POPULATION ECOLOGY

Distribution and Phenology of *Dasineura oxycoccana* (Diptera: Cecidomyiidae) in Michigan Blueberries

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ABSTRACT The blueberry gall midge, *Dasineura oxycoccana* Johnson, is a serious pest of rabbiteye blueberries in Florida, Georgia, and Mississippi, and a potential pest of southern and northern highbush blueberries. Its damage has been observed with increasing frequency in highbush blueberry plantings in the Great Lakes region, including in Wisconsin and in Michigan. Unlike in rabbiteye blueberry plantings, where blueberry gall midge primarily damages flowering buds, it is found to damage only the vegetative shoots of northern highbush blueberry. In this study, farms throughout Michigan were surveyed for the presence of blueberry gall midge and it was found in 43 of 46 sampled farms in 11 counties. From 2009–2011, several monitoring techniques, including yellow sticky traps, emergence traps, observational sampling, and vegetative shoot dissections were used to determine the ecology of this species in blueberry fields in southwest Michigan. 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. Infestation was detected in vegetative shoot tips in all parts of the bushes, with initial infestation greatest at the base of bushes. Degree day accumulations until first midge detection and peak infestation suggest some potential for predicting key events in the pest's phenology. This information about the distribution and timing of infestation will be useful in developing management strategies for blueberry gall midge infestation.

KEY WORDS blueberry gall midge, phenology, monitoring, trap

The blueberry gall midge, *Dasineura oxycoccana* Johnson (Diptera: Cecidomyiidae), is a multivoltine pest that has caused high levels of yield reduction in rabbiteye blueberry (*Vaccinium ashei* Reade) in Florida, Georgia, and Mississippi (Lyrene and Payne 1992, Dernisky et al. 2005). This small fly infests and kills floral and vegetative buds of *Vaccinium* plants, including blueberries and cranberries (Gagné 1989). Blueberry gall midge has not yet been found to damage floral buds of northern highbush blueberry (*Vaccinium corymbosum* L.), but its larvae can feed on and damage the plant's vegetative shoots. In recent years, unpublished data and conversations with blueberry growers, scouts, and industry representatives have indicated increased vegetative shoot damage by blueberry gall midge in Great Lakes region blueberry plantings. This increase may be because of recent reductions in the use of broad-spectrum insecticides and the adoption of more selective insecticides. Development of an integrated pest management (IPM) program to target blueberry gall midge requires information about its distribution and basic biology.

Blueberry gall midge, also referred to as cranberry tipworm, has been reported in Wisconsin, Florida, Mississippi, Oregon, Maine, New Jersey, Washington, and Oregon (Mahr 1991, Lyrene and Payne 1992, Voss 1996, Sampson et al. 2002, Yang 2005, Reekie et al. 2008, Tanigoshi et al. 2010), with recent evidence for reproductive isolation of populations on these two crops (Cook et al. 2011). It can be a major floral bud pest in blueberry farms in Mississippi and Florida, whereas in other states it affects vegetative shoots. In a survey of 10 blueberry fields in Florida, damage was found in nine fields, five of which had >50% flower bud loss (Lyrene and Payne 1992). 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). There is relatively little published information regarding the biology of blueberry gall midge in northern highbush blueberry or cranberry, and it has not been extensively studied in Michigan, which has over 8,000 ha of highbush blueberry. Its distribution and level of infestation in blueberry farms across the state is unknown.

Blueberry gall midge is active throughout the growing and harvesting seasons. In Mississippi, it emerges

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in early February with larval density peaking in May and June. Populations continue to reproduce until November, and it is known to have up to 11 generations per year (Sampson et al. 2002). Understanding the phenology of pests, and availability of degree-day models can be useful for determination of the best time to apply management techniques (Preuss 1983, Jones et al. 1991). The 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 have been tested for this pest in Florida. Although time consuming, bud and shoot tip dissections were found to be the most effective for confirming the presence of larval infestation (Sarzynski and Liburd 2003). Emergence traps were later tested to determine the early emergence of the adult flies (Roubos and Liburd 2010a). Presence and phenology of the midge were also determined in Oregon and Washington northern highbush blueberries 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. 2008).

The goal of this study was to determine the distribution of gall midge across Michigan blueberries, and to determine the severity of infestation in the major blueberry producing areas of the state. Surveying for damage and midge presence in farms and nurseries across the state was used to determine their distribution. Phenology, distribution within bushes, and the levels of infestation of the insect were investigated. Yellow-sticky traps, adult emergence traps, shoot tip dissections, and rearing were compared to determine the most effective monitoring methods for use in highbush blueberry, and this information was used to predict first and peak emergence based on growing degree-days.

Materials and Methods

Surveying. Widespread sampling of blueberry fields was conducted in 2009 in *V. corymbosum* plantings in Michigan. Because the distribution of this pest in farms and nurseries was unknown, sites were selected across the primary blueberry production regions in the southwest region of the state, with some outlier locations in other regions to ensure a wide geographic spread of the sampling. In total, 46 conventionally managed blueberry farm plots in 11 counties and 11 nursery plots in one county were surveyed. The 11 nursery plots were located in four different nurseries in Van Buren County.

At each sampled farm, a two to three acre field was sampled for blueberry gall midge infestation from mid-June to mid-August 2009. Before surveying, a few infested shoots were sampled from the field and inspected to ensure that blueberry gall midge larvae were present on the farm. Surveys were conducted in each field along 10 transects, with five bushes per transect. On these 50 bushes, the number of blackening, infested shoots was counted by sampling the half of the bush facing the sampler. On 10 randomly selected bushes, the number of vulnerable shoots was counted. Vulnerable shoot tips were defined as young green shoot tips emerging from shoots that were elongating through the growing season. Percent infestation was calculated for each site by dividing the number of infested shoots observed by the average number of shoots per bush (total number of new shoots on 10 half-bushes). The average percent infestation was calculated for each sampled field for each sample week.

In August 2009, surveys were conducted at four nurseries in blocks of potted *V. corymbosum* bushes that were 2 to 3 yr old. At three of the nurseries, three blocks of nursery bushes were sampled, while at the fourth, two blocks of bushes were available for sampling. Because nursery plants were arranged in large blocks of tightly packed adjacent bushes, it was difficult to reach plants more than three plants in from the edge so 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 full 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, three blueberry plantings with the cultivar 'Bluecrop' on farms in southwest Michigan with a history of blueberry gall midge infestation were selected to be monitored. Every 2 wk from 22 June to 15 September, 25 bushes per site were observed for damage by this pest. Sampling was done on bushes in five transects spaced five 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 determine 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 highbush blueberry cultivar Bluecrop and one was of cultivar EarliBlue. Before the growing season, a section of 200 bushes was flagged and reserved for observational sampling. Once per week, from 12 May to 14 October, 30 randomly selected bushes in the (200-bush field) were observed for blueberry gall midge damage, and the number of damaged shoot tips was counted on each of these bushes. To determine whether infestation varied with height within the bushes, damaged shoot tips were counted separately within the top, middle, and bottom third of the bush. Additionally, on 10 randomly selected bushes, the number of vulnerable shoot tips was counted and then averaged for an estimate of the number of shoots per bush. Percent infestation was calculated, and average percent infestation was calculated for each field for each weekly sample. In 2011, this approach was repeated at the four fields containing the cultivar Bluecrop. Sampling was conducted from 9 May to 29 August, and 30 randomly selected bushes in the 200-bush fields were observed for damage. The number of vulnerable shoot tips was counted on all 30 bushes, and then averaged. Percent infestation was calculated.

Yellow Sticky Traps. In 2010, yellow sticky traps were used to monitor for adult blueberry gall midge in the four Bluecrop blueberry fields. Before the research season, a 200-bush section of each field separate from the section used in the observational sampling was flagged and reserved for these studies. Once per week from 10 June to 23 August, three yellow sticky traps were placed within the canopy on randomly selected bushes in the field and retrieved and replaced. The total number of blueberry gall midges caught on all traps was counted and recorded each week.

Emergence Traps. In 2010 and 2011, emergence traps similar to those tested by Roubos and Liburd (2010a) were deployed within the same four fields in which the yellow sticky traps were placed. In 2010, from 9 April to 23 August, 12 emergence traps were retrieved and replaced once per week at each farm, and the number of blueberry gall midge adults trapped in the petri dish was counted. In 2011, from 14 April to 29 August, 20 traps were deployed once per week at each farm. Traps were constructed from 2.5 qt plastic paint buckets (Home Depot, Atlanta, GA) with their bottoms cut off and covered by a clear 10 cm diameter petri dish. Tanglefoot glue was applied with a spatula to the inside of the petri dish to capture emerging blueberry gall midge adults. These bucket traps were turned upside down and placed on the soil adjacent to 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 divided evenly between the east and to the west of the bushes, while at the farms with bushes running west to east, traps were divided evenly between the south and north of the bushes.

Shoot Tip Dissections. In 2010 and 2011, shoots were collected from the same four fields in which the traps were placed. In 2010, 30 shoots were collected from 30 randomly selected bushes in the 200-bush fields each week from 12 May to 29 September, then placed in a plastic bag and in a cooler containing ice. In 2011, 10 shoots were collected from 10 randomly selected bushes from 9 May to 17 August. Shoots were randomly selected from the top, middle, or bottom third of each sampled bush. Shoots were not inspected beforehand to determine if they were infested. Within 24 h, these shoots were brought back to the laboratory and dissected with forceps and inspected under a microscope to count the number of eggs, first, second, and third instar larvae and pupae. The color of the vegetative shoot tip (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. 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.

Fruit Bud Dissections. Fruit buds were collected at the beginning of the growing season in 2011, on 1 May and 9 May, when fruit buds were beginning to swell. Ten fruit buds were collected from randomly selected bushes at each of four farms and dissected to look for eggs and larvae. The number of blueberry gall midge eggs and larvae was counted.

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, 2010, and 2011 observational sampling and shoot dissection data. Dates of peak infestation and of first and peak adult emergence were determined, and accumulated growing degree-days were determined using the Enviroweather Automated Weather Station Network (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 1 March using the Baskerville–Emin method with a base temperature of 10°C (Baskerville and Emin 1969).

Statistical Analysis. All analyses were conducted using JMP 8.0.2 (SAS Institute 2008). For the data gathered in 2010 and 2011, the percent infestation in all sampled farms was averaged for each week, and 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 was averaged across all farms for each week and plotted against sampling date. Percent infestation was compared among the three parts of the bush using one-way analysis of variance (ANOVA) and separation of means using Tukey's honestly significant difference (HSD) test. Data from farms with blueberries grown in north–south rows were used to compare the number of midges captured on the east and west aspects. Similarly, the number of midges found in farms with blueberries grown in east–west rows was used to compare the number of midges captured on the north and south aspects. These data were separated and analyzed by month. This was done by fitting the Poisson distribution to the data and conducting a likelihood ratio χ^2 test. The average number of larvae was compared among the color categories of vegetative buds using one-way ANOVA and means separation with Tukey's HSD.

Results

Surveys for Blueberry Gall Midge. The average percent infestation ($\pm$SE) of all farms was 7.2 ± 1.7. There was higher percent infestation by blueberry gall midge

Table 1. Cultivars of highbush blueberry surveyed for blueberry gall midge and their infestation levels in Michigan blueberry farms and nurseries

Site type	Cultivar	Number of farms	Percent infestation
Farms	Bluecrop	22	6.5 ± 1.7
	Blueray	2	4.9 ± 0.8
	Elliott	9	16.9 ± 5.9
	Jersey	7	9.8 ± 1.6
	Rubel	1	11.5 ± 0.0
	Weymouth	1	24.8 ± 0.0
	Unknown	4	1.8 ± 1.1
Nurseries	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

in nurseries than in farms, with 25.7 ± 4.5 average percent infestation across all nurseries. There was little evidence of significant variation in infestation levels by cultivar in nurseries ($F_{4,6} = 0.24$, $P = 0.91$; Table 1). Blueberry gall midge was found in 43 of the 46 farms sampled, and in all 11 of the counties sampled. Fields varied widely in the level of infestation, from one field at a farm in Ingham County with no infestation to an average of 17% infestation in Muskegon County (Table 2).

Observational Sampling for Blueberry Gall Midge Phenology. In 2009, peak infestation was found on 30 July, with an average of 6.5 ± 1.4% of vulnerable shoots showing signs of infestation. In 2010 and 2011, multiple peaks of infestation were found in June, July, and August. In 2010, the largest occurred on 15 July, with an average percent infestation of all vulnerable tips of 67.6 ± 13.4, and in 2011, the largest occurred on 11 July, with an average percent infestation of all vulnerable tips of 55.7 ± 10.6 (Fig. 1). In 2010, at the beginning of the season all three heights within the bushes had similar infestation levels (Fig. 2). However, as the season progressed, infestation in the bottom of the bush decreased quickly and maintained low levels of infestation, whereas infestation in the middle and top of the bush stayed high through the season until late July. In 2011, there was little infestation in the middle and top of the bush in the beginning of the season. Infestation in all three regions was similar for the remainder of the season. In both years, the average number of vulnerable shoot tips available for infestation by blueberry gall midge was high in the beginning of the growing season (35 ± 4.8 in 2010 and 68.1 ± 19.2 in 2011) in May, and sharply decreased at the beginning of June to an average of fewer than 10 vulnerable shoot tips per bush (Fig. 3).

Table 2. Average percent infestation (±SE) by blueberry gall midge in Michigan blueberry farms, by county

County	Number of farms surveyed	Percent infestation
Allegan	7	8.5 ± 3.0
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	7	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	46	7.2 ± 1.7

Yellow Sticky Traps. Seven blueberry gall midge adults were caught on yellow sticky traps in 2010 from 10 June to 23 July. These insects were detected across five farms with three traps deployed and checked weekly for 3 mo.

Emergence Traps. The first catch of a blueberry gall midge adult in an emergence trap was on 22 April 2010, with peak emergence occurring on 24 May, 5 July, and 3 August (Fig. 4). In 2011, the first adult catch was on 9 May, with emergence peaks on 6 June and 6 July. When comparing aspects (east–west vs. north–south) of the bush on which the traps were placed, in most months the aspect had no significant effect on blueberry gall midge captures. However, catches varied significantly between the east–west aspects in August, with a higher number of catches on the west aspect of the plant ($\chi = 4.37$; df = 1; $P = 0.04$).

Shoot Tip and Fruit Bud Dissections. Larvae were found in the dissected shoots from June through August 2010. The highest peaks of larval infestation were in early July in both growing seasons (Fig. 5). No blueberry gall midge larvae were found in the 80 dissected fruit buds.

Growing Degree-Days. Base temperatures were selected to determine the temperature at which there was the least variation among years in key blueberry gall midge parameters. Comparison of 4.4, 7.2, and 10°C found that 10°C had the lowest amount of variation (data not shown). There were 209.6 and 151.6 growing degree-days from 1 March to first adult emergence in 2010 and 2011, respectively. The peak of adult emergence was observed at 1,383, 1,317, and 1,369 growing degree-days (base 10°C) from 1 March in 2009, 2010, and 2011, respectively.

Discussion

Blueberry gall midge was present in almost all of the surveyed farms and in all of the surveyed nurseries, indicating that this insect is well-established and widespread in Michigan highbush blueberry. A higher percent infestation of blueberry shoots were seen in nurseries compared with farms. This is likely because of the increased prevalence and encouragement of new shoot growth in nurseries compared with established blueberry farms. It may also reflect the high plant density, closer proximity of plants, warmer temperatures in greenhouses, fewer natural enemies, or lower insecticide use in nurseries, as these sites do not require protection of fruit from insect pests. The higher infestation rate in nurseries would also facilitate introduction and dispersion of blueberry gall midge to farms that buy bushes from Michigan nurseries, but because this pest seems ubiquitous it is unlikely that

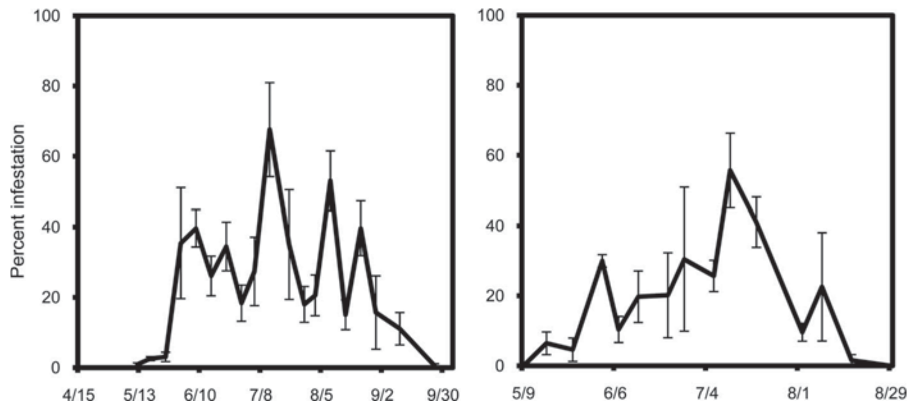

Fig. 1. Variation in percent infestation (±SE) of elongating highbush blueberry shoot tips by larvae of blueberry gall midge, sampled at Michigan farms in 2010 and 2011.

any restrictions on plant material would reduce its prevalence.

Infestation levels varied considerably among farms and nurseries sampled. Blueberry gall midge has multiple generations and peaks of emergence during the season. Because surveys were conducted over a 2 mo period, sampling days may have been concurrent with a range of midge emergence and infestation, resulting in the observed variability. Additionally, because of different growth rates of bushes from field to field, there was little to no new shoot growth on some bushes, and fewer reproduction and feeding sites available for the fly. This species also has a suite of natural enemies that attack the larvae (Voss 1996, Sampson et al. 2006), and these may vary among sampled sites.

Fruit bud dissections conducted during 2 wk in 2011 when swelling buds were predominantly present throughout blueberry fields with known populations of blueberry gall midge revealed no damage and no presence of eggs or larvae. Dernisky et al. (2005) found blueberry gall midge larvae present in stages two through four of blueberry bud development, before flowers expanded beyond their bracts (Spiers 1978). Blueberry gall midge adults were first caught in emergence traps on 1 May when buds were swelling, so it is possible that their abundance was too low to detect using our sampling method, or our sample size was too small. Peak adult catches occurred in June and July, long after flowers had dropped, suggesting that bud feeding is not a concern for northern highbush blueberry in the Great Lakes region. In Florida, few blueberry gall midge larvae were found during dissections of floral buds of southern highbush blueberry (Sarzynski and Liburd 2003).

The earliest adult catch in 2010 was on 22 April, just before bud-break. 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 catches can occur as early as 14 January, with peak adult emergence on 21 March (Roubos and Liburd 2010a). There, the growing and harvest season are much earlier than in Michigan. In lowbush blueberries in Nova Scotia, blueberry gall midge larvae are present in high levels in July and August (Reekie et al. 2008). The estimated

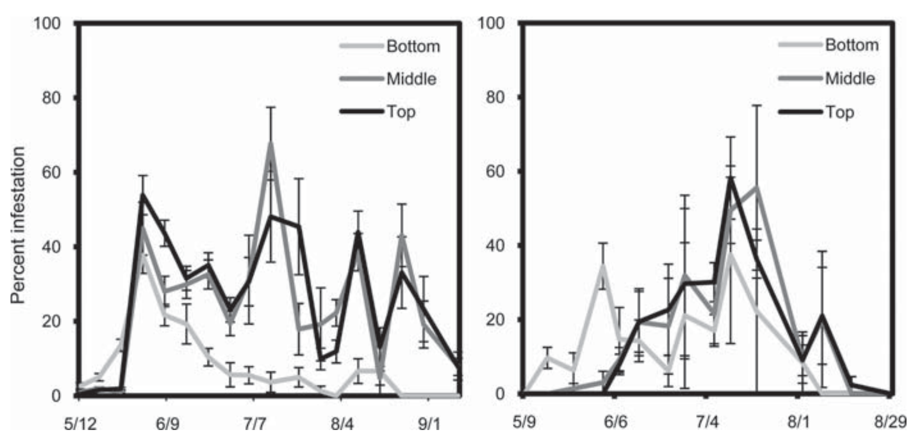

Fig. 2. Variation in percent infestation (±SE) of elongating shoot tips by larvae of blueberry gall midge in the bottom, middle, and top of bushes sampled at Michigan farms in 2010 and 2011.

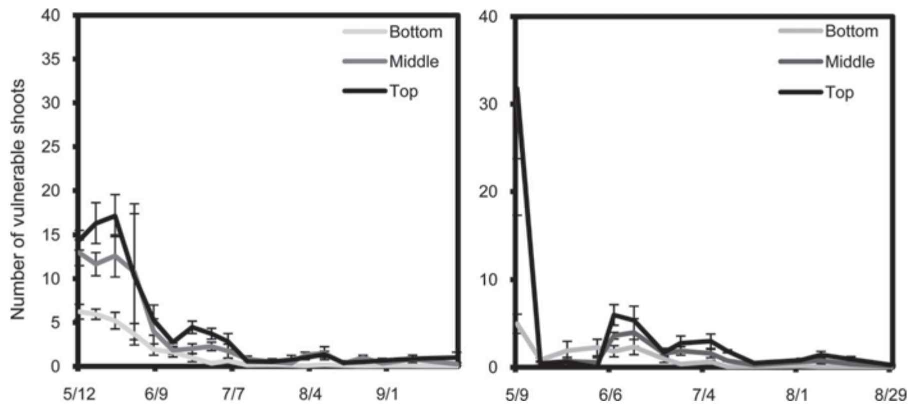

Fig. 3. Variation through the growing season in the number of elongating shoot tips (±SE) in the bottom, middle, and top of highbush blueberry bushes.

number of larvae per bush was highest in early June, and even with low numbers of larvae per shoot, the high number of elongating 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 populations of 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 per acre. 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 a large flush of growth occurs later in the season in response to summer rainfall or irrigation, adult midges would have the reproductive sites needed to quickly establish high populations.

All monitoring methods except yellow sticky traps indicated greater infestation in July than in other months. However, at that time, there was little vulnerable tissue compared with the beginning of the growing season in May. 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. In addition, adults are not strong fliers and may not be attracted to yellow. Emergence traps caught more adults than yellow sticky traps, and were the first monitoring technique to detect adults during the season. Although some traps were destroyed by harvesters and sprayers, they could still prove to be an effective method to determine the initial spring emergence and help identify when to protect bushes from this pest.

Significantly higher catches were seen 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 heats the soil later in the day. However, all blueberry gall midges caught in August were caught in five individual traps, pointing to the within-field variability of this species.

Vegetative shoot dissection was an effective method to determine the number of larvae present but growers may be unwilling to adopt the use of shoot dissections because it is time consuming and requires a high-power microscope. This method does help to pinpoint the ideal time to target the presence of larva,

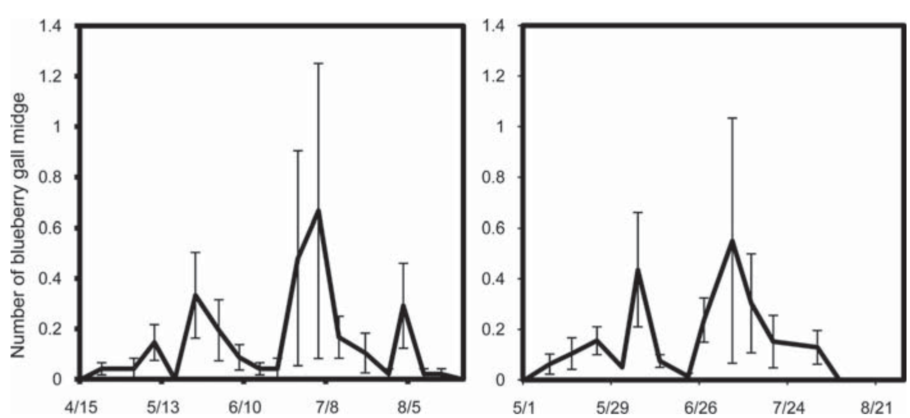

Fig. 4. The average number (±SE) of adult blueberry gall midges caught in on emergence traps placed over the soil beneath highbush blueberry bushes in Michigan during 2010 and 2011.

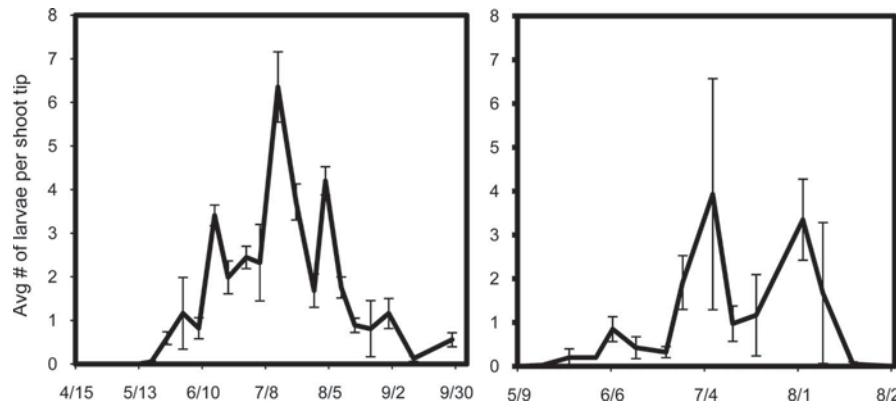

Fig. 5. Temporal variation in the number of blueberry gall midge larvae (±SE) detected in dissections of shoots collected at infested highbush blueberry fields.

however, and may be a useful method for consultants and extension agents to help identify early infestations. The pink 2-mm third 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 systemic insecticides effective at controlling blueberry gall midge. Insecticide treatments may be applied at different times of the season to control blueberry maggot, cherry fruitworm, and Japanese beetle and while it is possible that these sprays may control blueberry gall midge, their abundance and ubiquity suggests that they would be able to repopulate fields within a short period of time. Because no unmanaged fields were monitored in this study, whether or not this is occurring is unknown.

The growing degree-days calculated from the Enviroweather weather stations can be used to determine peak blueberry gall midge activity and target control measures. The growing degree-days corresponding with the largest peak of adult emergence in 2009 and 2010 were ≈1,300; additional studies in controlled growth chambers would be useful to determine a more accurate estimate. Our use of a base temperature of 10°C was confirmed by Roubos and Liburd (2010b), with their finding of a developmental threshold for pupation at 9.8°C. These studies on blueberry gall midge biology and monitoring will aid in the development of a management plan for this pest, should its injury to plants be determined to cause an economic impact on productivity.

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