BIOLOGY AND MANAGEMENT OF BLUEBERRY GALL MIDGE AND SCALE INSECTS IN MICHIGAN BLUEBERRIES

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ABSTRACT

BIOLOGY AND MANAGEMENT OF BLUEBERRY GALL MIDGE AND SCALE INSECTS IN MICHIGAN BLUEBERRIES

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Blueberry gall midge (*Dasineura oxycoccana)*, European fruit lecanium scale (*Parthenolecanium cornii*) and Putnam scale (*Diaspidiotus ancylus*) are potential pests of *Vaccinium* crops, including blueberry and cranberry. The blueberry gall midge has recently increased in abundance in Michigan blueberries, causing high levels of damage to young green shoot tips. Scale insects have been found in localized areas with erratic population levels. The distribution of these pests in Michigan blueberries, their phenology and the effects of their damage on blueberry plants are unknown, limiting development of management programs. During 2009, surveys were conducted in blueberry farms and nurseries in Michigan to determine the distribution of *D. oxycoccana* in the state. To determine the phenology of blueberry gall midge, during 2009 and 2010, adult midges in blueberry fields were sampled using emergence traps, yellow sticky traps, and shoot tip dissections. Multiple peaks of damage and larval infestation were found in June and July during shoot growth. Due to the lack of scale-infested fields, monitoring of scale insects was limited to select farms known to be infested with the pest. Insecticide trials on both the blueberry gall midge and Putnam scale were conducted at farm sites and as bioassays in the laboratory. To determine the level of economic impact of blueberry gall midge, in the falls of 2009 and 2010, fruit bud abundance was compared between branched infested shoots and single uninfested shoots. Individual branches of infested shoots were found to have fewer flower buds than uninfested shoots, but overall bud numbers per shoot were similar.

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CHAPTER 1

BLUEBERRY GALL MIDGE AND SCALE INSECTS: EMERGING PESTS OF MICHIGAN BLUEBERRY FARMS

THE BLUEBERRY INDUSTRY IN MICHIGAN

Blueberries are plants of the genus *Vaccinium* that have become an important specialty crop to consumers. There has been increasing production globally and in the United States. According to the Food and Agriculture Organization of the United Nations statistical database, globally since 1990, blueberry yield has increased from 124,324 metric tons to 288,600 tons per year. The United States is the leading blueberry producer in the world (Table 1.1), growing 51% of the world's supply. Since 1990 in the United States, blueberry production has increased twofold from 79,940 to 158,032 metric tons. Michigan is the leading producer and exporter of highbush blueberries (*Vaccinium corymbosum* L.) in the United States (Table 1.2), and contains a third of the country's acreage of this crop.

Table 1.1. World production of blueberries and percent of production, Selected countries. (FAO, 2009).

Country	Production (metric tons)	Percent
United States	158,032	55
Canada	95,516	33
Poland	7,857	3
Germany	4,116	1
Netherlands	4,000	1
Ukraine	3,000	1
Lithuania	2,500	1
Other countries	13579	5
World	288,600	

Table 1.2. Highbush blueberry rankings by state, Utilized Production (FAO, 2005)

State	Rank	Production (1,000 lbs)
Michigan	1	83,000
New Jersey	2	52,000
Oregon	3	35,600
Georgia	4	31,500
North Carolina	5	25,500
Washington	6	19,000
California	7	10,000
Florida	8	7,000
Mississippi	9	4,600
Indiana	10	3,400
Total		271,600

INSECT PESTS IN BLUEBERRIES

The blueberry industry in Michigan has historically needed to respond to invasive and native pest species to maintain high yields and fruit quality. These pests include direct pests, those that attack the fruit, and indirect pests, those that feed on foliage, sap and growing buds that may have an effect on yield. Invasive pests are non-native species that are introduced into an ecosystem and cause economic or environmental damage. For example, the spotted wing Drosophila (*Drosophila suzukii* Matsumura), an invasive vinegar fly that directly infests blueberries with the potential to cause massive loss of marketable fruit, was first found in late 2010 in Michigan. In Washington and Oregon, it has already caused considerable damage to the blueberry industry (Steck et al. 2009). An example of a native pest that indirectly affects blueberry plants is the blueberry aphid (*Illinoia pepperi* McGillivary), an insect of the family Hemiptera that feeds on the sap of blueberry plants and is a vector of blueberry shoestring virus. Blueberry maggot (*Rhagoletis mendax* Curran), cranberry fruitworm (*Acrobasis vaccinii* Riley) and obliquebanded leafroller (*Choristoneura rosaceana* Harris) are three other common native blueberry insect pests that require active management. There are also secondary pests, which are insects that under normal conditions would not be causing damage over the economic threshold. Circumstances such as loss of its natural enemies from habitat loss or insecticide use or the opening of a favorable niche could provide the insect with the opportunity to become a pest.

INTEGRATED PEST MANAGEMENT IN BLUEBERRIES

Integrated pest management (IPM) is an approach to pest management that was developed after synthetic pesticides were introduced in the 1940s (Stern et al. 1959, Kogan 1998). IPM includes a variety of practices that incorporate economic thresholds, monitoring, prevention, and control using biological and chemical approaches. The first step in an IPM program is the establishment of economic thresholds, to determine the point at which the insect pest is causing substantial economic damage to the crop, and action thresholds, the point at which an insect pest's population is high enough to warrant management (Pedigo 2006). The second step is to monitor for the pest using traps or scouting to determine if populations have reached the action threshold. The third is to prevent pests from becoming economically threatening. Prevention measures include cultural controls such as the selection of resistant cultivars and rotation of crops. If the pest manages to become established at threshold levels, management techniques are needed to control it. Management of a pest includes use of mechanical control such as tilling and pruning, biological control such as introduction of natural enemies, and chemical control with insecticides. IPM has been successful in many systems, such as with the management of Southwestern corn borer, *Diatraea grandiosella* (Dyer), in North Carolina (Chippendale and Sorenson 2006) and control of soybean insect pests in Ohio (Hammond 2006).

In blueberries, key pests that are currently being managed are blueberry maggot, cherry (*Grapholita packardi* Zeller) and cranberry fruitworms, aphids and Japanese beetle (*Popillia japonica* Newman). Phenological and growing degree day models for these and other insects have been developed, and the most effective insecticidal, cultural and mechanical treatments have been determined. For example, a growing degree day model has been developed for the whitemarked tussock moth, *Orgyia leucostigma* (J. E. Smith), a pest that defoliates blueberry bushes (Isaacs and Van Timmeren 2009). This information should help growers determine the optimal timing to apply insecticides that will target eggs and young larvae while avoiding risk to pollinators and natural enemies.

BLUEBERRY PESTS AND THE GUTHION PHASEOUT

Blueberry pests are typically controlled through the use of broad or narrow-spectrum insecticides that can target a wide range or a narrow range of species, respectively. Common broad-spectrum insecticides tend to be less expensive than narrow-spectrum insecticides, and they do not require multiple sprays to target different insects. However, in addition to killing pest insects, broad-spectrum pesticides are likely to also kill beneficial insects (Hull and Starner 1983, Gentz et al. 2010). The Food Quality Protection Act of 1986 (FQPA) amended the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Federal Food, Drug, and Cosmetic Act (FFDCA). The FIFRA set guidelines for the use of pesticides, their registration and their classification. The FFDCA regulates the establishment of tolerances for pesticide use in food crops. Under the FQPA amendments, numerous changes were made including new standards for pesticide residues on food, streamlining of reduced-risk pesticide registration, and pesticide reassessment by the US Environmental Protection Agency (EPA) every 15 years to see if they meet current standards. These led to changes in pesticide labeling and use to reduce the magnitude and toxicity of pesticide as well as exposure of workers and environment to residues, and the decreased use of broad-spectrum pesticides in favor of narrow-spectrum insecticides (DiFonzo 2006).

In 2006, US-EPA made the decision to phase out the remaining uses of the organophosphate azinphosmethyl from fruit and nut crops by September 30, 2012. This insecticide has been a crucial part of Michigan blueberry pest management to control cranberry fruitworm, *Acrobasis vaccinii*, and cherry fruitworm, *Grapholitha packardii,* in mid-summer. In Michigan blueberries in 2007, azinphosmethyl was the most-sprayed insecticide in June when fruitworm is active, with 9,420 acres treated, and was the second most used insecticide in the entire season, having been sprayed on 50.8% of blueberry acreage (Isaacs et al. 2008).

This phaseout is in line with one of EPA's goals, to promote the use of safer insecticides. Azinphosmethyl has a relatively high risk to farm workers, pesticide applicators, and aquatic ecosystems. During the phaseout, several changes have been made to the use of azinphosmethyl in blueberries, such as a decrease in the number of applications that can be made per season, elimination of aerial applications, and increased sizes of buffer zones around aquatic areas and houses. This is forcing growers to quickly adopt new strategies to control for fruitworm pests. Under the auspices of the Michigan Blueberry Azinphosmethyl Transition Strategy, the blueberry industry is being educated on the use of other IPM practices and insecticides that can control pests. Alternative insecticides such as neonicotinoids, spinosyns, and insect growth regulators are being evaluated and some of these have shown performance similar to the level provided by azinphosmethyl.

Data from the USDA-NASS show a decrease in the use of broad-spectrum organophosphates and carbamate insecticides as well as the increased use of reduced-risk pesticides, such as methoxyfenozide and imidacloprid, and pyrethroids. Due to the reduction in the use of broad-spectrum insecticides and the inability of narrow-spectrum insecticides to target all insects, it is predicted that secondary pests will have the opportunity to increase their populations. However, it is also possible that secondary pest populations could be stabilized by natural enemies with the reduced insecticide pressure on those natural enemies. Pyrethroids and reduced-risk pesticides have been shown to have a variety of different effects on natural enemies of pests. In Pennsylvania apple orchards, pyrethroids were very toxic to predatory mites, but less toxic to other natural enemies (Hull and Starner 1983). Grape berry moth has been found to experience comparable or better control with the use of reduced-risk insecticides, but the natural enemies experienced no change in population (Jenkins and Isaacs 2007).

SECONDARY PESTS

Secondary pests are those that under normal conditions would not be a significant problem for growers; however, circumstances can give the insect the opportunity to invade and proliferate. One example of a secondary pest is the invasion of rats resulting when the World Health Organization sprayed large quantities of DDT in Borneo to control for mosquitoes. The gecko population that fed on flies was weakened by the consumption of DDT-filled flies. In turn, the cats that consumed the geckos died, allowing a rat infestation to take hold of many villages (Time 1969). Another example of secondary pests is occurring in India with the overuse of transgenic Bt cotton, which has protected their cotton crop from the American bollworm (*Helicoverpa armigera* Hubner), and the consequential reduction in the number of sprays used.

However, this has led to mealybug infestations on cotton, possibly due to introduction through Bt corn seeds (Ho 2010)

Research focusing on understanding the biology and ecology of secondary pests has often been a low priority because of their generally low economic impact. However, when they experience a rapid population increase and become an economic threat, the need to understand these topics aid development of management programs targeting these pests. The primary insect pests of Michigan blueberries can be controlled with prudent IPM practices. There are other pests of blueberries that do not pose as large an economic threat as the primary pests. However, these secondary pests may be primary pests in other locations in the US or world.

BLUEBERRY GALL MIDGE

Blueberry gall midge (*Dasineura oxycoccana* Johnson*)* is one such secondary pest, and is a potential pest of *Vaccinium* crops, including blueberry and cranberry. In the past few years, this cecidomyiid species has been found more frequently in Michigan blueberry farms, where it can cause high levels of damage to young vegetative shoot tips. It lays its eggs inside growing vegetative shoot tips, and the larvae hatch and feed on the developing plant tissue. Feeding by larvae induces a branching reaction in damaged shoots due to loss of apical dominance. Blueberry gall midge has three instars, the first of which is only detectable with a high-powered dissecting microscope. The third instar is about 2 mm long, and is an orange-pink color. The length of time the midge takes from egg to adult is not known, but observations in the lab indicate anywhere from two to four weeks. The distribution of *D. oxycoccana* in Michigan blueberries, its phenology and the effects of its damage on fruit yield and bud set are unknown, limiting development of a management program for this insect of increasing abundance.

Blueberry gall midge was found to be a pest in New Jersey cranberries by Marucci (1977), but was said to be under control through the use of broad-spectrum insecticides such as Guthion and Parathion. It was later found to be a problem in rabbiteye blueberries, *Vaccinium ashei* Reade, in Florida, where it destroyed as much as 80% of the floral buds in commercial plantings (Lyrene and Payne 1992). This floral bud damage was not observed in Michigan and so there has been relatively little research conducted on blueberry gall midge in Great Lakes blueberries. There has been some research by in Wisconsin cranberries, where the same insect is called the cranberry tipworm and it causes shoot damage especially in more northern farms where the new shoots that are produced after damage may not have time to harden before frost (Mahr and Perry 2005). However, vegetative bud damage has recently become noticeable throughout the year in Michigan blueberry fields, yet many questions remain about this insect's biology and management in this system.

MONITORING AND MANAGEMENT OF BLUEBERRY GALL MIDGE

Understanding a pest's phenology and distribution are the first key steps to developing an effective IPM program. These can be determined by sampling and trapping the pest. The presence and level of biocontrol agents can also be surveyed while sampling. This gives an indication of their ability to control the pest population in a farm setting. When the distribution and peak infestation periods of the insect are known, sampling schemes can be used to target the pest at specific times and locations to eliminate populations before they expand.

Following IPM practices, the economic threshold of blueberry gall midge should be determined before making recommendations to growers. Although the midge has a significant impact on rabbiteye blueberries in Florida (Lyrene and Payne 1992), evidence of damage to floral buds has not been seen in Michigan highbush blueberries. However, the damaged shoots experience lateral branching that could potentially cause a reduction in floral buds. There may also be an increase in the susceptibility of young lateral shoots to winter kill. There have thus far been no studies investigating the floral bud yield of shoots that have been damaged by blueberry gall midge.

Monitoring techniques have been developed in other regions to track the populations of this pest. Yellow sticky traps placed within fields have been used to detect adult midges and their natural enemies and were found to catch significantly fewer adult midges than allowing for adult emergence from collected buds. Fruit bud dissection to count larvae were found to be equally effective at detecting the insect (Sarzynski and Liburd 2003). Emergence traps have also been designed and tested to determine their effectiveness in trapping blueberry gall midge early and throughout the season (Roubos and Liburd 2010). They were found to be useful in detecting adults before any larval damage was apparent in fruit and vegetative buds.

Prior to widespread use in the field, pesticides should be tested on the pests in field and laboratory settings to determine their efficacy. Thus far, only a handful of pesticide trials have been conducted on blueberry gall midge. One study in Washington State blueberries tested whether *Bacillus thuringiensis* (Gnatrol™), cyantraniliprole (Cyazypyr™), spinetoram (Delegate™), spirotetramat (Movento™) or vegetable oil surfactant (Dyne-Amic™) applications would reduce larval populations in infested shoot tips. Cyantraniliprole and spirotetramat reduced larval levels 13 days after treatment (Tanigoshi et al. 2010). Another study in rabbiteye blueberries indicated control by malathion, phosmet or spinosad, where malathion was extremely effective and killed 94% of larval midges and phosmet and spinosad killed 50%

of larval midges (Sampson et al. 2002). These studies have utilized canopy sprays; there have not been any trials investigating soil applications of systemic insecticides.

Biocontrol is another important part of an IPM program. Natural enemies and parasitoids of blueberry gall midge were catalogued from Florida and Mississippi (Sampson et al. 2006). Parasitoid eulophid wasps of the genus *Apostocetus* and *Quadrastichus* (Hymenoptera, Platygastridae) were found to be present in gall midge populations. During peak blueberry gall midge activity, 34% of larvae were found to be parasitized. Over the entire season, 7% of gall midge larvae were found to be parasitized. The syrphid fly *Toxomerus geminatus* was also found to be a predator of blueberry gall midge larvae.

SCALE INSECT PESTS

Scale insects, of which there are over 7,300 species, are phloem-sucking insects of the order Hemiptera that are sporadic pests of fruit crops throughout the world (Miller and Davidson 2005). One-third of these, about 2,400 species, are armored scales (Family Diaspididae), and about 1,000 species are soft scale insects (Family Coccidae). Others include mealybugs (Family Pseudococcidae) and cottony cushion scales (Family Margarodidae). Armored scale insects have been extensively reviewed by Miller and Davidson (2005) and by Rosen (2005). Ben-Dov and Hodgson (2005) reviewed soft scale insects.

Scales are pests of perennial plants, and can cause substantial losses to fruit and nut trees, forest trees, ornamentals, greenhouses, and other cultivated plantings. Miller and Davidson (1990) list 199 armored scale pest species in the world, many of which are citrus pests. Economic loss due to all scale insects has been estimated to be 5 billion US dollars annually

(Kosztarab and Kozár 1988). Due to the economic importance of scale insects, knowledge of their biology and proper management is crucial.

Armored scales and soft scales are two economically important types of scale insects. McClure (1990) describes the ecology of armored scales, which differs widely among species and also within species. The ability of a scale insect to perform well in an environment depends on many factors including climate, the attributes of the host, soil conditions, competition and natural enemies. Suitability of host plants and habitat for scales can vary so much that introduced species can often invade and infest hosts and habitats that are different from those of its native range. The San Jose scale *Quadraspidiotus perniciosus* (Comstock), a pest of many tree fruits including apple, peach and pear, has been found from China to Afghanistan to the United States (Scalenet, http://www.sel.barc.usda.gov/scalenet/scalenet.htm). Stressed growing environments and the lack of natural enemies can facilitate the establishment of invading scale insects. Studies by McClure in 1990 showed that two ordinarily rare armored scales, *F. externa* and *Nuculaspis tsugae* (Marlatt), could reach pest populations in cultivated fields of two plants, *Tsuga diversifolia* Masters and *Tsuga sieboldii* Carrieré, that are ordinarily highly resistant to invasion of scale in natural conditions. It was found that the scale insects were able to take advantage of the stressed plants in poor growing habitat.

SCALE BIOLOGY

The rates of scale development and numbers of generations per year vary depending on the temperature and climate of the region. For example, the olive scale, *Parlatoria oleae*, has two generations in the Judean Hills of Israel, but at least three in the Beit-She'an Valley. Those found in the Judean Hills experienced a longer overwintering period than those in the Beit-She'an

Valley (Applebaum and Rosen 1964). These authors concluded that temperature was the driving factor in differing voltinism. This was tested in the lab on white peach scale, *Pseudaulacaspis pentagona*, and the time required for one generation in the laboratory at 11-15˚ C was almost three times longer than the time needed at 26˚ C (Ball 1980). In Maryland, this scale has three generations per year; in Florida it has up to five per year.

Immature scale insects are called crawlers. While the female adult stage is sessile and immobile, the crawlers are able to move to new feeding sites. Crawlers hatch from underneath the scale covering of their parent and wander around until they settle (Greathead 1990). Although most crawlers settle close to the parent, some wander to different parts of the plant and others can be dispersed by the wind. Moving crawlers can be caught by using double-sided tape wrapped around shoots. Elongate hemlock scale crawlers, *Fiorinia externa*, can be trapped on sticky plates located in the canopy of a forest of Eastern hemlock (McClure 1979).

MANAGEMENT OF SCALE INSECTS

Damage by scale insects can destroy plant tissue, reduce plant growth and vigor, and lead to twig dieback and premature leaf drop, increasing the plant's susceptibility to frost and disease. Damage by soft scales can lead to contamination with honeydew, which is an ideal growing medium for sooty mold. Sooty mold can spread over a leaf surface and cover it with black spots, which impede photosynthesis and reduce growth.

In order to develop an integrated pest management (IPM) program for scale insects, a comprehensive approach including biological, mechanical, chemical and cultural control must be developed and implemented. Detection of scale insects through inspection of plants underneath bark, around wounded areas, trunk and leaves is an important first step in the control of scale insects. Because the biology and voltinism of scale insects differs so much between and even within species, it is important to correctly identify potential scale pests and continue monitoring for crawler emergence for use in a management program

Once scale insects have been detected and identified, the crawler stage and natural enemies should be monitored to find peak emergence and to see if scale populations are sufficiently suppressed by natural enemy populations. Control methods include chemical control with horticultural oils and soaps, cultural control with pruning and use of resistant cultivars, and biological control, either by introducing the scale's natural enemies or by timing insecticidal sprays to not coincide with peak natural enemy populations.

Use of natural enemies to control populations is an important component of IPM that can reduce the amount of pesticide use while reducing pest populations below the economic threshold. Since scale insects are sessile, they are ideal targets for biological control, which include pathogens, predators and parasites. Fungi account for some of the mortality in scale populations, but have not yet been successfully used for scale control. Predators include ladybeetles and mites. Parasites include hymenoptera of the families Aphelinidae, Encrytidae, Signiphoridae and Aphelinidae.

SCALE INSECTS IN MICHIGAN

Recently, Lecanium scale (*Parthenolecanium corni* Bouché) and Putnam scale (*Diaspidiotus ancylus* Putnam) have been found in blueberry plantings in localized regions of southwest Michigan, and these insects may be experiencing high populations in these areas due to the changing pesticide use. Lecanium scale has over 350 host species and is found throughout most of the northern hemisphere. It has been a pest of a variety of food plants, from peaches in

Pennsylvania (Asquith 1949) and prunes in California (Bailey 1964) to ornamental plants in Tbilisi (Japoshvili 2008). While this scale insect does not attack the fruit directly, accumulated populations can cause plant death and high populations and the associated honeydew can cause sooty mold on fruit, thereby reducing fruit quality. Putnam scale also has a number of hosts, having been reported on 17 plant families and 30 genera (Borchsenius 1966). On blueberries, heavy infestations can kill twigs and branches, and reduce plant vigor (Antonelli et al. 1992).

It is important to understand the scale insects' life cycle throughout the year so that the vulnerable life stages can be targeted with cultural and insecticidal controls. Reports on the life cycle of Putnam scale vary. Putnam scale was found to have one generation (Polvarapu 2000) or two (Bray 1974). The life history of Lecanium scale and Putnam scale in Michigan blueberries is unknown. Further information is needed to develop a management program for these scale insects in Michigan.

Some scale insects first emerge in the spring from underneath their dead mother's protective covering. Others overwinter as nymphs and enter a period of dormancy. In the spring, scale insects in their nymph crawler stage will feed until later instars, when they settle on shoots and form their waxy cover, becoming sessile (Miller 1997). The number of generations is variable depending on the species. Putnam scale in New Jersey emerged as second instar nymphs in the spring and proceed through two generations before overwintering again as nymphs. Lecanium scale overwinters as second instar nymphs that mature in April and May, and have one to two generations per year.

Scale insects are typically monitored for by careful visual inspection of plants to seek out the adult stage. They can also be monitored for in their early-instar crawler phase through the use of double-sided sticky tape wrapped around individual shoots. The crawlers are caught in the sticky glue and can be counted for abundance under a dissection microscope (Polavarapu 2000).

Management of scale insects can be difficult due to their protective covering. However, the crawlers are more susceptible to insecticide control because of their lack of scale covering and mobility. Due to this fact, knowledge of crawler emergence and their susceptibility to different insecticides is vital. Control methods include spraying of dormant oil in the late spring to suffocate the immatures, as well as pyriproxifen (Esteem™), an insect growth regulator timed to disrupt molting in the spring so that adult scales are not formed. Additionally, well-timed applications of scale-active insecticides to target the crawler stage can reduce populations. Regular pruning of infested branches and older shoots also suppresses populations (Marucci 1966).

Natural enemies of Putnam scale have been found. In New Jersey, nine parasitoids and two lady beetles were found to prey on Putnam scale (Polavarapu 2000). Many parasitoids have been found from Lecanium scale, mostly of the families Aphelinidae and Encyrtidae (Miller 1997).

JUSTIFICATION FOR RESEARCH

The lack of information regarding the life history and biology, detection and sampling methods, insecticidal and biocontrol measures, and potential economic impact of blueberry gall midge and scale insects in Michigan blueberries is limiting the development of integrated pest management programs for them. While some details are known about these pests in other states, their behavior, phenology and ecology could be different in Michigan. Information about the pests' life history and biology as well as detection and sampling methods will help growers and scouts to know where and how to find the pests and the ideal timing of insecticides.

Blueberry gall midge is of great economic importance in Florida, where it damages floral buds. However, floral bud damage has not been observed in Michigan. Even so, blueberry gall midge may still have an indirect effect on plant vigor and flower bud growth. Putnam scale and Lecanium scale, although found in localized regions of southwest Michigan, could still pose problems to some growers that may not have robust IPM programs. If left unchecked, they have the potential to also reduce blueberry vigor and yield.

With the diminished use of broad-spectrum insecticides such as azinphosmethyl, and the adoption of different insecticides, populations of secondary pests are expected to increase and could become major pests. Blueberry gall midge and scale insects are two such secondary pests that are increasingly being observed in Michigan blueberries. Increased sightings by scouts and growers of the pests and their damage in recent years have prompted investigations into their biology and effective control measures. Whether or not these pests are economically important is not known, as blueberry gall midge and lecanium scale do not attack the fruit directly, and Putnam scale has thus far been found in very small numbers. Research was conducted to determine if these insects do a significant amount of damage to blueberry bushes. To develop a management plan, first the distribution and phenology of these insects must be known to determine what areas must be targeted and the best time to apply insecticides. Pesticides that can control these pests must then be determined. It would also be useful to know if any natural enemies exist in the system, and their role in controlling the populations of this insect.

CHAPTER 2

DISTRIBUTION AND PHENOLOGY OF BLUEBERRY GALL MIDGE (*DASINEURA OXYCOCCANA*) IN MICHIGAN

ABSTRACT

Blueberry gall midge is a potential pest of Michigan blueberries whose damage has recently been sighted with increasing frequency in the state. In Florida, it causes economic damage to the flowering buds. However, in Michigan blueberry gall midge has been found to damage only vegetative shoots, the impact of which unknown. In this study, farms throughout Michigan were surveyed for the presence of blueberry gall midge. Blueberry gall midge was found in 43 of the 46 surveyed farms in 11 counties. Multiple monitoring techniques, including yellow sticky traps, emergence traps, observational sampling, and vegetative shoot dissections were used to describe the general biology of blueberry gall midge in blueberry fields in southwest Michigan that were known to be infested. Yellow sticky traps were not effective at catching blueberry gall midge. Emergence traps were most useful in early detection of blueberry gall midge in April, and observational sampling for damage symptoms and vegetative shoot dissections revealed multiple population peaks throughout July and August. This information about the biology and distribution of blueberry gall midge will be useful in timing control methods in the future if it becomes an economic pest of Michigan blueberries.

INTRODUCTION

Blueberry farms are inhabited by beneficial insects such as pollinators and natural enemies, as well as key pests such as cranberry fruitworm (*Acrobasis vaccinii* Riley), blueberry maggot (*Rhagoletis mendax* Curran) and Japanese beetle (*Popillia japonica* Newman). In Michigan blueberries, other major pests include leafrollers, aphids and cutworms. Pests that damage fruit and floral structures are especially concerning because they can directly impact fruit yield and quality. The blueberry gall midge, *Dasineura oxycoccana* Johnson, is one such pest that has caused bud damage and yield reduction in rabbiteye blueberry (*Vaccinium ashei* Reade) (Lyrene and Payne 1992, Dernisky et al. 2005). In recent years, personal observation and conversations with blueberry growers, scouts and industry representatives have indicated increased numbers of blueberry gall midge throughout Michigan farms. This increase may be due to reductions in the use of broad-spectrum insecticides and the adoption of more selective insecticides in recent years.

Distribution

Blueberry gall midge, described by Gagné (1989), is a small cecidomyiid fly, about 3 mm in length, that infests and kills floral and vegetative buds of *Vaccinium* plants, including blueberries and cranberries. Outside of Michigan, the midge has been recorded in blueberry fields located in Florida, Maine, New Jersey, Wisconsin, Washington and Oregon (Mahr 1991, Lyrene and Payne 1992, Yang 2005, Reekie et al. 2009, Tanigoshi et al. 2010). In Wisconsin and in Cape Code, Massachusetts, this insect is known as the cranberry tipworm where it is found in cranberry bogs (Mahr 1991, personal communication with Sunil Tewari). In Florida, it is the major pest of blueberries, and in 1992 caused upwards of 90% death of flower buds in several fields (Lyrene and Payne 1992). There is relatively little published information regarding the biology of *D. oxycocanna* in northern highbush blueberry or cranberry, and it has not been extensively studied in Michigan. Its distribution and level of infestation across the state and in farms is unknown. Surveys of farms in Oregon in 2005 indicated its presence in 10 of 10 surveyed blueberry fields, with infestation ranging from 1% to 80% of total vegetative shoot tips (Yang 2005).

Biology

Adult blueberry gall midges emerge from pupae in the soil and oviposit in unopened shoot tips and the developing larvae eat tissue from the inside of the bud. The larvae develop through three instars, the first of which is difficult to see without a high-powered microscope. The second and third instars are small but visible to the naked eye. The third instar is about 2 mm long and an orange-pink color. These late-instar larvae drop to the ground to pupate in the soil. The development time of the gall midge is unknown, but it is known to have up to 11 generations per year (Sampson et al. 2002).

Damage and symptoms

Damage by the gall midge leads to death of the apical meristem revealed by the blackening of the bud and curling of surrounding leaves (Gagné 1989). These symptoms are often confused with frost damage in the spring, nutrient deficiency or herbicide, fungicide or insecticide damage. Due to these misdiagnoses and the midge's small size, some growers dismiss the damage and remain unaware of the insect in their fields. However, simply unfurling a single damaged bud often exposes multiple larvae. Damage from larval blueberry gall midge can also cause a branching response in the blueberry plant with the growth of lateral side shoots. This increased number of fruiting terminals may be beneficial to fruit yield. However, the effect of shoot branching on blueberry production has not yet been examined (Chapter 5).

Phenological and degree day models can be useful tools to determine the ideal time for applying management techniques (Preuss 1983, Jones 1991). For example, a model for white-marked tussock moth (*Orgyia leucostigma* J.E. Smith) has been developed to assist growers by maximizing the effectiveness of pheromone traps and insecticide applications with knowledge of peak pest emergence (Isaacs and Van Timmeren 2009). Phenology of blueberry gall midge has been studied in rabbiteye blueberry in Florida through the use of various monitoring techniques. Yellow sticky traps, adult emergence, and bud and shoot tip dissections were used in blueberry fields in Florida; although time consuming, bud and shoot tip dissections were found to be the most effective technique (Sarzynski and Liburd 2003). Emergence traps were later tested to determine the early emergence of the adult flies (Roubos and Liburd 2010). Presence and phenology of the midge were also determined in Oregon and Washington using shoot tip dissections and observations for damage (Yang 2005, Tanigoshi et al. 2010). In lowbush blueberries, phenology was determined through the use of shoot tip dissections, trapping with yellow sticky boards, insect sweeps and rearing (Reekie et al. 2009).

The goal of this study was to determine the severity of infestation by blueberry gall midge in the major blueberry producing areas of Michigan and to get a better understanding of their biology in Michigan blueberries. To improve understanding of the impact of blueberry gall midge, the phenology, distribution and level of infestation of the insect were assessed. Surveying for damage and presence of the midge in farms and nurseries across the state was used to determine their distribution. Yellow-sticky traps, adult emergence traps, shoot tip dissections, and rearing were tested to determine the most effective monitoring methods and to develop phenology curves and predict peak emergence based on growing degree-days.

METHODS

Selecting surveying sites

Widespread surveying was conducted in 2009. Since the presence of blueberry gall midge within farms and nurseries was unknown, farms were selected in the primary regions of blueberry production with some outlier locations to ensure a wide geographic spread of sampling. The majority of survey sites were in southwestern Michigan. In total, 46 conventionally managed blueberry farm plots in 10 counties and 11 nursery plots in one county were surveyed (Table 2.1). The 11 nursery plots were located in four nurseries in Van Buren County. All cultivars are listed in Table 2.2.

Table 2.1. Number of farms and nurseries surveyed for blueberry gall midge in counties in Michigan

County	# of farms surveyed	# of nurseries surveyed
Allegan	6	0
Berrien	7	0
Genessee	2	0
Grand Traverse	1	0
Ingham	1	0
Manistee	2	0
Mason	2	0
Muskegon	7	0
Ottawa	8	0
Van Buren	8	4
Washtenaw	2	0

Table 2.2. Cultivars of highbush blueberry surveyed for blueberry gall midge

Cultivar	# of farms	# of nursery plots
Bluecrop	22	4
Blueray	2	0
Duke	0	1
Elliott	9	4
Jersey	7	1
Rubel	1	1
Weymouth	1	0
Unknown	4	0

Surveying methods

One two to three acre field per farm was surveyed for blueberry gall midge infestation from mid-June to mid-August 2009. Before surveying, infested shoots were sampled from the field and inspected to ensure that blueberry gall midge larvae were present on the farm. Surveying was conducted in each field along 10 transects spaced one bush apart. Each transect contained five bushes spaced one bush apart. In total, 50 bushes were surveyed per field. For each observation, the number of blackening, infested shoots was counted on the top, bottom, and side of one-half of the bush. Due to the bush spacing and size within a planting, it was difficult to count all of the shoots on both sides of a bush. Percent shoot infestation was calculated by dividing the number of infested shoots by an average total number of shoots (total number of new shoots on 10 half-bushes divided by 10). Average percent infestation was calculated for each sampled field for each weekly sample.

In the beginning of August 2009, surveys were conducted at four nurseries in blocks of potted blueberry bushes that were two to three years of age. At three of the nurseries, three blocks of nursery plants were surveyed. At the fourth, one block of bushes was surveyed. Since nursery plants were arranged in large blocks of adjacent bushes, it was difficult to reach plants more than three plants in from the edge. Only pots close to the perimeter of the blocks were sampled, and 50 bushes were sampled per cultivar per nursery. The number of infested shoots was counted on each of the sampled plants. Percent infestation on bushes was calculated by dividing the number of infested shoots by an average total number of shoots (total number of new shoots on 10 bushes divided by 10). Average percent infestation was calculated for each cultivar at each sampled nursery.

Phenology of blueberry gall midge infestation

Observational sampling: In 2009, to determine the phenology of blueberry gall midge, three blueberry fields of cultivar 'Bluecrop' on farms in southwest Michigan with a history of blueberry gall midge infestation were selected. Every two weeks from June 22 to September 15, 25 bushes per site were observed for damage by this pest. Sampling was done on bushes in five transects spaced 5 rows (13.7 m) apart, with each transect containing five bushes each spaced 10 bushes (12.2 m) apart. The number of shoot tips damaged by blueberry gall midge was counted on each bush. To determine the number of new growing shoots that could be infested, at the beginning of the season the number of new shoots was counted on ten plants per field, and then averaged to get an average number of new shoots per bush. Percent infestation on bushes was calculated by dividing the number of infested shoots by an average total number of shoots. Average percent infestation was calculated for each field.

In 2010, five different fields with known infestations of blueberry gall midge were selected. Four fields were of cultivar 'Bluecrop' and one of cultivar 'EarliBlue.' Prior to the growing season, a section of 200 bushes was flagged and reserved for observational sampling. Once per week, from May 12 to October 14, 30 randomly selected bushes in the 200-bush field areas were observed for damage by blueberry gall midge, and the number of damaged shoot tips was counted on each of these bushes. Additionally, on 10 randomly selected bushes, the number of vulnerable shoot tips was counted and then averaged to get an average number of susceptible green shoots per bush. Vulnerable shoot tips were defined as young fleshy shoot tips emerging from shoots that are elongating through the growing season. Percent infestation was calculated by dividing the number of infested shoots by the average number of susceptible green shoots per bush. Average percentage infestation was calculated for each field for each weekly sample.

Yellow Sticky Traps: In 2010, trapping techniques were used to monitor for adult blueberry gall midge in the four ‘Bluecrop’ blueberry fields. Prior to the research season, a 200-bush section of each field was flagged and reserved for these studies. Three yellow sticky traps were placed within the canopy on randomly selected bushes in the field and retrieved and replaced once per week from June 10 to August 23. The number of blueberry gall midge found on each trap was counted and recorded. The total number of blueberry gall midge caught was counted per week.

Emergence traps: Emergence traps similar to those of Roubos and Liburd (2010) were deployed within the same 200-bush fields as were sampled for blueberry gall midge damage, described above. Traps were constructed from 2.5 qt plastic paint buckets (Home Depot, Atlanta, GA) and clear 10 cm diameter Petri dishes (Figure 2.1). Tanglefoot glue applied with a spatula to the inside of the Petri dish was used as an adhesive to capture emerging blueberry gall midge adults. Traps were placed on six randomly selected bushes in the four fields, positioning them next to the crown of the plants, within 30 cm of the base. Bush rows ran south to north at two farms, and west to east at two farms. At the farms with bushes running south to north, traps were placed on the east and to the west of the bushes, while at the farms with bushes running west to east, traps were placed on the south and north of the bushes. Each week, these emergence traps were retrieved and replaced, and the number of blueberry gall midge adults trapped in the Petri dish was counted.

Figure 2.1. Emergence trap used to capture adult midges. The trap is comprised of a bucket with the bottom removed, covered with a large Petri dish that has tanglefoot glue smeared on the inner surface. For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.

Shoot dissections: Shoots were collected from the same four blueberry fields for dissection. Thirty shoots were collected from 30 randomly selected bushes in the 200-bush fields each week from May 12 to September 29, then placed in a plastic bag and in a cooler containing ice. Shoots were randomly selected from the top third, middle third, or bottom third of each sampled bush. Shoots were not inspected beforehand to determine if they were infested. Within 24 hours, these shoots were brought back to the laboratory and dissected with forceps and inspected under a microscope to determine the number of eggs, 1st, 2nd and 3rd instar larvae and pupae. The color of the vegetative bud (green, black, or mottled) was also recorded to determine whether color may be used as a crude assessment of damage caused by blueberry gall midge damage.

An estimate of the number of larvae per bush was calculated by multiplying the average number of larvae found per week in the shoot dissections and the average number of shoot tips per bush from the observational samples.

Degree day-based phenology

To determine the phenology of blueberry gall midge based on degree day accumulation, growing degree days were calculated for peak activity as determined by the 2009 and 2010 observational sampling and shoot dissection data. Dates of peak infestation and adult emergence were determined, and accumulated growing degree days were found using the Enviroweather Automated Weather Station Network (http://www.agweather.geo.msu.edu/mawn/). The closest weather stations to the farms were used to calculate the growing degree days. These were the Benton Harbor, Grand Junction and South Haven stations. Growing degree days were calculated from March 1 using the Baskerville-Emin method with a base temperature of 50 ˚F.

Statistical analysis

All analyses were conducted using JMP 8.0.2 (SAS, Cary, NC). Percentage of shoots infested with blueberry gall midge was plotted for each surveyed farm and nursery. The percent infestation in all farms was compared to the percent infestation in all nurseries using a Student's t-test.

Infestation data: For the data gathered in 2009 and 2010, the percent infestation in all sampled farms was averaged for each week. For the 2010 data, the percent infestations within the top, middle and bottom third of the bush were also averaged across all sampled farms. The number of vulnerable shoots each week was also plotted. Percent infestation was compared among the three parts of the bush using one-way analysis of variance and separation of means with Tukey's Honestly Significant Difference test.

Emergence traps: Data from farms with North-South rows were used to compare the number of midges captured on the east aspect of the rows and the number of midges found on the west aspect. Similarly, the number of midges found on the north aspect was compared to the number of midges found on the south aspect. Data was separated and analyzed by month. This was done by fitting the Poisson distribution to the data and a likelihood ratio Chi-Square test.

Shoot tip dissections: The average number of larvae per shoot was calculated, and phenology curves were drawn. The average number of larvae was compared among each color category of vegetative bud using one-way analysis of variance and means separation with Tukey's HSD (JMP 8.0.2, Cary, NC).

RESULTS

Surveys for blueberry gall midge

There was higher percent infestation by blueberry gall midge in nurseries than in farms ($t(13)=3.43$, $P < 0.005$). Blueberry fields varied widely in the level of blueberry gall midge infestation, from one field at a farm in Ingham County with no infestation to an average of 17%

infestation in Muskegon county (Table 2.3 and Figure 2.2). The average percent infestation (±S.E.) of all farms was 8.3 ± 1.6. At blueberry nurseries, infestation levels were generally higher than at farms (Table 2.4 and Figure 2.3), with 25.7 ± 4.5 average percent infestation across all nurseries. There was little evidence of significant variation in infestation levels by cultivar (Table 2.4). There was considerable variability in average percent infestation (Tables 2.3 and 2.4).

Table 2.3. Average percent infestation of shoots (±S.E.) by blueberry gall midge infestation in Michigan blueberry farms, by county

County	Number of farms surveyed	Percent infestation
Allegan	7	8.5 ± 3.0
Barry	1	4.5 ± 0.0
Berrien	7	14.3 ± 6.6
Genesee	2	4.9 ± 0.8
Grand Traverse	1	13.5 ± 0.0
Ingham	1	0.0 ± 0.0
Manistee	2	1.3 ± 1.3
Mason	2	0.1 ± 0.1
Muskegon	6	17.0 ± 4.2
Ottawa	6	7.9 ± 5.3
Van Buren	9	6.1 ± 1.7
Washtenaw	2	5.1 ± 5.1
All farms		8.3 ± 1.6

Table 2.4. Average percent infestation (±S.E.) by blueberry gall midge at Michigan blueberry nurseries, by cultivar

Cultivar	Number of nurseries surveyed	Avg percent infestation
Bluecrop	4	20.1 ± 4.2
Duke	1	26.3 ± 0.0
Elliott	4	30.9 ± 11.9
Jersey	1	20.1 ± 0.0
Rubel	1	30.4 ± 0.0
All nurseries		25.7 ± 4.5

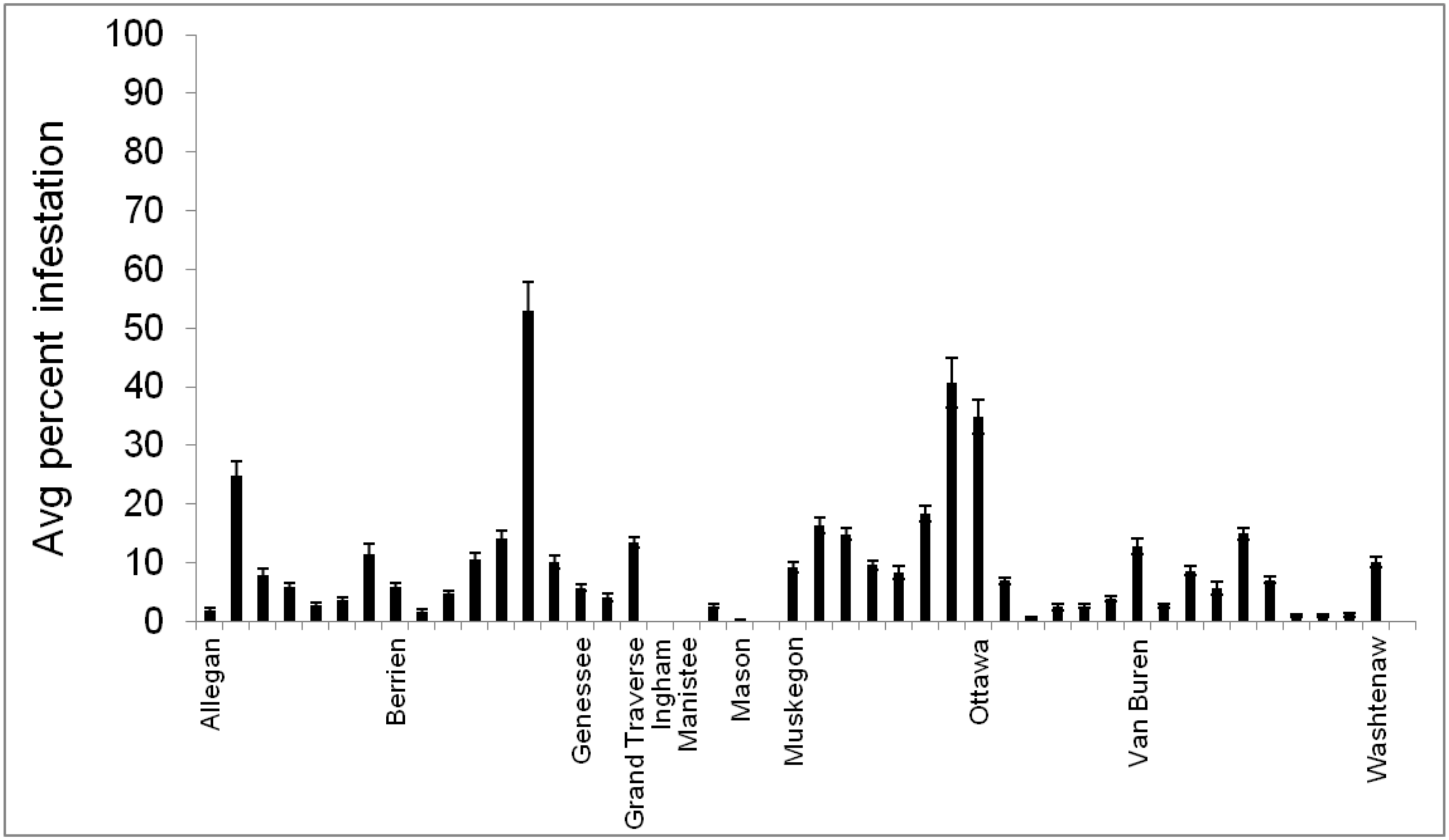

Figure 2.2. Average (± S.E.) percent infestation of Michigan blueberry farms by blueberry gall midge. Bars following county name differentiate individual surveyed farms within a county.

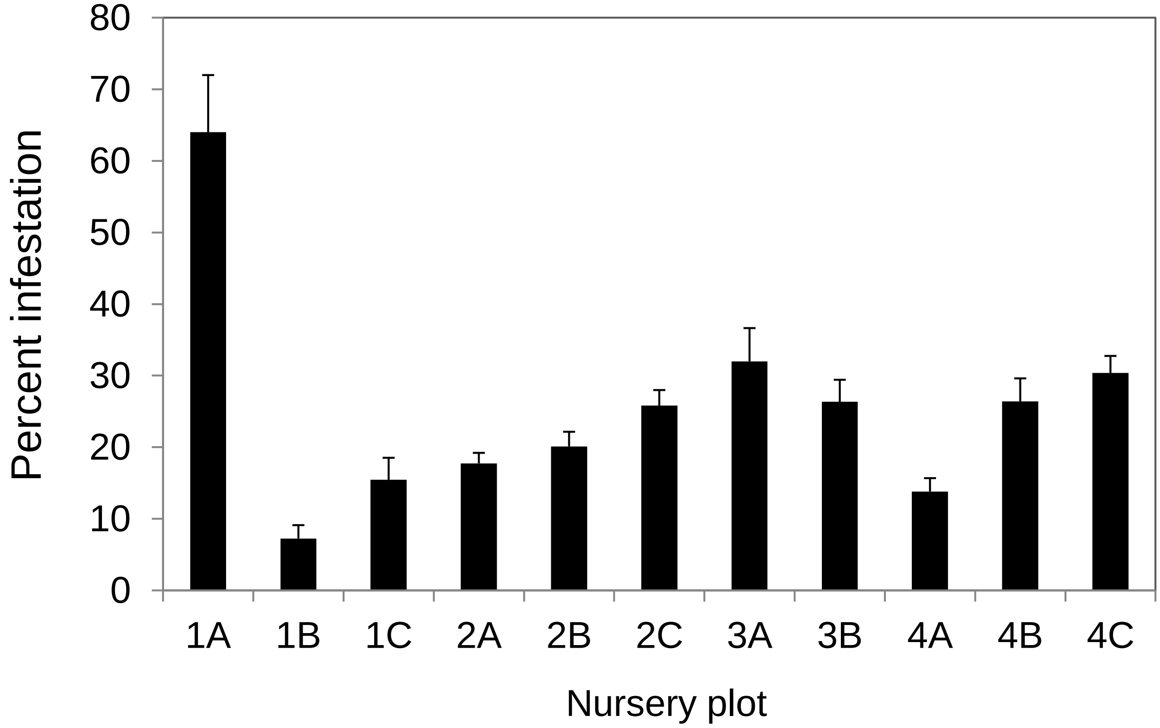

Figure 2.3. Percent infestation of blueberry gall midge (± S.E.) in Michigan blueberry nursery plots. Numbers 1-4 indicate different nurseries. Letters A, B, and C indicate different surveyed plots within nurseries.

Observational sampling for blueberry gall midge phenology

In 2009, a peak of infestation was found on July 30 (Figure 2.4), when an average of 6.5 ± 1.4 shoots showed signs of infestation. In 2010, multiple peaks of infestation were found June, July and August, with the largest (68% of green tips) occurring July 15 (Figure 2.5), with an average percent infestation of all green tips of 67.6 ± 13.4. The average number of vulnerable shoot tips available for infestation by blueberry gall midge was 35 ± 4.8 in the beginning of the growing season in May, and sharply decreased at the beginning of June to an average of one to three vulnerable shoot tips (Figure 2.7). The levels of infestation in the top, middle and bottom third of the bush show the same timing of the peaks of infestation (Figures 2.6 and 2.8)

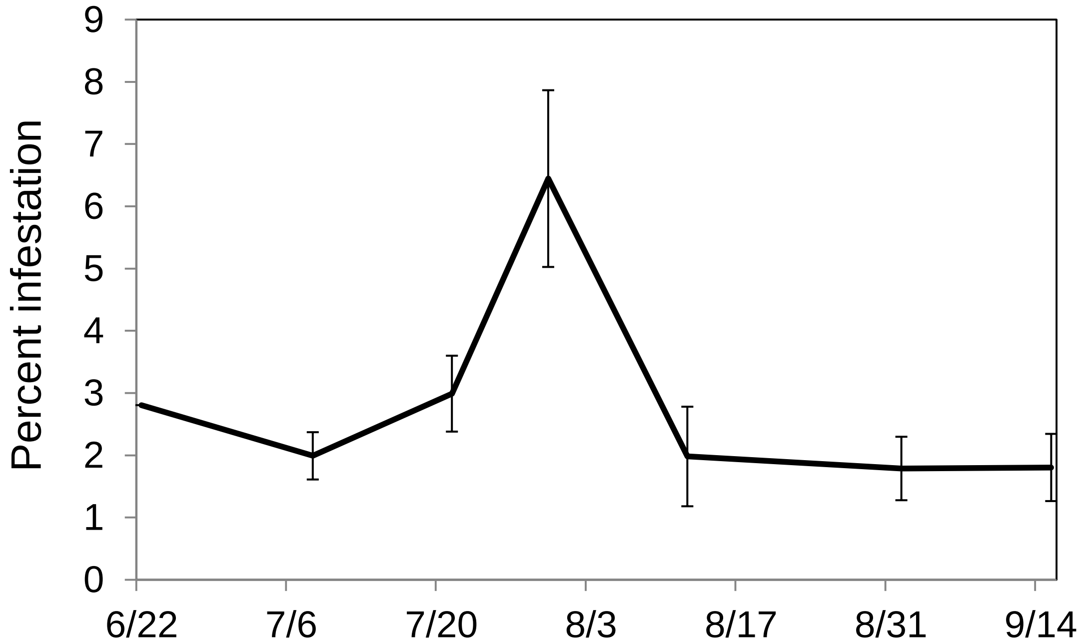

Figure 2.4. Variation in percent infestation (± S.E.) of new shoots by blueberry gall midge at Michigan farms during 2009. The number of growing new shoots was counted at the beginning of the growing season.

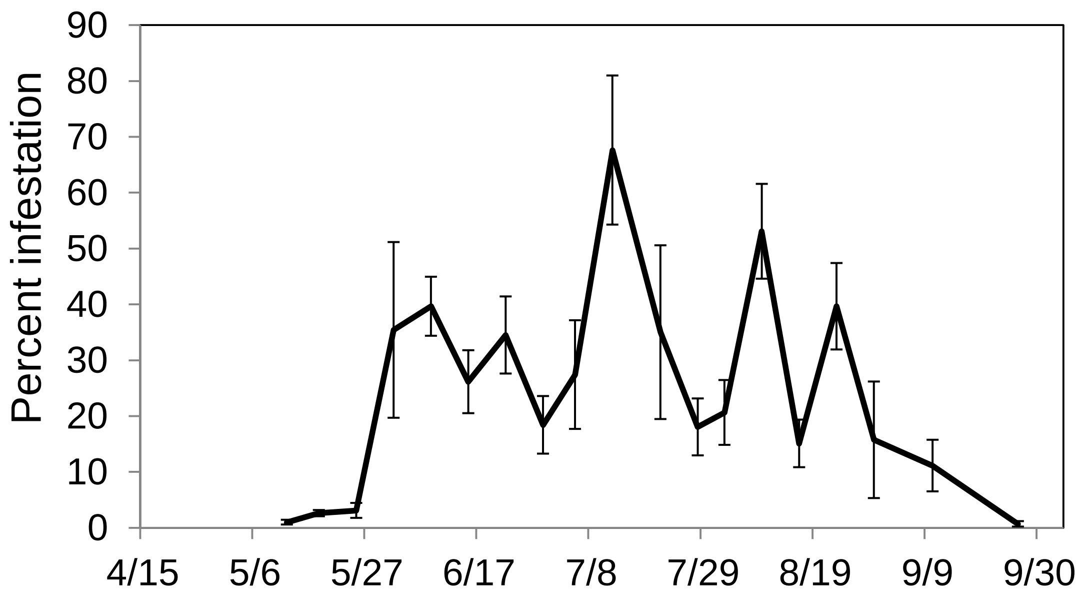

Figure 2.5. Variation in percent infestation (± S.E.) of elongating shoot tips by blueberry gall midge at Michigan farms during 2010. The number of vulnerable shoot tips was counted each week.

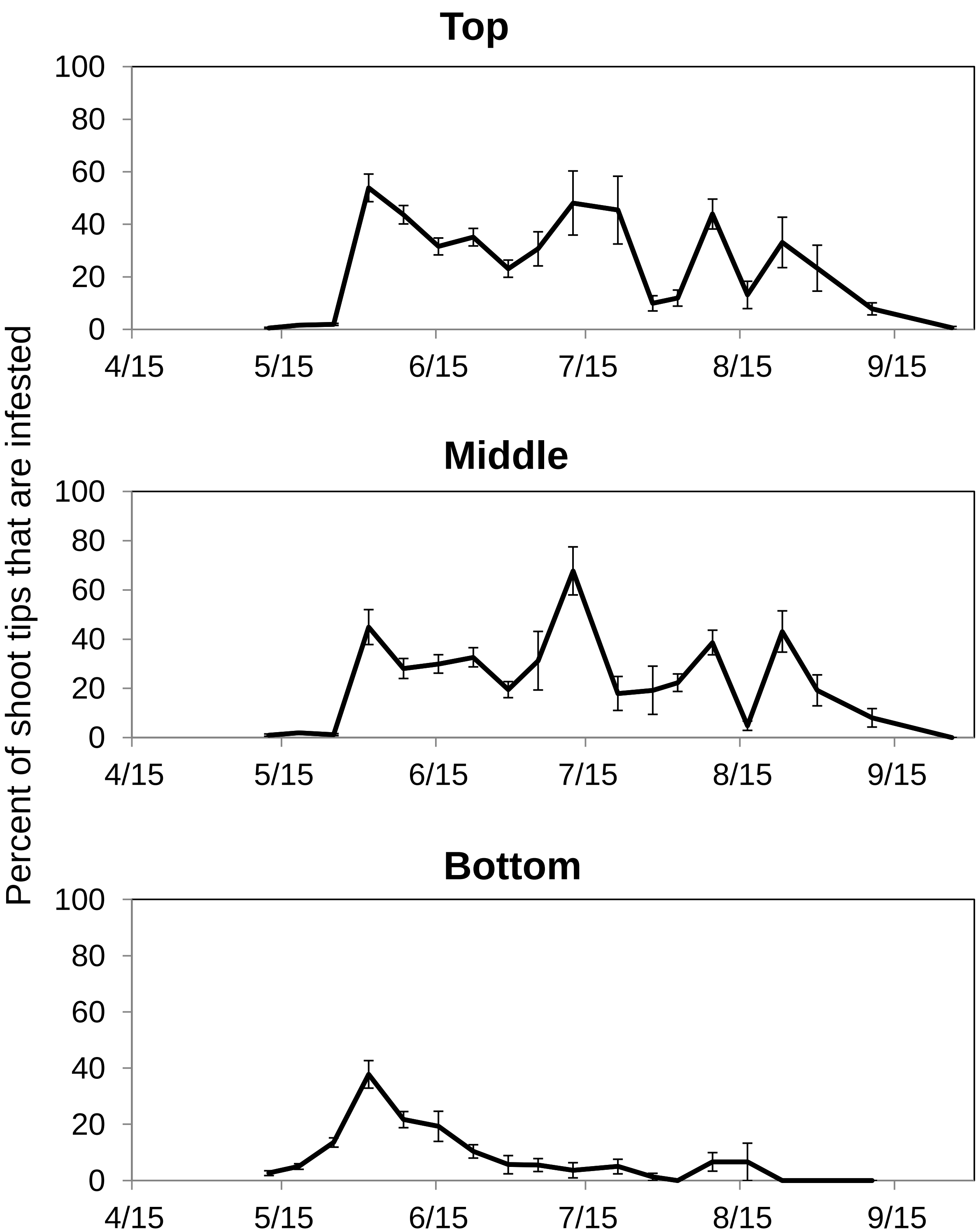

Figure 2.6. Variation in the percent infestation (± S.E.) on the top, middle and bottom third of blueberry bushes at Michigan farms during 2010.

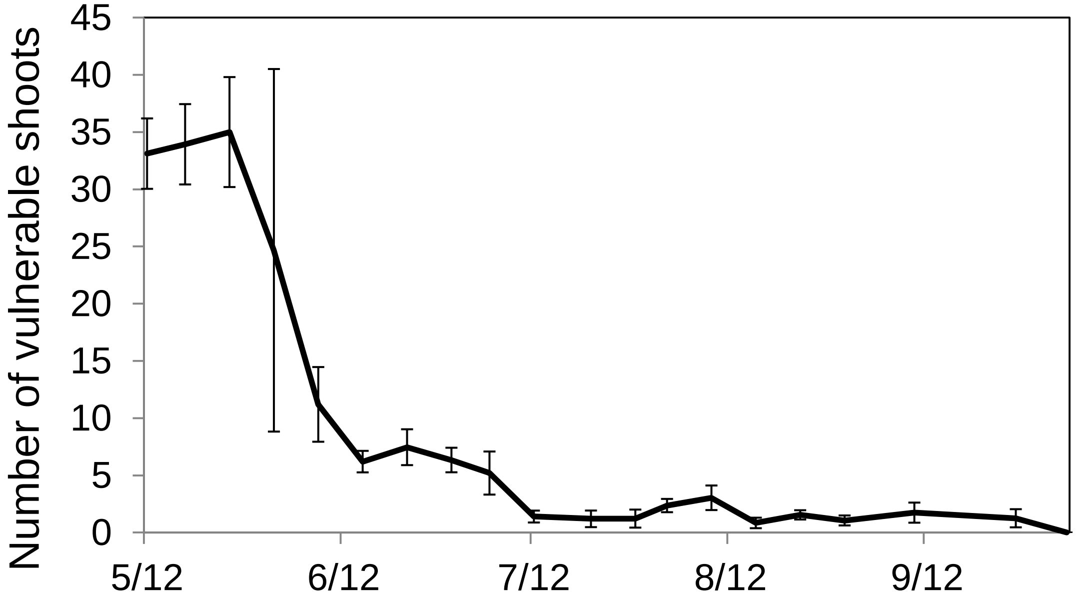

Figure 2.7. Variation in the number of vulnerable shoot tips (± S.E.) on blueberry bushes at Michigan farms during 2010.

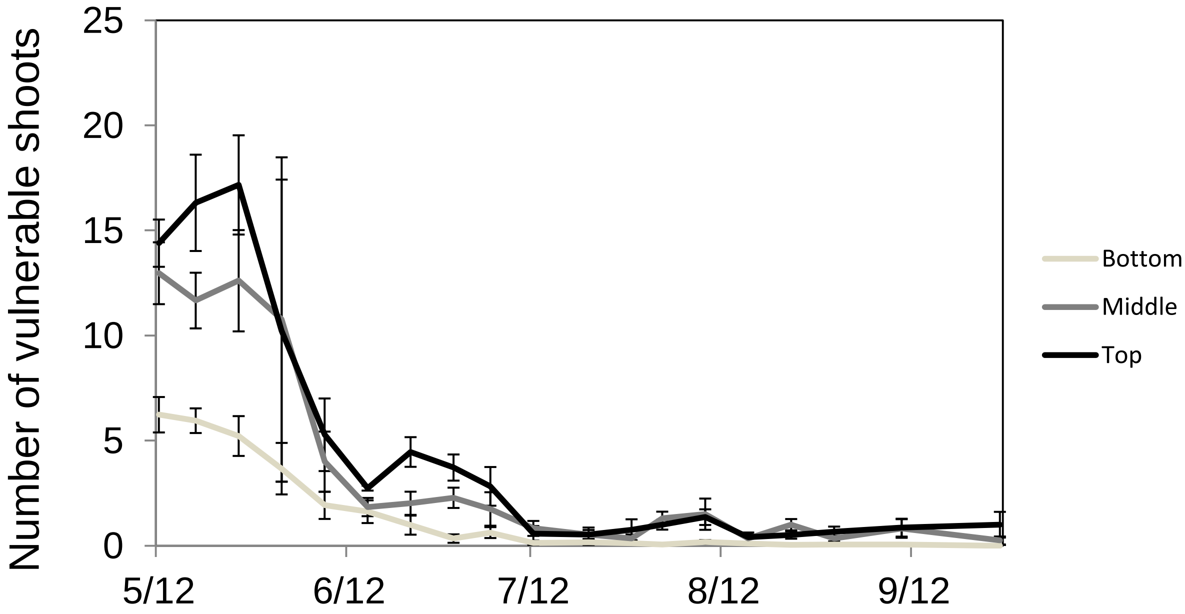

Figure 2.8. Variation in the number of vulnerable shoot tips (± S.E.) in the top, middle, and bottom third of blueberry bushes at Michigan farms during 2010.

Yellow sticky traps

Only seven blueberry gall midge adults were caught on yellow sticky traps (Figure 2.8) in 2010. Blueberry gall midge adults were trapped on yellow sticky traps from June 10 to July 23. Captures were low using this method, with these seven samples detected across 5 farms and 3 traps deployed each week for three months. Specimens were caught at four of the five farms.

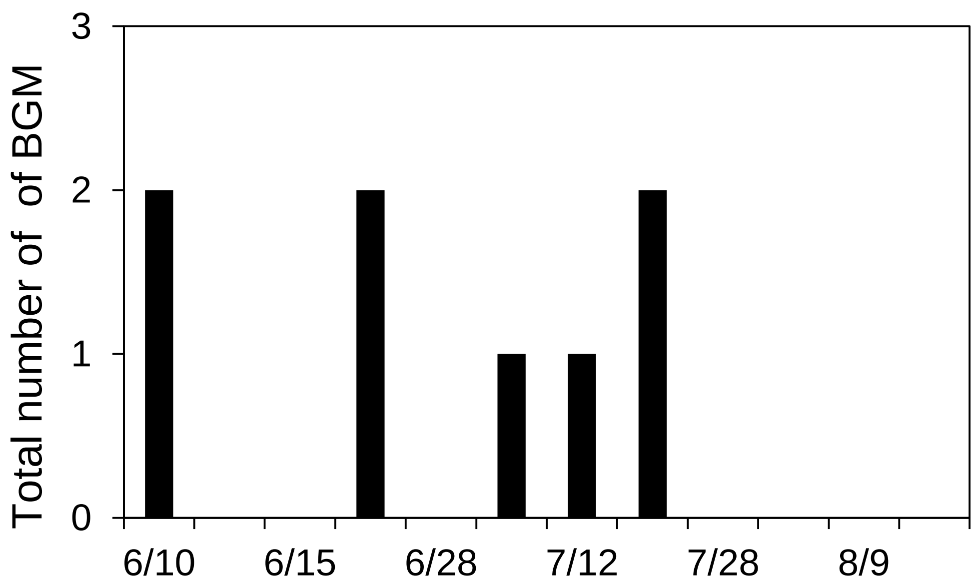

Figure 2.9. The total number of blueberry gall midge caught on yellow sticky traps placed in infested blueberry fields in 2010.

Emergence traps

Using emergence traps placed over soil under bushes, the first catch of a blueberry gall midge adult was on April 22, 2010, with peaks of emergence on May 24, July 5, and August 3 (Figure 2.9). When comparing aspects of the soil on which the traps were placed. In most months, aspect had no significant effect on blueberry gall midge captures. However, the east-west aspect had a significant effect on blueberry gall midge captures in the month of August, with a higher number of catches on the west aspect of the plant (χ = 4.37, df = 1, P = 0.04) (Table 2.5).

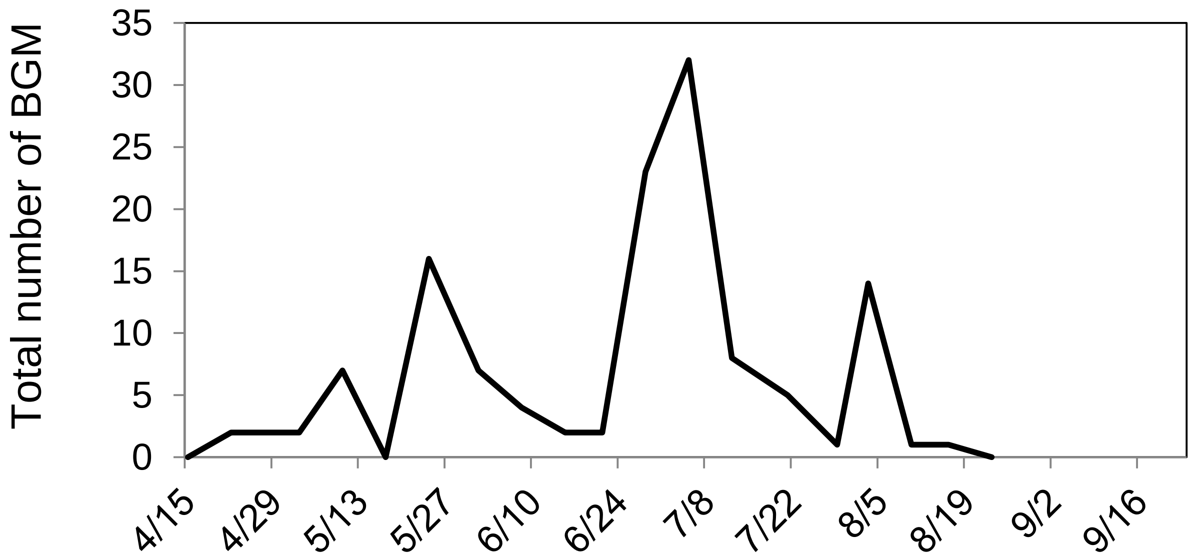

Figure 2.10. The total number of adult blueberry gall midge caught in emergence traps during 2010.

Table 2.5. Average number of adult blueberry gall midge (± S.E) caught in emergence traps at the east, west, north and south aspects at four fields on six randomly selected bushes during each month in 2010.

Month	Soil aspect	Avg. number of BGM
April	E	0.04 ± 0.04
	W	0.0 ± 0.0
	N	0.0 ± 0.0
	S	0.04 ± 0.04
May	E	0.11 ± 0.07
	W	0.20 ± 0.18
	N	0.10 ± 0.05
	S	0.13 ± 0.07
June	E	0.17 ± 0.09
	W	0.36 ± 0.15
	N	0.08 ± 0.04
	S	0.08 ± 0.04
July	E	0.44 ± 0.26
	W	0.33 ± 0.14
	N	0.16 ± 0.09
	S	0.02 ± 0.02
August	E	0.03 ± 0.03
	W	0.25 ± 0.12
	N	0.04 ± 0.03
	S	0.08 ± 0.05

Shoot tip dissections

There were multiple peaks of larval infestation in the dissected shoots, from June through August 2010. The largest peak of larval infestation was on July 15 (Figure 2.10). First instar larvae were present throughout the season and reached a peak in June. The number of 2nd and and 3rd instar larvae was lower in May and increased later through the season until late-August (Figure 2.11). There were significantly more blueberry gall midge larvae found in mottled and green shoot tips than in the black shoot tips (F = 4.33, df = 2,57, P = 0.018) (Figure 2.12). The estimated number of larvae per bush was highest on June 6, 2010, with 32.6 ± 23.2 larvae per bush (Figure 2.13). This number steadily decreased until the end of sampling.

Growing Degree Days

From the 2009 observational sampling data, growing degree days from March 1st to the largest peak of adult emergence was 1383 at a base temperature of 50 ˚F. From the 2010 observational sampling data, growing degree days to the largest peak of emergence was 1317 at a base temperature of 50 ˚F. Growing degree days to the largest peak of larval infestation in 2010 was 1369 at a base temperature of 50 ˚F.

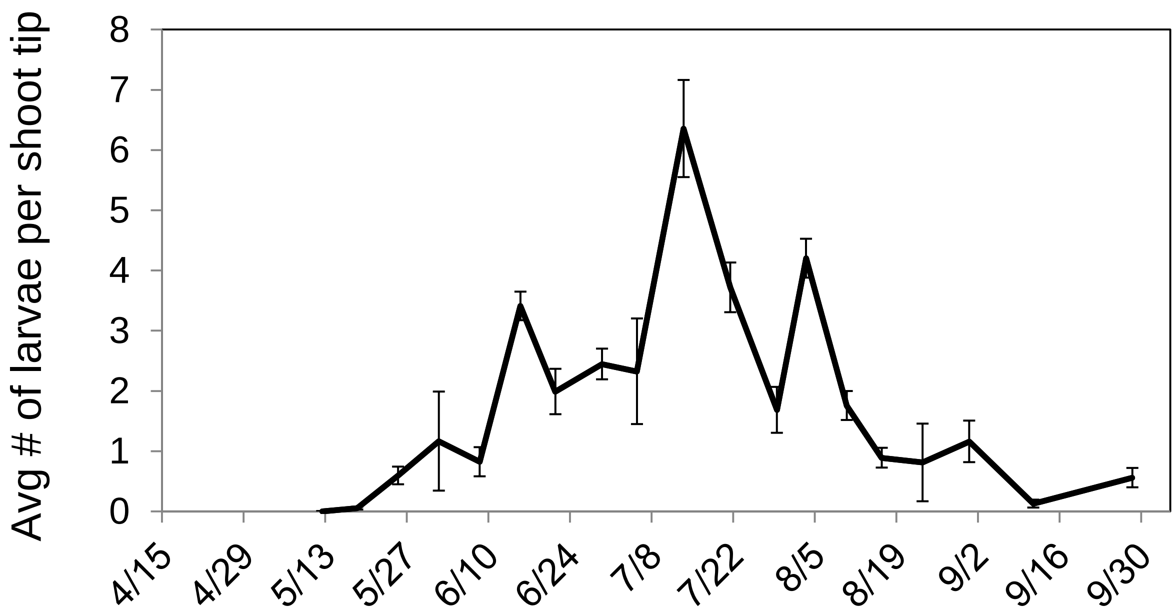

Figure 2.11. Variation in the number of blueberry gall midge larvae (± S.E.) from dissections of shoots collected at infested blueberry fields in 2010.

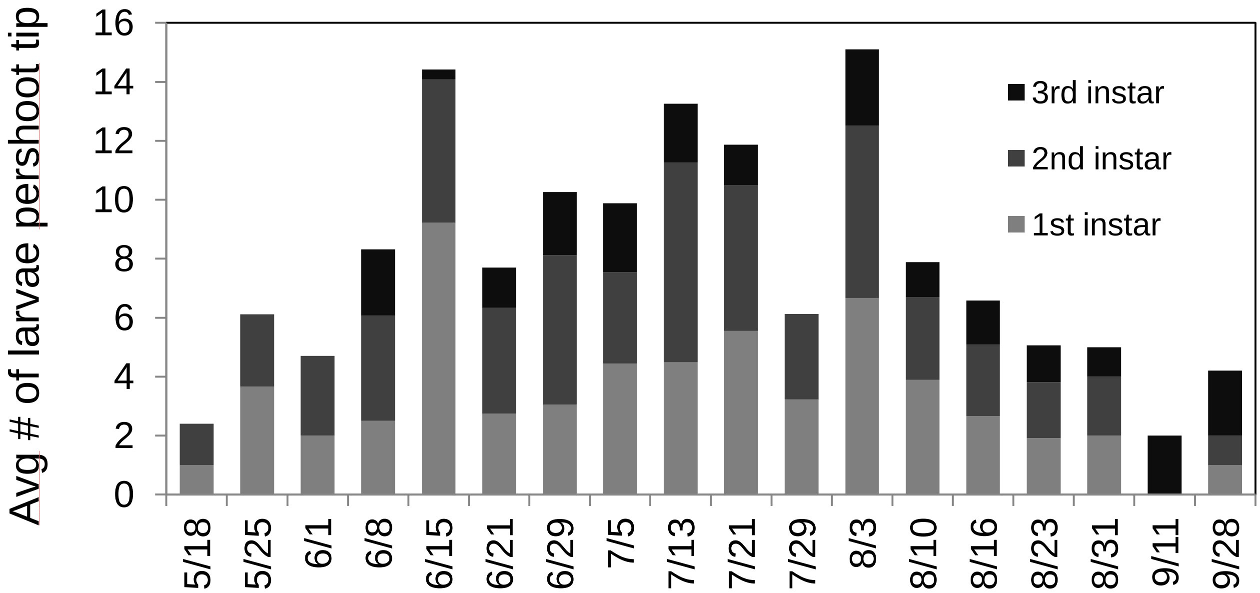

Figure 2.12. The number of blueberry gall midge larvae found in shoot tips of blueberry shoots, separated by instar.

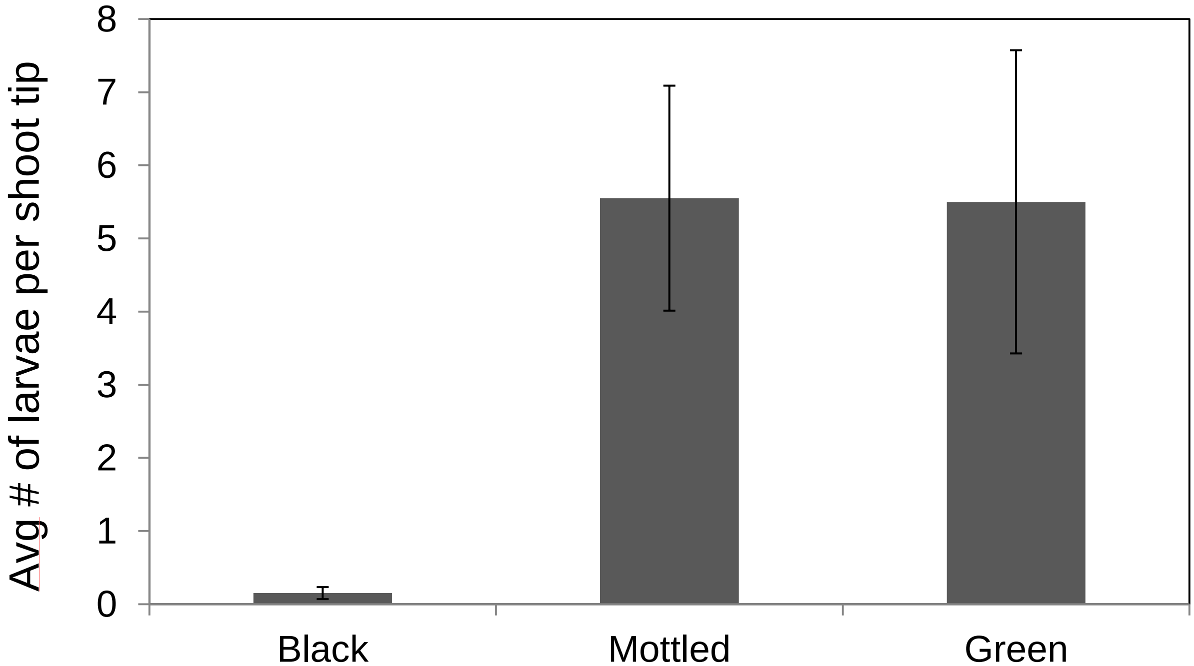

Figure 2.13. Average (± S.E.) number of blueberry gall midge larvae found in shoot tips of differing colors.

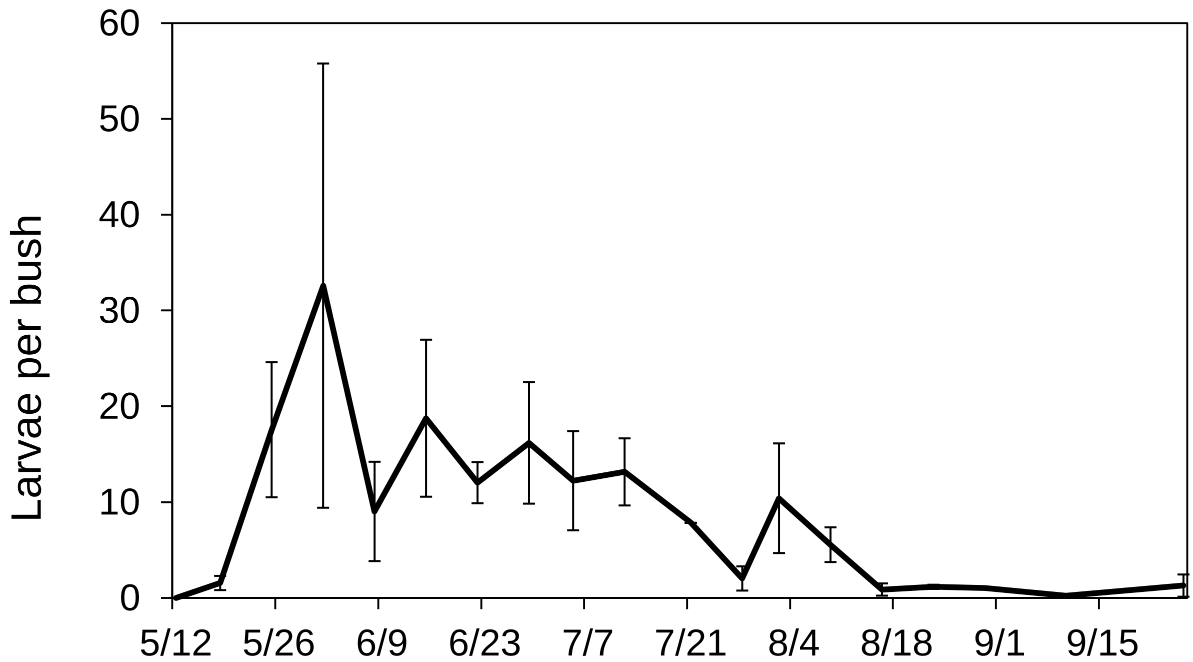

Figure 2.14. Estimate of the number of blueberry gall midge larvae per bush (± S.E.) in 2010.

DISCUSSION

Blueberry gall midge was present in almost all of the surveyed farms and in all of the surveyed nurseries. This was also true in Washington state, where a smaller survey of 21 farms was conducted (B. S. Gerdeman, personal communication). There was also a significantly higher percent infestation in nurseries than in farms. This is most likely due to the increased prevalence and encouragement of new shoot growth in nurseries compared to established blueberry farms. It may also be a reflection of the lower level of insecticide use in nurseries, as a result of these sites not requiring protection of fruit from insect pests. The high infestation rate within nurseries would facilitate introduction and dispersion of blueberry gall midge to farms in the state and country that buy bushes from nurseries.

Infestation levels also varied considerably among farms and nurseries sampled. Blueberry gall midge has multiple generations and peaks of emergence during the growing and harvesting seasons. Since this surveying was conducted over a period of two months, surveying days may have been concurrent with a range of midge emergence and infestation, resulting in the observed variability. Additionally, during some of the late surveying dates in July and August, there was little to no new shoot growth on the bushes, and fewer reproduction sites for blueberry gall midge.

The earliest catch of blueberry gall midge in 2010 was on April 22, just before bud-break, using the emergence trap sampling method. Peaks of emergence and infestation occurred through July and August. In Florida, where blueberry gall midge is an economically important pest of rabbiteye blueberry, initial catch was as early as January 14, with peaks of adult emergence on March 21 (Roubos and Liburd 2010). There, the growing and harvest season are much earlier than in Michigan. In lowbush blueberries in Nova Scotia, blueberry gall midge larvae were present in high levels through July and August (Reekie et al. 2009). The estimated number of larvae per bush was highest in early June, and even with low numbers of larvae per shoot, the high number of growing shoot tips offered the adults numerous reproduction sites. As the season progressed, the number of shoot tips decreased, but the number of larvae per shoot tip increased. This allowed blueberry gall midge to maintain steady populations between 10 and 20 larvae per bush until August. With individual blueberry fields containing hundreds of bushes, there may be thousands of blueberry gall midge. At the beginning of the growing season, there is a large flush of new growth and occasional flushes of growth at varying times during the season, depending on the rainfall conditions. If there were to be a large flush of growth later in the season, adult midges would have the reproductive sites needed to quickly establish high populations.

During my sampling, all monitoring methods except for the yellow sticky traps indicated greater infestation by blueberry gall midge in July than in other months. However, at that time, there was a very small amount of vulnerable tissue compared to the beginning of the growing season in May. The yellow sticky traps were not an effective method for trapping blueberry gall midge, possibly because they were not close enough to the vegetative shoots, or because they were not placed on heavily infested bushes. The flies may also not be attracted to yellow. Emergence traps had more adult catches than yellow sticky traps, and were the first monitoring technique to detect adult midges during the season. Although some of these traps were destroyed by harvesters and sprayers, they could still prove to be an effective method for growers to determine the initial emergence of this pest in the spring to help identify when to protect bushes from this pest.

There was a significantly higher catch in the emergence traps placed on the west aspect of bushes in August. This could indicate that blueberry gall midge pupal survival is better when the sun is heating the soil later in the day. All blueberry gall midge caught in August were caught in five individual traps, pointing to within-field variability.

Vegetative shoot dissection was an effective method to determine the number of blueberry gall midge larvae present, and was the quickest way to confirm the presence of gall midge in a field. However, growers are unlikely to adopt shoot dissections to look for eggs and early-instar larvae because it is time consuming and requires a high-power microscope. This method helps to pinpoint an ideal time to target the larval stage of the blueberry gall midge, and may be a useful method for consultants and extension agents to help identify infestations. The pink 2-mm 3rd instar larvae are easy to spot with a hand lens, but they are not common until late in the season. Additional research to examine the relationship between temperature accumulation and infestation may provide a more practical way to identify risk periods from this pest. Knowing the initial peak times of larval infestation will be useful in conjunction with the use of insecticides effective at controlling blueberry gall midge. Many blueberry farms apply multiple insecticide treatments at different times of the season to control blueberry maggot, cherry fruitworm and Japanese beetle. At all monitored farms, insecticide sprays were applied days before peak larval infestation and adult emergence. It is possible that some of these sprays are in fact controlling blueberry gall midge, but that their numbers are so high that they are able to repopulate within a short period of time. Since no unmanaged fields were monitored in this study, whether or not this is true is unknown.

The growing degree days calculated from the Enviroweather weather stations can be used to determine peak blueberry gall midge activity for targeting it with control measures. The growing degree days corresponding with the largest peak of adult emergence in 2009 and 2010 were around 1300; a third year of growing degree day data and additional studies in controlled growth chambers would be useful to determine a more accurate estimate. These studies on blueberry gall midge biology and monitoring will aid in the development of a management plan for blueberry gall midge.

CHAPTER 3

BIOLOGICAL AND CHEMICAL CONTROL OF BLUEBERRY GALL MIDGE (*DASINEURA OXYCOCCANA*) IN MICHIGAN BLUEBERRIES

ABSTRACT

Blueberry gall midge, *Dasineura oxycoccana* (Johnson) is a potential pest of *Vaccinium* crops, including blueberry and cranberry, in Michigan. Although insecticide-based management may be able to control key pest species, use of broad-spectrum pesticides could additionally decrease natural enemy populations, leading to pest outbreaks. To evaluate new insecticides for control of blueberry gall midge, a laboratory bioassay was conducted using infested shoots and a Potter spray tower to apply acetamiprid, cyazypyr, methomyl, phosmet or spirotetramat. A field trial was also conducted to compare the efficacy of acetamiprid, cyazypyr, cypermethrin, methomyl, phosmet, spinetoram, spirotetramat. In the bioassay, all of the insecticides were effective at killing blueberry gall midge, whereas in the field trial, none of the insecticides significantly reduced the level of infestation. Parasitoids and natural enemies of blueberry gall midge were surveyed at field sites using shoot tip dissection and observational sampling. Shoots were also collected to allow for adult midge and parasitoid emergence. Although no natural enemies were found through observational sampling, shoot tip collection for rearing of parasitoids yielded eight *Apostocetus* and one *Platygaster*, and shoot tip dissections yielded two specimens of *Synopeas synopeas*.

INTRODUCTION

Blueberry gall midge, *Dasineura oxycoccana* (Johnson) is a pest of blueberries in Florida (Lyrene and Payne 1992). Information gathered from scouts, growers and personal observations indicate that its population in Michigan blueberries is increasing. Midges are small flies of the family Cecidomyiidae, and gall wasps in this group induce the creation of gall tissues in their host plants. One of the most damaging gall midge pests in North America is the Hessian fly, *Mayetiola destructor*, an invasive species that infests cereal crops. The Hessian fly has caused yield reductions of up to 50% of dry matter yield of red winter wheat (Buntin and Raymer 1989). Blueberry gall midge, which attacks and kills the flowering and vegetative buds of growing shoots, has been cited as one of the most damaging pests of rabbiteye blueberries (*Vaccinium ashei* Reade) in Florida, causing up to 90% mortality in flowering buds (Lyrene and Payne 1992) and it is known to affect cranberry (*Vaccinium Macrocarpon*) as well. It has a rapid generation time; larvae remain in buds for one to two weeks before pupating. The larvae feed on plant juices, damaging the shoot tip meristematic tissues, and their damage becomes visible as dark shoot tips 7-12 days after infestation. The impact of the fly's increase in population and its biology in the main blueberry production region of Michigan is unknown.

Observations by growers and scouts have indicated that secondary pests such as blueberry gall midge have recently increased in abundance in Michigan blueberries. This could be a response to the reduced use of broad-spectrum insecticides such as azinphosmethyl in preparation for banning of the use of this product in 2012 and the development of IPM programs relying on new selective insecticides. This larger population of blueberry gall midge has resulted in high levels of damage to young vegetative shoot tips, which can induce lateral branching similar to witches' broom (Tanigoshi et al. 2010).

Although the economic impact of blueberry gall midge is not yet known in Michigan (see Chapter 4), if it is found to be economically damaging, it would be valuable to have developed effective control measures. Non-insecticidal methods of controlling blueberry pests such as mass trapping with pheromone traps, reliance on biological control agents, and use of resistant cultivars are not commonly employed in commercial blueberry farms in Michigan. To reduce the frequency of pesticide application, it would be useful to know whether current spray programs targeting major blueberry pests such as blueberry maggot and Japanese beetle will provide some control of blueberry gall midge. Although spray programs are able to eliminate pest species, they can also have detrimental effects on the pests' natural enemies (Croft and Brown 1975; Theiling and Croft 1988), and may have significant sub-lethal effects on hymenopteran parasitoids (Williams et al. 2003; Desneux et al. 2007).

Insecticide treatments for control of blueberry gall midge in blueberries have been evaluated in Mississippi, Florida, and Washington. In Mississippi, bench-top bioassays found that phosmet and spinosad cause approximately 50% mortality of larvae in bud galls. Malathion was found to be very effective, killing 94% of larvae in treated bud galls (Sampson et al. 2002). Field insecticide trials in Florida found a significant decrease in blueberry gall midge larval infestation in bushes treated with diazinon or malathion (Finn 2003). In a field insecticide trial conducted in Washington blueberries, spirotetramat and cyazypyr were found to reduce levels of blueberry gall midge larvae (Tanigoshi et al. 2010). In cranberries, azinphosmethyl and phosmet were found to control blueberry gall midge (Mahr 2005).

Parasitoids of blueberry gall midge were studied in Mississippi rabbiteye blueberries (Sampson et al. 2006). Three platygastrids of the genera *Synopeas*, *Platygaster* and *Inostemma* and one Eulophid of the genus *Aprostocetus* were collected from midge larvae and described. No information of blueberry gall midge parasitoids is available in populations in the Midwest. Although insecticide studies have been conducted (Sampson et al. 2002, Tanigoshi et al. 2010), many pesticides remain to be tested. Here, I study the effect of various insecticides on blueberry gall midge damage in lab bioassays and a field trial. Parasitoids affecting blueberry gall midge were also collected to determine the potential for biological control of this pest.

METHODS

Bioassay

A bioassay was performed using 400 shoot tips infested with blueberry gall midge collected from six untreated rows (~1/10 acre) of highbush blueberry cultivar 'Bluecrop' at the Southwest Michigan Research and Education Center in Benton Harbor, MI. This mature planting is located in sandy soil in Berrien County, Michigan. The bioassay was conducted at the Trevor Nichols Research Complex in Fennville, MI on a still, calm day. The experimental design consisted of eight treatments (Table 3.1), and 10 replicates, each containing five shoots tips infested with blueberry gall midge that were placed on a Petri dish. A Potter Spray Tower was used to apply the insecticide to the dishes. The shoot tips were then flipped and treatments reapplied to ensure coverage of insecticide.

Table 3.1. List of insecticides used for the bioassay of blueberry gall midge.

Treatment	Trade name	Rate per acre
water control		
acetamiprid	Assail	5.3 oz
cyazypyr	Cyazypyr	10.0 oz
cypermethrin	Mustang Max	4.0 oz
methomyl	Lannate	3.0 pt
phosmet	Imidan	1.33 lb
spinetoram	Delegate	3.0 oz
spirotetramat	Movento	8.0 oz

Treatments (Table 3.1) consisted of one rate of acetamiprid 30SG (Assail 30SG at 5.3 oz/acre), cyazypyr 10SE (10 oz/acre), spinetoram (Delegate 25WG at 3 oz/acre), phosmet (Imidan 70 WP at 1.33 lbs/acre), methomyl (Lannate 2.4LV 3 pt/acre), spirotetramat (Movento 2SC at 8 oz/acre), cypermethrin (Mustang Max 0.8EC at 4 oz/acre), and a control of water. All treatments were applied to shoots on June 23, 2010 using a Potter spray tower.

After insecticides were applied, shoot tips were transferred to non-vented Petri dishes layered with filter paper and a 1-inch diameter circle of fine sand as a pupation substrate. All dishes were kept at room temperature for two weeks until all blueberry gall midges had emerged. Water from a spray bottle was used to keep the samples moist. All blueberry gall midge adults were allowed to emerge, and were then collected and counted.

Field insecticide trial

This study was performed in three untreated rows of highbush blueberry bushes cultivar 'Bluecrop' at the Southwest Michigan Research and Education Center in Benton Harbor, Berrien County, MI. This planting is established in sandy loam soil. The experimental design consisted of five treatments (Table 3.2), with four replicates arranged in a completely randomized design. Each replicate contained 13 bushes, one bush for each of the treatments with one buffer bush in between treatments. The rows were 10 feet apart and each bush was 4 feet apart within rows.

Treatments, listed in Table 3.2 were applied on May 4, May 19, June 1, and June 16 in 2010 on sunny, low-wind days using a CO_2 backpack sprayer (R&D Sprayers) equipped with a single TeeJet nozzle. By May 4, no visible sign of blueberry gall midge damage was apparent. However, the insect was caught in an emergence trap earlier that week, prompting the start of treatment applications. They consisted of one rate of acetamiprid (Assail 30SG at 5.3 oz/acre), cyazypyr 10SE (20.5 oz/acre), phosmet (Imidan 70WP at 21.3 oz/acre), and two rates of spirotetramat (Movento 2SC at 5 oz/acre and 8 oz/acre) and water as a control.

Table 3.2. List of insecticides used for the field insecticide trial of blueberry gall midge.

Treatment	Trade name	Rate per acre
Water/Control		
acetamiprid	Assail	5.3 oz
cyazypyr	cyazypyr	10.0 oz
phosmet	Imidan	1.33 lb
spirotetramat	Movento	5.0 oz
spirotetramat	Movento	8.0 oz

Plots were sampled on the Mondays or Tuesdays following treatment on May 10, May 17, May 24, June 1, June 8, June 15, June 22. During sampling, each bush was examined for damage and the number of damaged shoots and the number of elongating green shoots was counted. The proportion of infested shoots in each treatment was calculated.

Survey for natural enemies and parasitoids

In 2010, once every week from the beginning of the growing season until the end of August, shoot tips were collected at each of five blueberry fields with a history of infestation by blueberry gall midge, located in Berrien and Van Buren counties in Michigan. Four of these fields were at conventionally managed blueberry farms. Three of these contained blueberries of the cultivar ‘Bluecrop.’ One of them contained blueberries of the cultivar ‘Earliblue.’ The fifth blueberry field was at the Southwest Michigan Research and Extension Center located in Benton Harbor, MI, and was also of the cultivar ‘Bluecrop.’ At each of these fields, a 200-bush block of blueberries was flagged at the beginning of the growing season. Each week, up to 30 growing, green shoot tips were selected from randomly chosen bushes. If these bushes did not have any shoot tips, a shoot tip was selected from an adjacent bush. Some weeks, there were very few or no green shoot tips found. Shoot tips were placed in a one quart Ziploc® plastic bag and immediately placed into a cooler to prevent larval emergence.

In the laboratory one day after collection, the shoot tips were removed from the plastic bag and placed into non-vented Petri dishes layered with moist filter paper and with a small circle of fine sand as a pupation substrate. Each Petri dish contained up to five shoot tips. Any remaining larvae that had emerged from the shoot tips were removed from the bags and placed onto a Petri dish with filter paper and sand. The Petri dishes were held in the laboratory at 22˚ C and 25% humidity; to prevent desiccation, every one to two days, the Petri dishes were misted with water, taking care to prevent larvae from escaping. After the shoot tips were in the Petri dishes for one week, they were removed to reduce mold. Petri dishes were inspected for larvae and pupae using a high-powered dissection microscope. Adult blueberry gall midge and parasitoids were allowed to emerge about two to three weeks after shoots were placed into the Petri dishes. The number of adult midges and parasitoids was counted, and parasitoids were collected and shipped to Dr. Blair Sampson for identification.

During observational sampling for shoot tip damage (Chapter 2) at five sites each week, interactions between natural enemies and infested shoots were recorded. Any syrphid flies, lady beetles, and parasitoids were noted. Observations examined 30 bushes and typically took 30 minutes. Also, during shoot tip dissections (Chapter 2), any parasitoids found were collected and reserved for identification.

Statistical Analysis

Data from the laboratory bioassay were used to compare the number of emerged adult midges among treatments. The average number of blueberry gall midge per replicate Petri dish was square root transformed and compared among treatments using the Wilcoxon rank-sum test (JMP 8.0.2, Cary, NC). Data from the field insecticide trial was used to compare the proportions of infested shoots among treatments. The proportions were arcsin transformed and compared among treatments using analysis of variance (JMP 8.0.2, Cary, NC). Values for parasitoids and other natural enemies were too low for statistical analysis.

RESULTS

Bioassay

When treated in the bioassay, significantly fewer blueberry gall midge emerged in the insecticide treatments when compared to the control (Table 3.3) ($\chi^2 = 35.1$, df = 7, $P > \chi^2 = 0.0001$). There were no differences among insecticides in the number of gall midge that emerged, although there was low survival in the cyazypyr treatments compared with no survival in the other insecticide treatments. These results show that all insecticide treatments have activity on blueberry gall midge under these controlled conditions.

Table 3.3. Average number of blueberry gall midge adults emerging (± S.E.) after treatment with different insecticides. Values followed by the same letters were not significantly different.

Treatment	**# of *D. oxycoccana***
water/control	2.1 ± 1.3 A
acetamiprid	0.0 ± 0.0 B
cyazypyr	0.3 ± 0.2 AB
cypermethrin	0.0 ± 0.0 B
methomyl	0.0 ± 0.0 B
phosmet	0.0 ± 0.0 B
spinetoram	0.0 ± 0.0 B
spirotetramat	0.0 ± 0.0 B

When insecticides were compared under field conditions, there were no significant differences among treatments at any sampling date (Table 3.4). There were no strong trends in the data that suggest any of the treatments would control blueberry gall midge. There was no significant difference between the treatments and the controls on the 6/1 sampling date ($F = 0.52$, $df = 5,18$, $P = 0.76$) and the 6/22 sampling date ($F = 0.48$, $df = 5,18$, $P = 0.79$).

There were no natural enemies found through observational sampling. The shoot collection for adult emergence yielded nine parasitoids of the family Eulophidae. Eight of them were female *Apostocetus* and one was a male *Platygaster*, the species of which are not described yet. Two *Synopeas synopeas* parasitoids were found during the shoot dissections (Chapter 2), from collected on 7/13/2010.

Table 3.4. Average (± S.E.) proportion of susceptible shoots infested with blueberry gall midge per bush as a function of insecticide treatments applied during the spring of 2010. There was no significant difference between the treatments and the controls on any sampling date.

Treatment	**Rate per acre**	**5/10**	**5/17**	**5/24**	**6/1**	**6/8**	**6/15**	**6/22**
Vulnerable shoots per bush		12.5 ± 1.4	9.6 ± 0.8	9.8 ± 0.9	2.3 ± 0.3	1.1 ± 0.4	0.2 ± 0.1	3.2 ± 0.6
Water/control		0	0	0	0.5 ± 0.2	0	0.2 ± 0.2	0.4 ± 0.2
Acetamiprid	5.3 oz	0	0	0	0.2 ± 0.1	0.1 ± 0.1	0	0.8 ± 0.1
Cyazypyr	20.5 oz	0	0	0	0.4 ± 0.2	0	0	0.5 ± 0.2
Phosmet	1.33 lb	0	0	0	0.2 ± 0.1	0.2 ± 0.2	0	0.5 ± 0.2
Spirotetramat	5 oz	0	0	0	0.1 ± 0.1	0.1 ± 0.1	0	0.5 ± 0.3
Spirotetramat	8 oz	0	0	0	0.2 ± 0.2	0.1 ± 0.1	0	0.7 ± 0.2

DISCUSSION

Our findings indicate that insecticides provided significant control of blueberry gall midge larval development into adults in the laboratory bioassay, but not in the field. Insecticides were chosen from a range of chemical classes that have different modes of action, all requiring contact or ingestion. All of the insecticides in the bioassay reduced adult emergence from infested shoots, providing high or complete control of larval development to pupae. This assay allowed us to determine the insecticides' activity under a controlled setting when blueberry gall midge was most abundant while eliminating the effects of drift and rain that could affect insecticide efficacy in the field.

It is difficult to judge the effectiveness of the insecticides from the field trial. Although there were no significant effects of treatment, this could have been due to several factors. The blueberry bushes used were not pruned in 2009, and thus produced few susceptible green shoots in 2010. Pruning controls for plant growth and also encourages new cane development and allows for increased photosynthesis (Gough 1994). On each sampling date, each bush had between zero and three susceptible vegetative shoots, which affected our ability to measure differences among treatments. This lack of resources would cause the plot to be a poor refuge for blueberry gall midge reproduction. Fields at other locations had a greater number of vegetative shoots at the same time as the trial. Although Chapter 2 indicates a high number of susceptible shoots through May and early June, this was not the case at this particular site. Additionally, the blueberry gall midge is an insect that has multiple overlapping generations throughout the season. Since the bushes were treated with a foliar application of insecticides once every two weeks, adults could have emerged from pupae in the ground and infested shoots after pesticide residue had diminished. Future studies should be timed with periods of greatest infestation, using the monitoring techniques used in Chapter 2 to focus on proper application timing.

In Washington State, a foliar efficacy trial was run in which a greater number of replicate bushes were included in each treatment, and the number of blueberry gall midge larvae was assessed every four days after treatment (Tanigoshi et al. 2010). They found significant decreases in larval abundance in bushes treated with cyazypyr and spirotetramat at both nine and 13 days after treatment. However, sampling at further dates showed no significant differences among treatments. In Florida, diazinon and malathion were found to be effective insecticides (Finn 2003). In both of these studies, insecticide applications were done once populations of blueberry gall midge were established, and these results indicate that conventional and reduced-risk insecticides can provide some short-term control of blueberry gall midge. In these studies, entire bushes were treated, targeting the adults and larvae. Treatments targeting the pupae in the soil have not been tested. Winter sanding of blueberry beds has been shown to reduce the number of first generation adult midges (Mahr 1990). Additionally, cultivar resistance to blueberry gall midge has not been investigated.

While we found no natural enemy interactions through observational sampling, nine parasitoids were found from the adult emergence in Petri dishes and two more were found through the shoot dissections described in Chapter 2. While identifying the parasitoids collected in Michigan, Blair Sampson (USDA-Poplarville) noted that they were almost twice the size of blueberry gall midge parasitoids of the same genus in Mississippi. He also noted that the larvae and adult midge samples from Michigan were larger than those found in Mississippi. The parasitoid complex in Michigan is similar to that of the complex in Mississippi, with *Synopeas*, *Platygaster*, and *Synopeas* species all occurring in blueberry gall midge both states (Sampson et al. 2006).

In Mississippi blueberry nurseries, percent parasitism by parasitoids of the genus Platygastridae reached up to 40 % immediately after peaks of blueberry gall midge larval infestation during flower and vegetative bud development (Sampson et al. 2006). This rate was considered very high, but could be due to the nature of blueberry nurseries, with many vigorously growing plants in a small space. Nurseries also receive little to no insecticide treatments compared to conventional farms. The low rate of parasitism on Michigan blueberry farms could be attributed to the low survival rate of midges. The low number of midges collected in this study may not have been sufficient to detect parasitoids. Future studies should increase the sampling size of midge larvae and use more refined methods of adult midge and parasitoid rearing to calculate percent parasitism.

To avoid killing natural enemies and parasitoids, knowledge about their life cycle and biology is crucial to avoid injury from insecticide application. With the lack of information regarding parasitoids and natural enemies of blueberry gall midge in Michigan blueberries, and the low numbers of parasitoids found thus far, it is difficult to recommend when insecticide sprays should be applied to prevent blueberry gall midge infestation without harming parasitoids. Although blueberry gall midge parasitoid numbers were found to be low in Michigan, it is encouraging to know that they are present despite the reliance on chemical control. If blueberry gall midge is found to be economically damaging, it would be wise to make efforts to conserve natural enemy and parasitoid populations to avoid the need for application of chemical insecticides.

Chapter 4

ECONOMIC IMPORTANCE OF BLUEBERRY GALL MIDGE IN HIGHBUSH BLUEBERRIES

ABSTRACT

Blueberry gall midge, *Dasineura oxycoccana*, is a potential pest of blueberries in Michigan that has damaged blueberries in Florida, destroying up to 90% of all flower buds in some fields. Economic damage from blueberry gall midge in southern US states is estimated to be over $20 million annually. Although it attacks blueberry flower buds in Florida, it has only been found in vegetative blueberry shoots in Michigan. Blueberry gall midge lays eggs inside susceptible, young green shoot tips. Their larvae hatch and their feeding kills the shoot tip. This shoot damage causes branching in the infested shoot, resulting in one or more lateral shoots growing off the primary growth, creating a witches broom effect, which is suspected of reducing plant growth and bud set. In this study, I examined whether infestation by blueberry gall midge reduces the number of flower buds set when compared to uninfested shoots. Infested and uninfested shoots of bushes at blueberry farms were counted and compared to determine whether there is any effect of the branching caused by the blueberry gall midge damage on fruit bud production. There was no significant reduction in the number of flower buds set on shoots that were damaged in the early summer when the majority of new growth is seen, but there were significantly fewer buds set on shoots damaged later in the summer.

INTRODUCTION

Blueberries are an important specialty crop to consumers due to their high nutritional value and antioxidant content whose production has been increasing worldwide. The United States is the leading blueberry producer in the world, and Michigan is the leading producer and exporter of blueberries. The blueberry industry in Michigan has historically needed to manage insect pests that can cause significant losses in yield. Typically, these insects feed directly on berries, such as the spotted wing drosophila (*Drosophila suzukii* Matsumura) that oviposit their eggs inside the berries, and pose an obvious threat to fruit marketing. Insects that consume foliage, limiting photosynthesis, or reduce the vigor by feeding on sap such as leafrollers or aphids are indirect pests that are often overlooked because the effects of their damage are not seen until it becomes apparent.

Blueberry gall midge (*Daineura oxyoccana* Johnson) is a potential indirect pest of blueberries in Michigan whose larvae cause damage to the young shoot tips of growing vegetative shoots. In Florida, southern Mississippi and southeastern Georgia, this insect has been shown to damage flower buds and vegetative buds (Steck et al. 2000); this has not been observed in Michigan blueberries. Losses of up to 90% of flower buds in some southern US blueberry fields have been attributed to damage by blueberry gall midge (Lyrene and Payne 1992), and damage to the Florida blueberry industry by this insect has been estimated at $20 million (Dernisky et al. 2005). In Michigan, gall midge larvae have not been seen in flower buds, but they have been found inside young vegetative shoots.

BLUEBERRY SHOOT DEVELOPMENT

To understand the potential impact of blueberry gall midge damage, information about blueberry bush growth should be reviewed. Blueberry growth and development was reviewed by Eck (1988) and Gough (1994). Leaf bud break in the early spring is influenced by temperature, light, internal water balance and hormone levels. Blueberry shoot growth is variable during the season, with cycles of slow and fast shoot elongation. This cycle repeats until the fall when shoot growth stops as a result of changes in temperature and photoperiod. Many factors influence an individual shoot's growth patterns, and shoots will elongate at different times. Some shoots will experience bud break and shoot growth in the fall, resulting in growth that cannot harden and survive the winter. These shoots are known as proleptic shoots, and are known to have poor productivity (Gough 1994).

Hardening of shoots begins when growth stops in the fall and continues during the first frost. Flower buds are able to withstand temperatures as low as -40 ˚C, but fluctuating temperatures can also detrimentally affect buds. Flower buds can be damaged by ice crystal formation within the bud as well as damage to the vascular tissue, which restricts nutrients, water, and hormones from the bud. The location of the flower bud on the stem influences its ability to survive through winter temperatures. Those at the tips of shoot are not able to harden as well as those lower on the branch, and are more likely to be killed. There are other factors that promote hardening, such as low nitrogen content and dry soil. In addition, certain cultivars are known to be "hardier" than others. For example, blueberry cultivars 'Bluecrop' and 'Elliott' are known to be hardier than cultivars 'Coville' and 'Berkeley'.

BLUEBERRY GALL MIDGE DAMAGE

When blueberry gall midge larvae damage the apical meristem of vegetative blueberry shoots, lateral shoots are induced to grow, resulting in an effect similar to witches' broom (Tanigoshi et al. 2010). Witches' broom is a deformity in woody plants typically caused by a pathogen in which shoots cluster together, forming a dense mass of twigs that looks like a broom. True witches' broom with a mass of twigs has not been observed; however, up to three lateral branches have been observed growing from shoots infested by blueberry gall midge. This outgrowth of extra shoots could potentially cause a decrease in net fruit bud formation if the plant is spending resources in the additional lateral branching. Additionally, freezing temperatures may damage shoots, especially buds, if they do not have the time to become winter-hardy. Cold injury often results in the loss of the terminal flower buds, and hence reduce yield. A damaged shoot that has a greater number of younger lateral shoots with more terminal buds than a single undamaged shoot may be more likely to sustain damage during Michigan's cold winter months.

Conversations with growers indicate little concern regarding blueberry gall midge. None have mentioned reductions in fruit yield, and some have even suggested that blueberry gall midge is beneficial because its damage to vegetative shoots promotes extra lateral growth and perhaps flower bud formation. However, indirect effects may include reduction in fruit bud formation, flower and fruit set, and increased risk to frost damage. This has not been investigated in any past studies.

Since evidence of damage by blueberry gall midge on the fruit-bearing parts of the blueberry bush has not been found in Michigan, it would be useful to know if damage to the vegetative shoots is indirectly causing a reduction in fruit bud or flower numbers. To determine the effect of blueberry gall midge damage on fruit bud yield, uninfested and infested shoots were tracked through two fall-to-spring seasons to determine the effect of this potential on highbush blueberry.

METHODS

Effect of blueberry gall midge on highbush blueberry

In October 2009, the number of developing flower buds was counted on 30 shoots showing symptoms of blueberry gall midge and 30 uninfested shoots at each of four highbush blueberry farms. Whenever possible, the uninfested shoots were selected from the same bush where the infested shoot was selected. Farms were located in Berrien County (1), Van Buren County (2), and in Grand Traverse County (1), Michigan. Infested and uninfested shoots were selected from a small section of each field.

The number of flower buds was counted on each of the selected infested and uninfested shoots as well as on each of the lateral branches of the infested shoots. On the uninfested shoots, the number of flower buds was counted along the whole length of the shoot (Figure 4.1). After counting, the shoot was flagged and the number of surviving buds were counted in the spring of 2010.

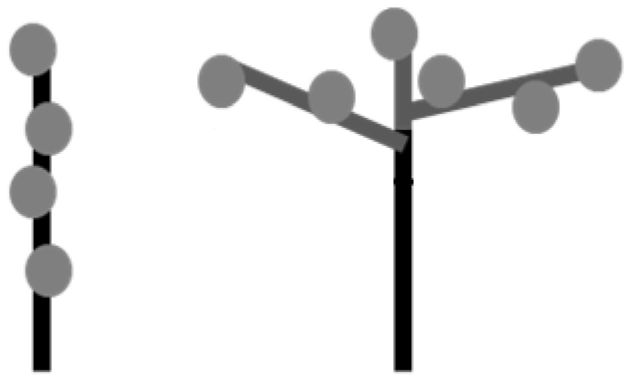

Figure 4.1. Buds on a highbush blueberry shoot that is uninfested (A) and infested (B) by blueberry gall midge.

In the fall of 2010, three blueberry fields in Van Buren County and one field in Grand Traverse County were assessed. The bushes assessed were all of cultivar ‘Bluecrop’. In the three blueberry farms in Van Buren County, up to 20 damaged infested shoots were flagged in each of June, July and August. These 20 shoots were not all flagged at the same time, but rather throughout each month. All shoots were selected within a field of 100 bushes, and were confirmed to be infested by blueberry gall midge through inspection of the damaged shoot tips. Shoots were assessed in Grand Traverse County in November. Since assessment was conducted after leaf drop, these shoots were not confirmed to be infested by blueberry gall midge during the summer. Depending on the amount of infestation, some bushes had multiple infested shoots, whereas others had one. Uninfested shoots were not selected until the bud count in November, when these shoots showed no sign of lateral branching.

In November, at each farm, the number of flower buds on each infested and uninfested shoot was counted. On the infested shoots, the number of branches and the number of flower buds on each of those branches were counted. On the uninfested shoots, the number of flower buds was counted. In March 2011, the number of flower buds was recounted on each shoot, and the lengths of the shoots were measured. To quantify growth over the winter, each branch of shoots infested in June, July and August, the length from the point of damage to the apex of each branch was measured.

Statistical analysis

All data were analyzed using JMP 8.0.2 (SAS, Cary, NC). To determine the effect of blueberry gall midge infestation on the number of buds per shoot, the number of flower buds on uninfested shoots and infested shoots was compared using one-way analysis of variance and with means separation using Tukey's HSD test. Data on the number of flower buds on uninfested shoots and shoots infested in June, July or August did not meet the assumptions of ANOVA and were compared using a nonparametric Kruskal-Wallis one-way analysis of variance. Shoot lengths were compared by month of damage using one-way analysis of variance.

RESULTS

In both years, the number of flower buds on uninfested shoots and infested shoots was not significantly different. In the fall of 2009 ($F = 1.69$; $df = 1,10$; $P = 0.22$) and the fall of 2010 ($F = 0.39$; $df = 1,12$; $P = 0.55$) (Table 4.1) there was no significant difference. In the fall of 2009, the number of flower buds on uninfested shoots was 4.7 ± 0.4, compared with 5.6 ± 0.6 on infested shoots. In 2010, the number of flower buds on an uninfested shoot was 5.4 ± 0.8, compared with 4.6 ± 0.8 on infested shoots.

When shoots damaged in 2009 and 2010 were checked in the spring of 2010 and 2011, respectively, the number of flower buds on uninfested and infested shoots was not significantly different. In the spring of 2010, although there was a lower number of flower buds on uninfested shoots than on infested shoots, it was not significantly different (F = 4.36, df = 1,10, P = 0.06), and the trend was not consistent between years. The number of flower buds on uninfested shoots was 4.0 ± 0.2, compared with 5.3 ± 0.6 on infested shoots (Table 4.1). In the spring of 2011, there was no significant difference (F = 0.43, df = 1,10, P = 0.53). The number of flower buds on uninfested shoots was 4.7 ± 1.0, compared with 3.7 ± 0.7 on infested shoots.

Table 4.1. The number of flower buds (± S.E.) in fall of 2009 and 2010 and spring of 2010 and 2011 on uninfested shoots and shoots infested by blueberry gall midge.

	Number of flower buds			
	Fall 2009	**Fall 2010**	**Spring 2010**	**Spring 2011**
Uninfested	4.7 ± 0.4	5.4 ± 0.8	4.0 ± 0.2	4.7 ± 1.0
Infested	5.6 ± 0.6	4.6 ± 0.8	5.3 ± 0.6	3.7 ± 0.7

When examined at the individual branch level, as expected the number of flower buds on infested shoots was significantly lower than on uninfested shoots. In fall of both years, this difference was statistically significant (F = 9.68, df = 1,12, P < 0.001) (Table 4.2). In fall of 2009, the number of flower buds on uninfested shoots was 4.7 ± 0.4 compared with 2.3 ± 0.2 on branches of infested shoots. In fall of 2010, the number of flower buds on uninfested shoots was 5.4 ± 0.8 compared with 2.7 ± 0.5 on branches of infested shoots.

When shoots damaged in 2009 were checked in the spring of 2010, the number of flower buds on uninfested and infested shoots was found to be significantly different. There were significantly fewer flower buds on branches of infested shoots than on uninfested shoots (F = 40.22, df = 1,10, P < 0.0001). The number of flower buds on uninfested shoots was 4.0 ± 0.2 compared to 2.1 ± 0.2 on branches of infested shoots (Table 4.2). When shoots damaged in 2010 were checked in the spring of 2011, there was no significant difference between the number of flower buds on uninfested shoots and branches of infested shoots (F = 4.4, df = 1,10, P = 0.06), although the average number of buds was slightly lower on uninfested shoots. The number of flower buds on uninfested shoots was 4.7 ± 1.0 compared with 2.3 ± 0.6 on branches of infested shoots (Table 4.2).

Table 4.2. The number of flower buds (± S.E.) in fall of 2009 and 2010 and spring of 2010 and 2011 on uninfested shoots and branches of shoots infested by blueberry gall midge.

	Number of flower buds			
	Fall 2009	**Fall 2010**	**Spring 2010**	**Spring 2011**
Uninfested	4.7 ± 0.4	5.4 ± 0.8	4.0 ± 0.2	4.7 ± 1.0
Infested	2.3 ± 0.2	2.8 ± 0.5	2.1 ± 0.2	2.3 ± 0.6

When uninfested shoots and the three different timings of damage were compared, there was a trend towards lower bud production per shoot on branches damaged later in the season but no significant difference among treatments in the number of flower buds (H = 3.56, df = 3, P = 0.31) (Figure 4.2). However, the data indicate a reduction in the number of flower buds in shoots damaged later in the summer. When the spring 2011 bud counts were compared by month of damage in spring 2011, there was no significant difference (H = 3.31, df = 3, P = 0.35). There was also no significant difference between the number of flower buds on uninfested shoots and branches of infested shoots (H = 5.77, df = 3, P = 0.12).

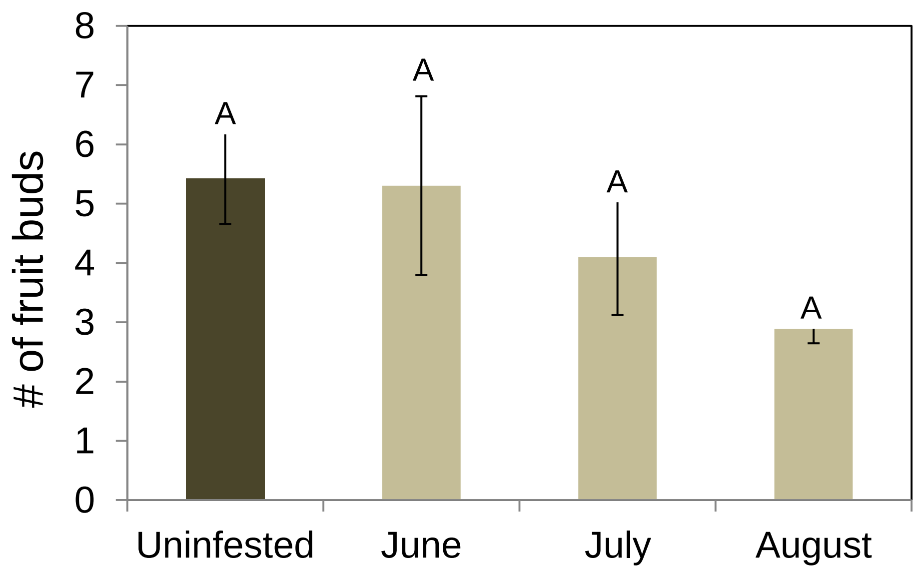

Figure 4.2. Mean (± S.E) number of flower buds (± S.E) in fall of 2010 and 2011 on uninfested blueberry shoots and shoots infested by blueberry gall midge compared by month of damage. Bars with the same letter are not significantly different ($P < 0.05$).

When comparing length of branches of shoots infested in different months, there was no significant difference in the length of branches of shoots infested in all months ($F = 0.19$, df = 2,6, $P = 0.83$). The average length of a shoot infested in June was 16.5 ± 5.1, in July, 13.9 ± 1.9, and in August, 14.2 ± 1.8.

DISCUSSION

Blueberry gall midge infests vegetative shoots of blueberry bushes in Michigan, and since infestation of a shoot can induce lateral branching, this could indirectly cause a reduction in fruit bud and yield in the year following damage. In Washington, lateral branching was mentioned but the economics of it were not explored (Tanigoshi et al. 2010). The data presented here indicate that there was no significant difference between the number of flower buds on uninfested shoots and infested shoots. This suggests that blueberry gall midge injury to highbush blueberry in temperate climates poses a minimal threat to blueberry production. This is encouraging for growers, some of whom do not mind or even welcome the damage because it stimulates growth. Since the terminal buds are the most susceptible to frost damage (Gough 1994), there may be a greater number of flower buds lost on infested shoots than on uninfested shoots during the cold conditions of the winter. However, my samples collected in the spring indicate no significant change in the number of flower buds, and no significant difference in the number of flower buds on uninfested and infested shoots. Further investigations will compare the flower and fruit yield on uninfested and infested shoots. Thus far, the data are encouraging since there is no evidence for a reduction in fruit bud set overall, and there does not seem to be greater fruit bud death in infested shoots as a result of the winter temperatures.

When compared by the month of infestation, the number of flower buds on shoots that were damaged in June, July and August were not found to be significantly different from the number of flower buds on uninfested shoots. Additionally, the length of damaged shoots was not found to be different depending on the month of damage. However, the data suggest a trend towards a reduction in the number of flower buds in shoots damaged in July and August. These shoots had the least amount of time to grow and develop flower buds before winter. Although shoots damaged in August had fewer flower buds, at that time there were low populations of blueberry gall midge (Chapter 2). These trends in declining bud numbers with time of shoot growth may also simply reflect a change in the inherent bud production of the blueberry bushes since there was no internal untreated control for each month. Also, the largest number of vulnerable green shoots appeared in the beginning of May, over two months before the peaks of blueberry gall midge infestation in July and August, when there were very few vulnerable shoots suitable for infestation (Chapter 2). Although late-blooming cultivars such as “Elliott” may have more vulnerable shoots later in the season than earlier varieties such as ‘Bluecrop’, the number of vulnerable shoots may still be comparatively low compared with the abundance in the spring.

Due to its quick generation time and continuous emergence throughout the summer, blueberry gall midge would be a difficult insect to control. However, since blueberry gall midge does not directly damage flower buds of blueberries in Michigan and its vegetative shoot damage does not seem to have an effect on fruit bud yield, the need for control of this insect seems to be minimal in mature highbush blueberry fields.

CHAPTER 5

PHENOLOGY AND CHEMICAL CONTROL OF SCALE INSECTS IN HIGHBUSH BLUEBERRY

ABSTRACT

Putnam scale and European fruit lecanium scale are occasional pests of blueberries that have recently been found infesting a small number of blueberry farms in localized regions of Southwestern Michigan. Although their biology has been studied in other states, scale insects of the same species are known to vary regionally in their phenologies and voltinism. In Michigan, the number of generations of both scale insects and the timing of crawler emergence is not known. This knowledge would be useful for growers targeting crawlers to prevent future infestation. I investigated crawler emergence and movement of Putnam and European fruit lecanium scales and found Putnam scale at very low levels in few blueberry farms. In 2010, I found a peak of lecanium scale crawler movement in late June. To test activity of insecticides commonly used in conventional blueberry farms, a laboratory bioassay and field trial were conducted on adult scale insects. The laboratory bioassay indicated activity of acetamiprid, imidacloprid, spirotetramat, and sulforix on adult scale insects, whereas the field insecticide trial was inconclusive due to lack of a control sample.

INTRODUCTION

Scale insects are occasional pests of blueberries, *Vaccinium corymbosum*. Putnam scale, *Diaspidiotus ancylus* (Comstock), and terrapin scale, *Mesolecanium nigrofasciatum* (Pergande), have been cited as the most common scale insects on blueberry stems (Eck 1988). Azalea scale, *Eriococcus azaleae* Comstock, was found on blueberries in the Pacific Northwest in 2006, and is controlled with IPM techniques such as winter pruning and application of dormant oil (Walton 2006). In Michigan blueberries, Putnam scale and European fruit lecanium scale, *Parthenolecanium corni*, (Bouché) have been found. Other scale insects are present as economic pests in Michigan, such as the pine tortoise scale, *Toumeyella parvicornis* Cockerell, which infests many species of pine and has been a pest of Michigan Christmas trees (Bishop et al. 1994).

The biology and ecology of Putnam scale has been reviewed by Miller and Davidson (2005). It is a species of armored scale that is native to North America with a wide range of host plants in many different plant families and genera. It has either one or two generations per year depending on its location and host. In both one and two-generation Putnam scale, the insect overwinters as second-instar crawlers on the bark of the host plant, although adult females have been found overwintering in Ohio. In New Jersey blueberries, Putnam scale has two generations per year with peaks of crawler emergence in late May and in early to mid-August (Polavarapu et al. 2000). High levels of infestation by Putnam scale can kill twigs and branches. In addition, it occasionally infests and deforms blueberries, which affects berry marketing by causing cosmetic damage that is unsightly to consumers. Pruning old canes and application of dormant oil can keep this pest from becoming an economic problem in blueberries (Marucci 1966). Nine species of parasitoids have been found from canes infested by Putnam scale, and the lady beetle *Microwesia misella* (LeConte) was found interacting with the scale (Polavarapu 2000).

The biology and management of European fruit lecanium has been reviewed by Pfeiffer (1997). It is a soft scale that occurs throughout most of the northern hemisphere, and is mostly a pest of stone fruits in orchards. Lecanium scale typically has one generation per year, but it has also been found to have two generations in southern Hungary and in southern Pennsylvania. Egglaying occurs in mid-May and continues through June. Crawlers appear throughout those months and continue into July. In England, however, egglaying was found to occur at the end of June with crawlers appearing in August (Wardlow and Ludlam 1975). The most threatening source of damage by lecanium scale is from the growth of sooty mold on honeydew excreted from the insect. Dormant oil sprays are an effective chemical control of crawlers (Smith 1961). Numerous parasitoids have been reported from lecanium scale, all chalcid wasps, and natural enemies such as lady beetles and lacewings have been documented.

In Michigan blueberries, scale insects have generally been classified as minor pests that have been controlled through biological control and the use of dormant horticultural oils and pruning. In recent years, however, scouts and growers have noticed higher numbers of Putnam and European fruit lecanium scale in localized areas of the blueberry production region in southwest Michigan. If left unchecked, these populations could reach economic thresholds by killing bushes and making berries unmarketable. Although the life cycles of Putnam and lecanium scales are known in other locations, their life cycles and phenologies are unknown in Michigan blueberries.

Mature scales that have developed their scale covering are difficult to control using contact insecticides, and many commonly used pesticides such as organophosphates, carbamates and pyrethroids have long residual activity, which could decrease natural enemy populations. Horticultural oils were some of the first chemicals used to control scale insects, and act by suffocating the insects in their first instar. They are typically applied as dormant-season sprays to avoid suffocation of plant buds and leaves, and have been effective at controlling many types of scale, including European fruit lecanium in peaches (Asquith 1949) and euonymus scale (*Unaspis euonymi*) in Japanese pachysandra (*Pachysandra terminalis*) (Sadof and Sclar 1995). Timing of application is crucial so that first instar crawlers are targeted. Insect growth regulators, insecticides that can disrupt the molting process, have been found to be effective on the earliest instars of scale insects. The insect growth regulator pyriproxifen (Esteem) is labeled for use in blueberries and targets scale crawlers by mimicking juvenile hormone. This has been found to be active on California red scale, *Aonidiella aurantii*, causing mortality of 80% to 100% of first instar crawlers (Eliahu et al. 2007).

The purpose of this study was to determine the number of generations of Putnam and lecanium scale on Michigan blueberries and their phenology in this region through monitoring, and to determine the effects of insecticides on scale survival in a laboratory bioassay and field trial.

MATERIALS AND METHODS

Monitoring of Putnam scale and lecanium scale crawlers

In 2009, three blueberry farms with known infestations of Putnam scale and lecanium scale were selected for monitoring. All three of these sites were located in western Michigan. One was located near Grand Junction, another near West Olive, and the third near Grand Haven. At all farms, bushes were of the cultivar ‘Bluecrop.’ Bushes were spaced 1.22 m apart and rows were spaced 2.74 m apart. At all three of the farms, five transects containing five bushes each were flagged. At two of the farms, selected bushes were separated by 10 bushes. At the other farm, due to availability of space, selected bushes were separated by 3 bushes each. The separation between these bushes at this farm was smaller because infestation was localized to a smaller portion of a field. At this farm, we also found heavy scale infestation of surrounding trees, whereas no scale was found in the surrounding trees of the other two farms. At all of the study sites, monitoring was conducted with the use of double-sided sticky tape (3M, Two Harbors, MN). First, black electrical tape was wrapped around a randomly selected branch picked within the canopy of the bush. Double-sided tape was then wrapped around the electrical tape. Two of these crawler traps were placed on each bush for a total of 50 pieces of tape per site. Each week, beginning on July 21, 2009 and ending on September 12, 2009, the 150 pieces of tape were retrieved and replaced with new tape. The number of crawlers on each piece of tape was counted under a dissecting microscope, and the average abundance per tape and per farm was calculated for each week.

Due to the low numbers of Putnam scale in 2009, sampling was discontinued for this insect and only casual observations were made in 2010. In 2010, three blueberry farms with known infestations of lecanium scale were chosen to be monitored. These farms were located near Holland and West Olive, MI. At one of the farms, most of the 2.42-hectare field was infested. There was no infestation of surrounding trees. At the other two farms, only one forested edge of the blueberry field was infested. At all three sites, 10 infested bushes were randomly selected to be monitored. Double-sided tape was wrapped around one branch on each bush. Every week, beginning on May 27th and ending on August 9th, the 30 pieces of double-sided tape were retrieved and replaced. The number of crawlers on each piece of tape was counted under a dissecting microscope, and the average abundance per tape and per farm was calculated for each week.

After crawler densities on the double-sided tape had declined in August, and as crawlers moved onto blueberry leaves, 10 leaves were collected per site for a total of 30 leaves. Beginning on August 9th and ending on September 27th, the number of crawlers on each leaf was counted under a dissecting microscope, and the average abundance per leaf and per farm was calculated for each week.

Fruit sampling for Putnam scale

The farms located near West Olive, MI and Grand Haven, MI that were used for monitoring were also used for fruit sampling for Putnam scale in 2009. At the farm near West Olive, MI, on August 31st, ripe berries from bushes of the cultivars 'Bluecrop' and 'Elliott' were sampled for thirty minutes. All berries were picked from a portion of the field closest to the forest edge. The number of berries and the number of scale insects observed on the berries was counted. At the farm near Grand Haven, MI on August 31st, ripe berries from bushes of cultivar 'Bluecrop' were sampled. The number of berries and the number of scale insects on the berries was counted.

Insecticidal control of lecanium scale

A laboratory bioassay was conducted to compare the efficacy of insecticides for control of lecanium scale insects in highbush blueberry. The bioassay was conducted on May 5, 2010. Over 100 shoots infested with live adult lecanium scale were collected at a farm in West Olive, MI, transported to the laboratory and placed in water picks. Water was replaced in the water picks as needed. Prior to treatment, the number of live lecanium scale was counted on each shoot. Shoots were then dipped in one of eight treatments (Table 5.1) for 10 seconds. Solutions were mixed in a wide mouthed Nalgene bottle to be equivalent to field rates of insecticides in 100 gallons of water per acre. Treated shoots were allowed to dry in a fume hood and held at room temperature for one week before assessment. At that time the number of live and dead lecanium scale per shoot was counted, recorded and used to calculate percent mortality for each of 10 replicates. Percent scale mortality values for each treatment were arcsin transformed and compared among treatments using analysis of variance (JMP 8.0.2, Cary, NC) and between treatments using Tukey's HSD (JMP 8.0.2, Cary, NC) for means separation.

Table 5.1. Treatments used in the insecticide bioassay of European fruit lecanium scale.

Treatment	Trade name	Rate (per acre)
water control	-	-
acetamiprid	Assail 30SG	5.3 oz
esfenvalerate	Asana XL	9.6 fl oz
imidacloprid	Provado 1.6 F	8.0 fl oz
pyriproxifen	Esteem 35WP	5.0 oz
spirotetramat	Movento 2SC	5.0 fl oz
spirotetramat	Movento 2SC	8.0 fl oz
calcium polysulfide	Sulforix	128.0 fl oz

Field evaluation of an un-replicated field trial was conducted to compare azinphos-methyl (Guthion), acetamiprid (Assail), and esfenvalerate (Asana) for control of lecanium scale. This demonstration was performed using a six-acre, lecanium scale-infested field of mature highbush blueberry, cultivar 'Jersey', at a farm in West Olive, MI. The field was divided into three areas and each area received a different insecticide treatment. Three acres received azinphos-methyl (Guthion WP at 0.5 lb/acre), one and half acres esfenvalerate (Assail at 5.3 oz/acre), and one and half acres received acetamiprid (Asana at 9.6 oz/acre). Insecticides were applied on June 3 and 17, 2010 by the farm owner using 25 gallons of water per acre. The middle three rows of each treated section of the field were assessed before insecticide application, seven days after treatment (DAT) and 14 DAT. Assessments were conducted to record the number of live and dead lecanium scale on 20 infested canes in each treated area. Since there was no control treatment, no statistical analysis was conducted.

RESULTS

Monitoring of Putnam scale and lecanium scale crawlers

In 2009, Putnam scale crawlers were caught from July 21 until September 12. The number of crawlers caught per tape was highest at the beginning of trapping with an average of 15 ± 2 crawlers per tape (Figure 5.1). There was another small increase in crawler numbers in early September.

In 2010, European fruit lecanium scale early instar crawlers were caught within a five-week period, between June 10 and July 20 (Figure 5.2). The largest catch of crawlers was on June 28, with an average of 216 ± 45 crawlers caught per tape. There were 1084 accumulated growing-degree days, base 50 ˚F, from March 1 at this date. Inspection of blueberry leaves showed high levels of crawler infestation from the beginning of August through the end September, with an average of over 20 crawlers per leaf at all sampling dates except for September 11, which had an average of 8 ± 2 crawlers per leaf (Figure 5.3).

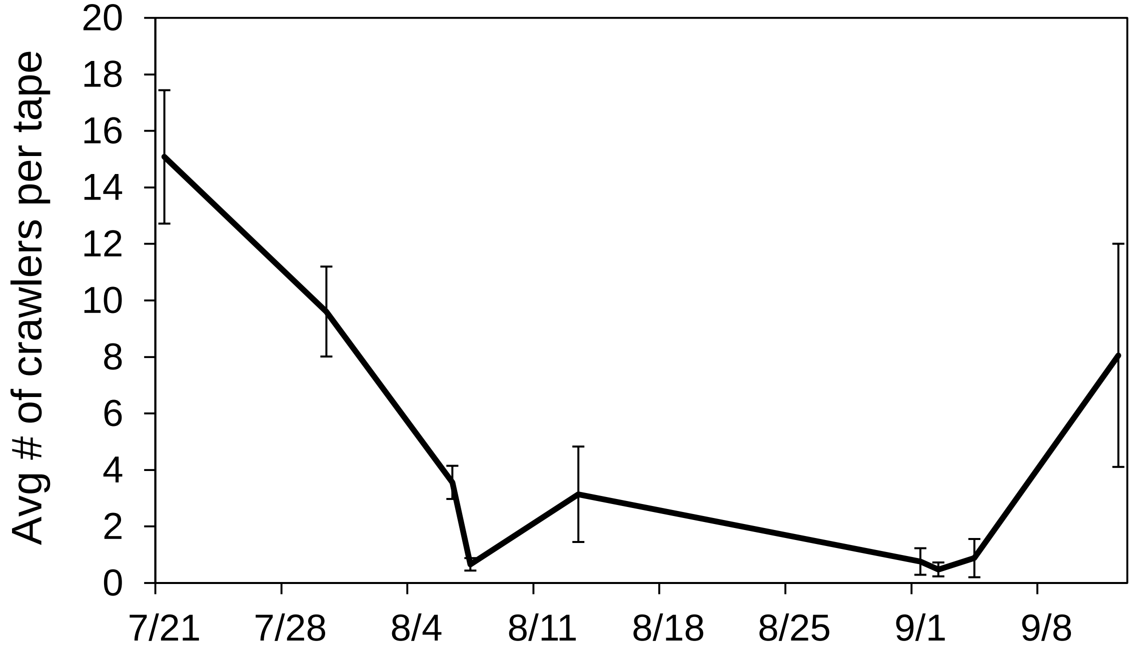

Figure 5.1. Phenology (crawlers per tape ± S.E.) of Putnam scale and European fruit lecanium scale crawlers on Michigan blueberry in 2009. Species could not be separated at the crawler stage.

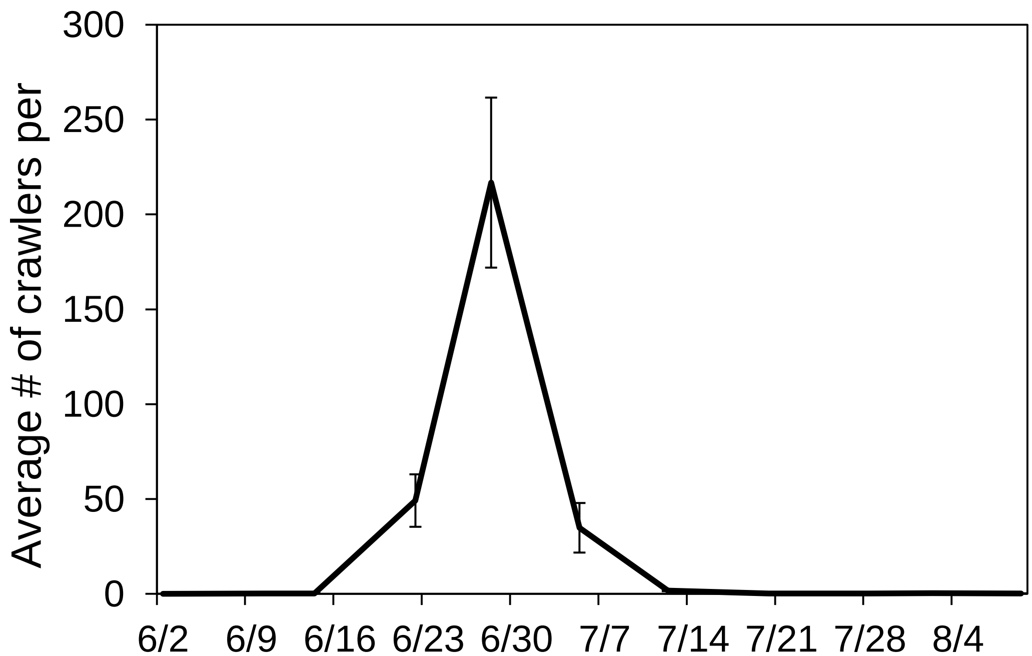

Figure 5.2. Phenology (crawlers per tape ± S.E.) of European fruit lecanium scale crawlers on Michigan blueberry in 2010.

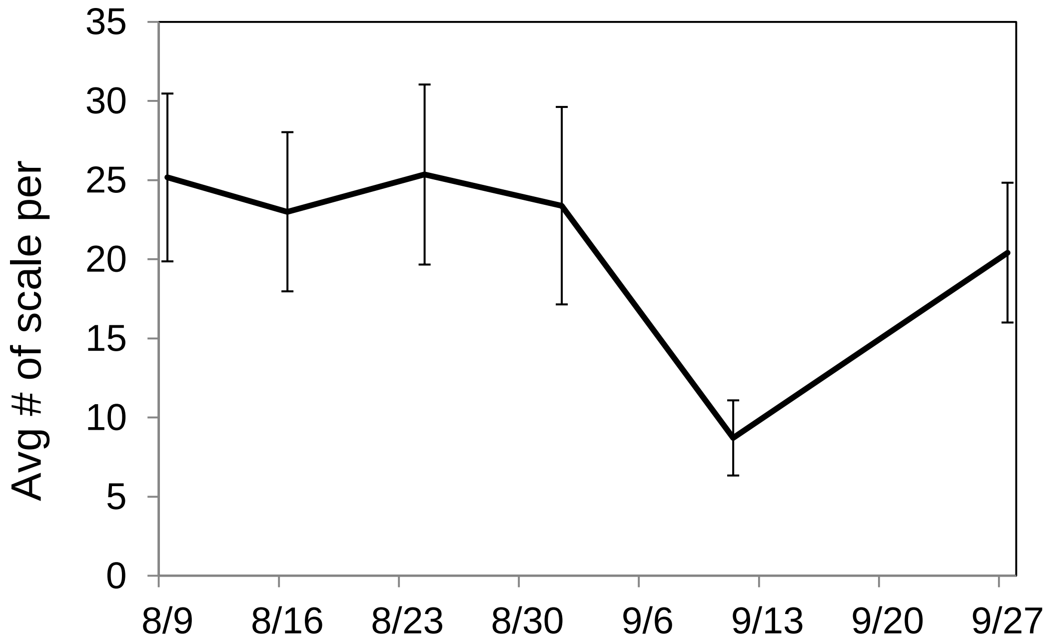

Figure 5.3. Phenology (crawlers per tape ± S.E.) of European fruit lecanium scale on blueberry leaves in 2010.

Fruit sampling for Putnam scale

At the farm near West Olive, MI, 54 Putnam scale were found on 592 sampled Bluecrop' berries (9.1% infested with Putnam scale). On 'Elliott' berries there were 22 Putnam scale found on 373 sampled berries (5.9% infested with Putnam scale). Only one scale per berry was found in these samples. Over 1000 berries were collected from the farm in Grand Haven, MI, but no scale insects were found on them.

Insecticidal control of lecanium scale

In the bioassay, the control and pyriproxifen treatments had the lowest scale mortality. The other treatments had significantly higher mortality. There was significant mortality compared to the control in all treatments except for pyriproxifen (F = 8.3, df = 7,32, P < 0.0001), with the highest levels of control provided by imidacloprid and sulforix (Table 5.2).

Table 5.2. Control of European fruit lecanium scale in laboratory bioassay. Mortality values followed by the same letter are not significantly different. Average mortality (± S.E) was compared using analysis of variance.

Treatment	% mortality	
water/control	18.2 ± 6.9	B
acetamiprid	76.2 ± 12.2	A
esfenvalerate	56.7 ± 20.8	AB
imidacloprid	100.0 ± 0.0	A
pyriproxifen	13.0 ± 8.3	B
spirotetramat (5 oz)	94.4 ± 5.6	A
spirotetramat (8 oz)	66.7 ± 33.3	AB
sulforix	100.0 ± 0.0	A

In the precount before the field insecticide trial, the shoots had low scale mortality (Table 5.3). The mortality of scale increased to 20% seven days after treatment and to about 65% fourteen days after treatment, with similar levels of mortality among the three treatments.

Table 5.3. Field insecticide trial for control of European fruit lecanium scale. Values are % scale mortality (± S.E) per shoot. There was no control treatment.

	Treatment		
	acetamiprid	azinphos-methyl	esfenvalerate
Precount	1.7 ± 0.9	1.3 ± 0.6	1.35 ± 0.65
7 DAT	22.7 ± 3.9	17.5 ± 3.1	25.1 ± 4.1
14 DAT	71.1 ± 4.1	67.0 ± 5.0	61.6 ± 4.3

DISCUSSION

Putnam scale has been known to be an occasional pest on blueberries. Infestation can cause shoot dieback, reduce plant vigor (Antonelli et al. 1992) and cause deformities on the berries (Polavarapu et al. 2000). Lecanium scale is mostly a pest of stone fruit orchards, but can also utilize blueberries (Polavarapu et al. 2000) and non-fruit trees as hosts (Pfeiffer 1997). Scale insects have had a limited effect on the Michigan blueberry industry and have not shown a large economic impact on blueberry production and yield. In recent years in Michigan farms, there have been increased reports of blueberry bushes infested with Putnam scale and lecanium scale.

Although Putnam scale and lecanium scale were present in 2009, they did not reach high enough levels to cause significant damage to the fruit or to the bushes. No distinct peak of crawler movement was found that year because trapping was started so late in the season. In New Jersey, Putnam scale has two generations per year (Polavarapu et al. 2000), and crawler emergence occurs in late May and again in early to mid-August. In addition to the late start with trapping, it was not known which crawlers were Putnam scale and which were lecanium scale, so it is difficult to determine the number of generations per year of either scale. There may have been overlapping emergence of Putnam scale and lecanium scale crawlers, causing a longer flush of crawlers to be caught. The fruit sampling for Putnam scale was done to show that the numbers of scale found on berries was not at high enough populations to significantly damage fruit. Those berries that did have Putnam scale had only an individual scale on them that was easily washed off.

In 2010, with the focus on blueberry fields infested with lecanium scale, monitoring indicated a distinct peak of crawler emergence at the end of June. Typically, there is one generation of crawlers that emerges between mid-May and early June in Virginia (Pfeiffer 1997), although other active crawler periods have been found. Two generations of lecanium scale have been found in southern Hungary (Kosztarab 1959) and in southern Pennsylvania (Asquith 1949). In the monitored farms in Michigan, only one generation of lecanium scale was evident. The crawlers that had moved onto the blueberry leaves were second-instar nymphs that were preparing to overwinter.

Two of the farms had heavy infestation only near the forested edge, where there were alternate hosts for the lecanium scale, including maples, sassafras, wild blueberry and oaks. Some of these trees were so highly infested that it was impossible to see the bark underneath the numerous insects. It is reasonable to say that those bushes near the forested edge were infested by crawlers that had drifted down from the trees. The other farm had heavy infestation throughout the entire field, where there were no surrounding infested trees. Most likely, the infestation had been present in the field for multiple seasons and had been allowed to increase.

The insecticide bioassay indicated that there was significant control of adult lecanium scale by all compounds tested except for pyriproxifen, Esteem, which is labeled for control of lecanium scale insects in blueberries. Although pyriproxifen did not lead to higher mortality of lecanium scale, as an insect growth regulator, it is a product that is meant to be used on the crawler stage of scale insects, so the timing was not appropriate in this study. The label also recommends that it be used with a delayed dormant oil, which has been shown to be effective at controlling lecanium scale (Asquith 1949). The bioassay was conducted on May 5, 2010, which was seven weeks before the peak crawler emergence we determined from monitoring. I was unable to draw any conclusions from the field insecticide trial due to the lack of any control. Although there was a reduction in the number of live adult scales, it is unknown if that is attributed to natural death or to the insecticide application. In future studies, insecticide trials should take crawler emergence into account so that applications are made to coincide with crawler activity.

Having only been found in a small region of Michigan, scale insects have not had a noticeable impact on Michigan blueberries, most likely due to pruning practices, pesticide application for other insects, and natural enemy populations that maintain the populations at low levels. However, given the opportunity, with changing pesticide regulations and changes in the environment, scale could become a more significant pest in this region. In preparation, it is useful to have guidelines on when to monitor for and manage scale if it becomes a problem.

Chapter 6

CONCLUSIONS AND FUTURE RESEARCH

The blueberry industry in Michigan has historically been the target of insect pests. With the implementation of integrated pest management techniques, growers have become more aware of the need to understand the biology of pests in order to more effectively manage them. With the reduced use of broad-spectrum insecticides and the switch to specialized reduced-risk spray programs, this need for knowledge has become even more important. Secondary pests that have previously been controlled with the broad-spectrum insecticides may have had an opportunity to increase in population. For example, blueberry gall midge and scale insects are two such secondary pests that have been sighted in Michigan blueberry fields with greater frequency in recent years, but it is not known if they pose a threat to the industry.

Prior to this study, the distribution and biology of blueberry gall midge in Michigan blueberries was unknown. Our survey revealed that blueberry gall midge is present throughout the state's blueberry fields, from Berrien County north to Grand Traverse County and east to Genesee County. With this distribution, their potential to be economically destructive is easily seen. This study investigated the biology of blueberry gall midge through multiple monitoring techniques, tested insecticide treatments and documented natural enemies. Although some phenological research has been done in Florida and the Pacific Northwest, their climates and *Vaccinium* species grown are different from those in Michigan. The data from this study show the time of the year when blueberry gall midge is most active, and when infestation is highest.

With the approaching phaseout of azinphosmethyl, there may be a need to find alternative pesticides that can also be effective on blueberry gall midge. Pesticides tested in other studies do not include many insecticides commonly used in Michigan. Our data show that although many insecticides are able to kill blueberry gall midge, their effectiveness in the field is unreliable. Although blueberry gall midge parasitoids were present in Michigan, their numbers were found to be low. If blueberry gall midge is found to be economically damaging, it would be wise to make efforts to conserve natural enemy and parasitoid populations to avoid the need for application of chemical insecticides.

Since blueberry gall midge does not attack the flower buds and targets the vegetative shoots in Michigan blueberries, have a much lower risk of impacting fruit yield. It is unknown why they do not affect highbush blueberry flower buds, but it could be due to the different *Vaccinium* species being cultivated in Florida, rabbiteye blueberry (*Vaccinium ashei* Reade). A comparison between species has not yet been conducted. My investigation of any indirect costs of vegetative shoot damage has thus far shown no significant difference in fruit bud yield in infested and uninfested shoots. Future studies will look at the resulting flower and fruit yield of infested shoots, and the effects of cold injury on infested and uninfested shoots.

Putnam scale and European fruit lecanium scale were documented in Michigan blueberries. One year prior to the beginning of this research, in 2008, Putnam scale seemed to be increasing to threshold populations to the point of infesting and deforming fruit in a select few fields. The year this study began, in 2009 the previous population of Putnam scale that had been deforming fruit was found infrequently on berries, and it was deemed an occasional pest. This emphasizes the rapid change in pest populations from year to year in this system. One grower that had some problems with scale insects had sprayed dormant oil and took care to prune off infested canes and reported no problems the following year, so there are relatively effective and low risk options available for scale management.

European lecanium scale was found in 2009, although in low numbers and localized to a small region of southwest Michigan. My study investigating its phenology found one peak of crawlers in late-June; this can be a useful aid for growers to know when to apply mid-season insecticide sprays. Our insecticide trial indicated control of adult scale with acetamiprid, imidacloprid, spirotetramat, and sulforix. Future studies should look at the effects of post-harvest sprays on crawlers beginning to overwinter.

APPENDIX

Record of Deposition of Voucher Specimens*

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

Voucher No.: 2011-05

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

Biology and Management of Blueberry Gall Midge and Scale Insects in Michigan Blueberries

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

Entomology Museum, Michigan State University (MSU)

Other Museums:

Investigator's Name(s) (typed)

Noel Hahn

Date 8/19/2011

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

Deposit as follows:

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

Copies: Include as Appendix 1 in copies of thesis or dissertation.

Museum(s) files.

Research project files.

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

Table A.1.

		Number of:							
Species or other taxon	Label data for specimens collected or used and deposited	Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Parthenolecanium corni	West Olive, MI in Ottawa County Quincy St. and Butternut Dr. Blueberry farm 8/3/2010		10						
Parthenolecanium corni	West Olive, MI in Ottawa County Quincy St. and Butternut Dr. 11/15/2010 Blueberry farm					10			
Diaspidiotus ancylus	Benton Harbor, MI in Berrien County Napier Ave. and Hillandale Rd. Blueberry farm 8/11/2009					10			
Dasineura oxycoccana	Covert, MI in Van Buren County 72nd St. and 44th Ave. Blueberry farm								
	6/1/2010		20						
	7/1/2010					10	10		

(Use additional sheets if necessary)

Investigator's Name(s) (typed)
Noel Hahn

Date 8/19/2011

Voucher No. 2011-05

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

Gary Parsons 8/19/2011
Curator Date

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