = 1.99$; $P = 0.0020$) (Table 4-2). In 2004, bucket traps caught 884

GRB (66%) and wing traps caught 455 (34%) (Table 4-1). Bucket traps captured significantly more GRB per week ($P < 0.05$), but to a lesser degree than in 2003 ($df = 1,158$; $t = 1.98$; $P = 0.0392$) (Table 4-2). The percentage of zero trap captures was lower in bucket traps than in wing traps (Table 4-2). Figure 4-3 shows the weekly GRB trap captures for bucket and wing traps for the three vineyards in the study with the highest GRB densities. The vertical lines on the second and third graphs in Figure 4-3 indicate the dates the sticky bottoms of the wing traps were changed. It is evident from the graphs that the number of trap catches decreases with the age of the sticky board in wing traps.

Discussion

Bucket traps recovered significantly more GRB than the wing traps over the entire season. This was true for all individual vineyards except one, (vineyard HV in 2004). The reason why wing traps caught more GRB than bucket traps on this farm is unknown but may be due to trap placement.

The poorer performance of the wing traps may be due to the fact that they become saturated with GRB, other insects, and plant debris over the period of their use. This reduces the sticky surface and diminishes the effectiveness of the trap over time. This is shown in Figure 4-3, which shows a decrease in trap captures with each successive week and an increase in trap captures with each replacement. Also, the wing trap treatments had higher percentages of zero counts than the Unitraps, with 62.2% and 53.2% of their weekly counts as zeros, compared with 33.7% and 41.6% respectively for bucket traps. The weeks with zero counts occurred more often later in the six-week period when the traps were saturated, rather than earlier when the traps were fresh. When one compares the number of GRB caught on the first and second week after changing the sticky board to bucket trap counts, the wing trap caught slightly more insects at these times, although not significant (P>0.05). This experiment was designed to find a practical way for farmers to monitor for GRB. Changing sticky boards on a weekly basis is impractical for most vineyard operations, especially for large acreages, so a 6-week interval was chosen for sticky board replacement. Some studies suggest that the wing trap may be more effective at low population densities, but Schmidt and Roland (2003) showed that not to be true for forest tent caterpillar *Malacosoma disstria* Hubner. Most importantly, in my monitoring experiment, I often had weekly trap catch numbers in the bucket traps from 40 to 70 with highs in the 150-170 range during peak emergence and wing traps are incapable of capturing this volume of moths. The wing trap can be an effective monitoring device, but it must be changed weekly and changed daily during periods of high activity. Clearly, the bucket trap is the superior trap for GRB, for use by growers.

Several factors may contribute to the greater effectiveness of bucket traps. Perhaps the greater success of the bucket trap can be attributed to the more open design. The pheromone cage at the top allows the plume to be dispensed relatively uninterrupted whereas the wing trap is closed on two sides, and this may distort the plume structure. The Unitrap's success may also be attributable to its trapping method. The moths are trapped within a lower enclosure and killed quickly by the Vaportape. Moths trapped on sticky boards have greater opportunity to escape via other debris, autotomy, or perhaps being near the edge.

In addition to its greater efficiency, the bucket trap may be more cost-effective in the long run. The Unitrap is the more expensive trap initially, at $8.95 per trap (Great Lakes IPM, Vestaburg, MI), whereas the wing trap is only $2.32 per trap (IPM Tech, Portland, OR). However, Unitraps are more durable and can be used year after year.

They are easy to assemble and are placed in the field once per season. The frequency at which the wing traps would have to be changed would make them more expensive than bucket traps over time. Due to the volume of wing traps needed per season, they would be far more costly to use, not only due to the price of the traps, but also in labor.

For monitoring purposes, the Unitrap is easier to use and gives a more accurate insect count as shown by the current data. A saturated sticky board is often difficult to count; exposure to the elements leads to rapid deterioration. Predators, such as lizards and frogs, are often observed on the sticky boards, along with partially eaten GRB. Frogs would often be found living in the wing trap; it is unknown how many of the potentially trapped insects were consumed. Frogs and other predators were found in the Unitraps also, but not to the extent of the wing traps, and they were usually killed by the Vaportape. Jumping spiders, *Phidippus regius* (Araneae: Salticidae), were the primary predators found within the bucket traps. They did not affect counts since they left the dried insect husk of their prey. The only problem with the jumping spiders was that they would often lay their web-encased eggs at the lower end of the funnel, which would prevent GRB from getting captured.

The trap used in this study was all green in color. Shaver et al. (1991) caught significantly more Mexican rice borers *Eoreuma loftini* (Dyar) with green-yellow-white traps than with all green. Future studies should focus on trap colors and distance apart.

The results of this comparison of wing traps vs. bucket traps should be useful to farmers, crop consultants, and scientists. It is concluded that bucket traps were significantly more efficient at capturing grape root borers in vineyards than traditional wing-style traps. In addition to their greater efficiency, Unitraps are easier to manage, less time-consuming, and more cost-effective.


Figure 4-1. Unitrap, or Universal Moth Trap

Figure 4-2. Wing-style sticky trap

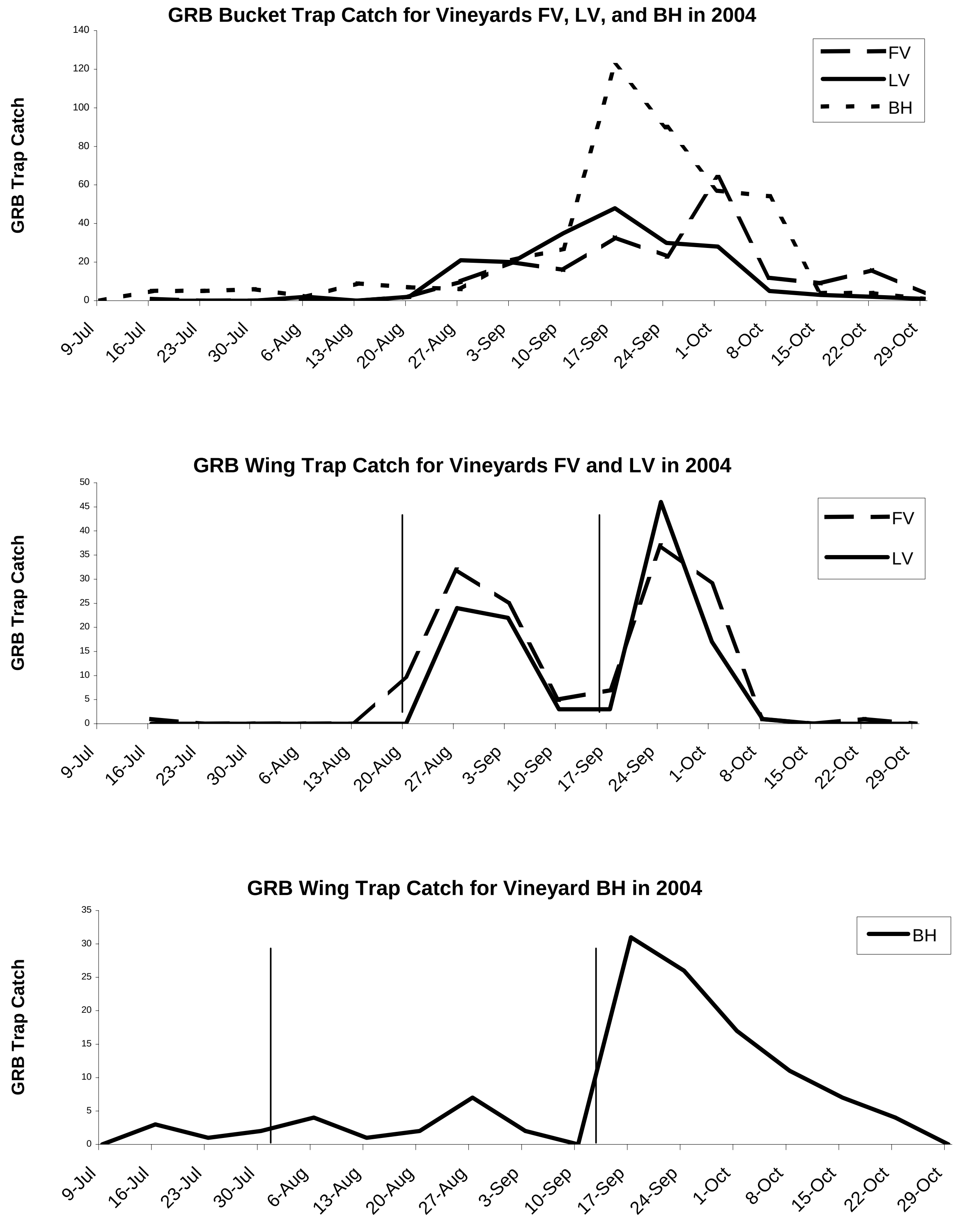

Figure 4-3. Graphs show the GRB trap catch for bucket traps and wing traps in vineyards FV (Alachua County), LV (Putnam County), and BH (Hillsborough County) for the 2004 season. The vertical lines indicate the date the sticky boards were changed.

Table 4-1. GRB trap catch totals for bucket vs. wing traps in 3 vineyards in 2003 and 5 vineyards in 2004

		Total GRB catch	
Vineyard	Trap type	2003	2004
HV	Bucket	156	32
	Wing	25	73
OB	Bucket	11	24
	Wing	3	0
BH	Bucket	386	420
	Wing	76	118
FV	Bucket	--	211
	Wing	--	148
LV	Bucket	--	197
	Wing	--	116
Totals	Bucket	553	884
	Wing	104	455

-- indicates vineyards that were not sampled in 2003

Table 4-2. Total GRB trap catches, mean ± SEM of weekly captures, and frequency of weeks with zero captures for two trap types for 2003 and 2004.

	Trap Catch		Weekly mean		Zero frequency (%)	
Trap type	2003	2004	2003	2004	2003	2004
Bucket	553	884	10.24 ± 2.55 A	11.05 ± 2.33 a	33.7%	41.6%
Wing	104	455	01.93 ± 0.63 B	05.69 ± 1.11 b	62.2%	53.2%

Weekly mean trap catch for 2003 (t = 1.99; df = 1, 106; P = 0.002) and 2004 (t = 0.98; df = 1,158; P = 0.0392) using t-pairwise comparison (α=0.05). Treatments with capital letters represent differences for 2003 and lower-case letters represent differences for 2004.

CHAPTER 5
MATING DISRUPTION AND ATTRACT-AND-KILL AS REDUCED-RISK CONTROL STRATEGIES FOR GRAPE ROOT BORER IN FLORIDA

In recent years, the public has been getting more concerned over the use of pesticides. Their concern is not strictly over pesticide residues in their foods, but also with environmental contamination due to the heavy use of pesticides in agricultural systems. Today, many farmers are reducing or eliminating the use of chemicals in order to meet consumers' demands. Furthermore, the Food and Drug Administration, through several programs including the 1996 Food Quality Protection Act has been phasing out some of the more dangerous chemicals. New integrated pest management techniques must be developed to reduce pest populations without the use of traditional pesticides.

The key pest of grapes (*Vitis* spp.) in Florida is the grape root borer, *Vitacea polistiformis* (Harris), (Lepidoptera: Sesiidae) (Liburd et al., 2004). The larvae bore into the roots and cut off the nutrient flow, and can result in girdling of the vine. In mild infestations, the vines become weakened and the yields decrease. In severe cases, entire vineyards are lost (Dutcher and All, 1979b). Traditionally, chlorpyrifos (Lorsban 4E) has been used as a soil drench to control burrowing larvae and newly emerged adults. Lorsban is a dangerous organophosphate and is suspected of being carcinogenic (Food Quality Protection Act, 1996). Previously, the 4E formulation was a restricted pesticide, and farmers needed an application license in order to use it. Recently, the 4E formulation was replaced by the safer 75 WG, but many farmers in Florida are uncomfortable using it, and choose to not use chemical control measures. As a result, GRB have become a serious threat to the Florida grape industry and feasible, alternative control methods need to be investigated.

The potential for modifying an insect pest's behavior through the use of pheromones in order to control its impact on a crop has been investigated widely in the last 30 years (Carde and Minks, 1995). This approach has great promise in managing GRB and other lepidopteran pests, especially through the use of mating disruption and attract-and-kill strategies.

Mating disruption is a control strategy that has been quite successful for other lepidopteran pests. It was first proved to be successful in controlling cabbage looper moths- *Trichoplusia ni* (Hubner) at the University of California-Riverside (Shorey et al., 1967). Since then, it has been used successfully with pink bollworm *Pectinophora gossypiella* (Saunders), oriental fruit moth *Grapholita molesta* (Busck), tomato pinworm *Keiferia lycopersicella* (Walsingham), light brown apple moth *Epiphyas postvittana* (Walker), and the codling moth *Cydia pomonella* L., as well as others (Carde and Minks, 1995). Among the sesiids, some success has been obtained in mating disruption with the currant clearwing moth *Synanthedon tipuliformis* (Clerck) (Carde and Minks, 1995), the peachtree borer *Synanthedon exitosa* (Say) and the lesser peachtree borer *S. pictipes* (Grote and Robinson) (Yonce, 1981).

There is still some debate of how mating disruption works. Bartell (1982) proposed five mechanisms and suggested that mating disruption occurs most often as a result of false trail following and sensory fatigue caused by habituation. Both mechanisms result in sensory fatigue, but the means are different. In sensory adaptation, as an insect is exposed to a constant source of odor, the output of the insect's olfactory receptors declines within a few seconds, but is quickly restored once the stimulus is removed. Habituation occurs in the central nervous system and results in the decline in the insect's behavioral response to a repeated or prolonged stimulus. The recovery occurs slowly, beginning many minutes to several hours after the stimulus is removed. Both are dependent on the concentration of pheromone, and the result of both is sensory fatigue. False trail following occurs when males lock on to the plume of the lure and expel mating energy following false leads. Practically, this works by placing many more sources of pheromone emissions per acre than the probable numbers of naturally occurring females in the system. The male will spend its mating energies tracking the false females. The odds are greater that it will find the artificial source more times than the virgin female and will die before it encounters the female and successfully mates. To be effective, the potency of the pheromone has to be equal to that of the female, or greater. However, disruption will most likely occur as a result of several of these mechanisms working at the same time. Mating disruption shows great potential as a viable control method for GRB; it is non-harmful to the environment and is permitted by organic growing standards.

Several studies have shown promising results for disruption of mating for grape root borers. Pearson and Meyer (1996) affixed 254 dispensers per ha in vineyards over four years and found a significant reduction in mated females compared with untreated controls: 54% mated in 1988, 0% mated in1989, 0% mated in 1990, and 15.8% mated in 1991. Webb (1991) explored the control of GRB by mating disruption in Florida and recorded a significant reduction in trap-catch, mated females, and pupal case counts (in the following two years) compared with the untreated control, indicating a high degree of mating disruption.

In most successful cases, mating disruption employs the target insect's complete pheromone blend. Some studies suggest that off-blends (partial mixtures or off-ratios) might, in fact, work better at disruption of mating than the synthetic pheromone that is most similar to the natural pheromone (Minks and Carde, 1988). The authors suggest that the mechanism by which off-blends might work is by camouflaging the female pheromone, rendering it indistinguishable from the background. Another way in which off-blends may function is by creating a sensory imbalance in which the male becomes attuned to the more predominant off-blend, and the ratio in the true blend is interpreted as unnatural (Bartell, 1982).

Before the development of the current GRB pheromone, earlier work with mating disruption of grape root borer was carried out with the peachtree borer pheromone (Z,Z-3,13-ODDA). This ingredient is the minor component, or 1% of the current GRB pheromone which contains 99% E,Z-2,13-ODDA. Mating disruption experiments by Johnson and Mayes (1980), Johnson et al. (1981), Johnson et al. (1986) were performed using Z,Z-3,13-ODDA alone and all resulted in significant reduction of GRB. Johnson et al. (1991) found 99.1% reduced trap-catches for vineyards saturated with E,Z-2,13-ODDA and 87.5% reduced trap-catches for the Z,Z-3,13-ODDA treatment, as well as significantly reduced pupal skin counts compared to untreated controls. Pearson and Meyer (1996) compared the use of single ingredients to the complete blend and concluded that the individual ingredients were more effective at mating disruption for GRB than the complete blend.

Attract-and-kill (A&K) is a promising new technology that involves an attractant, such as a pheromone, and a toxicant. Unlike mating disruption, which functions by confusing the insect, attract-and-kill technology attracts the insect to a pesticide laden gel matrix and the insect makes contact with the pesticide (toxicant) before it is killed. The attracticide droplet contains small amounts of pheromone so that they can attract male moths rather than cause mating disruption. It has been successfully used on several lepidopteran species including codling moth (Ebbinghaus et al., 2001), and Oriental fruit moth (Evenden and McLaughlin, 2004), among others. Recently, IPM Tech (Portland, OR) developed an attracticide for grape root borer, called Last Call-GRB. This had not previously been tested under field conditions.

For these reasons, I decided to compare the use of attract-and-kill with traditional mating disruption for control of the GRB.

Materials and Methods

Four vineyards were chosen for this experiment, one from each of the major grape-growing areas of Florida: Altha (Panhandle), Palatka (north-central Florida), Fruitland Park (central Florida), and Lithia (south Florida). Each vineyard was sampled in 2002 to determine the occurrence of GRB. All vineyards consisted of muscadine grapes (*Vitis sp*) and all farmers implemented similar management practices. No other vineyards occurred within 16 kilometers, but wild grapes were nearby. Each vineyard was divided into four, one-acre (0.4 ha) treatments: 1) Mating disruption with pheromone twist-ties (Shin-Etsu Chemical Co. Ltd. Tokyo, Japan), 2) Attract-and-kill with Last Call-GRB, 3) Chemical control with chlorpyrifos (Lorsban 4E) (Dow AgroSciences LLC, Indianapolis IN), and an untreated control. Buffer zones between treatments were on average 15 m apart. This experiment was initiated in the 2003 grape-growing season and repeated for the 2004 season. Grape root borers begin emerging at different times of year for different regions, so experiments were initiated at different times.

Mating Disruption with Pheromone Twist-Ties

Pheromone twist-ties emitting the leopard moth *Zeuzera pyrina* L. (Lepidoptera: Cossidae) pheromone (95% E,Z-2,13-ODDA: 5% E,Z-3,13-ODDA) (70 mg of chemistry per unit) were applied to one-acre (0.4 ha) treatment plots at a rate of 254 dispensers per acre (625 per ha), approximately one twist-tie per vine. Because it was possible to cause mating disruption using individual ingredients, and the fact that the leopard moth *Zeuzera pyrina* pheromone contained the major component and it was commercially available and significantly cheaper, we chose to use an off-blend for our mating disruption experiment. Leopard moth pheromone shares the same major component with the GRB, although a smaller percentage (95% rather than 99%), and has a different minor component. This pheromone has not been tested in GRB mating disruption experiments previously. The dispensers were evenly distributed throughout the plot, and hung from the vine near the trellis wire at roughly 1 to 1.5 meters above the ground.

Attract-and-Kill with Last Call-GRB

Last Call-GRB contains 0.16% GRB pheromone, 6.0% pyrethrins (CAS 8003-34-7), and 93.984% inert ingredients. The rate of application is 1.59 oz per acre (112.5 grams per ha), which is equal to 900 drops per acre (2250 drops per ha) (each drop = 50µl) . To achieve a uniform distribution of drops, the 900 drops were divided by the number of vines per acre in each vineyard. So roughly 2, 3, or 4 drops were applied to each vine depending on the total number of vines per treatment area. Last Call-GRB drops were applied through a calibrated hand pump to the trunks of vines. Drops were distributed on the trunk from 0.5 to 1.5 meters (near the trellis wire) from the ground.

Attract-and-kill was reapplied every 6 weeks for the duration of the season (roughly three times per season).

Chemical Control with Lorsban

Lorsban 4E (chlorpyrifos) (44.9% a.i.) was applied once per season at the labeled rate of 1.06 L to 378 L of water to treat 200 vines. It was applied post-harvest, coinciding to the allowable time (under the pesticide application restrictions) closest to the period of greatest GRB emergence. In the Panhandle, it was applied 35 days pre-harvest.

Experimental design was a randomized complete block with four replicates. Each block was a vineyard from a distinct grape-growing region of Florida. Two wing-style sticky traps were placed in each treatment at least 20 m apart. Trap catches were counted weekly and recorded from the initiation of the project until the end of the GRB flight period for each region. Total number of GRB captures was analyzed using analysis of variance (ANOVA) and differences among means were determined by a Tukey's multiple comparison procedure ($P < 0.05$) (SAS Institute, 2004).

Results

In 2003, the mean number of male moths captured in wing traps in the area treated with mating disruption was significantly ($P < 0.05$) fewer than the untreated controls and the Lorsban treatments, and showed no statistical difference from the attract-and-kill treatment, $F = 9.81$; df = 3, 264; $P < 0.0001$ (Table 5-1). Wing traps deployed in the attract-and-kill areas caught significantly fewer adult male moths than traps deployed in the Lorsban sections with no differences than the untreated controls. There were no significant differences ($P < 0.05$) in trap catches between the Lorsban and the untreated control sections.

In 2004, the pheromone twist-tie treatments caught significantly ($P < 0.05$) fewer GRB than the attract-and-kill and untreated control sections, and showed no differences ($P < 0.05$) from the Lorsban treatments, $F = 11.42$; df = 3,234; $P < 0.0001$. There were no differences between the attract-and-kill and the untreated control sections.

Discussion

Trap shutdown was used to measure moth activity throughout the vineyard and consequently, mating disruption success. If the males were not able to locate the female pheromone in a trap, it is assumed that it would be unlikely for them to find a calling female. In an experiment by Webb (1990), males were unable to locate caged calling females in traps in a vineyard saturated with synthetic pheromone. Complete trap shutdown was achieved in all of the pheromone twist-tie treatments for both years, indicating that males were unable to orient to the female pheromone source; therefore it is reasonable to assume that disruption of mating occurred. It should be noted that trap shutdown alone does not prove that mating disruption has occurred. Previous studies confirmed mating disruption success in pheromone-saturated vineyards by determining if males could locate caged calling females, counting pupal skins, production of fertile or infertile eggs by females caught within the vineyards, and trap shutdown. The mating disruption study of GRB by Webb (1990) showed a significant degree of mating disruption by trap shutdown as well as the reduction of pupal skin counts indicating a correlation between the two. Johnson et al. (1991), and Yonce (1981) also showed a correlation between reductions of pupal skin counts and trap shutdown.

Mating disruption prevents most mating of GRB moths but it is possible that some mating may still occur. The greater problem with mating disruption is that this technique does not prevent immigration of gravid females from nearby wild grapes. A study by

Pearson and Schal (1999) suggests that the female pheromone might attract mated females from nearby plantings and wild grapes into the treated area. This occurred for the squash vine borer *Melittia cucurbitae* Harris; females were attracted in greater numbers to pheromone saturated plots than to the controls (Pearson, 1995). In field observations, behavioral responses of calling females were altered in the presence of the synthetic stimuli, with changes in calling heights, times, and movements, and increased wing fanning and gland dragging. Johnson et al. (1986) observed gravid females flying into pheromone treated plots from control plots to oviposit. This behavior was also observed for the peachtree borer, *Synanthedon exitosa* Say in a pheromone-saturated peach orchard (Snow et al., 1985). This perceived intraspecific competition under mating disruption might cause females to disperse and mate elsewhere, but return to oviposit. It is unknown what effect immigrating GRB have on treatments, and what proportion they have in comparison with localized emerging GRB. There was a high degree of variation between vineyards and it is difficult to draw conclusions. More research is needed on female response to synthetic pheromone saturated vineyards. Nevertheless, mating disruption can decrease GRB populations and yearly twist-tie deployments should be able to reduce infestations below the economic threshold level.

Trap catches in the attract-and-kill (A&K) treatment plots during 2003 were not significantly different than the twist-tie sections and resulted in trap shutdown. This was not true in 2004 when traps in the A&K section caught 48% of the total GRB collected, compared with only 13% in 2003. Why this occurred is unknown, but it is believed that the producers of A&K failed to include the correct amount of pheromone in the 2004 batch, since there was no difference from the control. Studies are underway to determine the amount of pheromone that was included in the A&K matrix.

I observed that the A&K drops often deteriorated quite rapidly under Florida conditions. The protocol called for A&K to be reapplied every 6 weeks. However, I noticed that many drops were almost dry after 3 weeks and totally missing during the 4th through 6th week. In a few instances, I observed drops that lasted the entire 6-week period. The drops that deteriorated within 3-4 weeks were generally more exposed to the weather than the other drops. During the summer growing season, Florida vineyards experience powerful storms with pelting rain, plus intense heat and solar radiation, and these conditions may affect the stability and longevity of the A&K. Attract-and-kill warrants further investigation to determine the frequency of application under Florida conditions, and its overall effectiveness.

In 2003, there were no significant differences between the untreated (control) and the Lorsban-treated sections. The Lorsban treatment was included in the study as a standard chemical treatment for GRB control. Lorsban primarily controls first instar larvae as they emerge from eggs and burrow to the roots. It can also reduce the number of adults as they emerge from their cocoons. During 2004, traps in the vineyards treated with Lorsban caught significantly fewer GRB than the untreated controls.

LastCall-GRB costs $100 per acre and it requires roughly one hour to treat an acre and 3-4 applications per season. Depending on the size of the vineyard, this could be rather labor-intensive. Future studies should evaluate how many drops per acre would provide effective control. Instead of 900 drops per acre, perhaps the drops (1 drop = 0.05

g) could be consolidated into larger amounts and applied on fewer vines. For example, 1.5 g drops could be applied to 30 vines (= 45 g of A&K).

The results from the pheromone twist-tie treatments suggest a great degree of male confusion and warrant further investigation as a GRB control tactic. A twist-tie application rate of 254 units per acre is a large quantity and future studies should focus on different deployment numbers. It may be important to compare the leopard moth pheromone to the true GRB blend in further mating disruption studies. This was beyond the scope of this study, but future studies should also incorporate the counting of pupal skins as a means to determine GRB reductions from the treatments. Practically, 254 twist-ties per acre may be expensive for farmers ($116/ acre compared with $75/acre for Lorsban). However, this initial investment may be offset by the premium prices charged for organic grapes. A smaller deployment may be just as effective, as well as cost-effective; for instance, 100 twist-ties per acre would cost $45. Mating disruption with twist-ties is not a labor-intensive control strategy. It takes an average worker 75 minutes per acre to deploy the twist-ties and the pheromones last the entire season of 150-180 days under average conditions.

Mating disruption with the use of the leopard moth (*Zeuzera pyrina*) pheromone may be an effective, reduced-risk strategy for controlling grape root borer, and a good alternative to conventional chemical control. It will need to be implemented for several seasons concurrently to reduce moths to acceptable levels and then be implemented again when populations surpass the economic threshold level (73 larvae per ha). It should be incorporated into an IPM system that includes good weed management, and reduced pesticide use. Attract-and-kill technology may also be an effective strategy for GRB control, but more research is needed.

Table 5-1. Weekly mean number of grape root borers per trap for mating disruption, attract-and-kill, Lorsban and untreated control treatments in four Florida vineyards for 2003 and 2004.

	Weekly mean trap capture ± SEM			
Treatment	2003		2004	
Mating disruption	0.00 ± 0	c	0.00 ± 0	b
Attract-and-kill	1.07 ± .44	bc	3.50 ± .76	a
Lorsban	3.07 ± .73	a	0.84 ± .32	b
Untreated control	2.49 ± .62	ba	3.00 ± .75	a

Means in columns followed by the same letter are not significantly different (P = 0.05, Tukey's test)

CHAPTER 6
SUMMARY AND CONCLUSIONS

The threat of grape root borer (GRB) *Vitacea polistiformis* (Harris), (Lepidoptera: Sesiidae) is often overlooked or ignored by Florida grape farmers. The damaging life stage (larval stage) of the GRB occurs underground, and the adult goes unnoticed because of its resemblance to the common paper wasp. Farmers often attribute reduced yields to weather conditions or pathogens. The GRB is the most damaging insect pest of grapes and has the potential to not only reduce yields, but to destroy the entire vineyard.

Presently, chlorpyrifos (Lorsban 4E) is the only chemical control listed for use of GRB. Several studies have shown Lorsban to be ineffective for control of GRB (Wylie and Johnson, 1978; Adlerz, 1984). Lorsban can only be applied once per season and is effective for only 3-4 weeks in the soil, or less (in Florida) due to the volume and intensity of Florida rainstorms. GRB flight periods last 3-5 ½ months in Florida, so Lorsban would be able to kill only a small part of the GRB population.

Two other control tactics have been recommended in other states: mounding and use of landscape cloth. These tactics have shown promise in other states, however they would be impractical in Florida for several reasons. For instance, the act of ridging mounds under vines and then scraping them off can be destructive to roots, which grow quickly into the mounded soil in Florida's climate. Landscape cloth would initially be quite expensive and the cloth would be easily damaged by machinery in our sandy soils.

This study demonstrated the peak flight periods for GRB in 16 vineyards in 4 regions of Florida. Being able to determine peak flight will allow grape-growers to better time their Lorsban application to coincide with the period of highest GRB emergence. Lorsban can either be applied 35 day pre-harvest or post harvest. Bunch grapes ripen in late June and July and peak GRB flight occurs in August and September. However, for muscadine grapes, the period of highest GRB emergence and grape harvest coincide, and Lorsban restrictions do not allow it to be applied during harvest. Consequently, this limits the effect Lorsban can have on the majority of the population. Since Lorsban is most effective on first instars, a period slightly later than peak emergence would be ideal. Also, since eggs incubate for roughly two weeks, the best time to apply Lorsban would be two weeks after peak GRB emergence. Therefore if grape growers insist on using Lorsban, the best time will be after harvest. This is especially true for wine grapes, which are harvested all at once. However, an earlier Lorsban application might be more effective for farmers who run U-pick operations or sell grapes for the fresh-fruit market who often harvest their grapes over an extended period, up to 8 weeks.

A component of my GRB research was to compare pheromone baited Universal Moth Traps (Unitraps) with wing-style sticky traps. The results demonstrated that the Unitraps caught significantly more GRB than the wing traps. Not only were they more effective, but they are also easier to use and cheaper in the long run. Farmers should continue to monitor for severity of GRB infestation. Current economic threshold levels are based on pupal skin counts. New thresholds should be established using a more user-friendly method of monitoring with Unitraps.

One result of monitoring for two years is that I was able to compare the total trap catch of 2003 with 2004. The numbers of GRB decreased in 11 of the 17 vineyards and for total trap catch in each region. Also, I began trapping in 2002 but was only able to obtain data for late season emergence. This data for the same vineyards in 2003 showed a reduction in total trap catch for the same periods of time. This information suggests a trend and that mass-trapping may be a potential strategy for control of GRB. However, further research is necessary to document this preliminary finding.

The purpose of the survey and analysis was to determine if there was a relationship between cultural control practices, chemical usage, and environmental conditions with total GRB trap catch. The results showed a strong correlation for 2003 and suggest that GRB infestation may be predictable based on vineyard characteristics, farm management practices, and environmental conditions. Certain factors, including weed control, pesticide usage, and precipitation may favor the development of GRB. The data also pointed out that certain cultural control techniques can be implemented in order to disfavor the development of GRB and limit the potential infestation.

Mating disruption with pheromone twist-ties has been explored by a number of researchers, all with promising results (Johnson and Mayes, 1980; Johnson et al., 1981; Johnson et al., 1986; Johnson et al., 1991; Pearson and Meyer, 1996; Webb, 1991). However, there is no commercial product available to farmers for use in mating disruption of GRB. Several of the studies have compared the use of the current complete blend with either the major or minor components (Johnson et al., 1991; Pearson and Meyer, 1996). My study used an off-blend, the pheromone of the leopard moth *Zeuzera pyrina* L. (Lepidoptera:Cossidae), which contains the same major component as the GRB, to confuse the males of GRB. These treatments achieved complete trap shutdown and did significantly better than the untreated control and Lorsban in 2003, and the untreated control and attract-and-kill (A&K) in 2004, suggesting disruption of mating.

Trap shutdown does not prove disruption of mating, and further research is necessary, that will correlate the effectiveness of the twist-ties with reduced pupal skin counts. If successful, leopard moth twist-ties must be registered with the EPA for use in vineyards, and produced commercially.

The attract-and-kill (A&K) treatments gave mixed results. In 2003 trap shutdown was achieved and there were no differences with the twist-tie treatments. In 2004, A&K was not significantly different from the untreated control. Based on the 2003 data, A&K looks promising and warrants further investigation. No one tactic will be sufficient in controlling GRB. Wild grapes occur quite extensively in Florida, and GRB will always be immigrating into vineyards from forested areas. An integrated pest management program is necessary to control GRB in Florida vineyards. This includes good weed management, good site selection, reduction in chemical usage, as well as the adoption of reduced-risk pesticides. Farmers need to monitor GRB populations and implement control strategies under epidemic population densities. These strategies may include the use of Last Call-GRB (A&K), Lorsban, and the use of pheromone twist-ties for mating disruption.

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BIOGRAPHICAL SKETCH

Scott Weihman was born in Rockford, IL, on May 13, 1967. He began his academic career in 1985, studying marine biology at the University of the Virgin Islands. Later, he transferred to Hawaii and earned his BA in environmental studies from the University of Hawaii in May of 1992. Shortly thereafter, he joined the Peace Corps to teach sustainable agriculture to farmers in a remote region near the Panama Canal. Scott has 13 years of horticulture experience and had a successful landscape design business in Michigan.