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SEASONAL ACTIVITY AND SAMPLING METHODS FOR THE DECTES STEM BORER, *DECTES TEXANUS* LECONTE, IN NEBRASKA SOYBEANS

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by

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SEASONAL ACTIVITY AND SAMPLING METHODS FOR THE DECTES STEM BORER, *DECTES TEXANUS* LECONTE, IN NEBRASKA SOYBEANS

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The Dectes stem borer, *Dectes texanus* Leconte, has caused significant economic damage to soybean fields in south central Nebraska during recent years. Most economic injury occurs when soybean plants become susceptible to late season lodging due to larval girdling. Developing a comprehensive management plan for Dectes stem borer in Nebraska is limited by lack of knowledge of seasonal activity and effective sampling plans to monitor adult populations.

Field studies were conducted in 2013 and 2014 to describe Dectes stem borer adult emergence patterns, female ovipositional period and adult densities in soybean fields. Calendar date predictions for adult emergence varied, while degree-day predictions were similar across multiple years as the inflection point of both year's emergence curves occurred near 1250 degree-days since January 1 (50° F. base). Female Dectes stem borer beetles reached peak fecundity during the second and third weeks after emergence and densities in soybean fields peaked during mid-July, after a majority of adults had emerged according to degree-day predictions.

Field studies were conducted during 2013 and 2014 to develop a cost effective sampling plan for monitoring adult Dectes stem borer activity. Sticky traps, drop cloths and sweep nets were tested as potential sampling methods. Sweep net sampling was found to be a superior method while sticky traps and drop cloths resulted in low beetle

counts. Efficient sweep net sampling schemes were developed to minimize the cost required to achieve a given precision level. A plan consisting of two samples of 150 sweeps each was developed to minimize the field costs for an acceptable precision level for making pest management decisions.

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Literature Review

Dectes Stem Borer

Taxonomy and description. The Dectes stem borer, *Dectes texanus*, (Coleoptera: Cerambycidae) is a small longhorn beetle of the sub-family Lamiinae, tribe Acanthocinini and genus Dectes. In the United States, there are two species in the genus Dectes Leconte, *Dectes sayi* Dillon and Dillon, and *Dectes texanus* LeConte (Dillon 1956, Linsley and Chemsak 1995). *D. sayi* is distributed from North Dakota east to New York and Virginia. *D. texanus* is widely distributed across eastern North America from Montana and New Mexico to the Atlantic Coast. The second antennal segment of *D. sayi* is distinctly longer than it is broad. This character readily separates the two species as the second antennal segment of *D. texanus* is as long as it is broad. *D. texanus* adults are between 6 and 11 mm in length and 1.6 to 3.4 mm wide with prominent lateral spines near the base of the pronotum. Color ranges from grey, reddish brown, dark brown to black. The elytra are covered in dense grey pubescence with black setae extending beyond the pubescence (Dillon 1956, Hatchett et al. 1975, Linsley and Chemsak 1995).

Dectes stem borer eggs are elongate, and about 1.9 mm long by 0.43 mm wide. They are white to yellow in color with a smooth, shiny chorion. The larval stage is creamy white to yellow in color. Larvae have been reported to have four instars (Hatchett et al. 1973, Patrick 1973). The first, second, third and fourth instars range from 1.5 to 2 mm, 3 to 4 mm, 5 to 10 mm and 12 to 15 mm in length, respectively. Hatchett et al. (1975) reported six larval instars based on measurement of the head capsule width of larvae collected from ragweed in Missouri. Larvae are legless and use their accordion-like abdominal segments and mandibles to move inside the host plant. The larvae are creamy

white to light yellow in color with a brown head capsule. The pupal stage closely resembles the adult in size and shape and is a creamy yellow color.

Biology and ecology. Dectes stem borer is univoltine. Adult emergence varies by geography and generally occurs from late June to early August (Campbell 1980, Hatchett et al. 1975, Patrick 1973). Larval host plant does not appear to affect the time to emergence (Michaud and Grant 2005). After emergence, the adults feed prior to mating (Hatchett et al. 1975). Previous studies have reported that the pre-oviposition period averages 7 d in the laboratory (Hatchett et al. 1975) and lasts 10 to 14 d in the field (Patrick 1973). Michaud and Grant (2005) reported a 17 d pre-oviposition period in the laboratory for insects that were mated when 10 to 12 d old.

The lifespan and fecundity of Dectes stem borer adults vary depending on adult diet and larval host (Michaud and Grant 2005, 2010). Pupae from soybean weigh on average 40 percent less than those from sunflower and adults fed sunflower live significantly longer than adults fed soybean (Michaud and Grant 2005). It has been suggested that adults feed on alternate hosts before migrating onto soybean (Michaud and Grant 2005). Michaud and Grant (2005) reported an average reproductive lifespan of 56 d and average fecundity of 33 eggs for 20 females fed sunflower stalks or soybean petioles in the laboratory. Hatchett et al. (1975) reported an average of 53 eggs and longevity of 28 to 59 d for female adults fed fresh green beans in the laboratory. Eggs are oviposited in main stems, lateral branches and leaf petioles throughout July and August. In soybean, eggs are primarily laid in petioles located on the upper part of the canopy. The female chews a hole through the epidermis and oviposits a single egg inside the pith (Campbell 1980, Hatchett et al. 1975). Incubation lasts from 6 to 10 d in the field (Patrick 1973).

The larvae stay within the petiole feeding on pith for 1 to 2 wk prior to boring into the main stem. Once in the main stem, the larvae will tunnel up and down the plant feeding on pith. Near the end of the season, larvae tunnel down to the base of the plant, girdle the inside of the stem about 5 cm (2 in) above the soil line and plug the tunnel with frass. The onset of this larval girdling behavior occurs at the time of stalk desiccation (Michaud et al. 2009). Fourth instar larvae overwinter below this girdling point near soil level. Although more than one larva are may be found in a single plant, larvae are cannibalistic and only one overwinters in the base of the stem.

Dectes stem borer is polyphagous and has been recorded infesting several weedy species including *Ambrosia trifida* L. (giant ragweed), *Ambrosia artemisiifolia* L. (common ragweed), and *Xanthuim stumarium* L. (cocklebur) (Hatchett et al. 1975, Patrick 1973). Although *D. texanus* commonly infests cultivated *Helianthus annuus* L. (sunflower) (Phillips 1972, Rogers 1977), infestation of wild *H. annuus* is a rare occurrence (Michaud and Grant 2005). Dectes stem borer has expanded its host range from native composite hosts to include *Glycine max* (L.) Merr. (soybeans), a non native leguminous crop. Cultivated sunflower is the preferred host of Dectes stem borer.

Economic Importance in Soybeans.

Dectes stem borer reaches economic pest status in soybeans in three geographic areas, the high plains from the Texas panhandle to southern Nebraska, the Mississippi and Ohio River valleys, and the Atlantic coast from South Carolina to New Jersey, (Buschman and Sloderbeck 2010). Daugherty and Jackson (1969) were the first to report Dectes stem borer causing economic damage to soybeans. They described fields with 100 percent infestation rates and 17 percent lodging in southeastern Missouri and northeastern

Arkansas during the 1968 season. Since then, economic damage to soybeans by Dectes stem borer has been reported in Delaware, Tennessee, Kansas, Kentucky, Louisiana, Mississippi, Nebraska, North Carolina, New Jersey, South Carolina, South Dakota and Texas (Buschman and Sloderbeck 2010, Campbell 1976, Laster et al. 1981, Patrick 1971, Rogers 1977, Tindall et al. 2010).

Dectes stem borer has been a significant pest of soybeans in Kansas since the 1980's. In Nebraska, Dectes stem borer was first reported causing economic damage to soybeans in 2000 near the Kansas border and has since became a more serious pest throughout the south central portion of the state (Wright and Hunt 2011).

Damage to soybeans from Dectes stem borer is primarily due to the larval girdling behavior and subsequent late season lodging. Adult feeding is minor and does not cause yield loss. Damage from the larval stage can be divided into physiological yield loss and yield loss associated with lodging. There are data that suggests a 10 to 15 percent yield loss in soybean from larval tunneling alone (Buschman et al. 2005, Campbell 1980, Richardson 1975). Damage associated with late season lodging depends on multiple factors including the level of infestation and weather. Large soybean fields may have up to 100 percent infested plants (Daugherty and Jackson 1969, Michaud and Grant 2005, Tindall et al. 2010), but not all infested plants are girdled and lodge (Daugherty and Jackson 1969, Tindall et al. 2010, Michaud and Grant 2005). Strong storms late in the season also contribute to lodging.

Soybeans

Soybean, *Glycine max,* is an annual legume in the family, Fabaceae. Soybeans are native to East Asia and cultivation of the plant originated in China. Soybean is an

important crop because of its high protein and oil content, and large planted area. Soybeans are the world's largest source of animal protein feed and second largest source of vegetable oil. Other useful end products include fuel and industrial uses such as, biodiesel, lubricants and solvents (USDA Economic Research Service 2014). Soybean is cultivated in about 50 countries worldwide with major producers being the United States, Brazil, Argentina and China. In the United States soybean cultivation began as far back as 1765 (Hymowitz and Harlan 1983). However, production in the United States remained on a small scale until the mid 1900's (Singh 2010). Today, the United States is the largest producer and exporter of soybeans. In 2012, farmers in the United States harvested 30.8 million hectares (76.2 million acres) of the crop with an average yield of 2,677 kg per hectare (39.8 bushels per acre) totaling over 8.1 billion kg (3 billion bushels) (USDA Economic Research Service 2014).

Sampling Methods

A standard sampling plan for estimating Dectes stem borer populations has not yet been established. Dectes stem borer adults, eggs, and larval populations can be estimated by several sampling methods.

Sampling adults may be done by observation, ground cloth, sweep net, or sticky traps. Careful observation should start at the top of the plant and work down. Determining the presence of Dectes stem borer in a field is most easily done by observations near the field edges or alternate hosts. Campbell (1980) reported the ground cloth sampling method to be unsatisfactory. When disturbed, the adults readily fly, walk, or drop to lower foliage. The sweep net method is common when sampling for Dectes stem borer adults (Buschman et al. 2007a, 2005, Campbell 1980, Davis et al. 2008, Sloderbeck and

Buschman 2011). However, Sloderbeck and Buschman (2011) found virtually no correlation between season-long sweep net counts of adults and larval infestation rates. This method has not been calibrated to an absolute sampling method and no studies have determined the number of sweeps required for a given level of reliability. Campbell (1980) made sticky traps from a mesh screen coated with adhesive and attached to a 30 cm wood frame to record the seasonal abundance of Dectes stem borer in soybeans. This was effective when the traps were placed at canopy height.

In Nebraska, Dectes stem borer eggs can be found by dissecting soybean leaf petioles from July to August. Ovipostition scars left from female Dectes stem borer indicate petioles that are likely to contain eggs. Petioles are split with a razor blade while taking care not to destroy the small, fragile eggs. Sampling units for eggs have been based on splitting four petioles per plant from the upper half of 25 plants at each site (Campbell 1980).

Larval populations are estimated by using abscission scars, girdled stems or by splitting stems. When larvae leave the petiole and enter the main stem, the leaf wilts and falls off the plant leaving a reddish brown colored hole in the main stem. This abscission scar can be used to estimate densities prior to harvest. Later in the season, after larvae have tunneled down to the base of the plant, densities are estimated by counting the number of girdled or infested stems. Not all infested stems are girdled, thus splitting stems and counting larvae is a more absolute method than counting girdled stems. Lodged stems with a smooth concave break near soil level are an indicator of Dectes stem borer larval girdling (Campbell 1980).

Management

Careful harvest. There are no rescue treatments available for Dectes stem borer once the plants are infested with eggs and larvae. Management practices that may be employed at this point include harvesting earlier, and reducing the speed of harvesting equipment. Dectes stem borer larvae girdle the inside of soybean stems at the time of plant senescence. Early harvesting of soybean plants is sometimes difficult and slow, due to tough, green stems. Growers should spread out their planting dates to accommodate timely harvesting across large acreages.

Tillage. Burial of infested soybean or sunflower stems by tillage is effective at reducing overwintering larval populations. A 5 yr study conducted in North Carolina demonstrated that a burial depth of 5 cm (2 in) significantly increased larval mortality and reduced adult emergence (Campbell and Van Duyn 1977). Tillage is not an ideal control method in areas where soil erosion and moisture is of concern. An increase in no-till or minimum tillage may partially explain the recent increase in the pest status of Dectes stem borer in certain regions (Buschman and Sloderbeck 2010).

Trap crop. Trap crop plantings are grown to attract pests in an effort to prevent damage to a target crop. To be successful, the pest must prefer the trap crop to the target crop at the time the target crop is vulnerable to pest attack. Cultivated sunflower has potential as a trap crop because the risk of lodging can be minimized and it is the preferred host of the Dectes stem borer. The yield of cultivated sunflower is not affected by larval boring inside the stalk and low sunflower planting densities can prevent yield loss from lodging (Michaud et al. 2009). Sunflower stalk diameter increases and plant senescence occurs later with lower plant populations. Dectes stem borer larvae are only able to girdle a radius of about 1 cm, and the girdling behavior occurs at the same time as

plant senescence. Plant lodging is prevented at low population densities because the girdling behavior is delayed and thicker plant stalks are not girdled across their entire diameter (Michaud et al. 2009). A 3 yr study conducted in Kansas, where both crops are common, demonstrated successful control with sunflower trap crops. The most effective configuration was a perimeter planting of sunflower to intercept the adults moving into the soybean field. This reduced the larval infestation in the soybean field to less than five percent (Michaud et al. 2007). Other control methods may be integrated into the trap crop system. Tillage of the trap crop can effectively reduce overwintering larvae and insecticide sprays may be applied to the more attractive trap crop with high densities of DSB adults.

Natural enemies. Documented natural enemies of Dectes stem borer include eight Hymenopteran parasitoids and one Dipteran parasitoid (Hatchett et al. 1975, Tindall and Fothergill 2010, 2012). Hatchett et al. (1975) reared seven Hymenopteran species; *Bracon cerambycidiphagus* Muesbeck and *Bracon* sp., *Neocatolaccus tylodermae* Ashmead, *Habrocytus* sp., *H. languriae* Ashmead, *H. arkansensis* Girault, and *Melanichneumon brevicinctor* Say from Dectes stem borer larvae collected from giant ragweed. Only two parasitoid species have been reared from Dectes stem borer collected from soybean. Tindal and Fothergill (2012) reported *Dolichomitus irritator* F. infesting one percent of soybean stems collected from southeast Missouri. A single Tachinid fly, *Zelia tricolor* Coquillett, was reared from soybean stubble collected in southeast Missouri as well (Tindall and Fothergill 2010). No management programs for the Dectes stem borer have been developed using natural enemies and more study would be needed to understand how these parasitoids impact Dectes stem borer population dynamics.

Crop rotation. Crop rotation is of limited value for management of Dectes stem borer. Regions where Dectes stem borer reaches economic pest status in soybeans also have large areas planted to this crop. Although the adult beetles do not disperse over long distances, adults are strong enough flyers to infest soybean fields several km away (Buschman and Sloderbeck 2010). Therefore, unless soybean acreage is isolated and Dectes stem borer cannot find other fields or host plants to infest, rotating crops is not an effective tool for managing this pest.

Host plant resistance. Host plant resistance is defined as the relative amount of heritable qualities possessed by the plant which influence the ultimate degree of damage done by the insect (Painter 1951). Resistance can be divided into three categories; antixenosis, antibiosis and tolerance (Painter 1951, Smith 1989). Antixenosis affects the behavior of the insect pest and is a non-preference reaction by the pest to the resistant plant. Antibiosis resistance negatively affects the biology of the insect pest. This category of resistance results in lower fecundity, life span or increased mortality of the pest. Tolerance is the plant's ability to either withstand or recover from pest damage (Smith 1989).

There are no commercially available Dectes stem borer resistant soybean varieties available. Campbell (1976) tested 618 varieties for resistance and reported that eight percent of maturity group VIII varieties were girdled by Dectes stem borer compared to 44 percent among maturity groups VI and VII. Of the total 618 varieties tested, 18 varieties had moderate resistance to Dectes stem borer. Richardson (1975) studied soybean plant characteristics that influence larval girdling and infestation rates of Dectes stem borer. The study concluded that there was an effect of stem diameter, and a

significant correlation between total lignin content and infestation. There was no significant correlation between infestation rates and arrangement and number of vascular bundles, volume of pith, and carbohydrate content of the pith. Niide et al. (2012) measured the number of oviposition punctures (OP) to determine the level of antixenosis exhibited by soybean varieties, and used the ratio of oviposition punctures to live larvae as a measurement of antibiosis. The authors found significant differences in OPs and OP/larvae ratios among soybean varieties in maturity groups II, III, IV, VI, VII, and VIII. It was also concluded that petiole morphology had no affect on infestation rates.

Chemical control. Dectes stem borer spends most of its lifecycle inside the host plant, protected from foliar insecticide applications. The adult stage lives outside the plant and is susceptible to several chemical insecticides (Campbell and Van Duyn 1977, Kaczmarek et al. 2000), but insecticide applications have not been a reliable control tactic. The best timing of foliar applications is not fully understood and multiple well-timed applications may be needed to reduce larval infestations (Campbell and Van Duyn 1977, Sloderbeck and Buschman 2011). Sloderbeck and Buschman (2011) conducted a three yr field scale study measuring Dectes stem borer larval infestation and season long sweep net sampling densities under different aerial insecticide application dates. They found that well timed aerial applications of lambda-cyhalothrin insecticide (Syngenta Crop Protection, Inc., Greensboro, North Carolina) were successful in reducing adult population densities. However, two aerial applications were only able to reduce larval infestation rates by 46 to 75 percent. The systemic insecticide, fipronil (BASF Corporation, Research Triangle Park, North Carolina), has been shown to reduce larval infestations applied as either a seed or foliar treatment (Buschman et al. 2007b, 2007a,

Davis et al. 2008) but it is not registered for use in soybeans. Currently the only product that lists Dectes stem borer on the label is Hero® (zeta-cypermethrin plus bifenthrin) (FMC Corporation, Philadelphia, Pennsylvania).

Summary

Dectes stem borer on soybeans has been expanding its range in Nebraska since it was first detected in 2000. Developing a comprehensive management plan for this insect is limited by lack of knowledge of seasonal activity, and effective sampling plans to monitor adult activity. Therefore the following research objectives were developed for this thesis:

1. Describe the seasonal activity of the Dectes stem borer in Nebraska.
2. Develop cost effective sampling plans for the Dectes stem borer.

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CHAPTER 2

Seasonal activity of the Dectes stem borer, *Dectes texanus* Leconte, (Coleoptera: Cerambycidae) in Nebraska

Introduction

The Dectes stem borer, *Dectes texanus* Leconte, is a small grey longhorn beetle native to eastern North America. *Dectes texanus* is polyphagous and larval hosts include several native species including *Ambrosia trifida* L. (giant ragweed), *Ambrosia artemisiifolia* L. (common ragweed), *Helianthus annuus* L. (sunflower), and *Xanthuim strumarium* L. (cocklebur) (Patrick 1973, Hatchett et al. 1975). Although the Dectes stem borer commonly infests cultivated sunflower (Rogers 1977, Phillips 1972), infestation of wild sunflower is a rare occurrence (Michaud and Grant 2005). In certain geographies, Dectes stem borer has expanded its host range from native composite hosts to include *Glycine max* (L.) Merr. (soybeans), a non native leguminous crop (Buschman and Sloderbeck 2010).

Dectes stem borer has a univoltine life cycle. Adult emergence varies by geography and generally occurs from mid-June to early August (Campbell 1980, Hatchett et al. 1975, Patrick 1973). Larval host plant does not appear to affect the time to emergence (Michaud and Grant 2005). After emergence, the adults feed prior to mating (Hatchett et al., 1975). Previous studies have reported that the pre-oviposition period averages 7 days in the laboratory (Hatchett et al., 1975) and lasts 10 to 14 days in the field (Patrick 1973). The lifespan and fecundity of Dectes stem borer adults may vary depending on adult diet and larval host (Michaud and Grant 2005, 2010). Cultivated sunflower is the preferred host of Dectes stem borer (Michaud and Grant 2005, 2010) and adults fed sunflower live significantly longer than adults fed only soybean (Michaud and Grant 2005). Due to the fitness cost associated with soybean, it has been suggested that Dectes stem borer adults feed on alternate plants before migrating onto soybean (Michaud and Grant 2005). Based

on laboratory studies, it appears that the female adults may live as long as 30 to 60 days and can oviposit from 30 to 50 or more eggs in their lifetime (Hatchett et al. 1975, Michaud and Grant 2005). Eggs are oviposited in main stems, lateral branches and leaf petioles throughout July and August. In soybean, eggs are primarily laid in petioles located on the upper part of the canopy. The female chews a hole through the epidermis and oviposits a single egg inside the pith (Campbell 1980, Hatchett et al. 1975). Incubation time lasts from six to 10 d in the field (Patrick 1973). The larvae stay within the petiole feeding on pith for one to two wk prior to boring into the main stem. Once in the main stem, the larvae will tunnel up and down the plant. Near the end of the season, larvae tunnel down to the base of the plant, girdle the inside of the stem about 5 cm (2 in) above the soil line and plug the tunnel with frass. The onset of this larval girdling behavior occurs at the time of stalk desiccation (Michaud et al. 2009). Fourth instars overwinter below this girdling point near the soil level. Although more than one larvae may be found in a single plant, larvae are cannibalistic and only one typically overwinters in the base of the stem. Larvae have been reported to have four instars (Hatchett et al. 1973, Patrick 1973). Hatchett et al. (1975) reported six instars based on measurement of the head capsule width of larvae collected from ragweed in Missouri.

Dectes stem borer reaches economic pest status in soybeans in three geographic areas, the high plains from the Texas panhandle to southern Nebraska, the Mississippi and Ohio River valleys, and the Atlantic coast from South Carolina to New Jersey (Buschman and Sloderbeck 2010). The first report of Dectes stem borer causing economic damage to soybeans described fields with 100 percent infestation rates and 17 percent lodging in southeastern Missouri and northeastern Arkansas during the 1968 season (Daugherty and

Jackson, 1969). Since then, economic damage to soybeans by Dectes stem borer has been reported in Delaware, Tennessee, Kansas, Kentucky, Louisiana, Mississippi, Nebraska, North Carolina, New Jersey, South Carolina, South Dakota and Texas (Buschman and Sloderbeck 2010, Campbell 1976, Laster et al. 1981, Patrick 1971, Rogers 1977, Tindall et al. 2010).

The Dectes stem borer has been a significant pest of soybeans in Kansas since the 1980's. In Nebraska, Dectes stem borer was first reported causing economic damage to soybeans in 2000 near the Kansas border and has since became a more serious pest throughout the south central portion of the state (Wright and Hunt 2011).

Damage to soybeans from Dectes stem borer is primarily due to the larval girdling behavior and subsequent late season lodging. Adult feeding is minor and does not cause any significant yield loss. Damage from the larval stage can be divided into physiological yield loss and yield loss associated with lodging. Physiological yield loss is usually negligible, but there are data that suggests a 10 to 15 percent yield loss in soybean from larval tunneling alone in high levels of infestation (Buschman et al. 2005, Campbell 1980, Richardson 1975). Late season lodging causes most economic damage. Damage associated with late season lodging depends on multiple factors including the level of infestation and weather. Large soybean fields may have up to 100 percent infested plants (Daugherty and Jackson 1969, Michaud and Grant 2005, Tindall et al. 2010), but not all infested plants are girdled and lodge (Daugherty and Jackson 1969, Tindall et al. 2010, Michaud and Grant 2005). Strong winds late in the season cause the girdled stems to lodge, making harvest difficult or impossible with a combine harvester.

Dectes stem borer is difficult to control in soybeans, because farmers have few effective management options. There are no rescue treatments available for Dectes stem borer once the plants are infested with eggs and larvae. Management practices that may be employed at this point include early harvest, and adjusting the speed of harvesting equipment. By harvesting soybean fields earlier than usual, growers can prevent girdling and the lodging associated with weakened plants. After the larvae have girdled the stems, reducing the speed of harvesting equipment can minimize further lodging. Early harvesting of soybean plants is sometimes difficult and slow, due to tough, green stems. Growers should adjust their planting dates and variety maturities to accommodate timely harvesting across large acreages.

Burial of infested soybean stems by tillage is effective at reducing overwintering larval populations (Campbell and Van Duyn 1977). However, tillage is not an ideal control method in areas where soil erosion and moisture is of concern (Buschman and Sloderbeck 2010).

A trap crop of sunflower planted around the perimeter of a field can reduce larval infestations in soybeans (Michaud et al. 2007). Lodging in sunflowers can be prevented when planted at low plant populations because the girdling behavior is delayed and thicker plant stalks are not girdled across their entire diameter (Michaud et al. 2009). Since plant lodging can be prevented and Dectes stem borer adults are more attracted to sunflower than soybeans, sunflower shows good potential as a trap crop. Other control methods may be integrated into the trap crop system. Tillage of the trap crop can effectively reduce overwintering larvae and insecticide sprays may be applied to the more attractive trap crop with high densities of Dectes stem borer adults. Although trap

cropping has proven effective, few grain elevators buy sunflowers in Nebraska and many farmers have not adopted this practice because of economic reasons.

Crop rotation is of limited value for management of Dectes stem borer. Regions where Dectes stem borer reaches economic pest status in soybeans also have large areas planted to this crop. Although the beetles do not disperse over long distances, they are strong enough flyers to infest soybean fields several km away (Buschman and Sloderbeck 2010). Therefore, unless soybean fields are isolated and Dectes stem borer adults cannot find other fields or host plants to infest, rotating crops is not an effective tool for managing this pest.

Biological control programs have not been developed for managing Dectes stem borer. Documented natural enemies of Dectes stem borer include eight Hymenopteran and one Dipteran parasitoids (Hatchett et al. 1975, Tindall and Fothergill 2010, 2012). More study would be needed to understand how these parasitoids impact Dectes stem borer population dynamics.

There are no commercially available Dectes stem borer resistant soybean varieties. A few studies have discovered moderate resistance to this pest in soybean, but no resistant varieties are being developed for commercialization (Campbell 1976, Niide et al. 2012, Richardson 1975).

Insecticide applications for managing adult Dectes stem borer populations have not been reliable. Dectes stem borer spends most of its lifecycle inside the host plant, protected from foliar insecticide applications. The adult stage lives outside the plant and is susceptible to several chemical insecticides (Campbell and Van Duyn 1977, Kaczmarek et al. 2000). However, the best timing of foliar applications is not fully

understood and multiple well-timed applications may be needed to reduce larval infestations (Campbell and Van Duyn 1977, Sloderbeck and Buschman 2011). The systemic insecticide, fipronil (BASF Corporation, Research Triangle Park, North Carolina), has been shown to reduce larval infestations applied as either a seed or foliar treatment (Buschman et al. 2007a, Buschman et al. 2007b, Davis et al. 2008) but it is not registered for use in soybeans. Currently, the only product that lists Dectes stem borer on the label is Hero® (zeta-cypermethrin plus bifenthrin) (FMC Corporation, Philadelphia, Pennsylvania).

Good pest management programs are based on knowledge of the pest's biology. Developing a comprehensive management plan for this insect in Nebraska is limited by lack of knowledge of seasonal activity. The objective of this chapter is to describe the seasonal activity of Dectes stem borer adults in Nebraska soybeans.

Materials and Methods

Dectes stem borer emergence. Ten 1.8 by 1.8 m (6 by 6 ft) screen cages were set up in a fallow, non-irrigated field at the University of Nebraska-Lincoln South Central Agricultural Laboratory near Clay Center, Nebraska on 17 May 2013. Each screen cage (20x20 mesh) was placed over three rows of infested soybean stubble and additional infested stems from the same field were placed inside each cage to ensure an adequate rate of Dectes stem borer infested stems per emergence cage. A temperature logger (HOBO® data logger H08-032-08; Onset Computer Corporation, Bourne, MA) was placed inside four of the screen cages and one temperature logger was placed outside the screen cages to determine if the screen cages had an effect on degree-day accumulation. The emergence cages were checked twice per wk for emerged Dectes stem borer adults. The beetles were collected from each cage and placed in the refrigerator to slow their movement before sorting them by sex under a microscope using the characters described in Hatchett et al. (1975). The number of male and female beetles was recorded for each cage. Weather data from a local weather station at Clay Center (High Plains Regional Climate Center; http://hprcc.unl.edu) was used to calculate the accumulated degree-days by the averaging method with a 10 degrees Celsius (50 degrees Fahrenheit) minimal developmental temperature.

$$\mathrm{DD} = (\mathrm{TMAX} + \mathrm{TMIN})/2 - 50$$

In 2014, methods were similar, except the emergence cages were placed in an irrigated cornfield that was planted to soybeans the previous year at the South Central Agricultural Laboratory. This more closely simulated the environment that Dectes stem borer would likely encounter in south central Nebraska cropping systems.

The emergence data for each cage were fit to sigmoid emergence curves by nonlinear regression (PROC NLIN; SAS version 9.3) using the model (Stilwell et al. 2010):

$$\text{Percent Emergence } = a/[1 + \exp(b + c * x)]$$

where *a* is the upper asymptote, *x* is days or degree-days, and *b* and *c* are constants. Emergence curves were fit using both days and degree-days as values for *x*. Five characteristics of each emergence curve (fig. 2.1) were calculated using parameters from the model.

Slope, the emergence rate during linear emergence, was calculated using:

$$\text{Slope} = ca/4$$

Duration of linear emergence, was calculated by:

$$\text{Duration} = 4/c$$

Onset, or point at which linear emergence begins, was calculated by:

$$\text{Onset Point} = (b - 2)/c$$

Inflection point, point of maximum emergence rate, was calculated by:

$$\text{Inflection Point} = b/c$$

Termination point where linear emergence ends, was calculated by:

$$\text{Termination Point} = (b + 2)/c$$

Emergence curve fit was validated visually and one cage from 2014 was omitted from the analysis due to a lack of Dectes stem borer adult emergence. Differences between years in emergence curve characteristics were determined by a t-test (PROC TTEST; SAS version 9.3).

Oviposition. A field study was conducted to investigate Dectes stem borer oviposition in soybeans. Ten 1.8 by 1.8 m (6 ft by 6 ft) screen cages (20x20 mesh size)

were set up in an irrigated soybean field at the University of Nebraska South Central Agriculture Laboratory. One temperature logger was placed inside four of the screen cages and one temperature logger was placed outside the screen cages to determine if the cages had an effect on degree-day accumulation. A group of 10 to 20 beetles with a male to female ratio of about one to one were released into each cage as beetles were collected from the emergence study. All beetles inside an individual cage were of similar age, having emerged within the last 4 d. Beginning the week following infesting, five soybean plants were removed from each infested cage once per week to look for Dectes stem borer eggs and larvae. Plants were first inspected for oviposition scars. Petioles with signs of Dectes stem borer feeding and/or oviposition were carefully split lengthways with a scalpel under a stereomicroscope. The number of eggs per five plants in each cage was recorded. In 2014, the number of cages was reduced to five so that every cage could be infested with a greater number of Dectes stem borer adults. The data from both years were combined and categorized to weeks after infesting to show egg-laying activity over the lifespan of Dectes stem borer adults.

Seasonal activity in soybean fields. In 2013, eight commercial soybean fields in south central Nebraska were selected for sweep net sampling: (40°17’42”N 97° 53’8”W Nuckolls County; 40°22’46”N 97°48’ 52”W Fillmore County; 40°16’ 41”N 97°43’ 3”W Thayer County; 40°17’30”N 97°36’14”W Thayer County; 40°14’ 3”N 97°30’ 3”W Thayer County; 40°19’ 42”N 97°24’ 59”W Thayer County; 40°19’ 15”N 97°18’ 28”W Jefferson County; 40°25’ 14”N 96°55’ 37”W Saline County). Fields were selected based on a history of Dectes stem borer infestation and covered a wide geographical area. Fields were sampled once every one or two wk from late-June through August using a 38

cm (15 in) diameter sweep net. Sweep net sampling occurred between 10:00AM and 5:00PM to avoid excess variability in Dectes stem borer activity due to time of day. The sampling pattern consisted of four transects, 30.5 m (100 ft) apart, with four sampling locations in each transect for a total of 16 samples. Two samplers began at the field edge, walked to the center, and moved 30.5 m to either side before walking back. Samplers calibrated their steps to measure the distance from the field edge for each sampling location. A sample consisted of 20 sweeps across two rows, while walking a distance of roughly 15 m (50 ft). Samples were collected in plastic bags labeled with sample number (transect and location), sampler, date, and field, then placed in a cooler for transport. After transport, samples were frozen until later processing when the number of Dectes stem borer beetles in each sample bag was recorded. Beetles were placed in vials of 75 percent ethanol labeled with field and date information.

In 2014, six fields were selected for sweep net sampling sampling: (40°54'03"N 97°27'58"W York County; 40°53'40"N 97°27'15"W York County; 40°17'30"N 97°17'02"W Jefferson County; 40°17'06"N 97°42'30"W Thayer County; 40°14'02"N 97°30'05"W Thayer County; 40°19'42"N 97°24'26"W Thayer County). Sampling units were adjusted to 40 sweeps across two rows while walking a distance of 30.5 m (100 ft). This was adjusted due to the relatively low adult densities typical of Dectes stem borer in soybean fields.

Sampling data were analyzed separately each yr. In 2013, totals of the four sampling units at each sampling location (Dectes stem borer per 80 sweeps) were used for analysis. In 2014, the larger sampling units were analyzed without totaling sampling units at each location (Dectes stem borer per 40 sweeps). Each yr data were analyzed by repeated

measures analysis (PROC GLIMMIX; SAS version 9.3). The effects of sampling location (distance from the field edge) and sampling wk were treated as fixed and field was treated as a random effect. Covariance structures were compared by their Akaike's information criterion correction (AICC) values. In 2013, the covariance structure ar(1) was selected with an AICC value of 695. The covariance structure ante(1) was selected for 2014 data with an AICC of 2095. Significant differences in means were determined using least significant differences.

Results

Dectes stem borer emergence in days. The 2013 and 2014 Dectes stem borer emergence curves were similar in slope (t = 0.14; df = 17; P = 0.8939) and duration of linear emergence (t = 15; df = 17; P = 0.8818). There were highly significant differences between years in the onset points (t = 6.44; df = 17; P < 0.0001), inflection points (t = 8.31; df = 17; P < 0.0001) and termination points (t = 4.62; df = 17; P = 0.0002) as emergence in 2013 occurred 5 to 6 d earlier than emergence in 2014 (Table 2.1; Fig. 2.2).

Dectes stem borer emergence in degree-days. Dectes stem borer emergence during 2013 and 2014 were similar in slope (t = 0.69; df = 17; P = 0.5001), duration of linear emergence (t = 0.17; df = 17; P = 0.8676), onset points (t = 0.34; df = 17; P = 0.7397), inflection points (t = 0.70; df = 17; P = 0.4942), and termination points (t = 0.51; df = 17; P = 0.6191) (Table 2.1; Fig. 2.3). Table 2.1 and Fig. 2.4 show descriptive statistics and an emergence curve for both years' data combined.

Oviposition. The first Dectes stem borer eggs were recorded 7 d after infesting cages in both 2013 and 2014. The final eggs were recorded 42 and 39 days after infesting on 19 August 2013 and 15 August 2014, respectively. The average eggs per five plants dissected for each week are shown in Fig. 2.5.

Seasonal activity in soybean fields. There was a highly significant effect of wk on Dectes stem borer adult population densities during both 2013 (F = 13.31; df = 5,113.2; P < 0.0001) and 2014 (F = 43.10; df = 5,32.14; P < 0.0001). There was not a significant location effect or wk by location interaction in either year. The occurrence of peak Dectes stem borer density for each sampling field is shown in Table 2.2.

In 2013, the average Dectes stem borer adults per 80 sweeps across all sampled fields beetles are shown in Fig. 2.6. Densities were significantly higher during the weeks beginning on the 7, 14 and 28 July than all other sampling weeks in this season. There was a highly significant increase in Dectes stem borer density between the weeks of 30 June and 7 July (t = 4.15; df = 124; $P < 0.0001$). Populations were detectable well into August at lower densities. There was an observed trend of higher densities near the field edges than the field centers (Fig. 2.7), but there were no significant differences among sampling locations within fields.

Weekly mean Dectes stem borer beetles per 40 sweeps are shown in Fig. 2.8. There was a highly significant increase in adult densities between weeks beginning on 29 June and 6 July (t = 8.41; df = 13.4; $P < 0.0001$). Densities were significantly higher during the weeks of 6 and 13 July than the other four weeks in the analysis. Dectes stem borer beetles were present at low, but detectable population levels well into August. During the 2014 season, there were significantly greater Dectes stem borer densities near field edges than field centers (t = 2.34; df = 22.87; P = 0.0286) (Fig. 2.9).

Discussion

The emergence data presented demonstrate the potential to predict Dectes stem borer adult emergence on an annual basis using degree-days. Previous studies have described Dectes stem borer emergence, but this is the first time emergence has been fit to a degree-day model. Calendar date predictions for adult emergence vary, while degree-day predictions are similar across multiple yr. High accumulated degree-days at Clay Center, Nebraska early in 2013 relative to 2014 (Table 2.3) explain emergence occurring 5 to 6 d earlier that year. A minimum developmental temperature threshold for Dectes stem borer has not yet been established, and a development threshold of 10 degree Celsius (50 degrees Fahrenheit) was used to calculate degree-days in this study, as it is commonly used for many insects (Herms 2004). The cages' effect on degree-day accumulation was negligible for the purpose of the emergence and oviposition studies (Table 2.4).

Given that beetles were between 0 and 4 d old at the time of infestation, and an incubation time of 6 to 10 d (Patrick 1973), it appears that female Dectes stem borer adults reach peak fecundity during the second and third wk after emergence. Our results seem consistent with previous work done by Hatchett et al. (1975) that found an average preovipositional period of 7 d. Plants available for Dectes stem borer beetles to feed on in the emergence and oviposition cages may have affected our results because there are fitness costs associated with feeding on soybeans relative to other hosts such as cultivated sunflower (Michaud and Grant 2010).

Sweep net sampling data from both 2013 and 2014 show a dramatic increase in Dectes stem borer densities in early July as beetles initially migrate into soybean from adjacent areas. Dectes stem borer population densities in soybean fields are highest in

early to mid-July after a majority of adults have emerged and migrated into soybean fields. Peak densities observed in sampling fields occurred between 1419 and 2019 accumulated degree-days. This independently supports our emergence study since a large majority of Dectes stem borer adults would emerge prior to 1375 accumulated degree-days, the termination point of the emergence curve. Occurrence of observed peak densities in sampling fields varied by 600 degree-days. This might be caused by differences in the distance that adults migrated to reach the soybean fields sampled in this study. We were able to detect an edge effect in 1 of 2 yr of our study, which demonstrates the potential for perimeter treatments. Future work should be conducted to test the efficacy of well-timed insecticide applications and perimeter treatments. The fields sampled in this study were 1st yr soybean fields. The edge effect and steep increase in densities in early July are likely due to Dectes stem borer adult migration into the sampling fields from adjacent areas. Campbell (1980) reported higher Dectes stem borer densities near last years soybean crop and weedy field borders. Phenology of this insect may be somewhat different in locations where beetles have access to both sunflowers and soybeans.

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Tables and Figures

Table 2.1. Dectes stem borer emergence curve characteristics at Clay Center, Nebraska. Sample sizes were 10 during 2013 and 9 during 2014. Asterisks represent significant differences between years determined by a t-test (*P* = 0.05).

Year	Slope		Duration		Onset		Inflection		Termination	
	Days	Deg days	Days	Deg days	Days*	Deg days	Days*	Deg days	Days*	Deg days
2013	9.81 ± 1.02	0.4769 ± 0.0495	11.30 ± 1.28	235.7 ± 30.15	175.30 ± 0.60	1133.2 ± 14.11	181.00 ± 0.50	1251.1 ± 10.12	186.60 ± 0.98	1369.0 ± 21.45
2014	9.63 ± 0.85	0.4347 ± 0.0336	11.05 ± 1.00	242.0 ± 20.29	181.20 ± 0.69	1140.2 ± 15.07	186.70 ± 0.47	1261.2 ± 10.32	192.30 ± 0.68	1382.2 ± 13.84
Both	-	0.457 ± 0.03	-	239 ± 18	-	1137 ± 10	-	1256 ± 7	-	1375 ± 13

Table 2.2. Occurrence of peak observed Dectes stem borer adult densities in sweep net sampling fields for 2013 and 2014.

Year	Field	Weather station	Occurrence of maximum observed density	
			Day	Deg days
2014	1	York	7-11-14	1419
	2	York	7-11-14	1419
	3	Hebron	7-16-14	1717
	4	Hebron	7-8-14 – 7-17-14	1529 - 1733
	5	Hebron	7-8-14	1717
	6	Hebron	7-16-14	1717
2013	7	Hebron	7-24-13	2019
	8	Hebron	7-17-13	1821
	9	Hebron	7-9-13	1581
	10	Hebron	7-18-13	1854
	11	Hebron	7-10-13	1612
	12	Hebron	7-18-13	1854
	13	Hebron	7-10-13	1612
	14	Hebron	7-18-13	1854

Table 2.3. Weekly accumulated degree-days (base 50 degrees Fahrenheit begin 1 January) for three sites in south central Nebraska during 2013 and 2014.

Month	Day	2013			2014		
		Hebron	York	Clay Center	Hebron	York	Clay Center
April	6	40	19	117	33	20	19
	13	58	26	150	77	55	48
	20	63	26	155	115	85	78
	27	89	44	203	195	154	140
May	4	144	86	251	223	173	160
	11	204	117	308	339	262	239
	18	345	246	436	349	270	245
	25	450	326	522	497	399	384
June	1	595	441	641	670	565	544
	8	706	528	734	813	692	674
	15	889	681	885	940	813	793
	22	1101	865	1064	1138	1002	977
	29	1302	1040	1238	1302	1159	1127
July	6	1472	1187	1381	1474	1305	1268
	13	1713	1401	1572	1670	1469	1431
	20	1913	1580	1737	1802	1579	1538
	27	2078	1733	1882	2014	1769	1734
Aug	3	2227	1861	2009	2160	1900	1872
	10	2400	2015	2167	2345	2060	2041
	17	2545	2146	2297	2499	2218	2185
	24	2742	2331	2471	2698	2397	2364

Table 2.4. Accumulated degree-days (base 50 degrees Fahrenheit beginning on the date initiated) inside four screen cages and outside the cages on two dates for the emergence and oviposition studies.

Year	Study	Date initiated	Date	Accumulated degree-days				
				Cage 1	Cage 2	Cage 3	Cage 4	Outside
2013	Egg laying	6-14-13	7-1-13	471	467	474	468	472
			8-1-13	1197	1182	1204	1182	1191
	Emergence	5-30-13	7-1-13	712	717	717	716	717
			8-1-13	1478	1483	1488	1483	1492
2014	Egg laying	6-12-14	7-1-14	442	439	446	440	445
			8-1-14	1102	1086	1099	1087	1106
	Emergence	6-7-14	7-1-14	534	537	532	524	526
			8-1-14	1244	1248	1245	1233	1193

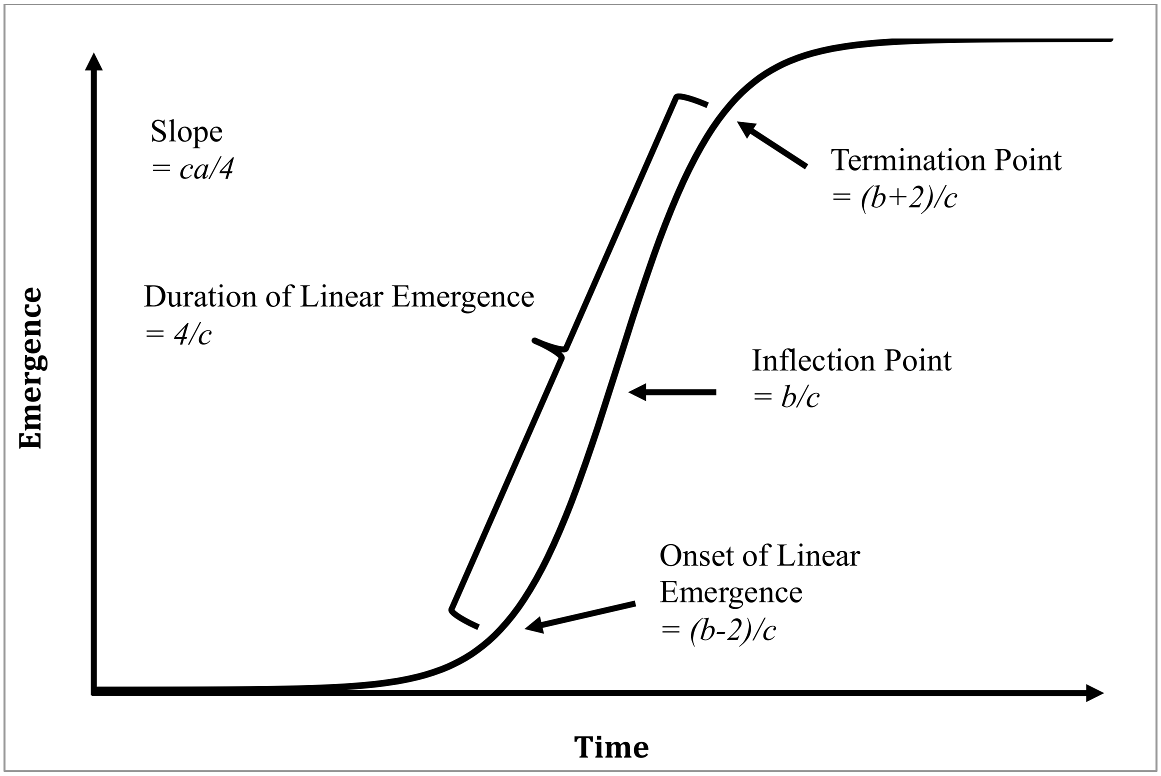

Fig. 2.1. Five characteristics of sigmoid emergence curves.

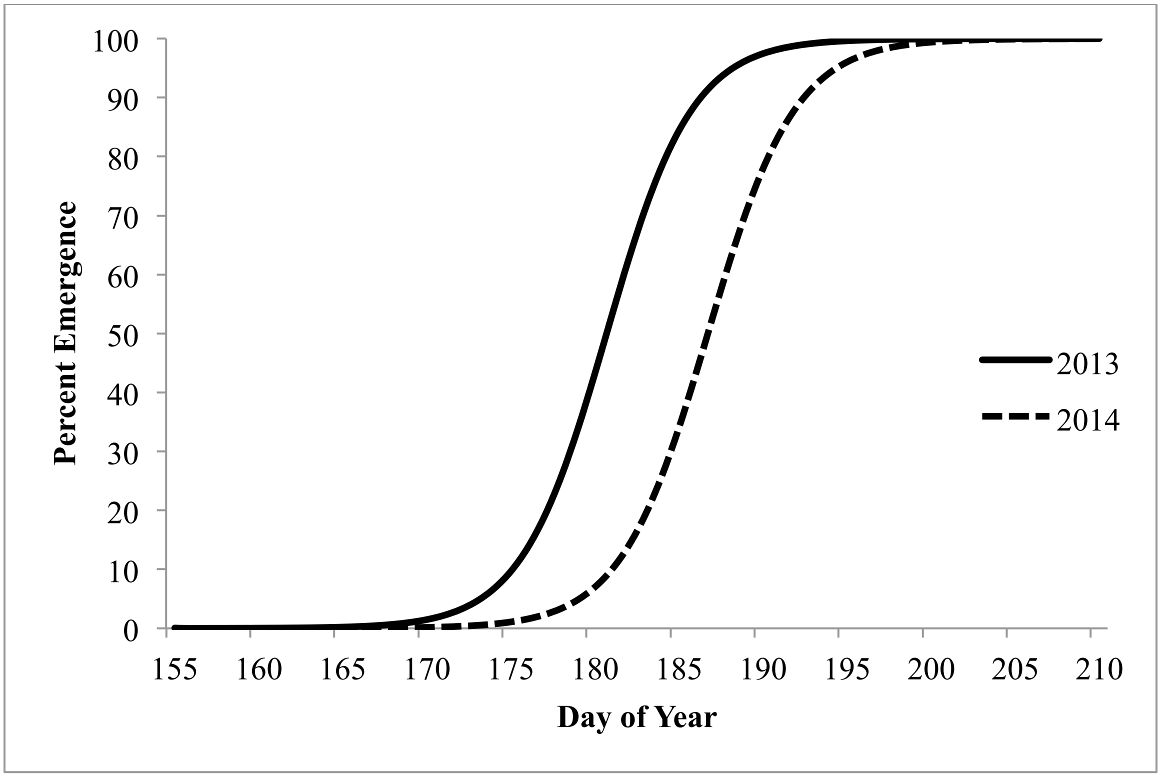

Fig. 2.2. Dectes stem borer adult emergence near Clay Center, NE for 2013 and 2014 by day of year.

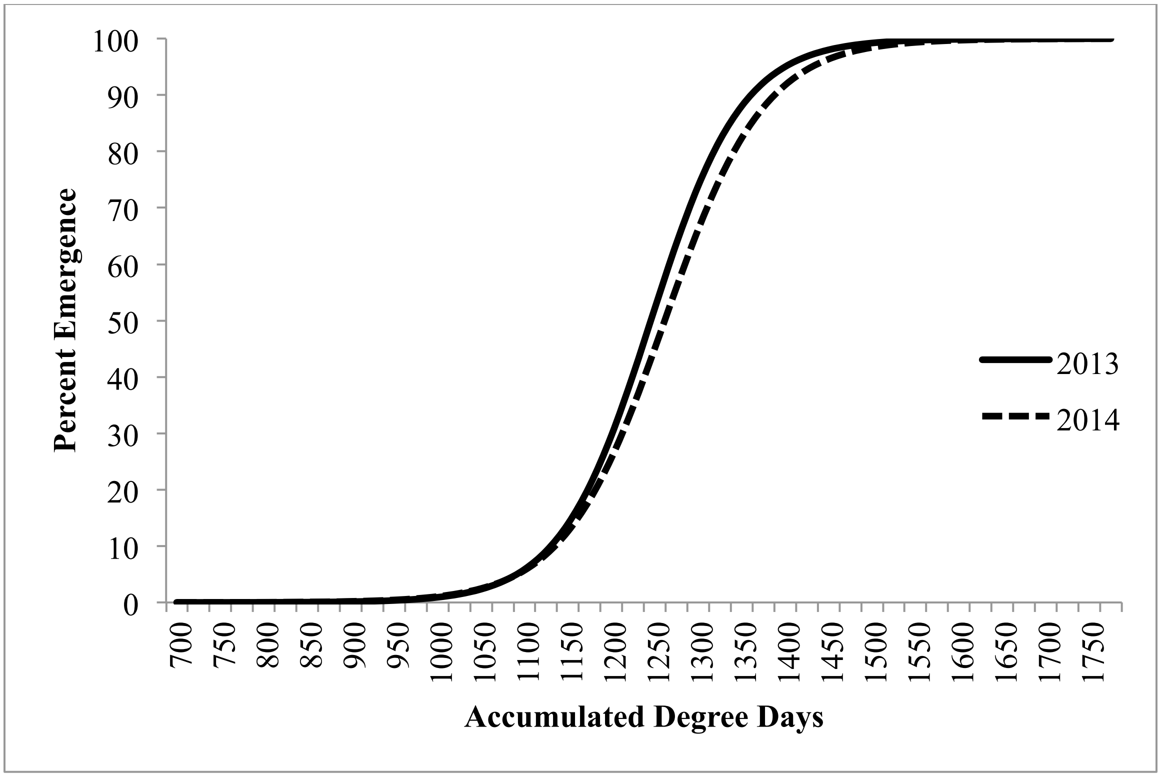

Fig. 2.3. Dectes stem borer adult emergence near Clay Center, NE for 2013 and 2014 by degree-days (base 50 degrees Fahrenheit begin 1 January).

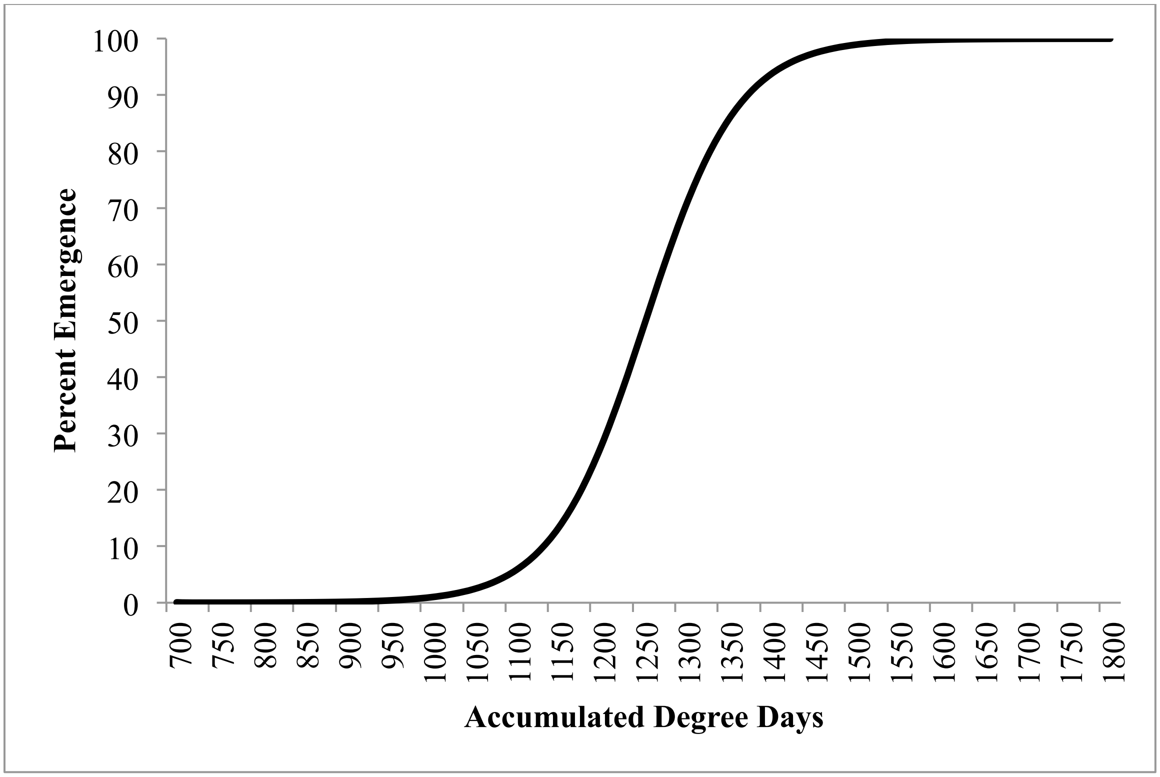

Fig. 2.4. Dectes stem borer adult emergence near Clay Center, Nebraska from 2013 and 2014 data combined. Degree-days were calculated by the averaging method with a base of 50 degrees Fahrenheit and beginning on 1 January.

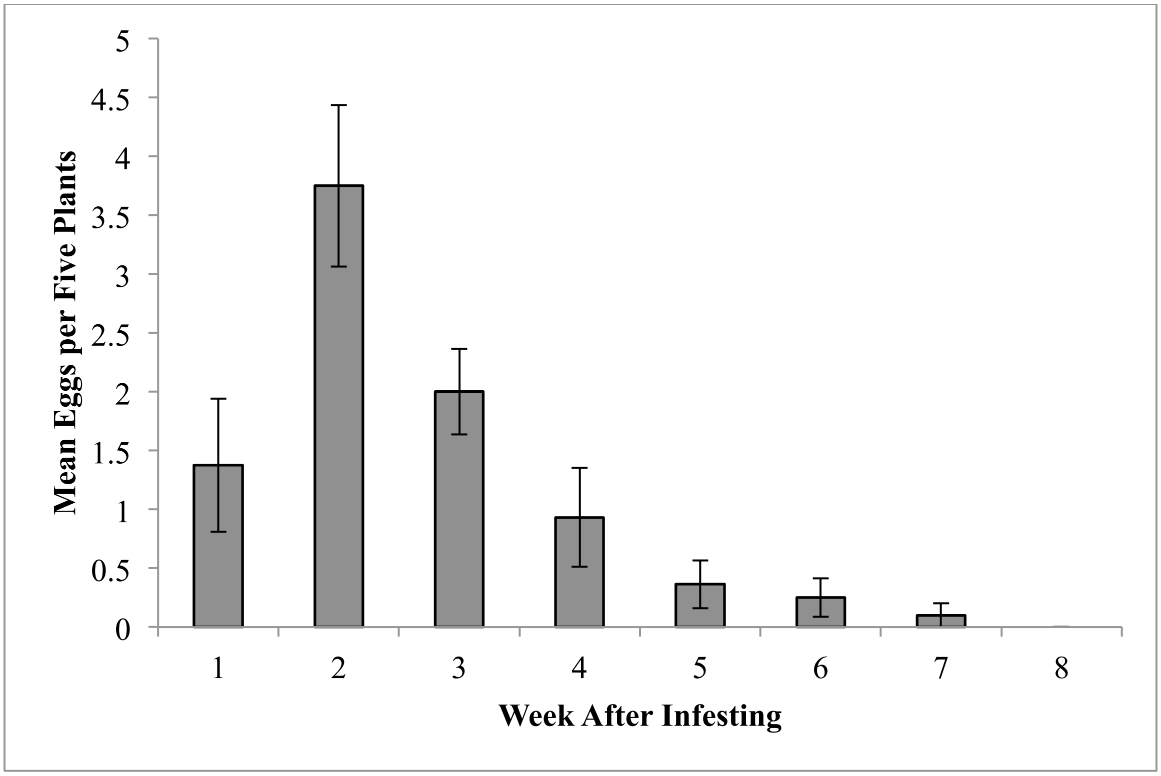

Fig. 2.5. Mean ± SE eggs per five plants dissected each week after infesting for both 2013 and 2014 combined. Sample sizes are 8, 12, 17, 15, 11, 8, 10 and 5 samples of 5 plants for weeks 1, 2, 3, 4, 5, 6, 7, and 8, respectively.

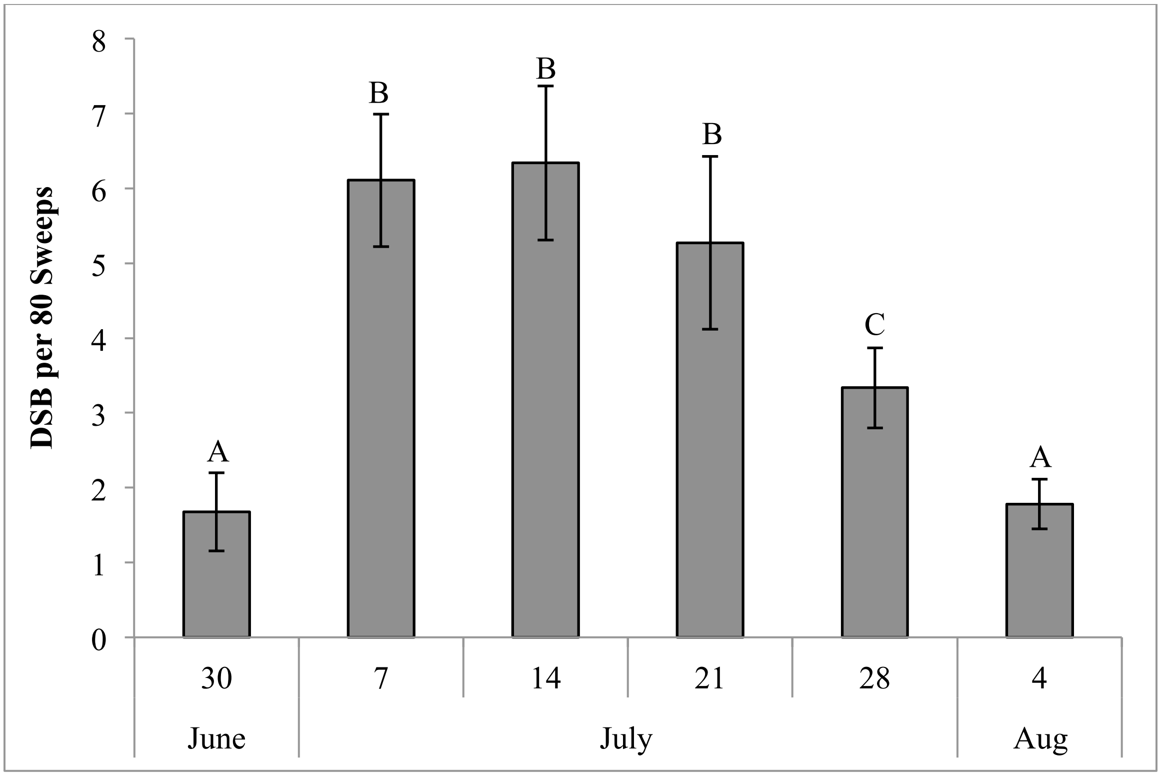

Fig. 2.6. Weekly mean Dectes stem borer (DSB) beetle densities in soybean fields for 2013. Means that share a letter are not significantly different by least significant differences ($P = 0.05$).

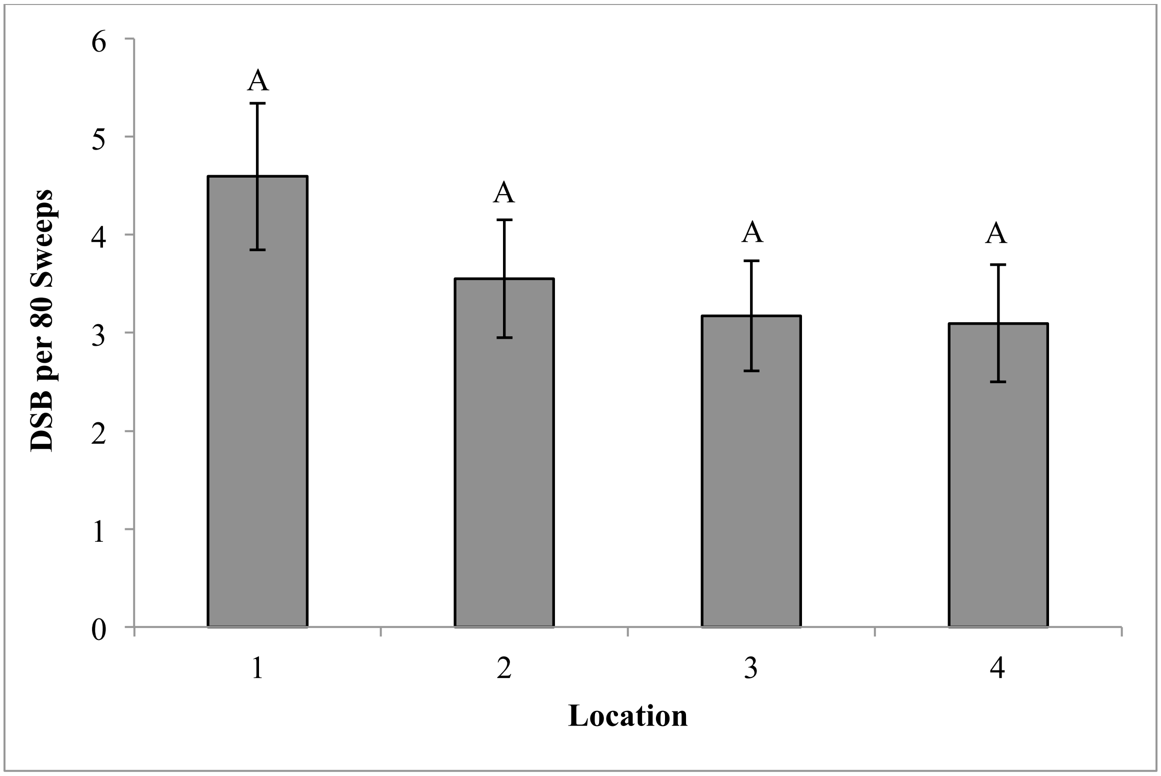

Fig. 2.7. Season long Dectes stem borer (DSB) mean densities at four sampling locations from field edge (location 1) to the field center (location 4) for 2013. Means that share a letter are not significantly different by least significant differences ($P = 0.05$).

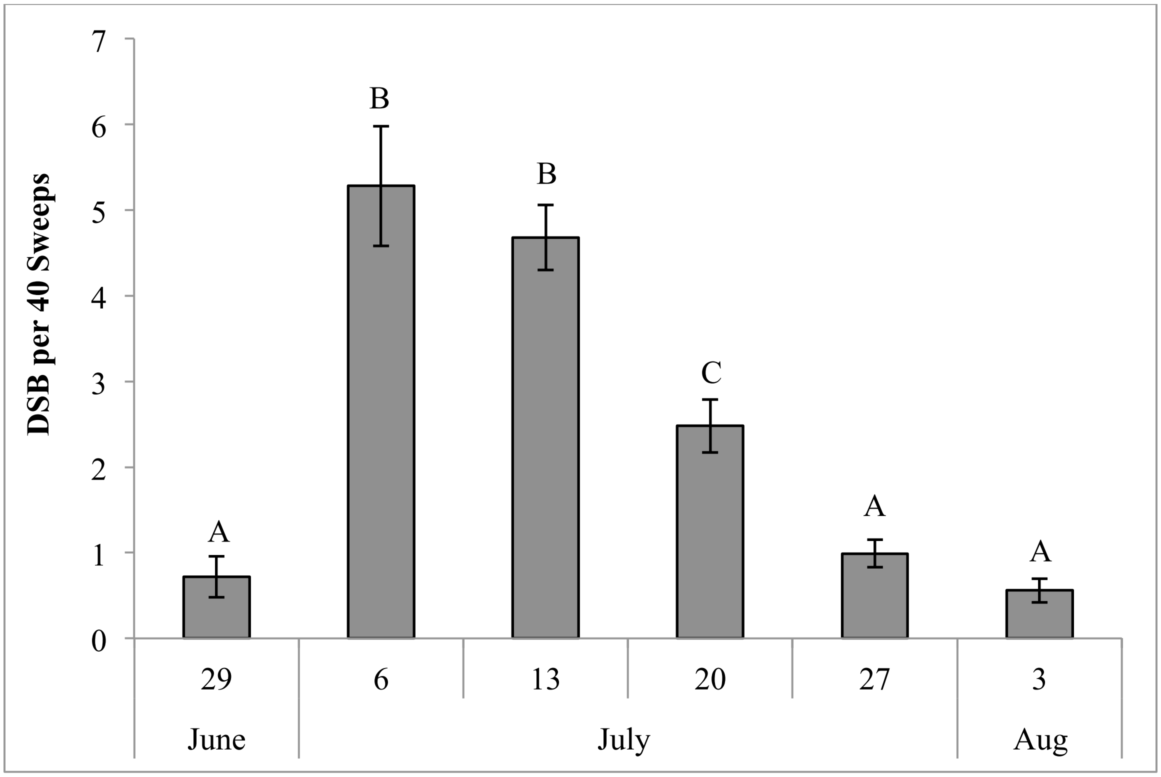

Fig. 2.8. Weekly mean Dectes stem borer (DSB) beetle densities in soybean fields for 2014. Means that share a letter are not significantly different by least significant differences (P = 0.05).

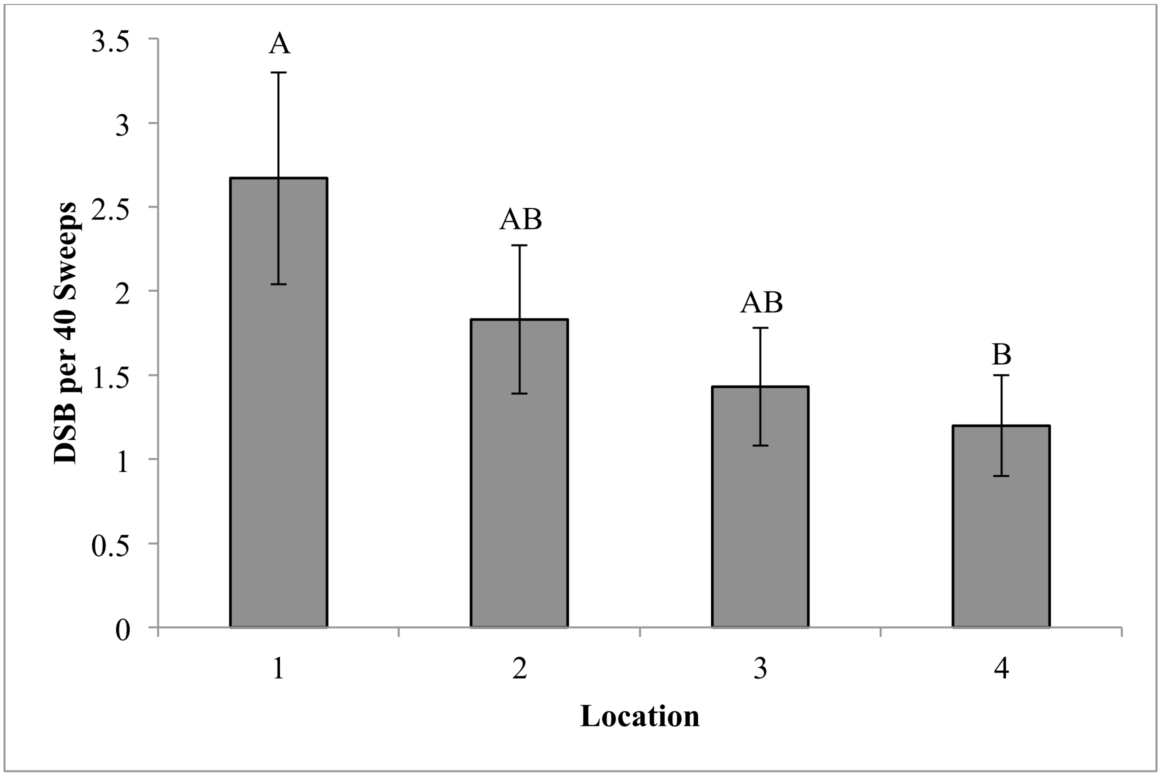

Fig. 2.9. Season long Dectes stem borer (DSB) mean densities at four sampling locations from the field edge (location 1) to the field center (location 4) for 2014. Means that share a letter are not significantly different by least significant differences (*P* = 0.05).

CHAPTER 3

Sampling methods for the Dectes stem borer, *Dectes texanus* Leconte, (Coleoptera: Cerambycidae) in Nebraska soybeans

Introduction

The Dectes stem borer , *Dectes texanus* Leconte, is a small grey longhorn beetle native to eastern North America. Dectes stem borer is polyphagous and larval hosts include several native species including *Ambrosia trifida* L. (giant ragweed), *Ambrosia artemisiifolia* L. (common ragweed), *Helianthus annuus* L. (sunflower), and *Xanthuim strumarium* L. (cocklebur) (Patrick 1973, Hatchett et al. 1975). Although Dectes stem borer commonly infests cultivated sunflower (Rogers 1977, Phillips 1972), infestation of wild sunflower is a rare occurrence (Michaud and Grant 2005). In certain geographies, Dectes stem borer has expanded its host range from native composite hosts to include *Glycine max* (L.) Merr. (soybeans), a non native leguminous crop (Buschman and Sloderbeck 2010).

Dectes stem borer has a univoltine life cycle. Adult emergence varies by geography and generally occurs from mid-June to early August (Campbell 1980, Hatchett et al. 1975, Patrick 1973). Larval host plant does not appear to affect the time to emergence (Michaud and Grant 2005). After emergence, the adults feed prior to mating (Hatchett et al. 1975). Previous studies have reported that the pre-oviposition period averages 7 d in the laboratory (Hatchett et al. 1975) and lasts 10 to 14 d in the field (Patrick 1973). The lifespan and fecundity of Dectes stem borer adults may vary depending on adult diet and larval host (Michaud and Grant 2005, 2010). Cultivated sunflower is the preferred host of Dectes stem borer (Michaud and Grant 2005, 2010) and adults fed sunflower live significantly longer than adults fed only soybean (Michaud and Grant 2005). Due to the fitness cost associated with soybean, it has been suggested that the adults feed on alternate plants before migrating onto soybean (Michaud and Grant 2005). Based on

laboratory studies, it appears that female Dectes stem borer beetles may live as long as 30 to 60 days and can oviposit from 30 to 50 or more eggs in her lifetime (Hatchett et al. 1975, Michaud and Grant 2005). Eggs are oviposited in main stems, lateral branches and leaf petioles throughout July and August. In soybean, eggs are primarily laid in petioles located on the upper part of the canopy. The female chews a hole through the epidermis and oviposits a single egg inside the pith (Campbell 1980, Hatchett et al. 1975). Incubation time lasts from 6 to 10 d in the field (Patrick 1973). The larvae stay within the petiole feeding on pith for 1 to 2 wk prior to boring into the main stem. Once in the main stem, the larvae will tunnel up and down the plant. Near the end of the season, larvae tunnel down to the base of the plant, girdle the inside of the stem about 5 cm (2 in) above the soil line and plug the tunnel with frass. The onset of this larval girdling behavior occurs at the time of stalk desiccation (Michaud et al. 2009). Fourth instars overwinter below this girdling point near the soil level. Although more than one larva may be found in a single plant, larvae are cannibalistic and only one typically overwinters in the base of the stem. Larvae have been reported to have four instars (Hatchett et al. 1973, Patrick 1973). Hatchett et al. (1975) reported six larval instars based on measurement of the head capsule width of larvae collected from ragweed in Missouri.

Dectes stem borer reaches economic pest status in soybeans in three geographic areas, the high plains from the Texas panhandle to southern Nebraska, the Mississippi and Ohio River valleys, and the Atlantic coast from South Carolina to New Jersey (Buschman and Sloderbeck 2010). The first report of Dectes stem borer causing economic damage to soybeans described fields with 100 percent infestation rates and 17 percent lodging in southeastern Missouri and northeastern Arkansas during the 1968 season (Daugherty and

Jackson 1969). Since then, economic damage to soybeans by Dectes stem borer has been reported in Delaware, Tennessee, Kansas, Kentucky, Louisiana, Mississippi, Nebraska, North Carolina, New Jersey, South Carolina, South Dakota and Texas (Patrick 1971, Campbell 1976, Buschman and Sloderbeck 2010, Tindall et al. 2010, Rogers 1977, Laster et al. 1981).

Dectes stem borer has been a significant pest of soybeans in Kansas since the 1980's. In Nebraska, this insect was first reported causing economic damage to soybeans in 2000 near the Kansas border and has since became a more serious pest throughout the south central portion of the state (Wright and Hunt, 2011).

Damage to soybeans from Dectes stem borer is primarily due to the larval girdling behavior and subsequent late season lodging. Adult feeding is minor and does not cause any significant yield loss. Damage from the larval stage can be divided into physiological yield loss and yield loss associated with lodging. Physiological yield loss is usually negligible, but there are data that suggests a 10 to 15 percent yield loss in soybean from larval tunneling alone in high levels of infestation (Buschman et al. 2005, Campbell 1980, Richardson 1975). Late season lodging causes most economic damage. Damage associated with late season lodging depends on multiple factors including the level of infestation and weather. Large soybean fields may have up to 100 percent infested plants (Daugherty and Jackson 1969, Tindall et al. 2010, Michaud and Grant 2005), but not all infested plants are girdled and lodge (Daugherty and Jackson 1969, Tindall et al. 2010, Michaud and Grant 2005). Strong winds late in the season cause the girdled stems to lodge, making harvest difficult or impossible with a combine harvester.

Dectes stem borer is difficult to control in soybeans, because farmers have few effective management options. There are no rescue treatments available for Dectes stem borer once the plants are infested with eggs and larvae. Management practices that may be employed at this point include early harvest, and adjusting the speed of harvesting equipment. By harvesting soybean fields earlier than usual, growers can prevent girdling and the lodging associated with infested plants. After the larvae have girdled the stems, reducing the speed of harvesting equipment can minimize further lodging. Early harvesting of soybean plants is sometimes difficult and slow, due to tough, green stems. Growers should adjust their planting dates and variety maturities to accommodate timely harvesting across large acreages.

Burial of infested soybean stems by tillage is effective at reducing overwintering larval populations (Campbell and Van Duyn 1977). However, tillage is not an ideal control method in areas where soil erosion and moisture is of concern (Buschman and Sloderbeck 2010).

A trap crop of sunflower planted around the perimeter of a field can reduce larval infestations in soybeans (Michaud et al. 2007). Lodging in sunflowers can be prevented when planted at low plant populations because the girdling behavior is delayed and thicker plant stalks are not girdled across their entire diameter (Michaud et al. 2009). Since plant lodging can be prevented and Dectes stem borer is more attracted to sunflower than soybeans, sunflower shows good potential as a trap crop. Other control methods may be integrated into the trap crop system. Tillage of the trap crop can effectively reduce overwintering larvae and insecticide sprays may be applied to the more attractive trap crop with high densities of DSB adults. Although trap cropping has

proven effective, few grain elevators buy sunflowers in Nebraska and many farmers have not adopted this practice because of economic reasons.

Crop rotation is of limited value for management of Dectes stem borer. Regions where Dectes stem borer reaches economic pest status in soybeans also have large areas planted to this crop. Although the beetles do not disperse over long distances, they are strong enough flyers to infest soybean fields several km away (Buschman and Sloderbeck 2010). Therefore, unless soybean fields are isolated and Dectes stem borer adults cannot find other fields or host plants to infest, rotating crops is not an effective tool for managing this pest.

Biological control programs have not been developed for Dectes stem borer. Documented natural enemies of this insect include eight Hymenopteran and one Dipteran parasitoids (Hatchett et al. 1975, Tindall and Fothergill 2012, Tindall and Fothergill 2010). More study would be needed to understand how these parasitoids impact Dectes stem borer population dynamics.

There are no commercially available Dectes stem borer resistant soybean varieties. A few studies have discovered moderate resistance to Dectes stem borer in soybean, but no resistant varieties are being developed for commercialization (Campbell 1976, Niide et al. 2012, Richardson 1975).

Insecticide applications for managing Dectes stem borer populations have not been reliable. Dectes stem borer spends most of its lifecycle inside the host plant, protected from foliar insecticide applications. The adult stage lives outside the plant and is susceptible to several chemical insecticides (Campbell and Van Duyn 1977, Kaczmarek et al. 2000). However, the best timing of foliar applications is not fully understood and

multiple well-timed applications may be needed to reduce larval infestations (Campbell and Van Duyn 1977, Sloderbeck and Buschman 2011). The systemic insecticide, fipronil (BASF Corporation, Research Triangle Park, North Carolina), has been shown to reduce larval infestations applied as either a seed or foliar treatment (Davis et al. 2008, Buschman et al. 2007a, 2007b) but it is not registered for use in soybeans. Currently, the only product that lists Dectes stem borer on the label is Hero® (zeta-cypermethrin plus bifenthrin) (FMC Corporation, Philadelphia, Pennsylvania).

A standard sampling plan for estimating Dectes stem borer adult populations has not yet been established. Sampling adults may be done by ground cloth, sweep net, or sticky traps. Sampling Dectes stem borer adults by the ground cloth sampling method is difficult because when disturbed, the adults readily fly, walk, or drop to lower foliage (Campbell 1980). Campbell (1980) made sticky traps from a mesh screen attached to a 30 cm wood frame and coated with adhesive to record the seasonal abundance of Dectes stem borer beetles in soybeans. This was effective when the traps were placed at canopy height. The sweep net method is common when sampling for adult Dectes stem borer populations (Buschman et al. 2005, Buschman et al. 2007a, Campbell 1980, Davis et al. 2008, Sloderbeck and Buschman 2011). However, season-long sweep net counts may not correlate well with end of season larval infestations (Sloderbeck and Buschman 2011). This method has not been calibrated to an absolute sampling method and no studies have determined the number of sweeps required for a given level of precision.

Dectes stem borer populations have been increasing in Nebraska for about 10 years. Good integrated pest management programs use sampling and thresholds to make therapeutic action decisions. Developing a comprehensive management plan for this

insect in Nebraska is limited by lack of a reliable sampling method for estimating adult Dectes stem borer population levels. The objective of this chapter is to develop cost effective sampling methods for Dectes stem borer in Nebraska soybeans.

Materials and Methods

Sweep net sampling. In 2013, eight commercial soybean fields in south central Nebraska were selected for sweep net sampling: (40°17’42”N 97° 53’8”W Nuckolls County; 40°22’46”N 97°48’ 52”W Fillmore County; 40°16’ 41”N 97°43’ 3”W Thayer County; 40°17’30”N 97°36’14”W Thayer County; 40°14’ 3”N 97°30’ 3”W Thayer County; 40°19’ 42”N 97°24’ 59”W Thayer County; 40°19’ 15”N 97°18’ 28”W Jefferson County; 40°25’ 14”N 96°55’ 37”W Saline County). Fields were selected based on a history of Dectes stem borer infestation and covered a wide geographical area. Fields were sampled every one or two weeks using a 38 cm (15 in) diameter sweep net. Sweep net sampling occurred between 10:00AM and 5:00PM to avoid excess variability in Dectes stem borer activity due to time of day. The sampling pattern consisted of 4 transects, 30.5 m (100 ft) apart, with four sampling locations in each transect for a total of 16 samples. Two samplers began at the field edge, walked to the center, and moved 30.5 m (100 ft) to either side before walking back. Samplers calibrated their steps to measure the distance from the field edge for each sampling location. A sample consisted of 20 sweeps across two rows, while walking a distance of roughly 15 m (50 ft). Samples were collected in plastic bags labeled with sample number (transect and location), sampler, date, and field, then placed in a cooler for transport. After transport, samples were frozen until later processing when the number of Dectes stem borer beetles in each sample bag was recorded. Beetles were placed in vials of 75 percent ethanol labeled with field and date information.

In 2014, six fields were selected for regular sampling: (40°54'03"N 97°27'58"W York County; 40°53'40"N 97°27'15"W York County; 40°17'30"N 97°17'02"W Jefferson

County; 40°17'06"N 97°42'30"W Thayer County; 40°14'02"N 97°30'05"W Thayer County; 40°19'42"N 97°24'26"W Thayer County). Sampling units were adjusted to 40 sweeps across two rows while walking a distance of 30.5 m (100 ft). This was adjusted due to the relatively low adult densities typical of Dectes stem borer adults in soybean fields and as an effort to increase the precision of the samples.

Sweep net sampling methods for both 2013 and 2014 were evaluated for statistical precision. Precision in this case is defined as the standard error expressed as a proportion of the mean. Sweep net sampling data were converted to beetles per 10 sweeps. Taylor's power law (Taylor 1961) was fit to s^2 and $\bar{x}$ values from sampling data by non-linear regression (PROC NLIN; SAS version 9.3). Taylor's power law is based on the mean-variance relationship

$$s^2 = a(m)^b$$

where *a* varies depending on sampling size and location and *b* is the index of aggregation. Population dispersion patterns can be described as uniform, random, or aggregated when *b* is less than, equal to or greater than one, respectively. One sample t-tests were used to determine if *b* was significantly different than one. Estimates of *a* and *b* were used to calculate the sample size *n* required for a desired level of precision *c* at the expected mean *m* using the following equation (Buntin 1993).

$$n = (am^{b-2})/c^2$$

Optimum sampling scheme. In 2014, a two-stage sampling plan was used to develop sweep net sampling schemes with the best combination of precision and cost. The sampling pattern was consistent with the pattern previously described except that 40 sweep primary sampling units were divided into four 10 sweep sub samples. This

method was repeated in three fields during the month of July, when Dectes stem borer adult densities are highest in Nebraska soybean fields.

The variance within primary sampling units s_2^2 and between primary sampling units s_1^2 was estimated by a nested ANOVA (PROC MIXED; SAS version 9.3). Cost in human minutes required for the addition of one sub unit c_2 and the addition of one primary unit c_1 was estimated by timing each sampler several times and averaging the time required. The following equations from Snedecor and Cochran (1967) were used to calculate the optimum number of primary units n_1 and sub units n_2 at the desired mean variance V.

$$n_2 = \sqrt{c_1 s_2^2 / c_2 s_1^2}$$

$$n_1 = (s_1^2 n_2 + s_2^2)/V n_2$$

Drop cloth sampling. In 2014, the drop cloth method was tested for sampling Dectes stem borer populations in three soybean fields. Two samplers walked four transects from the field edge to the center. Sweep net and drop cloth sampling sites were located at four points along each transect. At each of the four points along a transect, four drop cloth subsamples consisting of 2 m row length were collected. Four sweep net subsamples consisting of 10 sweeps across two rows were collected 10 rows across from the sweep net samples. The field costs required for one drop cloth sample was similar to the field costs required to take a 10 sweep sample and place the sample in a plastic bag. Sampling methods were randomly assigned to a sampler at the start of each transect to account for sampler bias. A t-test was used to determine significantly differences in number of Dectes stem borer beetles caught.

Sticky trap sampling. In 2013, sticky traps were tested as a Dectes stem borer sampling method in a soybean field at the South Central Agriculture Laboratory near Clay Center, Nebraska. Pherocon® AM yellow sticky traps were set at heights of 0.3, 0.9 and 1.5 m (1, 3, and 5 ft) from ground level. Traps were located 6 m (20 ft) apart and replaced weekly. Each height treatment was replicated five times in the same soybean field. Weekly DSB counts were recorded.

In 2014, Pherocon® AM yellow and Scentry® Multigard yellow-green sticky traps were tested in a soybean field at the South Central Agriculture Laboratory. Five traps of each color were randomly assigned to one of 10 stakes 6 m (20 ft) apart. The traps were installed at canopy height and replaced weekly. Weekly Dectes stem borer counts were recorded.

Results

Sweep net sampling. In 2013, sweep net samples averaged 0.41 Dectes stem borer adults per 10 sweeps and had a precision level of 0.32. Sample sizes of 27 and 167 sampling units would be required for a precision level of 0.25 and 0.10, respectively (Table 3.1; Fig. 3.1). Taylor's *a* estimate was 0.8702 and *b* estimate was 1.2719. The coefficient *b* was significantly greater than one (*t* = 3.3693; df = 56; *P* = 0.0014).

In 2014, sample unit size was increased to 40 sweeps and sweep net samples averaged 0.52 Dectes stem borer adults per 10 sweeps with a precision level of 0.24. Sample sizes of 14 and 89 sampling units would be required for a precision level of 0.25 and 0.10, respectively (Table 3.1; Fig. 3.2). Taylor's *a* estimate was 0.4882 and *b* estimate was 1.0856. The coefficient *b* was not significantly different than one (*t* = 0.5928; df = 51; *P* = 0.5559).

Taylor's *b* coefficients were not significantly different between 2013 and 2014 (*t* = 0.8276; df = 109; *P* = 0.4097). When sampling data from both 2013 and 2014 were combined, the overall mean of the 2 yr was 0.46 Dectes stem borer adults per 10 sweeps and the precision of the samples was 0.29. Sample sizes of 22 and 136 would be required for a precision level of 0.25 and 0.10, respectively (Table 3.1; Fig. 3.3). Taylor's *a* estimate was 0.6304 and *b* estimate was 1.0133. Taylor's *b* was not significantly different than one (*t* = 0.1567; df = 109; *P* = 0.8758).

Optimum sampling scheme. The results of the nested ANOVA are shown in Table 3.2. The mean density in this study was 1.18 Dectes stem borer adults per 10 sweeps. The average field costs associated with the addition of one primary sampling unit c_1 and with the addition of one sub unit c_2 were 1.15 and 0.133 min, respectively. The total

costs, including the time required in field costs and in processing samples outside of the field, averaged 2.4 and 0.133 min for c_1 and c_2, respectively. Sampling schemes to minimize field costs and total costs are shown in Tables 3.3 and 3.4.

Drop cloth sampling. In the three fields sampled the drop cloth method averaged 0.36 Dectes stem borer adults per 2 m of row. Sweep net samples averaged 1.18 beetles per 10 sweeps and resulted in significantly higher counts than the drop cloth method (t = 7.04; df = 264.56; P < 0.0001).

Sticky trap sampling. In 2013, the AM yellow sticky traps were not effective. Only one Dectes stem borer adult was recorded on the sticky traps in 2013.

In 2014, a total beetle count of eight was recorded. During the week of 30 June to 7 July, the yellow traps caught one Dectes stem borer and the yellow-green traps caught four. The following week, 7 to 14 July, the yellow traps caught one adult and the yellow-green traps caught two Dectes stem borer adults. The final week, 14 to 21 July, no Dectes stem borer adults were recorded on sticky traps.

Discussion

Sweep net sampling is a superior method to sample for Dectes stem borer adults than drop cloths or sticky traps. Drop cloth sampling is less ergonomic than sweep nets, since samplers need to work closer to ground level, rather than standing upright. A drop cloth sample consisting of 2 m of row length results in lower beetle counts than a sweep net sample of similar costs in time. We did not have difficulty counting the relatively low catches of Dectes stem borer in drop cloth samples even though the adults readily fly or crawl off of the cloth. Sticky traps appear ineffective as a sampling tool. In 2014, the yellow green traps did catch more beetles than the yellow traps, but overall catch numbers were too low to be reliable for pest management decision-making.

In 2013, Taylor's *b* estimate from our sweep net sampling indicated an aggregated dispersion pattern. In 2014, the *b* estimate from our sampling indicated a random dispersion pattern, even though *b* was not significantly different between years.

Based on data presented here, sweep net sampling schemes consisting of large sampling units should be considered when developing cost effective sampling plans for Dectes stem borer adult populations. Subsamples of 10 sweeps were the source of nearly 80% of the total variation in sampling counts. Since 10 sweeps costs only a few seconds time, a large sampling unit is more efficient than a smaller one. The improvement in precision between 2013 and 2014 may be explained by the increased sampling unit size.

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Tables and Figures

Table 3.1. Estimates of *a* and *b* from Taylor's Power Law, season-long means, and precision levels for Dectes stem borer sweep net sampling in 2013, 2014 and both yr combined.

	Sampling unit	*a*	*b*	95% CI (*a*)	95% CI (*b*)	Mean/10 sweeps	Precision	Required sample size	
								c = 0.10	*c* = 0.25
2013	20 sweeps	0.8702	1.2719	(0.799; 0.942)	(1.110; 1.433)	0.41	0.32	167	27
2014	40 sweeps	0.4882	1.0856	(0.402; 0.575)	(0.796; 1.375)	0.52	0.24	89	14.2
Both yr	-	0.6304	1.0133	(0.567; 0.694)	(0.845; 1.182)	0.46	0.29	136	22

Table 3.2. Results from nested ANOVA and costs for Dectes stem borer sweep net sampling. F-S, P/F-S, and S/P/F-S represent field and sampling date, primary samples, and subsamples, respectively.

Source of variation	df	S^2	Percent total	Field cost (min)	Total cost (min)
F-S	2	0.4209	18.35	-	-
P/F-S	15	0.0512	2.23	1.15	2.4
S/P/F-S	173	1.822	79.42	0.133	0.133

Table 3.3. Optimum sampling schemes for Dectes stem borer sweep net sampling.

	Precision	Primary samples	Sub samples	Field costs (min)	Total costs (min)
Total cost optimized	0.1	8.9	25.3	40.2	51.3
	0.25	1.4	25.3	6.3	8.1
Field cost optimized	0.1	11.2	17.5	38.9	52.9
	0.25	1.8	17.5	6.3	8.5

Table 3.4. Optimum sampling schemes for Dectes stem borer sweep net sampling rounded to whole numbers with a minimum of two primary samples.

	Precision	Primary samples	Sub samples	Field costs (min)	Total costs (min)
Total cost optimized	0.1	9	25	40.3	51.5
	0.25	2	15	6.3	8.8
Field cost optimized	0.1	11	18	39	52.7
	0.25	2	15	6.3	8.8

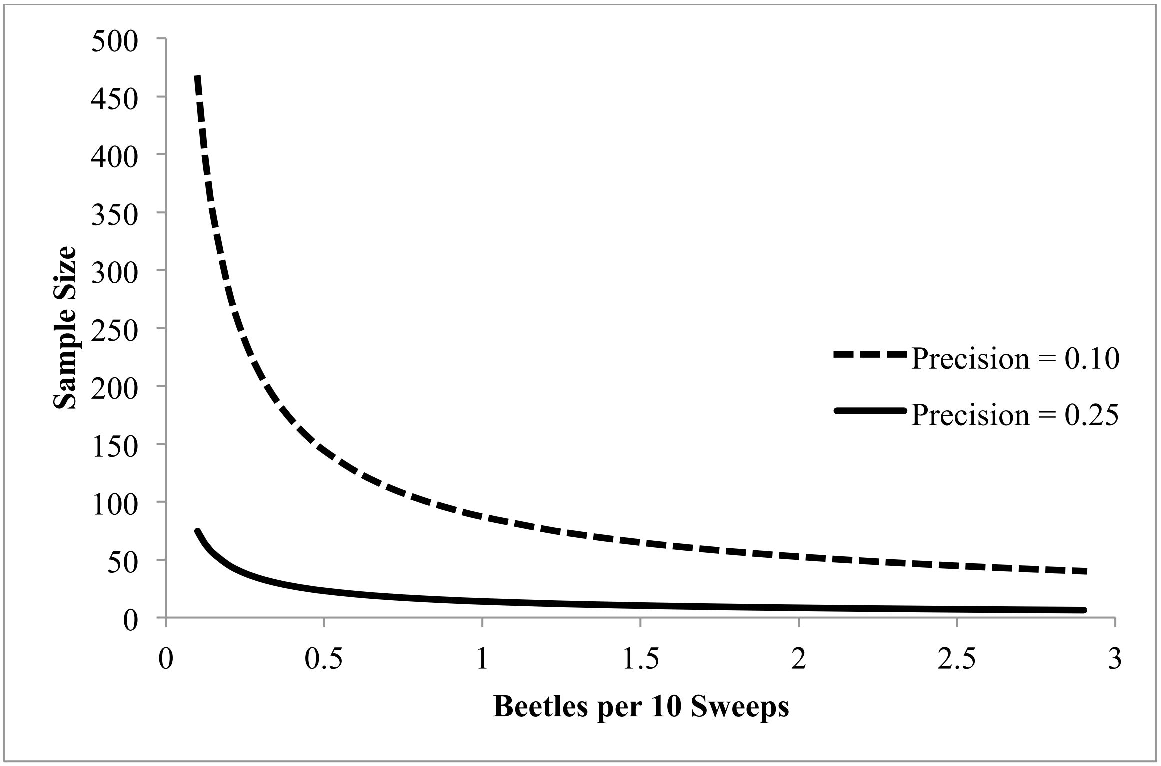


Fig. 3.1. Sweep net sample sizes required for precision levels of 0.10 and 0.25 across a range of expected mean Dectes stem borer adult densities during 2013.

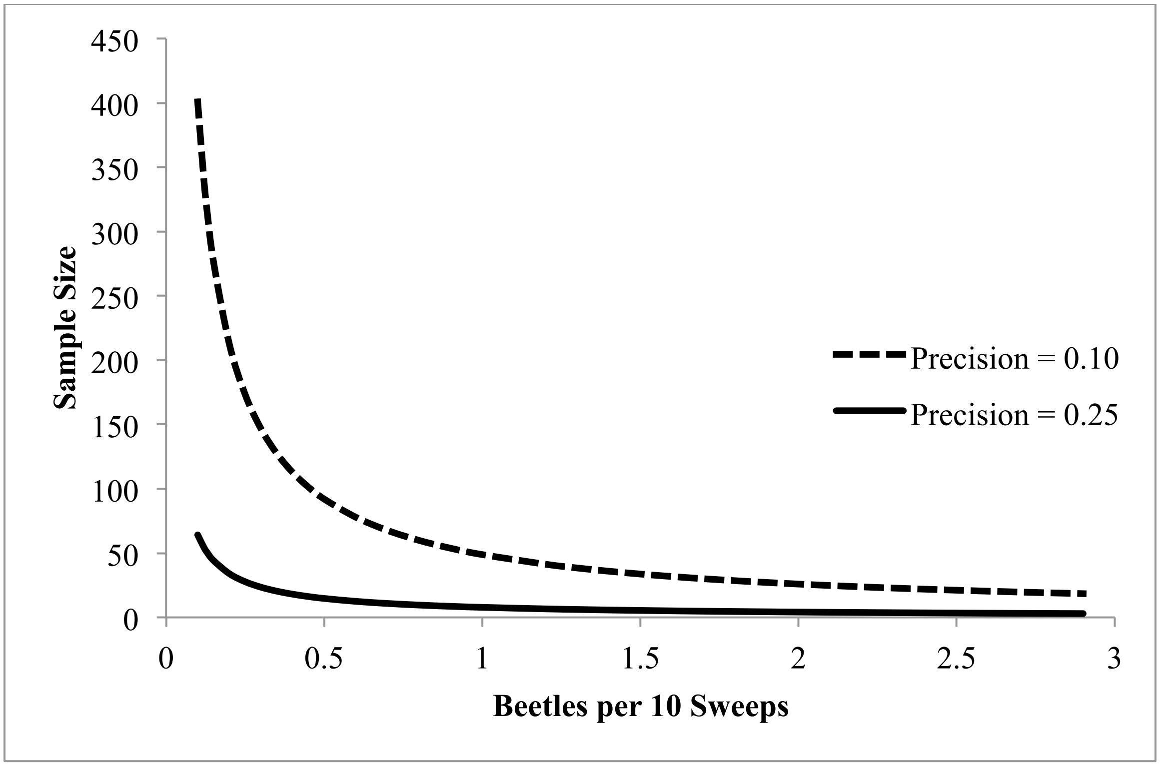


Fig. 3.2. Sweep net sample sizes required for precision levels of 0.10 and 0.25 across a range of expected mean Dectes stem borer adult densities during 2014.

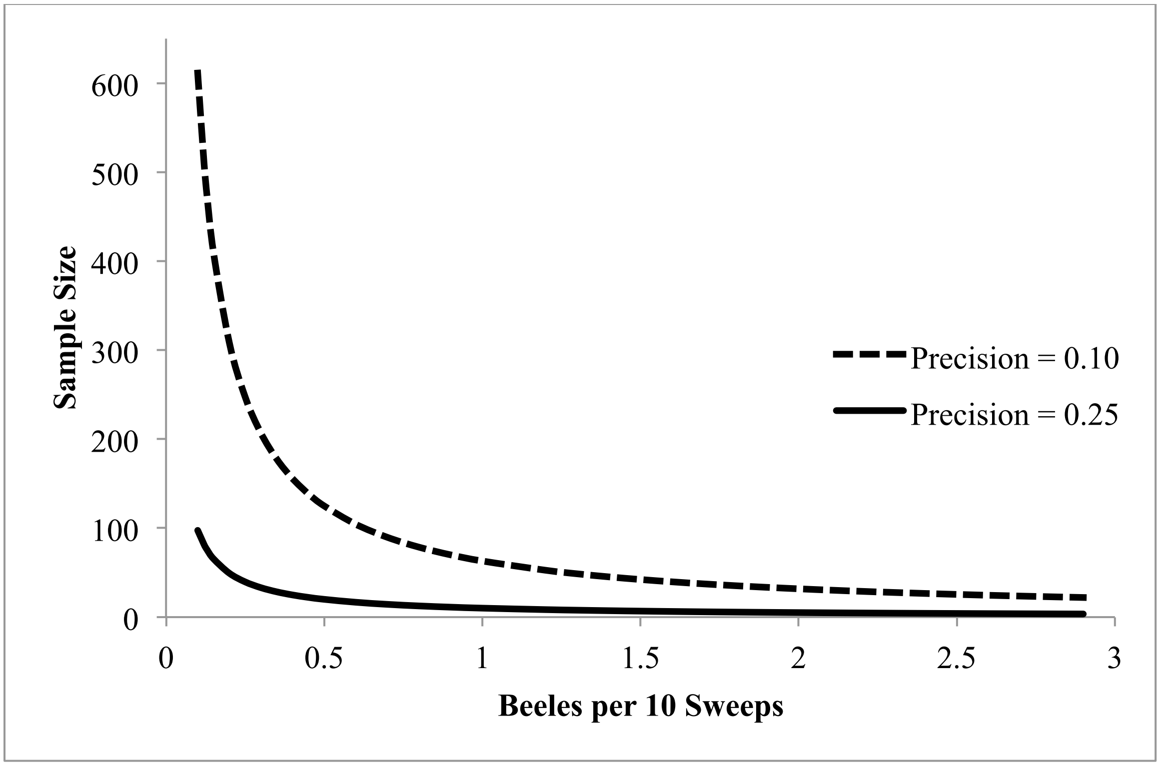
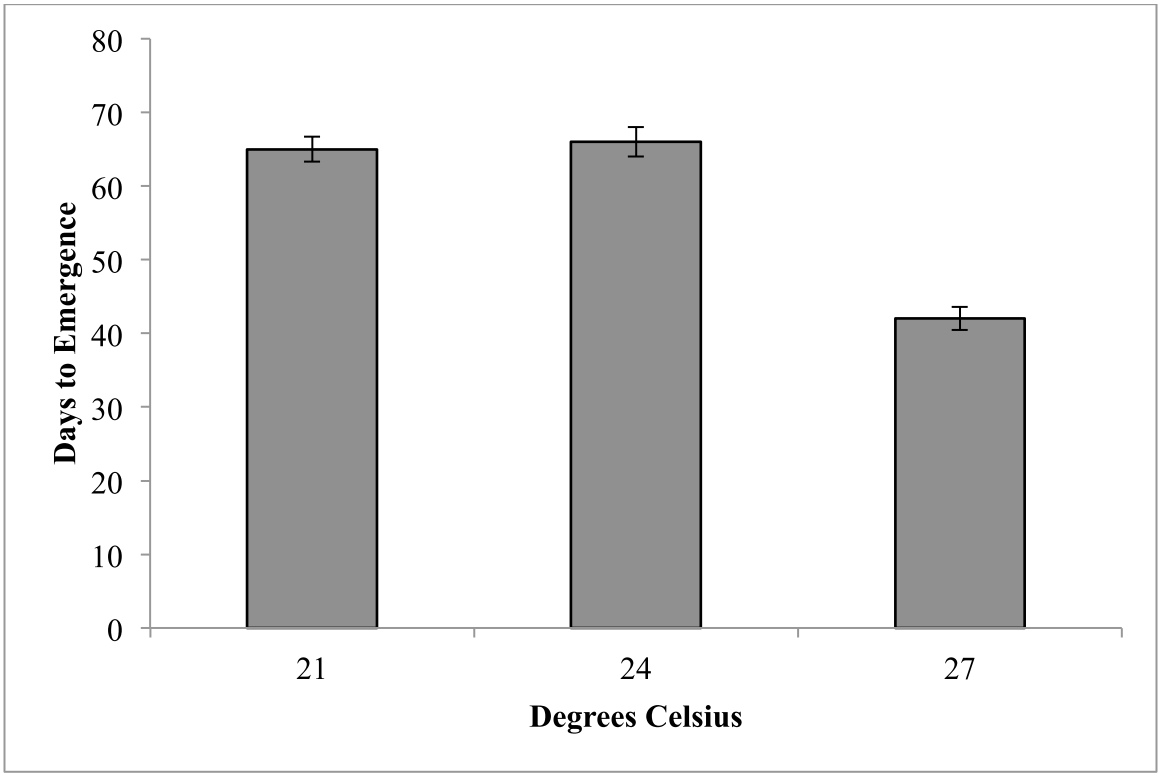


Fig. 3.3. Sweep net sample sizes required for precision levels of 0.10 and 0.25 across a range of expected mean Dectes stem borer adult densities during 2013 and 2014.

APPENDIX A: DECTES STEM BORER LARVAE EMERGENCE IN GROWTH CHAMBERS.



Dectes stem borer larvae days to emergence under three temperature regimes. Larvae were collected from infested soybean stubble in Jefferson, Thayer, Fillmore, Saline and Nuckolls county Nebraska and 63 larvae were assigned to each temperature regime randomly. Forty-six larvae emerged from the 21 and 27 degrees Celsius treatments and 35 larvae emerged from the 24 degrees Celsius treatment.