

POTENTIAL PREDATORS OF CORN-INFESTING PICTURE-WINGED FLIES
(DIPTERA: ULIDIIDAE) IN HOMESTEAD, FLORIDA: SEASONAL ABUNDANCE,
DISTRIBUTION AND FUNCTIONAL RESPONSE

By

MEGHA KALSI

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2011

1

© 2011 Megha Kalsi

To my father the biggest inspiration in my life and my mother for her unconditional love

ACKNOWLEDGMENTS

I would like to convey my sincere thank to my advisor Dr. Dakshina R. Seal for his continuous support, constructive challenge and guidance throughout my master's project. I want to thank my committee members Dr. J. L. Capinera and Dr. G. Nuessly for their guidance and valuable suggestions. My writing was greatly supported by all of them because of their advice and criticism throughout my thesis writing.

Our administrator Debbie Hall kept me on track if not on schedule, a special thanks to her. My thanks to all the lab personnel Ms. Catherine Sabines, Mr. Charlie, and Mr. Jacinto, for helping me with the entire field project. My parents have been a continuous source of my strength and I am indebted to them. I am grateful to my siblings Rhythm and Karam who helped me to stay determined towards my goals. Special thanks to all my friends Vivek, Garima, Nicki, Xiodan, Alina and Jian for their support. And above all, I thank the almighty for giving me this opportunity.

TABLE OF CONTENTS

	<u>Page</u>
ACKNOWLEDGMENTS.....	4
LIST OF TABLES.....	7
LIST OF FIGURES.....	8
ABSTRACT.....	9
CHAPTER	
1 LITERATURE REVIEW.....	13
Introduction.....	13
Taxonomy.....	14
Family: Ulidiidae.....	14
Subfamily: Ulidiinae.....	15
Genus <i>Euxesta</i>	15
Genus <i>Chaetopsis</i> Loew.....	16
Host Plant Range.....	17
Life Cycle.....	19
Management of Corn-Infesting Ulidiidae Flies.....	19
Chemical Control.....	19
Host Plant Resistance.....	20
Biological Control.....	21
Research Objectives:.....	23
2 SEASONAL ABUNDANCE AND DISTRIBUTION OF THE ARTHROPODS FOUND IN CORN EARS WITH IDENTIFICATION OF THEIR PREDATORY STATUS.....	27
Materials and Methods.....	30
Seasonal Abundance and Diversity of Arthropods.....	32
Spatial Distribution of Predators and Corn-Infesting Ulidiids.....	33
Laboratory Evaluation of Arthropod Species for Predatory Status.....	35
Functional Response of <i>O. insidiosus</i> to Eggs of <i>Euxesta</i> species.....	38
Results.....	40
Seasonal Abundance and Diversity of Arthropods.....	40
Spatial Distribution of Predators and Corn-Infesting Ulidiids.....	43
Laboratory Evaluation of Arthropod Species for Predatory Status.....	45
Functional Response of <i>O. insidiosus</i> to Eggs of <i>Euxesta</i> species.....	46
Discussion.....	46

3	DISTRIBUTION AND FUNCTIONAL RESPONSE OF <i>ZELUS LONGIPES</i> (L.) (HEMIPTERA: REDUVIIDAE) TO CORN INFESTING ULIDIIDAE FLIES (DIPTERA: ULIDIIDAE)	67
	Materials and Methods.....	70
	Within-Plant Distribution	71
	Within-Field and Temporal Distribution	72
	Functional Response of <i>Zelus longipes</i> to <i>Euxesta stigmatias</i> , <i>Euxesta</i> <i>eluta</i> and <i>Euxesta annonae</i>	73
	Results.....	77
	Within-Plant Distribution	77
	Within-Field and Temporal Distribution	79
	Functional Response of <i>Zelus longipes</i> to <i>Euxesta stigmatias</i> , <i>Euxesta</i> <i>eluta</i> and <i>Euxesta annonae</i>	81
	Discussion	82
4	CONCLUSIONS	96
	LIST OF REFERENCES	100
	BIOGRAPHICAL SKETCH.....	114

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1-1 Various host plants of corn-infesting Ulidiidae	18
2-1 Planting and sampling dates for the sweet corn experiments.....	53
2-2 Arthropods found in sweet corn during different season 2010.....	53
2-3 Mean number (\pm SE) of <i>Euxesta</i> spp. (eggs, larvae and adults) eaten by generalist predators.....	54
2-4 Distribution of predators and pests in sweet corn ears during spring 2010	55
2-5 Distribution of predators and pests in sweet corn ears during summer 2010	56
2-6 Distributions of predators and pests in sweet corn ears during fall 2010.....	57
2-7 Maximum-likelihood estimates from logistic regression.....	58
2-8 Type III functional response of <i>O. insidiosus</i> to eggs of <i>Euxesta</i> species	58
3-1 Distribution of corn-infesting Ulidiidae sampled in a cornfield at R1 stage	85
3-2 Distribution of corn-infesting Ulidiidae sampled in a corn field at R2 stage	86
3-3 Distribution of corn-infesting Ulidiidae sampled in corn field at R3 stage	87
3-4 Distribution of <i>Z. longipes adults</i> sampled in a corn field at R1 stage.....	88
3-5 Distribution of <i>Z. longipes adults</i> sampled in a corn field at R2 stage.....	89
3-6 Distribution of <i>Z. longipes adults</i> sampled in a corn field during R3 stage.....	90
3-7 Parameters (means \pm S.E) estimated by random predator equation	90

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1-1 Major sweet corn producing regions in Florida (Mossler 2008)	24
1-2 <i>Euxesta stigmatias</i> (Loew) eggs in corn silk.....	24
1-3 Third larval instar of <i>Euxesta stigmatias</i> (Loew)	25
1-4 Different stages of <i>Euxesta stigmatias</i> pupal development	25
1-5 Damaged sweet corn ear due to severe Ulidiidae larval feeding.....	26
2-1 The experimental set up for functional response study	59
2-2 Mean number of potential predators of ulidiid corn pest found in corn ears during spring 2010.....	60
2-3 Mean number of potential predators of ulidiid corn pest found in corn ears during summer 2010.....	61
2-4 Mean number of potential predators of ulidiid corn pest found in corn ears during fall 2010.....	62
2-5 Mean seasonal abundance of <i>O. insidiosus</i> during spring, summer, and fall 2010	63
2-6 Mean seasonal abundance of Ulidiidae eggs and larvae during spring, summer, and fall 2010.....	63
2-7 The first instar nymph of <i>O. insidiosus</i> feeding on a <i>Euxesta stigmatias</i>	64
2-8 Adult <i>O. insidiosus</i> feeding on a third instar larva of <i>Euxesta stigmatias</i>	64
2-9 Staphylinid larva feeding on <i>Euxesta stigmatias</i> eggs.....	65
2-11 Type III functional response of <i>Orius insidiosus</i> to eggs of <i>Euxesta</i> species.....	66
3-1 <i>Zelus longipes</i> female feeding on <i>Euxesta stigmatias</i> in sweet corn field	91
3-2 Mean number of <i>Z. longipes</i> and corn-infesting Ulidiidae adults per time interval in various plant parts	93
3-3 Type II functional response of male <i>Zelus longipes</i> to <i>Euxesta</i> species.....	94
3-4 Adult male, <i>Z. longipes</i> feeding on <i>Euxesta annonae</i> adult in lab experiment....	95

ABSTRACT OF THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

POTENTIAL PREDATORS OF CORN-INFESTING PICTURE-WINGED FLIES
(DIPTERA: ULIDIIDAE) IN HOMESTEAD, FLORIDA: SEASONAL ABUNDANCE,
DISTRIBUTION AND FUNCTIONAL RESPONSE

By

Megha Kalsi

August 2011

Chair: Dakshina. R. Seal
Major: Entomology and Nematology

Several picture-winged flies (Diptera: Ulidiidae) are serious pest of sweet and field corn in southern Florida. They include *Euxesta stigmatias* Loew, *Euxesta eluta* Loew, *Euxesta annonae* Fabricius and *Chaetopsis massyla* Walker. Management of these pests is principally based on chemical insecticides. It has been reported that farmers frequently use insecticides (every 1 to 3 d) to control these pests. My field and laboratory research focused on finding natural predators of the ulidiid corn pests found in sweet corn produced in Homestead. All the studies were conducted in a sweet corn field at the Tropical Research and Education Center (TREC), Homestead, Florida.

The study related to seasonal abundance and diversity of arthropods in corn ears was replicated during the spring, summer and fall seasons of 2010 (i.e. 3X). During each season, samples of corn ears were collected at three dates corresponding to corn ear development, i.e., silking, and blister and milk stages (R1, R2 and R3). The various arthropods found were *Orius insidiosus* Say (Hemiptera: Anthocoridae) (adults and

nymphs), unidentified thrips (Thysanoptera: Thripidae), unidentified mites, unidentified Staphylinidae larvae (Coleoptera), adults and larvae of *Chrysoperla carnea* Smith (Neuroptera: Chrysopidae), and adults and larvae of the sap beetles *Lobiopa insularis* (Castelnau) and *Carpophilus lugubris* Murray (Coleoptera: Nitidulidae). *Orius insidiosus* was the most abundant arthropod during the R1 stage and was found during all seasons. The unidentified staphylinid species were found only during the summer with greater numbers during the R3 stage. The eggs and larvae of Ulidiidae corn pests were most abundant during the summer and least abundant during the spring season 2010. In the laboratory studies, two arthropods fed on ulidiid corn pests. All five nymphal and the adult stage of *O. insidiosus* fed on eggs and larvae of ulidiids (*E. stigmatias*, *E. eluta*, and *E. annonae*). Larval staphylinids also fed voraciously on eggs and larvae of the above-mentioned ulidiids.

The distribution patterns of *O. insidiosus* nymphs and adults and staphylinid larvae in sweet corn ears were studied along with the distribution of corn-infesting ulidiid eggs and larvae. Both ulidiid eggs and larvae in corn ears showed an aggregated pattern of distribution during the three developmental ear stages throughout the study. The distribution pattern of *O. insidiosus* was aggregated at most sampling dates, except during the R3 in spring and fall 2010 when it was randomly distributed. The distribution pattern of staphylinid larvae was aggregated during summer (2010) at the R3 stage. Additional studies were conducted to check the efficacy of *O. insidiosus* as a predator. *Orius insidiosus* displayed a type III functional response to laboratory-reared eggs of *E.*

stigmatias, *E. eluta*, and *E. annonae*. The handling time and attack constant was nearly similar for the eggs of different *Euxesta* spp. that were tested.

In the experimental fields at TREC, Homestead, *Zelus longipes* Fabricius (Hemiptera: Reduviidae) was observed feeding on the adults of Ulidiidae corn pests. Within-plant, within-field and temporal distribution studies of *Z. longipes* and Ulidiidae adults were conducted at three different time intervals (0900-1000 h EST, 1300- 1400 h EST and 1700-1800 h EST) and at three developmental ages of ears (i.e., silking/R1, blister/R2, and milk/R3 stage). The plants were divided into four strata: basal leaves (i.e., leaves present on lower three collar bands of stem), middle leaves (i.e., leaves above the lower three collar bands and those surrounding the ear), fruit and top/tassels (i.e., leaves and tassels above the ear). The abundance of both *Z. longipes* and corn-infesting Ulidiidae adults varied depending on time interval, ear age, and within-corn plant location. During the R3 stage, *Z. longipes* and corn-infesting Ulidiidae adults occurred throughout the corn plant irrespective of time interval. The abundance of *Z. longipes* and corn-infesting Ulidiidae peaked on fruit and tassels at 1300-1400 and 1700-1800 h EST, respectively. The population abundance of corn-infesting Ulidiidae increased during the R2 stage with peak abundance on leaves (basal and middle), fruits, and top/tassels at 0900-1000, 1300-1400 and 1700-1800 h EST, respectively. The distribution pattern of *Z. longipes* was similar to ulidiid adults. Population abundance of both prey and predator at R3 stage was high on basal leaves at 0900-1000 h ES, and moved to corn ears and tassels as time intervals progressed (i.e., at 1700-1800 h EST). It was observed that at the time of silking (R1 stage), both corn-

infesting Ulidiidae adults and *Z. longipes* showed mostly aggregated and random distribution, respectively, at different time intervals. At R2 and R3 stages, both prey and predator exhibited aggregated distributions irrespective of time interval. A functional response experiment to test the efficacy of lab-reared *Z. longipes* (adult male and females) as a predator to lab-reared *Euxesta* spp. (*E. stigmatias*, *E. eluta* and *E. annonae*) adults was conducted in laboratory. The adults (of each fly species) in batches of 2, 4, 6, 8 and 10 were placed with one predator (either male or female) in a feeding arena (circular plastic box) for 24 h. Both male and female *Z. longipes* showed a type II functional response to adults of all three ulidiid species tested. Handling time was longer for males than females, but the attack rate constant was determined to be nearly the same for both male and female *Z. longipes*.

CHAPTER 1 LITERATURE REVIEW

Introduction

Sweet corn (*Zea mays* var. *rugosa* Bonaf.) originated in Pennsylvania in the 1700's as a result of a genetic mutation in the gene pool of field corn (Hansen 2011). Sweet corn was introduced there commercially in 1779 (Hansen 2011). The United States has been the largest producer of sweet corn in the world since the 1960's (ERS 2008). By 2004, Mexico had become the second largest producer (AgMRC 2010). In Unites states (2009), the value of fresh market sweet corn was \$ 835.3 million, and for processed corn, it was \$335.6 million (Hansen 2011). In the United States, Florida dominates the fresh market sweet corn production and contributes about 20 percent of the national sweet corn production. Half the sweet corn produced in Florida comes from the Everglades production area in Palm Beach County. In addition, a quarter of the state corn production occurs in Miami-Dade, Collier, and Hendry counties combined (Mossler 2008) (Fig.1-1). In 2006, fresh sweet corn was produced on 10,643 ha in Florida with a total volume of 212 million kg valued at \$117 million. Other major sweet corn producing states in the United States are California, Georgia, and New York (AgMRC 2010). Fresh corn is also important for export and has a high sale value for daily spot markets. Although production and revenue generated by fresh corn production depends highly on supply and demand in the marketplace, factors like cosmetic value are also very important.

The warm, humid climate of Florida provides a favorable environment for growth and proliferation of pest populations. Many species of pest insects attack sweet corn,

causing considerable economic losses (Nuessly and Webb 2010). The most common sweet corn pest species in Florida are: fall armyworm, *Spodoptera fugiperda* (Smith) (Lepidoptera: Noctuidae), corn earworm, *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae), lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller) (Lepidoptera: Pyralidae), and picture-winged flies, (Diptera: Ulidiidae) (Nuessly and Webb 2010). Four Ulidiidae species damage corn in Florida: *Euxesta annonae* (Fabricius 1794), *Euxesta eluta* (Loew 1868), *Euxesta stigmatias* (Loew 1868), and *Chaetopsis massyla* (Walker 1849) (Goyal et al. 2011).

Taxonomy

Flies in the family Ulidiidae are known as “picture-winged flies” because of their diverse wing patterns (Kameneva and Korneyev 2006). Ulidiidae, formerly known as Otitidae (Kameneva and Korneyev 2006, Thompson 2006, Goyal et al. 2010), is one of the least-studied families with knowledge on basic biology and behavior limited to a few species of economic importance (Harper 1962, Allen and Foote 1967, 1975, Frias 1978, Yoon et al. 1983, Seal and Jansson 1993, Seal et al. 1995, Nuessly and Hentz 2004). The Ulidiidae flies belong to the superfamily Tephritoidea (McAlpine 1989, Korneyev 2000, Brunel and Rull 2010). Ulidiidae is a small family of about 800 species (Díaz-Feischer et al. 2000, Brunel and Rull 2010) including saprophytic and phytophagous insects (Allen and Foote 1967, Korneyev 2000).

Family: Ulidiidae

The Ulidiidae are small to medium-sized (2.5-11.0 mm), diversely colored acalyprate flies (Kameneva and Korneyev 2006, Jindřich 2009). They can be shiny and metallic, partly yellow, and have black and grey microtomentose pubescence. They

have variable head shapes with setulosed or bare arista. Ocelli are present with parallel or divergent postocellar setae. Wings have variable patterns, and are rarely clear or uniform in color (Jindřich 2009). Wings may have dark bands, dark tips, or maculation with a specific type of venation. The costa is mostly complete or with a humeral break. The subcosta is complete, and the R1 vein is bare or setulose. The phallus is long and coiled. Females have a well-developed ovipositor with oviscape.

Subfamily: Ulidiinae

The family Ulidiidae includes two subfamilies Otitinae and Ulidiinae (Hennig 1939, Steyskal 1961). The subfamily Otitinae was considered a separate family by at least one author (Greve 1998). The Otitinae and Ulidiinae can be differentiated based on the aedeagus and wing vein R1. In Ulidinae, the R1 is bare (except in *Neoeuxesta* and *Pareuxesta*), whereas in Otitinae, it is setulose. Ulidinae males have a bare aedeagus that may have a specialized tip, but Otitinae males have a bristly or hairy aedeagus with a simple tip (Steyskal 1961). *Euxesta* and *Chaetopsis* are two important genera belonging to the subfamily Ulidinae.

Genus *Euxesta*

The adult flies have metallic body coloration (Steyskal 1952). The head of the adult flies with very fine, short, prescutellar bristles. There are three important *Euxesta* species that are known to be economic pests of sweet corn in southern Florida (Goyal et al. 2011).

***Euxesta stigmatias*:** The lunule (e.g., area on head between the antennae) is velvety black (Wulp 1903). The eyes are reddish brown, and wings darkly banded (Nuessly and Capinera 2010, Seal et al. 1995). The first three wing bands are complete

and the fourth band is incomplete. The first band is located near the wing base and reaches 15% of wing cell 'c'. There is a clear portion between the third and fourth bands. The clear portion does not reach the 'r1' cell and fades away as it approaches the rear wing margin (Nuessly and Capinera 2010). Males (3.8 mm) are shorter than females with short and rounded abdomens, whereas females (4.2 mm) have a trapezoidally shaped abdomen with a pointed end. The legs are black in color. The upper apex of the antennal flagellomere is round (Steyskal 1952, Goyal et al. 2010).

Euxesta eluta: The lunule is opaque black (Curran 1935, Nuessly and Webb 2010). The front of the head is a dull reddish color. The fore wings have four dark bands that continue completely from the front to the rear margins. A clear area between the third and fourth bands of the marginal cell that continues to the front wing margin varies in size between individuals.

Euxesta annonae: The head is reddish and somewhat metallic. The lunule is orange to silver and distinguishes this species from *E. stigmatias* and *E. eluta*. The first wing band covers almost 33% of the basal part of wing cell 'c'. The clear portion between the third and fourth band does not continue through the 'r1' cell and remains darker near the rear wing margin (Curran 1935, Nuessly and Webb 2010).

Genus *Chaetopsis* Loew

The head is broad and the upper apex of the third antennal segment is pointed or angulated rather than rounded as in the *Euxesta* spp. (Steyskal 1952). A few pairs of cruciate bristles are present on the medifrons. The apical anal cell of the wing has a prolonged angle.

Chaetopsis massyla: The length of the body is 6.4-7.6 mm. The thorax is greenish grey with a dark green to black abdomen (Nuessly and Webb 2010). In contrast to the *Euxesta* spp. described above, the legs of *C. massyla* are yellow. Three dark bands are found on the fore wings with a transparent region between all three bands. The non-pigmented area between the first and second dark bands is wider than between the last two dark bands. The frontal vita on the head is bare and lacks setae. The ovipositor is broad, depressed, and thin and laminar apically (Nuessly and Webb 2010, Goyal et al. 2010).

Host Plant Range

Some *Euxesta* species, such as *E. stigmatias* (Seal and Jansson 1989, Pacheco 1985, Cortez 2008), *E. eluta*, and *E. annonae* (Frias 1978, Goyal et al. 2010) feed on corn ears. Allen and Foot (1992) reported *C. massyla* as a saprophagous species inhabiting marine and fresh water environments. It was considered to be secondary pest until recently when Goyal et al. (2010) reported it to be a direct pest of sweet corn. The known host range of the four-ulidiid species that attack corn in Florida has been reported by numerous authors (Table 1-1) and includes many plant species other than *Z. mays*.

Table 1-1. Various host plants of corn-infesting Ulidiidae.

Ulidiidae fly species	Host plants
<i>Euxesta stigmatias</i>	Sweet Corn (<i>Zea mays</i>), Sorghum (<i>Sorghum bicolor</i> Moench), tomato (<i>Lycopersicon esculentum</i> Mill.), sugarcane (<i>Saccharum officinarum</i> L.), guava (<i>Psidium guajava</i> L.), banana (<i>Musa</i> spp.), sour orange (<i>Citrus aurantium</i> L.), atemoya (<i>Annona squamosa</i> L. and <i>A. cherimolia</i> Miller), orchid (<i>Dendrobium</i> spp.), and potato (<i>Solanum tuberosum</i> L.) (Seal and Jansson 1989, 1996) spiny amaranth (<i>Amaranthus spinosus</i> L.) , avocado (<i>Persea americana</i> Mill.), sorghum (<i>Sorghum bicolor</i> (L.) Moench), sugarcane (<i>Saccharum officinarum</i> L.), bell pepper (<i>Capsicum annum</i> L.), tomato (<i>Solanum lycopersicum</i> L.), johnsongrass (<i>Sorghum halepense</i> (L.) Pers.), habaero pepper (<i>Capsicum chinense</i> Jacquin), little hogweed (<i>Portulaca oleracea</i> L.), radish (<i>Raphanus sativus</i> L.), papaya (<i>Carica papaya</i> L.), and cattail (<i>Typha latifolia</i> L.) (Goyal 2010)
<i>Euxesta eluta</i>	Sweet corn, Spiny amaranth, hass avocado, sorghum, sugarcane, bell pepper, tomato, johnsongrass, habaero pepper, , little hogweed,, radish ,papaya, cattail ,(Allen and Foote 1992, Goyal 2010), and loquat (<i>Eriobotrya japonica</i> Thumb.) (Anonymous 20080
<i>Euxesta annonae</i>	Pineapple (Illingworth 1929), banana (<i>Musa</i> spp.) (Severin and Hartung 1912)
<i>Chaetopsis massyla</i>	Onions, <i>Allium cepa</i> L. (Merrill 1951), <i>Narcissus</i> sp. (Blanton 1938), spiny amaranth, avocado, sorghum, sugarcane, bell pepper, tomato,, johnsongrass, habaero pepper , little hogweed, radish, papaya, and cattail (Goyal 2010)

Life Cycle

Euxesta stigmatias completes its life cycle in 24-27 d, and adults can live up to 116 d under ideal food and water conditions (Nuessly and Capinera 2010). It can produce up to 20 generations per year (Bailey 1940). The egg (Fig.1-2), larval (Figs.1-3) and pupal (Fig.1-4) periods for *E. stigmatias* ranged from 1.4-4 d, 7.5-27 d and 5.6-9.2 d, respectively (App 1938, Seal and Jansson 1989, Hentz and Nuessly 2004, Goyal 2010). Larvae eclose from eggs that feeds on silk, corn kernels and cob (Fig.1-5). Allen and Foot (1992) reared *C. massyla* adults on decaying cattail stems (infested by Noctuidae larvae) at 22 to 25° C. They further reported that *C. massyla* requires 33 d, for development of eggs to adult stage. The egg, larval and pupal period for *C. massyla* ranged from 2-3 d, 11 d and 10 d, respectively (Allen and Foot 1992). Goyal (2010) studied the development of corn-infesting Ulidiidae (*E. stigmatias*, *E. eluta*, and *C. massyla*) in the field during three seasons and on an artificial medium at 26.5 ± 1 °C. In field studies the average developmental period ranged from 17.3 to 33.2 d, 18.7 to 35.2 d, and 17.2 to 33.6 d for *C. massyla*, *E. eluta*, and *E. stigmatias*, respectively. In the laboratory studies the developmental period for *C. massyla*, *E. eluta*, and *E. stigmatias* were 30.2 d, 21.6 d and 27.4 d, respectively. There have been no reports on developmental studies of *E. annonae*.

Management of Corn-Infesting Ulidiidae Flies

Chemical Control

The most widely used control methods for *Euxesta* spp. include insecticides belonging to various classes. Bailey (1940) recommended using a mixture of pyrethrin and mineral oil manually injected into ears (1:5) as an insecticide against adult flies in

Puerto Rico. Hayslip (1951) studied the effectiveness of parathion and suggested multiple applications of this chemical at 3-4 d intervals. Nuessly and Hentz (2004) studied the effectiveness of various insecticides (esfenvalerate, cyfluthrin, lambda-cyhalothrin, chlorpyrifos, methyl parathion, methomyl, and thiodicarb) against corn-infesting ulidiid through direct contact and dried leaf residues. In the direct application study of insecticides it was found that all but thiodicarb had quick killing or sublethal effects on > 75% of the flies. In the contact leaf residue study it was observed methyl parathion was most effective in killing in adult flies. Seal (2001) suggested ulidiid pest resurgence even after application of chemical insecticides. He reported after insecticide application, the count of ulidiid adults was 3-6/plant. In another experiment, Nuessly and Hentz (2002) observed 11% infestation by larvae after application of the best-performing insecticide, cyfluthrin (Baythroid 2) (Bayer Crop Science, Kansas City, MO). In Florida (2006), 98% of sweet corn acreage was sprayed with a total of 155,300 pounds of insecticide. Overall, 20 percent of expenses involved in sweet corn production are for pesticide application (Mossler 2008), but the pesticides are useful only for adult fly control. In addition to the above-mentioned problems, broad-spectrum insecticides not only kill pests but also reduce the number of natural enemies, adversely affecting their potential for use in integrated pest management (Duffie et al. 1998, Tillman and Mulrooney 2000, Musser et al. 2004).

Host Plant Resistance

In addition to chemical control, other methods have also been exploited to control corn-infesting Ulidiidae, for example, host plant resistance. Hybrid maize varieties with high maysin content, such as Zapalote Chico 2451 and Zapalote Chico sh2, have been

reported to effectively resist attack by *E. stigmatias* (Nuessly et al. 2007). Daly and Buntin (2005) found fewer *Euxesta* spp. larvae and adults on transgenic corn varieties expressing Cry1Ab toxin from *Bacillus thuringiensis* var *kurstaki* (Bt) as compared to other standard non-transgenic varieties. It was reported that decreased infestation of *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae) resulted in reduced attraction of corn-infesting ulidiids (as these flies are known to their lay eggs on corn area where damage is caused by the lepidopteran pests)

Biological Control

Given the difficulties with management strategies such as insecticidal control, host plant resistance, and cultural control, its important to explore the other management techniques such as biological control using natural enemy as a predator of the pest flies. An improved understanding of natural enemy population dynamics and its role in pest control are required to devise less invasive methods and to potentially integrate them at a commercial level, thus providing a cost effective option to the producer (Musser et al. 2004). The temporal and spatial distributions of predators in response to abiotic and biotic factors require effective sampling to estimate predator populations (Ewert and Chiang 1966, Kawai 1976, Coll and Bottrell 1991, Cottrell and Yeargan 1999, Nault and Kennedy 2000, Musser et al. 2004). Hence, studying predator populations combined with accurate sampling methods will help determine which natural enemy species and the sizes of their populations are required to control the pests. The insidious flower bug, *Orius insidiosus* Say (Hemiptera: Anthocoridae), can be common in corn (*Zea mays* L.) particularly during silking and pollination (Corey 1994, Corey et al. 1998). *Orius* spp. are polyphagous predators that feed partly or solely on

corn plant material like pollen (Kiman and Yeargan 1985, Sigsgaard and Esbjerg 1997). They also feed on arthropod pests such as aphids (Hemiptera: Aphididae) (Barber 1936, Dicke and Jarvis 1962, Bush et al. 1993, Fox et al. 2004, Rutledge et al. 2004, Lundgren and Fergen 2006), thrips (Thysanoptera: Thripidae) (van den Meiracker and Ramakers 1991, Sabelis and Van Rijn 1997, Funderburk et al. 2000, Ramachandran et al. 2001, Baez et al. 2004). The nymphs and adults of *Orius* spp. feed on eggs and larvae of eggs and larvae of Lepidoptera (Barber 1936, Bush et al. 1992) including corn pests, such as corn earworm, *Helicoverpa zea* (Boddie) (Barber 1936, Isenhour and Marston 1981, Isenhour and Yeargan 1981, Coll and Bortell 1991, Bush et al. 1993), and the European corn borer, *Ostrinia nubilalis* Hubner (Lepidoptera: Crambidae) (Isenhour and Marston 1981, Isenhour and Yeargan 1981, Coll and Bortell 1991, Corey et al. 1998). Recently, Baez et al. (2010) found different *Orius* spp. feeding on different life stages of *Euxesta* spp.

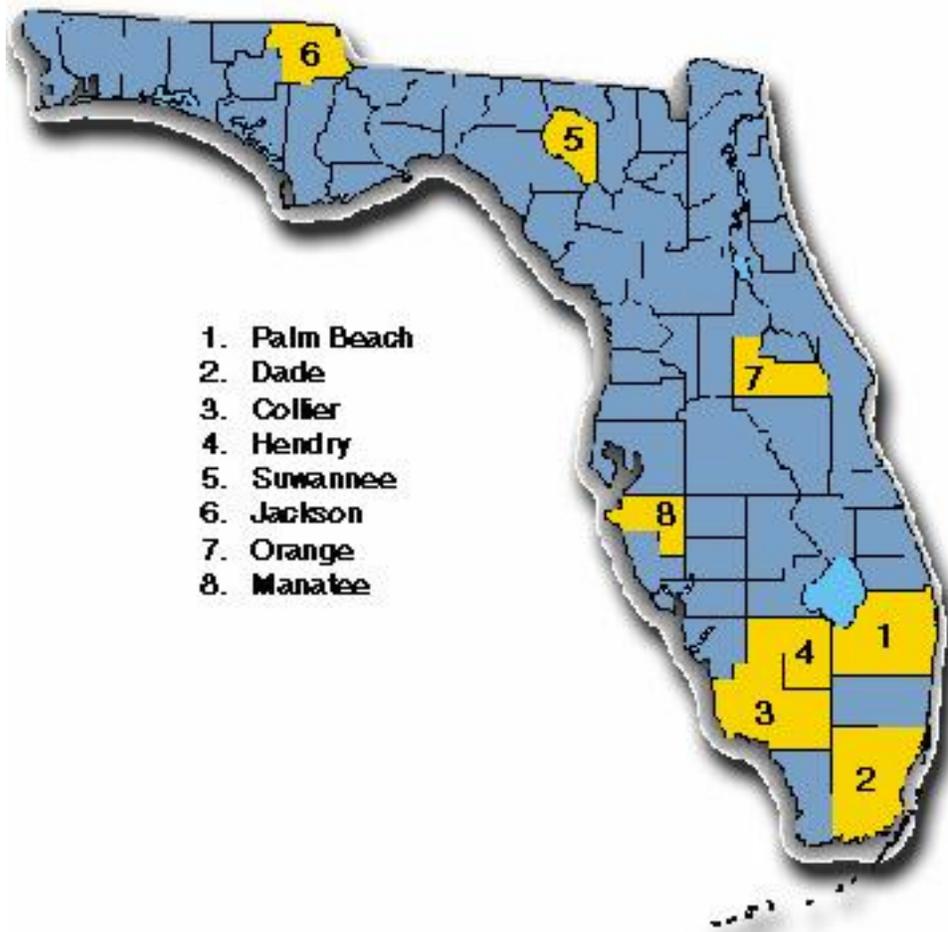
Milkweed assassin bug, *Zelus longipes* (Hemiptera: Reduviidae) is a generalist predator commonly found in corn fields in Florida (Nuessly et al. 2010). It has been reported to feed on the corn pest *S. fugiperda* (Cogni et al. 2000). Unigarro (1958) suggested that *Z. longipes* could be a potential biological control agent.

Other predators have been observed to feed on eggs of corn-infesting ulidiids. Van Zwaluwenburg (1917) observed a capsid bug feeding on *E. stigmatias* eggs. Seal and Jansson (1989) reported that earwigs (Dermaptera: Forficulidae, Labiidae), and mites preyed on eggs of *Euxesta* spp. In Mexico, wasps, *Spalangia* spp. (Hymenoptera: Pteromalidae) and Eurytomid (Hymenoptera: Eurytomidae) have been

reported to parasitize *Euxesta* spp. pupae (Baez et al. 2010). To develop a biological control strategy for corn-infesting Ulidiidae, it is important to know which natural enemies exist in the corn fields. A better understanding of the distribution of these prey species and their predators will help in developing control measures for the corn pests.

Research Objectives:

- To determine the abundance and diversity of arthropods in corn ears produced in sweet corn fields.
- To identify the arthropods found in ears and to determine their suitability as predators to egg, larvae, and adults of *Euxesta stigmatias*, *Euxesta eluta* and *Euxesta annonae*.
- To determine spatial distribution of the predators found in ears relative to the spatial distribution of corn-infesting ulidiid eggs and larvae.
- To determine functional responses of predators observed feeding on different life stages of ulidiid (*E. stigmatias*, *E. eluta* and *E. annonae*) in the laboratory.
- To find the within-plant and within-field distribution of ulidiid and their predator *Zelus longipes* in sweet corn field.



• Figure 1-1. Major sweet corn producing regions in Florida (Mossler 2008).



Figure 1-2. *Euxesta stigmatias* (Loew) eggs in corn silk.



Figure 1-3. Third larval instar of *Euxesta stigmatias* (Loew).



Figure 1-4. Different stages of *Euxesta stigmatias* pupal development showing change in color from yellow to dark brown.



Figure 1-5. Damaged sweet corn ear due to severe Ulidiidae larval feeding.

CHAPTER 2

SEASONAL ABUNDANCE AND DISTRIBUTION OF THE ARTHROPODS FOUND IN CORN EARS WITH IDENTIFICATION OF THEIR PREDATORY STATUS

Several species of picture-winged flies (Diptera: Ulidiidae) have become serious pests of sweet corn in United States (Van Zwaluwenberg 1917, Barber 1939, Hayslip 1951, Seal and Jansson 1989, Nuessly and Hentz 2004, Goyal et al. 2010). By 2011, four Ulidiidae fly species in the genera *Euxesta* and *Chaetopsis* were reported to infest sweet corn in Florida. These include *Euxesta stigmatias* (Loew), *Euxesta Eluta* (Loew), *Euxesta annonae* (Fabricius) and *Chaetopsis massyla* (Walker) (Diptera: Ulidiidae) (Goyal et al. 2010). The corn-infesting ulidiid pest deposits their eggs among silk strands in the silk canal. Upon emergence, first instar larvae feed on corn silk and progress down the silk towards the kernels. The larval infestation disrupts pollination by severing the corn silk (Baily 1940). Larvae may enter kernels through the soft R1 and R2 stage pericarp. Larvae that make it to the ears may also feed on the cob (App 1938, Seal and Jansson 1989, Scully et al. 2007). Sweet corn ears become unmarketable if the larval infestation damages corn kernels.

Since the 1960s, the United States has ranked highest in the world in sweet corn production (Hansen 2011). Sweet corn is marketed at three levels: fresh, processed, and canned food. Fresh corn is subject to high variability of supply and demand within a daily spot market, unlike processed and canned corn, which is produced on a more stable contract basis (Hansen 2011). In 2009, fresh corn was valued at \$835.8 million whereas revenue from processed corn (frozen and canned) was \$335.6 million (USDA 2010). Florida is a leading producer of fresh sweet corn in the United States (Mossler 2008). According to Economic Research Service (2010), Florida produced 67% of the

total national sweet corn from 2007 to 2009. Hence, pest management of Ulidiid flies infesting sweet corn is very important. Chemical insecticides are currently the only effective management technique to control these flies. Sweet corn fields in the R1 through R3 stages are often sprayed daily with insecticides (Gaurav 2010) that are effective at killing adult flies while other life stages remain protected the ears (eggs and larvae) or soil (pupae) (Nuessly and Capinera 2010). The sweet corn variety 'Zaplalote Chico' with a high maysin concentration has shown reduced damage to *E. stigmatias* indirectly (Nuessly et al. 2007). This was supported by decreased damage caused by *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) to these corn varieties as the damage caused by this lepidopteron pest provides ovipositional sites for ulidiids. But currently this variety is not used in management of the corn infesting ulidiids. As these corn varieties shows a reduced damaged to the lepidopteron corn pest, it will require reduced usage of insecticides supporting the natural enemy populations occurring in corn field. It would be very beneficial to find natural predators to control corn-infesting Ulidiidae.

According to Stern (1981), two important pest control techniques involve manipulating the agroecosystem to make it less favorable for the pests or more favorable for their natural enemies. Considering the latter resort, a first step in managing corn-infesting Ulidiidae involves examining the arthropod composition of corn ears including predators that specifically prey on ulidiid eggs and larvae.

In the northeastern United States, primary predators of sweet corn pests are *Coleomegilla maculata* (DeGeer) (Coleoptera: Coccinellidae), *Harmonia axyridis*

(Pallas) (Coleoptera: Coccinellidae) and *Orius insidiosus* (Say) (Hemiptera: Anthocoridae) (Andow and Risch 1985, Coll and Bottrell 1992, Coderre et al. 1995, Wheeler and Stoops 1996, Hoffmann et al. 1997, Musser et al. 2004). Albajes et al. (2003) studied predator composition and abundance in corn fields in Lleida, northeastern Spain using visual sampling and pitfall trapping. Carabidae (Coleoptera), Staphylinidae (Coleoptera), Coccinellidae, Heteroptera, and Araneae were abundant in visual samples of the corn foliage while Araneae, Opilionidae (Opiliones), Dermaptera, and Carabidae were common in pitfall samples. Asin and Pons (1999) found additional corn field predators in the families Chrysopidae (Neuroptera) and Syrphidae (Diptera) that were aphid specialists. Eckert et al. (2006) in Bonn, western Germany found arthropods on silk and husks to be in different feeding groups, such as herbivores [i.e., aphids (Hemiptera: Aphididae), thrips (Thysanoptera: Thripidae), and leafhoppers (Hemiptera: Cicadellidae)], saprophytes (i.e., beetles), predators (i.e., lacewings and minute pirate bugs), and parasitoids (Hymenoptera). He further suggested that sampling corn ears is a good method to find changes in arthropod abundance of specific feeding groups.

The potential of a predator to control a pest species can be determined by evaluating how it affects population dynamics of the pests over a prolonged time period (Brodeur 2006, Jafari and Goldasteh 2009). Because it is important to know the efficacy of a natural enemy before using it in a biocontrol program, an important first step is studying behavioral characteristics of the natural enemy directed towards its prey. One method for studying the efficacy of a natural enemy species is measuring its

functional response. Solomon (1949) defined functional response as a measure of the number of prey attacked per predator at a given prey density. The functional response is very useful for studying predator-prey relationships, because it indicates the ability of a predator to regulate prey density; specifically, how a predator increases or decreases its prey consumption with changing prey density (Hassell 1978, Livdahl and Steven 1983). The capacity to regulate prey density can be estimated by two parameters: handling time and attack constant. Handling time is the time required by a predator to encounter and eat its prey, and the attack constant is the time taken by predator to search for its prey (Ives et al. 1993).

Objectives of the present study were to 1) identify and determine the abundance of arthropod species in corn ears in the field, 2) determine the spatial distribution of the predators found in ears relative to the spatial distribution of corn-infesting Ulidiidae eggs and larvae, and 3) to determine the functional responses of selected predators to egg, larvae, and adults of *Euxesta* spp. (i.e., *E. stigmatias*, *E. eluta* and *E. annonae*) in the laboratory.

Materials and Methods

Field Preparation: The study was conducted at the Tropical Research and Education Center (TREC), Homestead, FL in a Krome gravelly loam soil (33% loamy soil and 67% limestone pebbles, >2 mm). The study was replicated through time during the spring, summer and fall of 2010. 'Obsession' sweet corn (Seminis Vegetable Seeds, Inc., Oxnard, CA) was planted in rows using a precision garden seeder (Model-1001-B, Earthway® Products, Inc. Bristol, IN) on 15 February, 2 June, and 1 October 2010 for the spring, summer, and fall tests, respectively. Seeds were planted 1 m apart

within each row with 0.9 m between rows. Granular fertilizer (8-16-16, N-P-K) was applied at 1,347 kg/ha at planting in parallel bands spaced 0.1 m from the seed rows. In addition, liquid fertilizer (4-0-8, N-P-K) was applied as a foliar spray at 2.77 kg of N₂/ha/d on the third and fifth weeks after planting. The pre-emergence herbicide trifluralin (Treflan™ 4EC, Dow AgroSciences LLC, Indianapolis, IN, USA) was applied at 0.09 kg/ha at planting. Plants were irrigated using drip irrigation as needed.

The sweet corn fields were sampled once during each of three ear development stages for studying abundance and spatial distribution of predatory arthropods in corn ears: R1 or silking stage (8-9 wk after planting), R2 or blister stage (10-14 d after first silk), and R3 milk stage (18-22 d after first silk) (Table 2-1) (Bean and Patrick 2011). According to Eckert et al. (2006), sampling ears to determine arthropod speciation involves simple techniques that are easily performed in the laboratory, and this sampling can be standardized in a cost effective manner. The first sampling date was 4 d after the first silk. The economically important infestation by corn-infesting Ulidiidae typically starts at the silking stage (Seal and Jansson 1993). Eggs deposited in corn silk at this stage have a higher survivorship than on other oviposition sites on corn plants, such as tassels or bases of leaf axils (Seal and Jansson 1993). The second sampling date during the R2 stage corresponded with maximum emergence of ulidiid larvae from eggs (Seal and Jansson 1989). The final sampling date at the milk stage was chosen when corn silk began senescing and turning brown, because it was thought that ulidiids would be less common then because they prefer fresh silk for oviposition (Seal and

Jansson 1993). At this last sample date, kernels with a thick, pasty endosperm fluid have undergone maximum damage from larval feeding.

Seasonal Abundance and Diversity of Arthropods

Each experimental field (0.4 ha) was divided into four equal blocks each measuring 0.1 ha (i.e. 10 rows wide x 55 m long) with each block subdivided into ten plots of 2 rows wide x 27.5 m long, for pseudo-replication. Such plotting of fields would be expected to reduce the effect of uncontrolled variables on samples. Two corn ears (1/plant) were randomly collected from each plot on each sampling date during the 1, R2 and R3 stages (i.e., 80 corn ears per date). Each ear was placed separately in a Zip Lock bag (17 X 22 cm) and transferred to the laboratory for further study where they were stored at $22 \pm 5^{\circ}\text{C}$, $30 \pm 5^{\circ}\text{C}$, and $26 \pm 5^{\circ}$ during the spring, summer, and fall 2010 experiments, respectively. The ears were removed from storage, cut in half at the mid point of the ears and placed in a 100 ml beaker filled with 75% ethanol for 5 m to collect the arthropods within the ears. The corn husk, silk, and pieces of corn cob were rinsed in alcohol to wash out the arthropod content. Later the washed ears were carefully removed with forceps and were discarded. The alcohol rinse was filtered using a 25- μm mesh USA Standard Testing Sieve (W. S. Tyler Co., Mentor, OH) to collect all arthropods, including corn-infesting ulidiid eggs and larvae. All collected arthropods were removed from the filter and saved in 70% ethanol for later identification. Arthropods were later identified to species where possible and counted using a microscope at 10 X magnification. Unidentified samples of each arthropod species were sent for identification and voucher specimens submitted to the arthropod collection

at the Institute of Food and Agricultural Sciences, Florida Division of Plant Industry (DPI), Gainesville, Florida.

The count data for arthropod abundance were transformed using square root transformation to improve normality and homogeneity of variance. Transformed data was analyzed using one-way analysis of variance (ANOVA) (PROC GLM, SAS Institute 2003). The dependent variable was the season (i.e., spring, summer, fall) and the independent variables estimated were the mean number of arthropods during which the arthropods were collected. Non-transformed means and standard errors of means (SEM) are reported in figures. Differences among mean (n=40) arthropod counts were separated using Tukey's HSD (honestly significant difference) test ($P < 0.05$). Data for abundance of eggs and larvae of corn-infesting Ulidiidae were similarly analyzed using ANOVA and means were separated using Tukey's HSD test ($P < 0.05$).

Spatial Distribution of Predators and Corn-Infesting Ulidiids

The data collected on seasonal abundance was also used to study within-field distributions of corn-infesting Ulidiidae eggs and larvae and other arthropods. Data on distribution patterns of predatory arthropods and ulidiid eggs and larvae were analyzed using Taylor's power law (Taylor 1961), Iwao's patchiness regression (Iwao 1968), and the Index of dispersion (ID). These metrics have been used to examine distributions of taxa ranging from protists to vertebrates (Kilpatrick and Ives 2003). However, none of these models have been used in previous studies for determining distribution patterns of predatory arthropods of these flies. In the present study, we applied these models to determine the distribution of the various arthropods found in corn ear.

Taylor's power law determines species-specific relationships between the temporal or spatial variance (s^2) of population abundance and their mean density per sample using the following linear regression model (in our case applied to predatory arthropods and corn-infesting Ulidiidae eggs and larvae):

$$\log s^2 = \log a + b \log x$$

where slope (b) is the index of aggregation characteristics for a species, and $\log a$ is a sampling factor (Southwood 1978). The value of b indicates if the distribution pattern is uniform, random, or aggregated. The distributions are found to be uniform, random, or aggregated when $b < 1$, $b = 1$, and $b > 1$, respectively.

Iwao's patchiness regression model measures the relationship between Lloyd's (1967) mean crowding index (m^*) and the mean (\bar{X}), which is expressed as follows:

$$m^* + \bar{X} = \alpha + \beta$$

where $m^* = \frac{s^2}{\bar{X}} - 1$, s^2 is the sample variance, and the intercept (α) is an index of basic contagion, which measures the tendency toward crowding. Slope (β) is the density contagiousness coefficient, which has a similar function to the slope value (b) from Taylor's power law; it describes uniform, random, and aggregated dispersions when $\beta < 1$, $\beta = 1$, and $\beta > 1$, respectively.

For both the Taylor's power law and Iwao's patchiness regression, regression parameters were estimated using a general linear regression model (PROC GLM, SAS Institute 2003). The goodness of fit for data from each field test to both the linear models was evaluated using regression coefficients (r^2). The student's t-test was used

to determine whether the slopes (b and β) of the two models were significantly different from 1.

The Index of dispersion was calculated to determine within-field distribution using the following formula:

$$ID = s^2/x$$

where s^2 is the sample variance and x is the mean number of predatory arthropods or corn-infesting ulidiid eggs or larvae per sample. Populations with ID values not significantly different from zero are regularly distributed, while those with ID > 1 is aggregated.

Laboratory Evaluation of Arthropod Species for Predatory Status

Arthropod collection: The study was conducted in summer and fall 2010 using 150 ears collected each season from a sweet corn field at TREC, Homestead, FL. These were placed in 17 X 22 cm Zip Lock[®] bags (S.C. Johnson & Son, Inc., Racine, WI, USA) at 10 ears per bag, transported to the laboratory, and then temporarily stored at $26 \pm 5^\circ$ and $30 \pm 5^\circ$ °C for the spring and summer tests, respectively. After one-hour corn ear tips (10 cm from top) were excised with a knife and inspected with a microscope at 10 X to collect arthropods. Live immature and adult stages of predator species were removed from corn ears using a fine insect brush, and transferred to Petri dishes (10.5 cm diameter) each containing one individuals of a particular species. Six individual of a similar age group for each species were collected to study their predatory status on different life stages of corn-infesting Ulidiidae. The age group of each species was confirmed by visually observing their size and color of individuals.

Predatory status experiment: Nymphs and adults of *O. insidiosus*, 3rd instar larvae of an unidentified rove beetle (Coleoptera: Staphylinidae), and 3rd instar larvae of *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) removed from field collected ears were evaluated for predation of ulidiid immature stages. These arthropods were selected, because they were already known to belong to the group of generalist predators. One predator belonging to a particular family and age was placed in a Petri dish along with honey and water as food (three sets of such Petri dishes were prepared). The predator arthropods were deprived of water and food for 24 h before being provided with ulidiid prey. In each Petri dish containing one predator was provided with 20 eggs (24 h old) of *E. stigmatias*, *E. eluta*, and *E. annonae* were provided as prey (20 eggs or larvae/predator). In the second set of Petri dishes, each predator was provided with twenty 1st, 2nd and 3rd larval instar (24 h old) of *Euxesta* spp. and in the third set each predator was provided with 20 adults of each *Euxesta* spp. (24 h old). Preys were supplied from separate laboratory colonies for each species as described below. The experiment was replicated twice for each predator with each prey type (eggs, larvae and adult). The Petri dishes were checked at 24 h intervals to record numbers of eggs and larvae of corn-infesting ulidiids. Dead (as evidenced by deflation) or missing eggs and larvae were assumed to feed upon by the predators. The study was conducted in a growth chamber at $28^{\circ} \pm 0.5^{\circ}\text{C}$ and 75% RH.

Insect colony maintenance: Colonies were begun using 100 adults of each of *E. stigmatias*, *E. eluta*, and *E. annonae* collected from corn fields in summer 2010. Each *Euxesta* spp. was reared in a separate cage (30.5 x 30.5 x 30.5 cm) and all stages of

each colony were maintained $30 \pm 5^{\circ}\text{C}$. Rearing methods were the same for all the fly species. Colonies were maintained using an artificial diet designed for beet armyworm (BAW, Southland Co., Lake Village, AR) and methods described by Seal and Jansson (1989). Adults were supplied with 1% honey solution and fresh water. The diet was prepared by adding honey 0.5 ml and green food coloring agent 0.2 ml (ESCO Food Co., San Jose, CA) to each 81 gm of dried diet along with 465 liter of boiling water. The color was added to facilitate fly oviposition by simulating the green color of corn silk or cob. Diets were placed in plastic cups (28.3 g) (BioServe™, Beltsville, MD, USA) and attached to the ceilings of cages to facilitate oviposition by the adults. To develop a homogeneous colony for each fly species, eggs were collected at 24 h intervals, and then transferred to fresh BAW diet for larval emergence in the same environmental conditions as the adults. Freshly eclosed first instar larvae were removed from the egg containers every 24 h and transferred to plastic cups (28.3 g) containing BAW diet and allowed to complete development into pupae. The diet cups were checked every 4 h to remove pupae. The pupae (≤ 4 h old) were washed gently with tap water to remove dietary residue and to reduce fungal infection. The pupae were then air-dried to remove excess water from the cuticle and placed in Petri dishes with a disk shaped moist filter paper (5 cm in diameter) to avoid desiccation. Petri dishes containing pupae were placed in cages (30.5 x 30.5 x 30.5 cm) to facilitate adult emergence. Pupae were checked every 2 h to collect newly emerged adults up to 2 h old. Colonies of each fly species were maintained throughout the year until spring 2011.

Functional Response of *O. insidiosus* to Eggs of *Euxesta* species

A laboratory study to evaluate the functional response of *O. insidiosus* to eggs of *Euxesta* spp. was conducted at TREC, Homestead, FL. Eggs of *E. stigmatias*, *E. eluta*, and *E. annonae* were obtained from a laboratory colony maintained for several generations as detailed above. *Orius insidiosus* adults were obtained from Koppert Biological Systems (Romulus, MI, USA).

The experimental unit for the functional response study was the same plastic cups (28.3 g) used for maintenance of the *Euxesta* spp. colonies. The cups themselves were used to support a layer of parafilm on which the predators were supplied with specific eggs densities; nothing was placed within the cups. A single layer of parafilm was placed over each cup (3.5 cm diam) and then depressed into the cup (2 cm) to form an area in which the predator and prey were introduced (Fig. 2-1). Prey eggs were killed by cooling to 2°C for 30 m prior to addition to the cups. *Euxesta* spp. eggs (24 h old) were added to the cups at the prey densities of 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, and 60 eggs per cup. Only one species of *Euxesta* spp. eggs was placed in each cup to determine functional responses for *O. insidiosus* adults for each fly species eggs. One *O. insidiosus* adult was then added to each cup. To standardize predator responses, adult *O. insidiosus* were starved for 24 h before beginning each experiment. Droplets of water (2 or 3) were added to the paraffin layer as a source of moisture. After placing prey eggs with predators into a cup, it was covered with a Petri dish lid to seal the experimental unit.

Eggs that were preyed upon by *O. insidiosus* became deflated with a visible air vacuole visible (Figure 2-7). After a 24 h feeding period, the number of deflated eggs in

each arena was counted. Deflated eggs were assumed to be attacked by *O. insidiosus* based on the observation and comparison with intact fly eggs in the absence of predators in a control group. Each treatment (number of eggs per arena) was replicated eight times. Containers were excluded from the experiment and discarded if the predator died or larvae emerged from the eggs.

The predation data allows us to determine two important things about a given predator-prey relationship: the shape or type of functional response (Type I, II or III), as well as the handling time and attack constant. The first step in analyzing predation data was to determine the type of functional response using a polynomial logistic regression model (CATMODE, SAS Institute 2003). The second step was to fit the mechanistic model (based on the type of functional response obtained) and estimate the parameters (i.e., handling time and the attack constant) using the NLIN procedure (SAS Institute 2003).

Because the number of prey eggs declined as they were consumed (the eggs consumed were not replaced with fresh eggs), Juliano's (1993) method was used to fit the data to Roger's (1972) random predator equation. The type of functional response shown by the data was first determined by logistic regression model in PROC CATMODE (SAS Institute 2003). The following model was used to determine shapes of the functional response curves:

$$\frac{N_e}{N_o} = \frac{\exp(P_0 + P_1 N_o + P_2 N_o^2 + P_3 N_o^3)}{1 + \exp(P_0 + P_1 N_o + P_2 N_o^2 + P_3 N_o^3)}$$

where N_e is the number of prey eaten, N_o the initial number of prey, and P_0 , P_1 , P_2 , and P_3 the parameters estimated using the CATMODE procedure (SAS Institute

2003). Hence, a polynomial equation describing the relationship between the proportion of eggs eaten at each prey density and each initial prey density was determined. If the first term (P_1) in the data analyzed was negative, the functional response for the predator was type II, and if the first term was positive, the functional response was type III. Once the type of functional response was determined, data were fit to the random predator equation (PROC NLIN, SAS 2003). In the PROC NLIN procedure a non-linear, least-square regression of the number of flies eaten versus the number of flies offered was used to estimate and compare the different parameters of the functional response.

The results of this experiment determined that *O. insidiosus* responded in a type III manner (Hassell 1978) to varying prey densities; therefore, only the following equation was used to estimate the search rate and attack constant parameters:

$$N_e = N_o \{1 - \exp [-a T N_o / (1 + b N_o + a T_h N_o^2)]\}$$

In the Hassell equation, a is the instantaneous search rate or the attack constant (time taken by a predator to search for its prey), b is a constant, T_h is the handling time, and T is total time available for *O. insidiosus* to search for and attack the prey eggs.

Results

Seasonal Abundance and Diversity of Arthropods

Several species of arthropods were found in corn ears during the 2010 survey. *Orius insidiosus* were found throughout 2010 in sweet corn (Table 2-2). The adults and larvae of sap beetles, *Lobiopa insularis* Castelnau and *Carpophilus lugubris* Murray (Coleoptera: Nitidulidae) was also found in sweet corn ears throughout 2010. Larvae of an unidentified rove beetle (Coleoptera: Staphylinidae) species were found in ears only during the summer of 2010. Unidentified species of book lice (Psocoptera) and earwigs

(Dermaptera: Forficulidae) were found in the brown and dried corn silk. In figures 2-2, 2-3 and 2-4, numbers of larval and of adult Nitidulidae are represented as cumulative means of both *L. insularis* and *C. lugubris*.

Spring 2010: The only potential ulidiid predator arthropod found during the R1 stage was *O. insidiosus* (Fig. 2-2A). The mean number of corn-infesting Ulidiidae eggs was significantly greater than the larvae ($t = 10.89$; $df = 1,39$; $P < 0.002$) (Fig. 2-2B).

Predatory arthropods found during the R2 stage (Fig. 2-3A) included *O. insidiosus*, unidentified species of thrips (Thysanoptera: Thripidae), and larval and adult Nitidulidae (*L. insularis* and *C. lugubris*). There were significant differences among numbers of different groups of arthropods found with the mean number of Nitidulidae larvae greatest ($F = 10.19$; $df = 5, 39$, $P < 0.0005$). The number of corn-infesting Ulidiidae larvae found was significantly greater than the number of eggs ($t = 61.69$; $df = 1, 39$; $P < 0.001$) (Fig. 2-2B).

Similar results were found in the R3 stage ear samples compared with those from the R2 stage. During the R3 stage (Fig. 2-3A), there were significant differences among numbers of predatory arthropods found in ears ($F = 17.49$; $df = 5, 39$; $P < 0.0001$) with the mean number of adult Nitidulidae greater than the other species. Significantly more ulidiid larvae were found in ears in this stage than eggs ($t = 48.2$; $df = 1,39$; $P < 0.0001$) (Fig. 2-2B).

Summer 2010: There was a greater diversity of arthropods found in ears in the summer than in the spring ear samples. Ulidiid eggs and larvae also were more common in the summer than the spring ear samples. In the R1 stage (Fig. 2-3A), there

were significant differences among the numbers of predatory arthropods found in the ears ($F = 21.67$; $df = 5, 39$; $P < 0.0001$) with the mean number of *O. insidiosus* greater than the other species. As in the spring, the mean number of corn-infesting Ulidiidae eggs was significantly greater than the number of larvae ($t = 53.17$; $df = 1, 39$; $P < 0.0015$) (Fig. 2-3B).

In the R2 and R3 stages (Fig. 2-3A), there were significant differences among numbers of predatory arthropods ($F = 61.13$; $df = 5, 39$; $P < 0.0001$; and $F = 69.11$; $df = 5, 39$; $P < 0.0001$, respectively) with the mean number of Nitidulidae larvae greater than the other species. The mean number of corn-infesting Ulidiidae larvae was significantly greater than the number of eggs in the R2 and R3 stages ($t = 69.66$; $df = 1, 39$; $P < 0.0001$; and $t = 72.9$; $df = 1$; $P < 0.002$, respectively) (Fig. 2-3B).

Fall 2010: In the R1 stage (Fig. 2-4A), There were significant differences among the numbers of predatory arthropods found in ears ($F = 20.29$; $df = 5, 39$; $P < 0.0001$) with the mean number of *O. insidiosus* greater than the other species. The mean number of corn-infesting Ulidiidae eggs was significantly greater than the number of larvae ($t = 10.98$; $df = 1, 39$; $P < 0.0015$) (Fig. 2-4B).

Results for ear samples were different in the fall, R2 stage sample than the previous two season samples. There were significant differences among the numbers of insects found in the arthropod groups ($F = 23.37$; $df = 5, 39$; $P < 0.003$) with the mean number of *O. insidiosus* the greater than the mean number of nitidulids and other species (Fig. 2-4A). Additionally, there was no significant difference between the mean

number of corn-infesting Ulidiidae eggs and larvae ($t = 10.45$; $df = 1, 39$; $P < 0.06$) (Fig. 2-4B).

There were significant differences among the numbers of predatory insects found in ears during the R3 stage ($F = 48.2$; $df = 5, 39$; $P < 0.005$) with the mean number adult Nitidulidae greater than the other species (Fig. 2-5A). The mean number corn-infesting Ulidiidae larvae were significantly greater than the number of eggs ($t = 53.11$; $df = 1, 39$; $P < 0.0002$) (Fig. 2-4B).

The mean number of *O. insidiosus* (adults and nymphs) was found to be greatest during summer 2010 and least during spring 2010 (Fig. 2-5). The numbers of corn-infesting Ulidiidae eggs and larvae were each greatest during summer 2010 (Fig. 2-6).

Spatial Distribution of Predators and Corn-Infesting Ulidiids

Spring 2010: (Table 2-4) During the R1 and R2 stages, *O. insidiosus* showed an aggregated distribution because the slopes (b and β) for the linear regression model (Taylor's power law and Iwao's patchiness of regression) were significantly > 1 ($P < 0.05$, Table 2-4). The coefficients of determination (r^2) for both models indicated a good fit; this was indicated r^2 value that was approximately equal to 1 (ranging between 0.97 to 0.99). The indices of dispersion (IDs) of 1.2 during R1 and 23.7 during R2 stage were each significantly > 1 ($P > 0.05$) indicating an aggregated distribution for *O. insidiosus* in agreement with the results from calculating Taylor's power law and Iwao's patchiness models. However, *O. insidiosus* appeared to be randomly distributed at R3 stage (Table 2-4), based on the slope values calculated from the Taylor's power law and Iwao's patchiness of regression ($b = 0.86$ and $\beta = 0.72$) being significantly equal to 1

($P < 0.05$). The ID value at R3 stage of 0.99 was not significantly different than 1 indicating a random distribution (Table 2-4).

The distribution of Ulidiidae eggs and larvae was aggregated in all three-ear stages sampled (i.e., silking, blister, and milk stages) (Table 2-2). This determination was based on the slope values (b and β) being significantly > 1 (ranging from 1.5 to 4.1) ($P < 0.05$, Table 2-4) for the Taylor's power law and Iwao's patchiness of regression models. An aggregated distribution was also indicated by the Index of dispersion model as the value was significantly greater than 1 (range: 1.2 to 23.7) ($P < 0.05$).

The numbers of Ulidiidae larvae found in sampled ears during R1 stage were not great enough to estimate a distribution pattern (Table 2-4). However, at both R2 and R3 stages, the larvae had an aggregated distribution based on slopes in Taylor's power law and Iwao's patchiness of regression model.

Summer 2010: (Table 2-5) Taylor's power law and Iwao's patchiness regression showed aggregated distributions for *O. insidiosus* during the R1 and R2 stages (Table 2-5). The slopes for Taylor's power law at R1 and R2 stages were 2.35 and 1.92, respectively, whereas the slopes for Iwao's patchiness of regression for R1 and R2 stages were 2.67 and 2.18, respectively. All these values were significantly greater than 1 ($P < 0.05$) indicating aggregated distribution patterns.

Staphylinid larvae were not present during the R1 and R2 stages (Table. 2-5). They were distributed in an aggregated fashion at the R3 stage based on the slopes for Taylor's power law and Iwao's patchiness of regression models.

Taylor's power law and Iwao's patchiness of regression models described aggregated distributions for corn-infesting Ulidiidae eggs throughout the R1, R2, and R3 stages of sweet corn (Table 2-5) due to slopes > 1 . The ID values for all the three sampling dates were also significantly > 1 ($P < 0.05$) indicating an aggregated distribution.

The Ulidiidae larvae were low during the R1 stage; their pattern of distribution patterns could not be determined. At R2 and R3 stages; however, these larvae showed aggregated distributions (Table 2-5). Slopes for Taylor's power law and Iwao's patchiness of regression model were each significantly greater > 1 ($P < 0.05$), as were ID values for each sampling date.

Fall 2010: All the models found distributions of *O. insidiosus* aggregated during R1 AND R2 stage as slope values (b and β) and ID values were significantly greater than 1 ($P < 0.05$) (Table 2-6). During R3 stage the distribution was random slope values (b and β) and ID values were significantly equal to 1 ($P < 0.05$). The distribution of Ulidiidae eggs was aggregated during both R1 and R2 stages. As the number of Ulidiidae eggs was low during R3 stage, their pattern of distribution patterns could not be determined. At R2 and R3 stage, the Ulidiidae larvae displayed an aggregated pattern of distribution.

Laboratory Evaluation of Arthropod Species for Predatory Status

In the laboratory, all the three predator species chosen were found to feed upon corn-infesting Ulidiidae species (Table 2-2,3). Both nymphs and adults of *O. insidiosus* fed on eggs and larvae of *E. stigmatias*, *E. eluta*, and *E. annonae* (Figs. 2-7 and 2-8).

Staphylinid larvae devoured eggs and larvae of *Euxesta* spp. (Fig. 2-9), and *C. carnea* larvae (3rd instar) fed on larvae and adults of *Euxesta* spp. (Fig.2-10).

Functional Response of *O. insidiosus* to Eggs of *Euxesta* species

Orius insidiosus displayed a type III functional response to eggs of *E. annonae*, *E. eluta*, and *E. stigmatias* because of positive first terms for linear regression equations of the proportions of *Euxesta* spp. eggs consumed at each density versus initial egg density available to predators (Table 2-7, Fig. 2-11). At the greatest prey density of 60 eggs per arena, *O. insidiosus* fed on an average of 39 *E. stigmatias* eggs, 40 *E. eluta* eggs and 41 *E. annonae* eggs. There was no significant difference in the predation rates for *O. insidiosus* among three tested prey species ($F = 31.3$; $df = 2, 23$; $P < 0.001$). Estimated handling times ranged from 0.43 - 0.45 h, while attack constants ranged from 0.03 - 0.05 for three *Euxesta* spp. eggs (Table 2-8).

Discussion

Our arthropod diversity results were consistent with other surveys of cornfield arthropods. Arthropods found within corn ears in this study were *O. insidiosus*, unidentified thrips, unidentified mites, beetles (adults and larvae of *C. lugubris*, *L. insularis*; and unidentified Staphylinids), and green lacewing larvae (*C. carnea*). In all the three seasons, the most abundant arthropod species during silking was *O. insidiosus* followed by unidentified thrips and mites. Knuston and Gilstrap (1989) also found *O. insidiosus* to be the most abundant predator accounting for 80% of total predators on corn. Eckert et al. (2006) reported *Orius* spp. were the most abundant predators when they surveyed the fauna of maize ears. *Orius insidiosus* occurred in spring, summer and fall of 2010 in sweet and field corn. Many authors reported that

flowering corn plants during tasseling and silking strongly attract *O. insidiosus*, as the host plants harbor an abundance of prey (Isenhour and Marston 1981, Elkassabany et al. 1996, Saulich and Musolin 2009). Mean numbers of *O. insidiosus* were lowest during spring and greatest during summer. *Orius insidiosus* populations only consist of fertilized females during the spring because males reach 100% mortality due to cold winter (Saulich and Musolin 2009). We observed that during the R1 period, the mean number of corn-infesting Ulidiidae eggs were greater than at either R2 or R3 stage. Nuessly and Capinera (2004) reported that *E. stigmatias* prefers to oviposit on fresh corn silk, and oviposition on other plant parts such as corn leaves results in greater egg mortality. With three seasons of data, we found that during the R1 stage when the mean numbers of corn-infesting Ulidiidae eggs were high, the first predators to colonize corn silk were *O. insidiosus* followed by smaller numbers of unidentified thrips and mites. Knuston and Gilstrap (1989) also observed that *O. insidiosus* was the first predator to colonize corn ears. They found that *O. insidiosus* nymphs were abundant during the early silking stage, which concurs with the present study where nymph populations were greatest during the silking stage and decreased during later developmental stages of corn. These results suggest that *O. insidiosus* reproduced soon after colonization of corn fields, which is supported by Richie and Hanway (1984). Barber (1936) also reported that *O. insidiosus* was the first arthropod to colonize corn ears during silking stage. He further observed that as the growing season began, *O. insidiosus* would first appear between the leaves and stalks of corn plants and later become more common on young tassels. He further noted that soon after first silk,

Orius insidiosus traveled to silk strands, which provided a substrate for oviposition. As generalist predators, *Orius* spp. are common in different agricultural systems, where they serve as biological control agents in integrated pest management (Isenhour and Marston 1981, Isenhour and Yeargan 1981, Isenhour et al. 1990, Reid 1991, Bush et al. 1993). Baez et al. (2010) in Sinaloa, Mexico also reported *Orius* spp. feeding on different stages of *E. stigmatias*. *Orius insidiosus* adults are commercially available in Europe and the U.S.A. Therefore, further research to understand relationships between *O. insidiosus* and Ulidiidae fly eggs and larvae is warranted. But we should not ignore the fact that in Florida, farmers are treating the sweet corn fields multiple times a week with synthetic insecticides like pyrethroids, organophosphates and carbamates (Dr. G. L. Nuessly, Everglades Research and Education Center, pers. Commun.). He further suggested that the number of *O. insidiosus* in such commercialized sweet corn field is very low. As these pesticides are broad-spectrum pesticides and they pose a great threat to the non-target insects such as natural enemies (Kazmer and Brewer 2009). Therefore, the compatibility of these insecticides should also be tested with the survival of natural enemies such as *O. insidiosus*.

As ears developed through the R1 stage to R3 stage, the numbers of Ulidiidae eggs decreased while numbers of Ulidiidae larvae increased suggesting eggs were deposited in a fairly limited time period. This may also be supported by the preference of the pest for fresh corn silk for oviposition (Barber 1936), but as corn matures to the milk stage, the silk becomes dry and brown-colored. Similarly, *O. insidiosus* adult populations decreased as the corn matured from the R1 to R3 stage,

which may have resulted from a lack of fresh corn silk rendering breeding conditions unfavorable (Barber 1936). A similar pattern of *O. insidiosus* abundance was reported in Ohio (Dicke and Jarvis 1962) and Kentucky (Isenhour and Yeargan 1981). Knuston and Gilstrap (1989) found the mean number of *O. insidiosus* was greatest during anthesis and whorl stage but the number declined as the corn silk became dried and brown during milk stage. The abundance of *O. insidiosus* increased during summer 2010, similarly the abundance of corn-infesting Ulidiidae eggs and larvae was greatest during the same season.

Another predatory species found in corn ears was an unidentified rove beetle larva (Staphylinidae). Its abundance was greatest during the summer of 2010 during the R3 stage. Everly (1935) studied arthropod compositions in corn fields of Ohio and found six different species of Staphylinidae including *Atheta* spp., *Barydoma* spp., *Coproporus* spp., *Leptolinus rubripennis* Lec., *Mycetoporus* spp., and *Philonthus* spp.. *Atheta* spp. He collected the *Coproporus* spp. from corn plants, while the others were found on the ground (Everly 1935). Albajes et al. (2003) reported that 50% of the total rove beetles found in a corn field in Spain were in the genus *Tachyporus*. Adults of the staphylinid *Stenus flavicornis* Erichson have been shown to feed on egg masses of *Ostrinia nubilalis* Hübner in corn fields (Andow 1990). Several staphylinid species are predaceous and potential biocontrol agents of agricultural pests (Cividanes et al. 2009). However, staphylinids have been infrequently used in IPM programs owing to the lack of knowledge on their feeding preferences, ecology, and taxonomy (Balog et al. 2008, 2009; Balog and Marko 2008). The distribution pattern of Staphylinidae larvae was

aggregated during summer 2010. Most of the Staphylinidae larvae were found at R3 stage, entangled in the dried corn silk.

Three different tools (Taylor's power law, Iwao's patchiness regression and Index of dispersion) were used to study the distribution pattern of corn ear associated arthropods, and corn-infesting Ulidiidae eggs and larvae. All of these tools provided a reliable index for measuring their degree of aggregation that was determined by a coefficient of determination (r^2): if the r^2 value is equal to 1 or approximately equal to 1, the model provides the best fit. None of these tools have been used for measuring the distribution of corn-infesting Ulidiidae eggs and larvae. However Goyal (2010) studied the distribution pattern of adult flies of *E. stigmatias*, *E. eluta* and *C. massyla* caught in sticky traps using Morisita's index. His studies were conducted in both large and small-scale fields during the time of first silk appearance until the time of corn ear harvest. He found that the distribution of flies was aggregated during most sampling dates in both the fields. Generally, insect population displays three types of distribution pattern: random, aggregated or uniform. According to Southwood (1978), the insect distribution is greatly influenced by their density within a field. He further stated, the distribution pattern is random if their density is lower due to low capture rate during sampling. While insects' displays aggregated distribution when their density is higher and they are more often caught during sampling. Distribution of corn-infesting Ulidiidae eggs and larvae was aggregated during all sampling dates. Gaurav (2010) found the distribution of adult Ulidiidae was mostly aggregated in sweet corn fields. However, in my studies distribution of larvae was not detected during the R1 stage, as larvae were either absent

or very low at this time. Similarly, the distribution pattern of *O. insidiosus* was aggregated in the majority of the sampling dates. *Orius insidiosus* displayed random distribution during R3 stage in summer 2010 and fall 2010. The random distribution occurred due to the low density of *O. insidiosus* that may be due to the lack of proper breeding conditions or lack of food at this stage of corn ear.

In the laboratory, *O. insidiosus* had a type III functional response to eggs of *Euxesta* spp. A type III functional response, also known as an accelerating functional response, is a density dependent response typically exhibited by generalist predators (Murdoch and Oaten 1975). According to Hassell et al. (1977), a type III functional response results in a sigmoid curve and is more characteristic of vertebrates than invertebrate predators or parasitoids. However, many invertebrates have also exhibited type III functional responses, such as *Geocoris* spp. feeding on cotton bollworm eggs (Shrestha and Parjulee 2004), *O. insidiosus* feeding on the Tetranychidae (Trombidiformes) *Panonychus ulmi* (Koch) and *Tetranychus urticae* (Koch) (Ashley 2003). Possible reasons for the type III functional response include a predator's capacity to switch to different prey species, selective foraging in arenas of high prey density, and where learning and experience benefits the search for prey (Holling 1959b, Murdoch 1969, Schaubert et al. 2004). *Orius insidiosus* is facultatively phytophagous and can feed on plant material during prey scarcity. Hence, it can maintain a high density during prey scarcity, an important characteristic for a biological agent (Wiedenmann and O'Neil 1991, Coll 1997). Ashley (2003) reported that Hemipteran predators including *O. insidiosus* limit their search area by high frequency turning

movements followed by feeding until they reach a threshold time (selective foraging). In case of prey scarcity, the predators straighten their path to reach and exploit an area with a high prey density. These examples suggest explanations for the type III functional responses of *O. insidiosus* to *Euxesta* spp. eggs. Type III functional response can also be observed in the corn silk that is tightly packed and ulidiid eggs are present in clusters but randomly distributed. *Orius insidiosus* can easily feed on the eggs without making much movement, as eggs are present in clusters. Once the eggs are depleted it can feed on other prey like thrips (which were also found in corn silk).

Table 2-1. Planting and sampling dates for the sweet corn experiments.

2010	Planting	First sampling	Second sampling	Third sampling
Spring	02/15/2010	04/5/2010	04/19/2010	04/26/2010
Summer	06/2/2010	07/28/2010	08/11/2010	08/18/2010
Fall	10/2/2010	11/19/2010	12/3/2010	12/10/2010

Table 2-2. Arthropods found in sweet corn during different season 2010.

(Order: Family)	Taxa	Season	Predatory status and feeding stage	Life stage of <i>Euxesta</i> spp.	Type of feeding
	Acari	Spring, Summer, Fall	Unknown		
(Neuroptera: Chrysopidae)	<i>Chrysoperla carnea</i>	Summer	Yes (Larvae)	Larvae, Adults	Piercing and sucking
(Hemiptera: Anthocoridae)	<i>Orius insidiosus</i>	Spring, Summer, Fall	Yes (Nymphs, Adults)	Eggs, Larvae	Piercing and sucking
(Hemiptera: Reduviidae)	<i>Zelus longipes</i>	Fall	Yes (Nymphs, Adults)	Larvae, Adults	Piercing and sucking
(Dermaptera: Forficulidae)	Unidentified	Summer	Unknown		
(Thysanoptera: Thripidae)	Unidentified	Summer	Unknown		
(Blattaria)	Unidentified	Fall	Unknown		
(Coleoptera: Staphylinidae)	Unidentified	Summer	Yes (Larvae)	Eggs, Larvae	Chewing
(Coleoptera: Nitidulidae)	<i>Lobiopa insularis</i>	Spring, Summer, Fall	No		
(Coleoptera: Nitidulidae)	<i>Carpophilus lugubris</i>	Spring, Summer, Fall	No		
(Diptera: Muscidae)		Summer, Fall	No		
(Hymenoptera: Formicidae)		Summer	Unknown		
(Lepidoptera: Noctuidae)	<i>Spodoptera fugiperda</i>		No		
(Orthoptera: Acrididae)			Unknown		
(Psocoptera)	Unidentified	Summer	No		

Table 2-3. Mean number (\pm SE) of *Euxesta* spp. (eggs, larvae and adults) eaten by generalist predators. Each predator was provided with 20 eggs, 20 larvae and 20 adults in separate Petri dish for 24 h.

Generalist predators	<i>Euxesta</i> spp.														
	Eggs	<i>Euxesta stigmatias</i>				Eggs	<i>Euxesta eluta</i>				Eggs	<i>Euxesta annonae</i>			
		1 st	2 nd	3 rd	Adults		1 st	2 nd	3 rd	Adults		1 st	2 nd	3 rd	Adults
<i>Orius insidiosus</i> adult	20	18.5 \pm 0.5	17.5 \pm 0.5	6.5 \pm 0.5	-	20	18.5 \pm 0.5	15	5.5 \pm 0.5	-	20	18.5 \pm 0.5	18	5.5 \pm 1.5	-
4 th instar nymph	20	18	15	6.5 \pm 0.5	-	20	17	14.5 \pm 1.5	6.5 \pm 0.5	-	20	17	11.5 \pm 0.5	6.5 \pm 0.5	-
3 rd instar	17.5 \pm 0.5	16.5 \pm 0.5	12	4	-	16	16.5 \pm 0.5	12	4	-	16.5 \pm 0.5	16.5 \pm 0.8	12	4	-
2 nd instar	14	15	9.5 \pm 0.5	2.5 \pm 0.5	-	13.5 \pm 0.5	15	11	3	-	11	15	9.5 \pm 0.5	4	-
1 st instar	6.5 \pm 0.5	7.5 \pm 0.5	3.5 \pm 0.5	-	-	6.5 \pm 0.5	7.5 \pm 0.5	3.5 \pm 0.5	-	-	6.5 \pm 0.5	7.5 \pm 2.0	3.5 \pm 0.5	-	-
Staphylinidae (3 rd instar)	20	20	20	13	-	20	20	20	12.5 \pm 0.5	-	20	20	20	14	-
<i>Chrysoperla carnea</i> (3 rd instar)	-	15.5 \pm 0.5	9.5 \pm 0.5	3.5 \pm 0.6	4.5 \pm 0.5	-	12	8.5 \pm 0.5	5.5 \pm 0.5	3.5 \pm 0.5	-	10.5 \pm 0.5	9.5 \pm 0.5	3	5

Table 2-4. Taylor's power law, Iwao's patchiness regression, and index of dispersion parameters for distributions of predators (*Orius insidiosus* adults and nymphs) and pests (Ulidiidae eggs and larvae) in sweet corn ears during spring 2010 at R1, R2, and R3 stages of corn growth.

Spring 2010, <i>Orius insidiosus</i>									
Stage of corn	Plot size (Ha)	Taylor's power law			Iwao's patchiness regression			Index of dispersion	
		<i>a</i>	<i>b</i>	<i>r</i> ²	<i>α</i>	<i>β</i>	<i>r</i> ²	ID	
R1	0.6	0.87	2.32 AGG	0.99	1.37	7.29 AGG	0.97	1.20	AGG
R2	0.6	0.36	2.03 AGG	0.98	1.08	3.34 AGG	0.99	2.96	AGG
R3	0.6	-0.18	0.86 RAN	0.99	-0.05	0.72 RAN	0.98	0.91	RAN
Spring 2010, Ulidiidae species eggs									
R1	0.6	1.55	4.1 AGG	0.99	1.61	3.39 AGG	0.97	1.2	AGG
R2	0.6	1.9	2.59 AGG	0.98	2.01	2.76 AGG	0.99	23.7	AGG
R3	0.6	1.68	1.5 AGG	0.99	1.67	2.0 AGG	0.98	13.7	AGG
Spring 2010, Ulidiidae species larvae									
R1	0.6	-	-	-	-	-	-	-	-
R2	0.6	-25.3	20.1 AGG	0.98	-36.13	14.7 AGG	0.99	18.0	AGG
R3	0.6	-2.83	4.12 AGG	0.99	-15.61	2.48 AGG	0.98	7.71	AGG

AGG, aggregated distribution: *b* significantly >1 ($P \leq 0.05$); REG, regular distribution: *b* significantly < 1 ($P \leq 0.05$); and RAN, random distribution: *b* not significantly different from 1 ($P > 0.05$).

Table 2-5. Taylor's power law, Iwao's patchiness regression, and index of dispersion parameters for distributions of predators (*Orius insidiosus* adults, nymphs, and Staphylinidae larvae) and pests (Ulidiidae eggs and larvae) in sweet corn ears during summer 2010 at R1, R2, and R3 stages of corn growth.

Summer 2010, <i>Orius insidiosus</i>								
Stage of corn	Plot size (Ha)	Taylor's power law			Iwao's patchiness regression			Index of dispersion
		<i>a</i>	<i>b</i>	<i>r</i> ²	<i>α</i>	<i>β</i>	<i>r</i> ²	ID
R1	0.6	1.3	2.35 AGG	0.97	1.22	2.67 AGG	0.99	4.42 AGG
R2	0.6	2.78	1.92 AGG	0.83	1.98	2.18 AGG	0.89	3.7 AGG
R3	0.6	-1.3	1.95 AGG	0.84	-0.95	1.99 AGG	0.91	1.2 AGG
Summer 2010, Staphylinidae larvae								
R1	0.6	-	-	-	-	-	-	-
R2	0.6	-	-	-	-	-	-	-
R3	0.6	1.24	3.21 AGG	0.98	2.22	3.09 AGG	0.99	5.6 AGG
Summer 2010, Ulidiidae species egg								
R1	0.6	2.9	3.56 AGG	0.98	3.33	3.98 AGG	0.99	5.43
R2	0.6	-1.65	4.32 AGG	0.89	-0.98	3.76 AGG	0.81	5.01
R3	0.6	1.87	2.09 AGG	0.73	1.73	2.13 AGG	0.69	2.19
Summer 2010, Ulidiidae species larvae								
R1	0.6	-	-	-	-	-	-	-
R2	0.6	-3.03	6.12 AGG	0.99	-1.83	5.98 AGG	0.97	7.59
R3	0.6	4.1	3.09 AGG	0.97	2.43	4.04 AGG	0.98	9.65

AGG, aggregated distribution: *b* significantly >1 ($P \leq 0.05$); REG, regular distribution: *b* significantly < 1 ($P \leq 0.05$); and RAN, random distribution: *b* not significantly different from 1 ($P > 0.05$).

Table 2-6. Taylor's power law, Iwao's patchiness regression, and index of dispersion parameters for distributions of predators (*Orius insidiosus* adults, nymphs, and Staphylinidae larvae) and pests (Ulidiidae eggs and larvae) in sweet corn ears during fall 2010 at R1, R2, and R3 stages of corn growth.

Fall 2010, <i>Orius insidiosus</i>									
Stage of corn	Plot size (Ha)	Taylor's power law			Iwao's patchiness regression			Index of dispersion	
		<i>a</i>	<i>b</i>	<i>r</i> ²	<i>α</i>	<i>β</i>	<i>r</i> ²	ID	
R1	0.6	1.05	1.82 AGG	0.99	10.20	1.75 AGG	0.97	9.4 AGG	
R2	0.6	0.21	1.62 AGG	0.99	-0.64	2.28 AGG	0.99	1.12 AGG	
R3	0.6	-0.12	0.96 RAN	0.99	-0.19	0.94 RAN	0.99	0.87 RAN	
Fall 2010, Ulidiide species eggs									
R1	0.6	-0.18	1.86 AGG	0.99	0.05	1.02 AGG	0.98	13.6 AGG	
R2	0.6	0.61	2.26 AGG	0.98	-5.11	1.75 AGG	0.99	21.9 AGG	
R3	0.6	-	-	-	-	-	-	-	
Fall 2010, Ulidiidae species larvae									
R1	0.6	-	-	-	-	-	-	-	
R2	0.6	-2.02	3.14 AGG	0.98	-23.89	2.26 AGG	0.99	23.7 AGG	
R3	0.6	-2.83	4.12 AGG	0.99	-15.61	2.48 AGG	0.98	7.71 AGG	

AGG, aggregated distribution: *b* significantly >1 ($P \leq 0.05$); REG, regular distribution: *b* significantly < 1 ($P \leq 0.05$); and RAN, random distribution: *b* not significantly different from 1 ($P > 0.05$).

Table 2-7. Maximum-likelihood estimates from logistic regression of proportion of prey eaten as a function of initial prey by *Orius insidiosus* adults.

Prey (eggs, n=60)	Parameters	Estimates	SE	χ^2	P
Euxesta stigmatias	Intercept (P_0)	1.425	1.62	0.77	< 0.0001
	Linear (P_1)	0.628	0.147	18.37	< 0.0001
	Quadratic (P_2)	-0.022	0.004	28.70	< 0.0012
Euxesta eluta	Intercept (P_0)	0.449	0.298	1.54	< 0.0001
	Linear (P_1)	0.356	0.16	29.67	< 0.0001
	Quadratic (P_2)	-0.044	0.001	32.12	< 0.0024
Euxesta annonae	Intercept (P_0)	1.723	1.322	0.65	< 0.0001
	Linear (P_1)	0.799	0.031	19.27	< 0.0001
	Quadratic (P_2)	-0.034	0.030	21.83	< 0.0011

Table 2-8. Type III functional response of *O. insidiosus* to eggs of *Euxesta* spp.

<i>Euxesta</i> spp.	Handling time T_h (h)	Attack constant (h^{-1})
<i>E. stigmatias</i>	0.45 ± 0.02	0.03 ± 0.05
<i>E. eluta</i>	0.43 ± 0.04	0.03 ± 0.02
<i>E. annonae</i>	0.44 ± 0.05	0.05 ± 0.01



Figure 2-1. The experimental set up for functional response study.

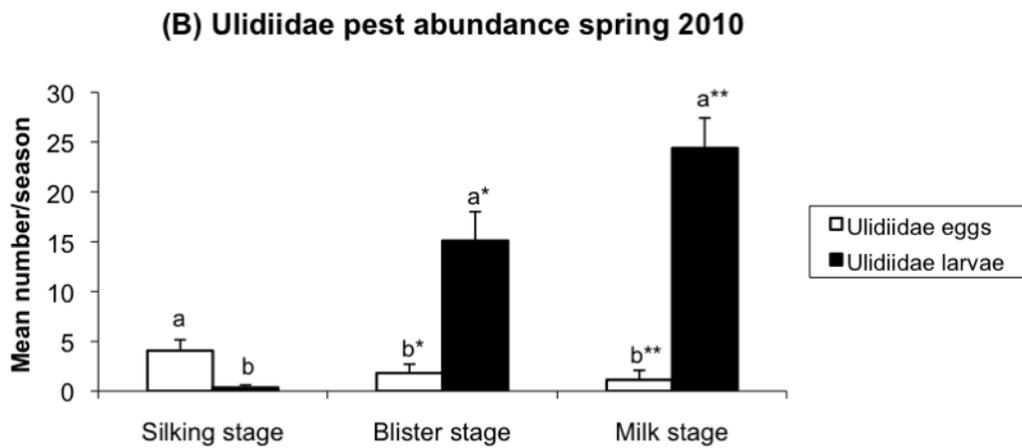
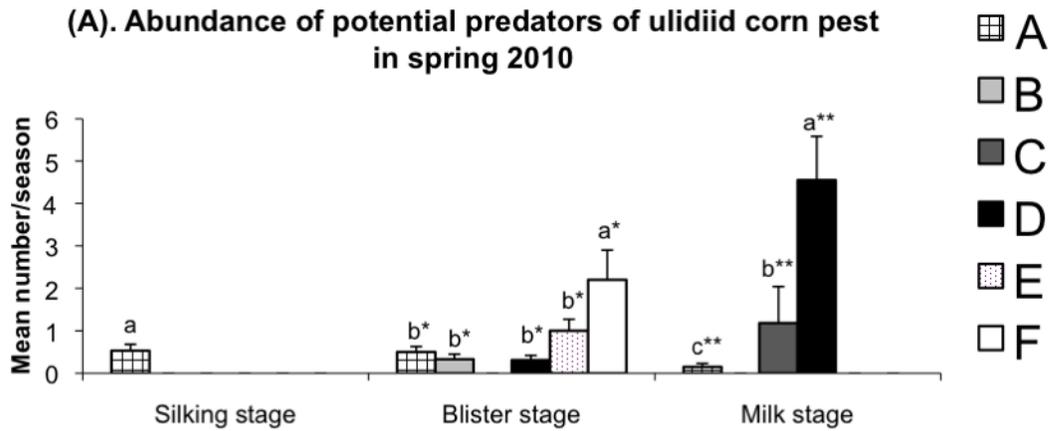


Figure 2-2. (A) Mean number ($n=40$) of potential predators of ulidiid corn pest found in corn ears during spring 2010 at three ear development stages. A= *Orius insidiosus*, B = Unidentified thrips, C = Unidentified mites, D = Nitidulidae adults, E = Staphylinid larvae, and F = Nitidulidae larvae. (B) Mean number of corn-infesting Ulidiidae eggs and larvae. T-bars above each column represent the SEM. Means within a stage represented with the same letter are not significantly different ($P < 0.05$, Tukey's HSD).

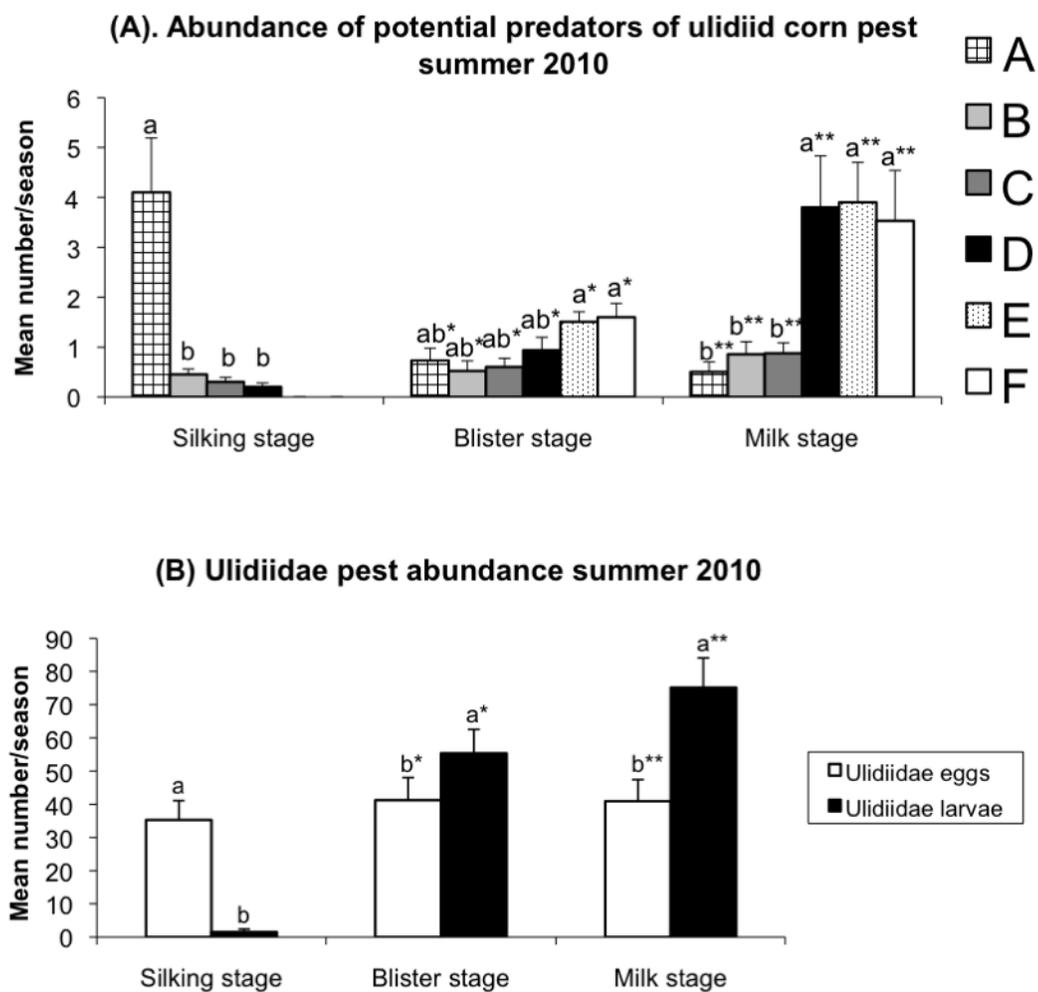


Figure 2-3. (A) Mean number (n=40) of potential predators of ulidiid corn pest found in corn ears during summer 2010 at three ear development stages. A= *Orius insidiosus*, B = Unidentified thrips, C = Unidentified mites, D = Nitidulidae adults, E = Staphylinid larvae, and F = Nitidulidae larvae. (B) Mean number of corn-infesting Ulidiidae eggs and larvae. T-bars above each column represent the SEM. Means within a stage represented with the same letter are not significantly different ($P < 0.05$, Tukey's HSD).

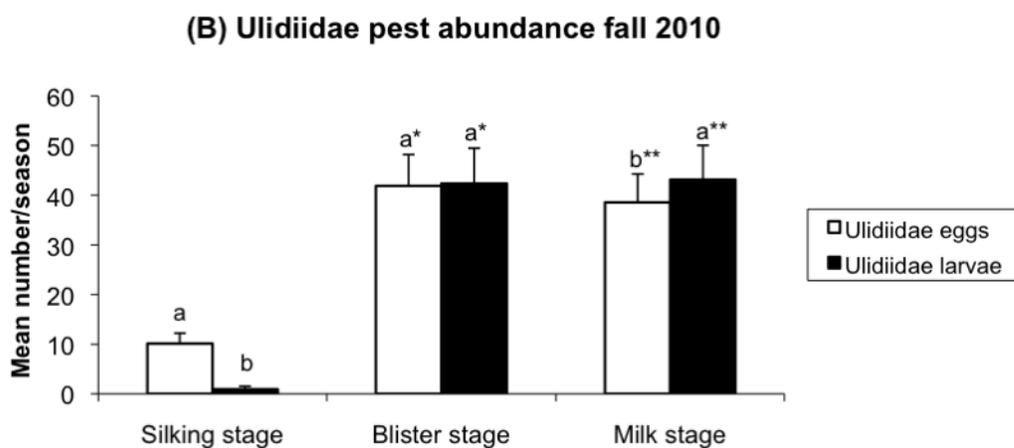
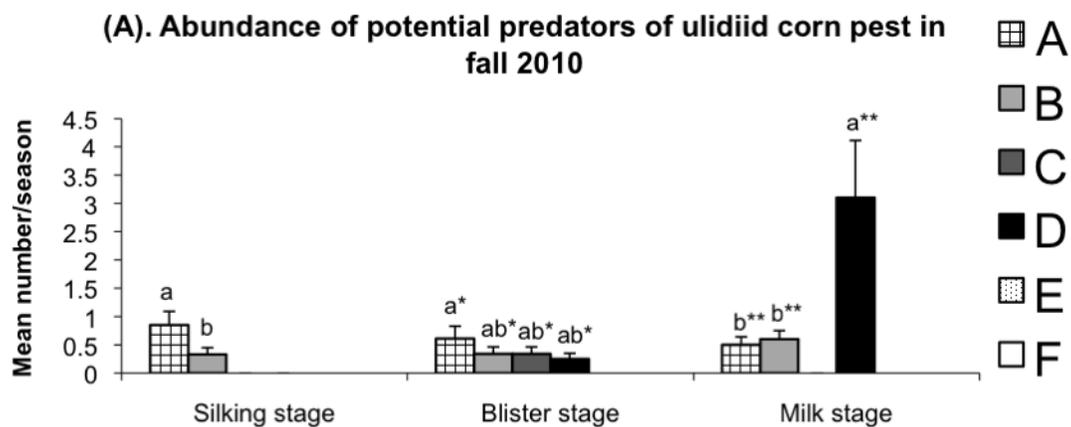


Figure 2-4. (A) Mean number (n=40) of potential predators of ulidiid corn pest found in corn ears during fall 2010 at three ear development stages. A= *Orius insidiosus*, B = Unidentified thrips, C = Unidentified mites, D = Nitidulidae adults, E = Staphylinid larvae, and F = Nitidulidae larvae. (B) Mean number of corn-infesting Ulidiidae eggs and larvae. T-bars above each column represent the SEM. Means within a stage represented with the same letter are not significantly different ($P < 0.05$, Tukey's HSD).

Seasonal abundance of *Orius insidiosus* 2010

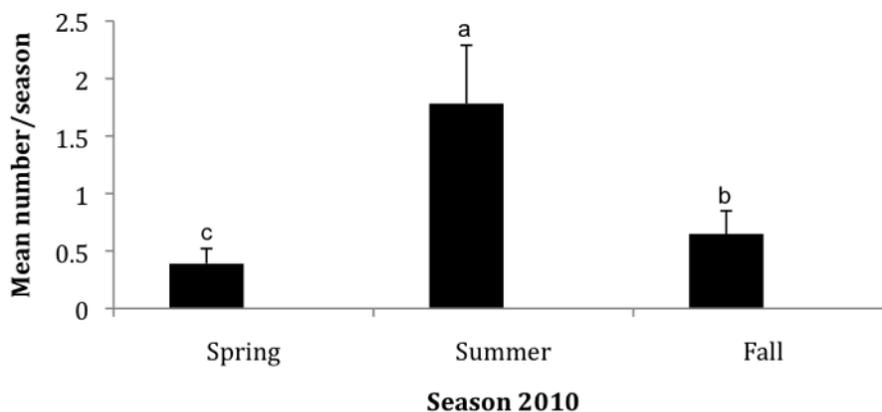


Figure 2-5. Mean seasonal abundance of *O. insidiosus* during spring, summer, and fall 2010. Each bar represents the mean \pm SE (n = 120). T-bars above each column represent the SEM. Means with the same letter are not significantly different ($P < 0.05$, Tukey's HSD).

Seasonal abundance of Ulidiidae pest of corn

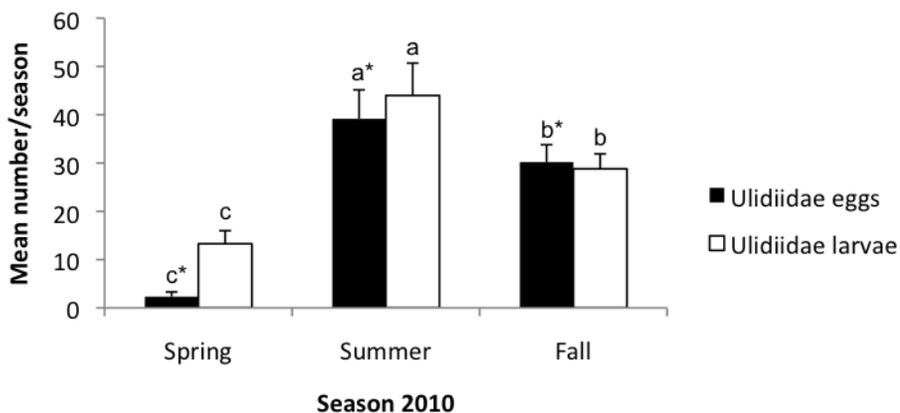


Figure 2-6. Mean seasonal abundance (n = 120) of Ulidiidae eggs and larvae during spring, summer, and fall 2010. T-bars above each column represent the SEM. Means with the same letter are not significantly different ($P < 0.05$, Tukey's HSD).

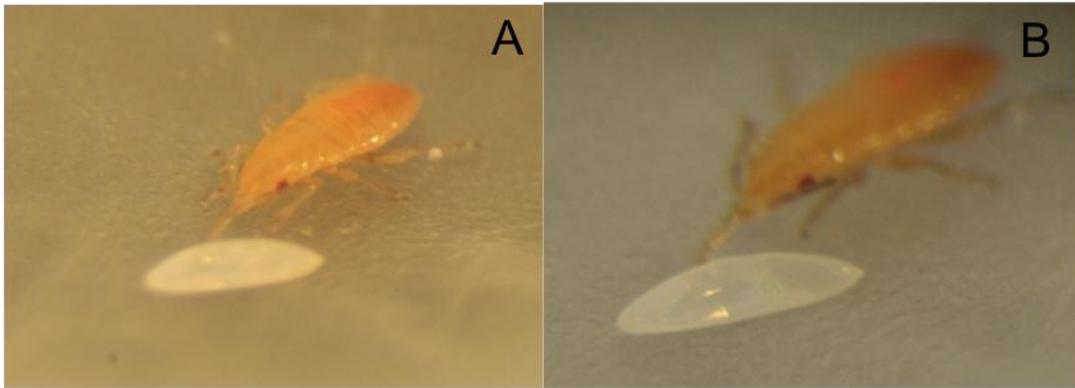


Figure 2-7. (A) The first instar nymph of *O. insidiosus* feeding on a *Euxesta stigmatias* egg, (B) After three minutes, egg contents sucked out by *O. insidiosus* created an air vacuole inside the egg.



Figure 2-8. Adult *O. insidiosus* feeding on a third instar larva of *Euxesta stigmatias*.



Figure 2-9. Staphylinid larva feeding on *Euxesta stigmatias* eggs.



Figure 2-10. Larva of *Chrysoperla carnea* feeding on an adult *Euxesta eluta* fly.

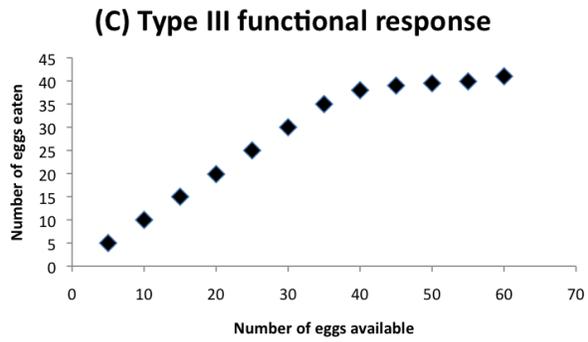
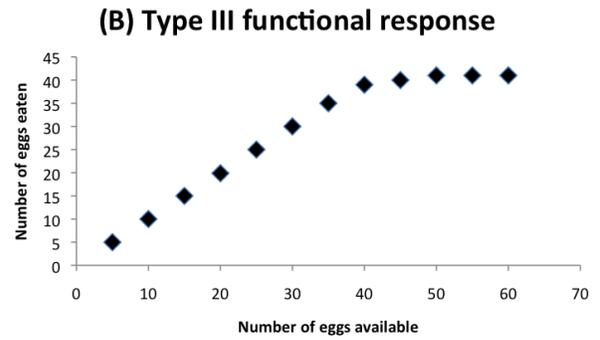
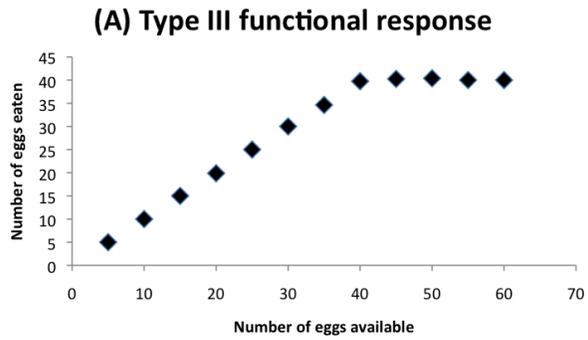


Figure 2-11. Type III functional response of *Orius insidiosus* to eggs of A) *Euxesta stigmatias*, B) *E. eluta*, and C) *E. annonae*. Total time of exposure was 24 h.

CHAPTER 3
DISTRIBUTION AND FUNCTIONAL RESPONSE OF *ZELUS LONGIPES* (L.)
(HEMIPTERA: REDUVIIDAE) TO CORN INFESTING ULIDIIDAE FLIES (DIPTERA:
ULIDIIDAE)

Increasing concerns about infestation of sweet corn by picture-winged flies (Diptera: Ulidiidae) have been expressed since the early 1900's (Barber 1939). Recently, Goyal et al. 2010 reported four species in two genera attacking corn in Florida: *Euxesta stigmatias* Loew, *Euxesta eluta* Loew and *Euxesta annonae* Fabricius and *Chaetopsis massyla* Walker. These flies deposit their eggs inside the corn silk at the tip of the corn ear (Seal et al. 1996). There are three larval instars. These larvae feed upon silk, corn kernel, and corn cob (Nuessly and Capinera 2010). The damage caused due to larval feeding makes the corn unfit for eating. Chemical insecticides have always been a prevalent control for adult flies whereas other life stages remain protected. It was reported that serious injury might occur even after application of insecticides (Seal 2001). Goyal (2010) reported these corn-infesting Ulidiidae keep reentering the corn fields even after the application of insecticide. He further reported due to the lack of knowledge on economic threshold for these pests, growers are applying insecticides daily to keep the corn marketable (Goyal 2010).

Nowadays awareness about the negative impacts of the chemical insecticides is growing rapidly. This has led to the greater adoption of biocontrol program in an integrated pest management. Only a few natural enemies are known for the corn-infesting Ulidiidae that including *Orius insidiosus* Say (Hemiptera: Anthocoridae) (Nuessly and Capinera 2010, Baez et al. 2010) which feed on eggs and larvae of these flies. Two parasitoids were reported to parasitize the pupae of *Euxesta stigmatias* that

belonged to the families Pteromalidae (*Splangia* spp.) and Eurytomidae (Baez et al. 2010). So far there have been no reports of a natural predator feeding or attacking the adults of the corn-infesting Ulidiidae.

Developing a biocontrol program strongly depends upon the ecological information about both the pest and its natural enemies in an agriculture system (Pearce et al. 2006). Information regarding the spatial distribution pattern of pests will help to develop more targeted integrated pest management techniques. In addition the knowledge about ecological or physical factors of a predator will help to better assess its potentiality. Spatial distribution information further helps in development of efficient sampling technique as well as realistic population models (Boiteau et al. 1979). Goyal (2010) reported the spatial and temporal distribution of corn infesting Ulidiidae adults in southern Florida and used Morisita's Index tool to measure the degree of their aggregation. Many other tools are also available to measure the degree of aggregation such as Taylor's power law, Iwao's patchiness regression, Index of dispersion and Lloyds patchiness regression. None of these tools have ever been used to study the spatial distribution of the corn-infesting Ulidiidae and their natural enemies.

The foraging success of a predator is dependent upon the prey dispersion pattern and interference produced by other predators present (Hassel 1980, Sutherland 1983, Wilson 2010). Predators aggregated around higher prey density displays functional and numerical responses. The functional response refers to the change in prey consumption per unit time in relation to prey density (Hassel 1978, Cogni et al. 2000). It can also be explained as a behavioral response because it involves searching (Coll and Ridgway

1995). Functional response plays a key role in determining the effectiveness of a predator for a biological control. The prey selection by the predator depends on the investment of its energetic values (Krebs and Davis 1993). These energetic values are two important parameters of functional response i.e., handling time and attack rate (Juliano 2001).

The handling time involves the subcomponents like time spent in attacking and capturing prey, time spent upon feeding, and time spent for digestive pause. The latter refers to the time period during which predator takes a rest before attacking another prey upon feeling hungry again (Holling 1963, Thompson 1975). Attack rate is dependent upon the probability of occurrence of factors such as predator-prey encounter, predator attacking on encounter, and attacking resulting successful capture of prey (Holling 1963, Thompson 1975).

For the present study, authors decided to test the potentiality of *Z. longipes* as a bio-controlling agent, based on the observation of its feeding on *E. stigmatias*, *E. eluta*, *E. annonae* and *C. massyla* adults in corn fields (Fig.3-1). *Zelus longipes* (Hemiptera: Reduviidae) is a generalist predator, feeding through extra-oral digestion (Cogni et al. 2000, Kalsi and Seal 2011). All the life stages of this predator are known to serve as potential biological control agents (Unigarro 1958). It has also been reported to feed on another corn pest *Spodoptera fugiperda* Smith (Lepidoptera: Noctuidae) (Cogni et al 2000).

The objectives of the present study were: (i and ii) to determine within-plant and within-plant distributions of *Z. longipes* and corn-infesting Ulidiidae, and iii) to determine the functional response of the predator to adult stage *Euxesta* spp. These objectives were investigated to assess the potential of *Z. longipes* in controlling corn-infesting Ulidiidae.

Materials and Methods

In the following section within-field and within-plant distribution of both *Zelus longipes* and corn infesting ulidiid has been described. Later in this section, methodology to study the functional response of *Z. longipes* (both male and female) to *E. stigmatias*, *E. annonae* and *E. eluta* is described.

Field Preparation: The field study was conducted in Tropical research and Education Center (TREC) research fields, Homestead, Florida. The soil type of the experimental field is Krome gravelly loam (loamy-skeletal, carbonatic hyperthermic lithic Udorthents), which consists of about 33% loamy soil and 67% limestone pebbles (> 2mm). 'Obsession' sweet corn (Semini's Vegetable Seeds, Inc., Oxnard, CA) was seeded using precision garden seeder (Model-1001-B, Earthway®) directly into the soil on rows in a 200m wide X 20 m long field on 5 October 2010. The seeds were planted 0.1 m apart within a row and 0.9 m between rows. Granular fertilizer 8-16-16 (N – P – K) at the rate of 1347 Kg/ha was applied at planting in a band 0.1 m from the seed rows. Supplemental liquid fertilizer (4-0-8, N-P-K) was applied foliarly to plants at the rate of 2.77 Kg/ha N/day on 26 October and 9 November 2010 (i.e., third and fifth wk after planting, respectively). Halosulfuron (Sanda® , Gowan Company LLC, Yuma, Arizona) was applied at 0.20 kg/ha during land preparation 3 wk before planting seeds to control

weeds. This field was used for both the experiments for within plant and within-field distribution studies. Sampling dates and sampling time were also same for these two studies.

Within-Plant Distribution

The experiment was organized as a simple plot design with four replications (blocks) 30 rows wide x 20 m long. Each block was subdivided into 12 plots, each 4 rows wide x 12.5 m long. The field was divided into subplots in order to increase the precision level and to reduce the experimental error or variability. Two such plots were randomly selected from each block for sampling at each date. Sampling was conducted by visually inspecting five randomly selected plants/plot for adults of *Z. longipes* (predator) and corn-infesting Ulidiidae (prey). Each plant was inspected thoroughly (approximately 1 minute/plant). Plants were divided into four strata for sampling purposes: basal leaves (i.e., leaves on the lower three bands on the stem), middle leaves (i.e., leaves above three collars band surrounding the corn ears), fruit (corn ear) and top/tassels (i.e., all the portion above the middles leave). The number of target insects present was counted separately for each stratum. Plants were sampled three times per day beginning at the following times: 0900-1000, 1300-1400 and 1700-1800 h EST. Sampling was initiated at silking stage (R1, 30 November) with additional sampling at blister (R2, 10 December) and milking (R3, 17 December) stages. Sampling time was initiated at the silking stage, because during the earlier vegetative stages the numbers of both predators and prey were very low.

Data on within-plant distribution were analyzed independently for each week and time interval. The count data was subjected to $\log_{10}(x+1)$ transformation to improve the normality and homogeneity of variance. As the objective was to determine abundance of adults of predators and prey on specified plant parts, data was analyzed using one-way analysis of variance (ANOVA) (PROC GLM, SAS Institute Inc. 2003). The ear age was used as a dependent variable. Independent variables were time and plant part. Untransformed means and the standard errors of the mean are reported in figures. Differences among mean numbers of adult of *Z. longipes* and among corn-infesting Ulidiidae on various plant parts were separated using Tukey's HSD (Honestly significant difference) test ($P < 0.05$).

Within-Field and Temporal Distribution

The study was conducted in same field as above. The field was divided into 48 plots three rows wide x 12.5 m long (83.3 m²). From each of these plots, five corn plants were selected randomly for non-destructive visual sampling. Each plant was checked thoroughly (one minute/plant). The number of adults of *Z. longipes* and corn-infesting Ulidiidae (*Euxesta stigmatias*, *Euxesta eluta*, *Euxesta annonae* and *Chaetopsis massyla*) was recorded. Plants were sampled at three time intervals per day (i.e., 0900-1000, 1300-1400 and 1700-1800 h EST), on the same sampling dates as indicated above for the within-plant study.

The data for each of these plots were later pooled for analysis in various combinations, forming variable sized plots for the study (i.e., 0.15, 0.3 and 0.6 ha corresponding to 6, 12 and 24 combined plots, respectively). Spatial and temporal distribution was determined by sample week for adults of both pest and predators on

corn plants using Taylor's power law (Taylor 1961), Iwao's patchiness regression (Iwao 1968), Index of dispersion and Lloyd's index of patchiness tools. Methods for using Taylor's power law, Iwao's patchiness regression and Index of dispersion is same as described in materials and methods section of chapter 2.

The Index of dispersion was calculated to determine within-field distribution using the following formula:

$$ID = s^2/x$$

where s^2 is the sample variance and x is the mean number of predatory arthropods or corn-infesting ulidiid eggs or larvae per sample. Populations with ID values not significantly different from zero are regularly distributed, while those with ID > 1 is aggregated.

Lloyd's index of patchiness (LIP) was also calculated to measure the degree of aggregation (Xiao et al. 1997):

$$LIP = m^*/m$$

where m = mean number of adults of *Z. longipes* adults of *Z. longipes* and corn-infesting Ulidiidae per sample, $m^* = \frac{s^2}{\bar{X}} - 1$ and s^2 = sample variance. If LIP > 1, it indicates an aggregated population whereas LIP < 1, indicates a random population.

Functional Response of *Zelus longipes* to *Euxesta stigmatias*, *Euxesta eluta* and *Euxesta annonae*

Source of predator: To test the potentiality of *Zelus longipes* as a predator, male and female adults were collected from an abandoned sweet corn field in Homestead, FL and returned to the laboratory for feeding studies. Male x female pairs were placed

singly in four separate cages (30.5 x 30.5 x 30.5 cm) at room temperature ($30 \pm 5^\circ\text{C}$). A moistened sponge (10 X 10 cm) placed on the floor of the dish to provide required humidity and it was replaced with another sponge once dried. Twenty, corn-infesting Ulidiidae (24 h old) collected from lab-reared colony, were added to the cage as a source of *Z. longipes* food. The cages were provided with water and 30% sugar solution in a glass vial covered with cotton ball (1 cm in diameter). These vials in an inverted position were attached to the walls of the cage. The cages were checked every day for *Z. longipes* eggs. Whenever eggs hatched, the first instar nymphs were transferred to Petri dishes (10.5 cm in diameter) with a moistened filter paper (5 cm in diameter). Two first instar nymphs of *Z. longipes* were placed in each Petri dish. These instars were provided with four Ulidiidae larvae (2nd or 3rd instar, 24 h old) daily, as a source of food. These first instars were checked every day to collect freshly molted second instars and other advance stages. All the stages were reared in similar manner until the adult stage. Rearing was continued until 16 (males and females) of *Z. longipes* adults were collected for the present study.

Source of pest: Colonies were begun using 100 adults of each of *E. stigmatias*, *E. eluta*, and *E. annonae* collected from corn fields in summer 2010. Each *Euxesta* spp. was reared in a separate cage (30.5 x 30.5 x 30.5 cm) and all stages of each colony were maintained $30 \pm 5^\circ\text{C}$. Rearing methods were the same for all the fly species. Colonies were maintained using an artificial diet designed for beet armyworm (BAW, Southland Co., Lake Village, AR) and methods described by Seal and Jansson (1989). Adults were supplied with 1% honey solution and fresh water. The diet was prepared

by adding honey 0.5 ml and green food coloring agent 0.2 ml (ESCO Food Co., San Jose, CA) to each 81 gm of dried diet along with 465 liter of boiling water. The color was added to facilitate fly oviposition by simulating the green color of corn silk or cob. Diets were placed in plastic cups (28.3 g) (BioServe™, Beltsville, MD, USA) and attached to the ceilings of cages to facilitate oviposition by the adults. To develop a homogeneous colony for each fly species, eggs were collected at 24 h intervals, and then transferred to fresh BAW diet for larval emergence in the same environmental conditions as the adults. Freshly eclosed first instar larvae were removed from the egg containers every 24 h and transferred to plastic cups (28.3 g) containing BAW diet and allowed to complete development into pupae. The diet cups were checked every 4 h to remove pupae. The pupae (≤ 4 h old) were washed gently with tap water to remove dietary residue and to reduce fungal infection. The pupae were then air-dried to remove excess water from the cuticle and placed in Petri dishes with a disk shaped moist filter paper (5 cm in diameter) to avoid desiccation. Petri dishes containing pupae were placed in cages (30.5 x 30.5 x 30.5 cm) to facilitate adult emergence. Pupae were checked every 2 h to collect newly emerged adults up to 2 h old. Colonies of each fly species were maintained throughout the year until spring 2011.

Functional Response Experiment: The functional response of *Z. longipes* adults (both male and female) to *E. stigmatias*, *E. annonae* and *E. eluta* was measured in a feeding arena (circular plastic box 11.5 cm wide x 14 cm high) lined with moist foam at the base. The lid of the plastic boxes was fitted with fine mesh cloth (3.5 cm in diameter) to allow circulation. A glass vial with 5% honey solution fixed with a cotton

plug was stuck to the wall of the box as a source of food for pest flies. The *Z. longipes* adults were provided with adults of *E. stigmatias*, *E. eluta* and *E. annonae* each in batches of 2, 4, 6, 8 and 10 prey flies. Eight replicates were conducted at each fly density (simultaneously with a control in a separate box) with each male and female *Z. longipes* adults. Replicates were discarded if the predator died during the 24 h feeding period.

The *E. stigmatias*, *E. eluta* and *E. annonae* adults were refrigerated at 10°C for 1-2 min to facilitate adding them to the feeding arenas without loss of adults. Predators were added to the arenas immediately following addition of the fly prey. One adult (male or female) was used in each feeding arena for each fly species. To standardize predator response, adult *Z. longipes* were starved for 24 h before conducting this experiment. After a 24 h feeding period, the number of dead flies in each arena was counted. The dead flies recovered were considered attacked or fed by *Z. longipes* based on the observations as well as on comparison with 100% survival of flies in absence of predators (i.e., control).

The predation data allows us to determine two important things about a given predator-prey relationship: the shape or type of functional response (type I, II or III), as well as the handling time and attack constant. The first step in analyzing predation data was to determine the type of functional response using polynomial logistic regression model (CATMODE, SAS Institute 2003). The second step was to fit the mechanistic model (based on type of functional response obtained) and estimate the handling time and attack constant parameters using the NLIN procedure (Juliano1993).

Because the number of adult preys, *E. stigmatias*, *E. eluta*, and *E. annonae* declined as they were consumed (the adults consumed were not replaced with new adults), Juliano's (1993) method was used to fit the data to Roger's (1972) random predator equation. The type of functional response shown by the data was first determined by logistic regression model in PROC CATMODE (SAS Institute 2003). The CATMODE procedure is same as described as in materials and methods section of chapter 2. Once the type of functional response was determined, data were fit to the random predator equation (PROC NLIN, SAS 2003). In the PROC NLIN procedure a non-linear, least-square regression of the number of flies eaten versus the number of flies offered was used to estimate and compare the different parameters of the functional response (As the predatory data displayed only type II functional response, equation for type III functional response is not shown here).

The following equation was used for a type II functional response:

$$N_e = N_0 \{1 - \exp [a (T_h N_e - T)] \}$$

where a is the instantaneous search rate or the attack constant (time taken by a predator to search for its prey), b is a constant, T_h is the handling time, and T is total time available for *Z. longipes* to search for and attack the prey eggs.

Results

Within-Plant Distribution

All the four species of Ulidiidae (i.e., *E. stigmatias*, *E. annonae*, *E. eluta* and *C. massyla*) that are known to infest sweet corn in south Florida has been referred as corn infesting ulidiid in this chapter. *Zelus longipes* and corn-infesting Ulidiidae started appearing in the corn fields before the emergence of tassels. Early in the vegetative

stages, population abundance of *Zelus longipes* and corn-infesting Ulidiidae was very low. Population increased thereafter with the progression of the season (Fig. 3-2), prior to tassel emergence (data not presented).

At the R1 stage, the *Z. longipes* population increased significantly on different locations within a corn plant, varying with daylight hours. The greatest numbers of *Z. longipes* were recorded on the basal leaves, corn ears and top/tassels at 0900, 1300 and 1700 h EST, respectively (Fig. 3-2A, 2B and 2C). Corn-infesting Ulidiidae showed a pattern of distribution similar to *Z. longipes*.

A similar pattern of within-plant distribution was observed when plants were sampled at the R2 stage of ear development. The mean number of *Z. longipes* was significantly greater on the middle leaves ($F = 4.02$; $df = 3, 192$; $P < 0.0084$), fruits and top/tassels than on other plant parts at 0900, 1300 and 1700 h EST, respectively.

At R2 stage, very few adults were observed on the basal leaves irrespective of sampling time (Fig. 3-2D, 2E and 2F). The mean number of corn-infesting Ulidiidae at 0900 h EST (R2 stage) was greatest on the middle leaves ($F = 9.23$; $df = 3, 192$; $P < 0.0001$), followed by the basal leaves, and fruit, while significantly lower on tassels than on other plant structures (Fig. 3-2D). At 1300 h EST, the mean number of corn-infesting Ulidiidae was greatest on the fruit ($F = 18.54$; $df = 3, 192$; $P < 0.0001$), followed by the middle leaves, basal leaves, and tassel/top (Fig. 3-2E). At 1700 h EST, mean abundance of corn-infesting Ulidiidae was greatest on top/tassels ($F = 41.94$; $df = 3, 192$; $P < 0.0001$), followed by the middle leaves and fruit. No ulidiid adults were observed on the basal leaves at the 1700h sample (Fig. 3-2F).

During the R3 stage, the mean abundance of *Z. longipes* adults at 0900 h EST was greatest ($F = 32.29$; $df = 3, 192$; $P < 0.0001$) on the basal leaves, followed by the middle leaves, fruits, and top/tassels (Fig. 3-2G). At 1300 h EST, the mean number of *Z. longipes* was greatest ($F = 27.15$; $df = 3, 192$; $P < 0.0001$) on the fruits, followed by the middle leaves and basal leaves. None of the predators were observed on top/tassels at 1300 h (Fig. 3-2H). At 1700 h EST, the mean number of *Z. longipes* was greater ($F = 18.46$; $df = 3, 192$; $P < 0.0001$) on the tassel/top than on the basal leaves, middle leaves, and fruits (Fig. 3-2I). Corn-infesting Ulidiidae showed a pattern of within plant distribution similar to *Z. longipes* across the three sampling times of a day (Fig. 3-2G, 2H and 2I).

Within-Field and Temporal Distribution

Corn-infesting Ulidiidae: Plot size did not have a significant affect on the distribution of the flies during the R1 stage. At 0900 and 1700 h EST, the slopes for both the Taylor's power law and Iwao's patchiness regression were significantly > 1 for all three modeled plot sizes (Table 3-1) indicating an aggregated distribution for adult ulidiids at the initiation of silking ($P < 0.05$, Table 3-1). However, the distribution was determined to be random during the middle of the day at 1300 h EST, because the slopes of these two equations were not significantly different than 1 ($P < 0.05$). The coefficients of determinant (r^2) for Taylor's power law and Iwao's patchiness regression ranged from 0.66 to 0.98 suggesting good fit of model. The Index of dispersion and Lloyd's index of patchiness for all the plot sizes at 09:00 and 1700 h EST showed value significantly >1 i.e., aggregated distribution while at 1300 h EST the values was not significantly different from 1 ($P > 0.05$) suggesting random distribution.

At the R2 stage, corn-infesting Ulidiidae were aggregated irrespective of sampling time based on the slopes of both models being significantly > 1 ($P < 0.05$) (Table 3-2). The Index of dispersion and Lloyd's index of patchiness for all the plot sizes at 0900, 1300 and 1700 h EST showed value significantly > 1 ($P < 0.05$) suggesting aggregated distribution.

During R3 stage, corn-infesting Ulidiidae was distributed on corn plants as they were during the blister stage (Table 3-3). At 0900, 1300 and 1700 h EST, the slope values for Taylor's power law and Iwao's patchiness regression were found to be significantly > 1 ($P < 0.05$) (Table 3-3). The coefficients of determinant (r^2) for these two models ranged from 0.54 to 0.96. Also, the Index of dispersion and Lloyd's index of patchiness for all the plot sizes at 0900, 1300 and 1700 h EST showed aggregated distribution as values were significantly > 1 ($P < 0.05$).

Zelus longipes: *Zelus longipes* showed variable patterns of distribution in corn fields depending on ear stage and diel time of sampling. During the R1 stage, at 0900 h EST and 1700 h EST the slope (b and β) values from two linear regression models for the entire plot sizes (Table 3-4) were not significantly different from 1 ($P < 0.05$, Table 3-1), indicating random distribution pattern. However at 1300 h EST, the b and β values were significantly > 1 ($P < 0.05$) for all the plot sizes indicated significant aggregation. The coefficients of determinant (r^2) for Taylor's power law and Iwao's patchiness regression indicated a good fit of models to data of all the plot sizes. The Index of dispersion and Lloyd's index of patchiness for all the plot sizes at 0900 h EST and 1700 h EST showed value not significantly different from 1 indicating lack of aggregation

while at 1300 h EST the value was significantly > 1 ($P > 0.05$) indicating significant aggregation.

Z. longipes populations were aggregated when corn plants were at R2 stage irrespective of sampling time (Table 3-5). During week six at 09:00, 13:00 and 1700 h EST, the slope (b and β) value for Taylor's power law and Iwao's patchiness regression were found to be significantly > 1 ($P < 0.05$) indicating aggregated distribution (Table. 3-5). The coefficients of determinant (r^2) for these two models ranged from 0.68 to 0.99 indicating good fit of model, as these values were approximately equal to 1. The Index of dispersion and Lloyd's index of patchiness for the entire plot sizes at 0900 h EST, 1300 h EST and 1700 h EST showed values significantly >1 ($P < 0.05$) indicating aggregated distribution of *Z. longipes*.

Zelus longipes distribution during R3 stage of sweet corn plants did not differ from the R2 stage sweet corn plants (Table 3-6). During R3 stage, at 0900, 1300 and 1700 h EST, the slope (b and β) values for Taylor's power law and Iwao's patchiness regression were found to be significantly > 1 ($P < 0.05$) indicating aggregated distribution (Table 3-6). The coefficients of determinant (r^2) for these two models ranged from 0.57 to 0.99. Also, the Index of dispersion and Lloyd's index of patchiness for the entire plot sizes at 0900, 1300 and 1700 h EST showed value significantly >1 ($P < 0.05$) indicating aggregated distribution.

Functional Response of *Zelus longipes* to *Euxesta stigmatias*, *Euxesta eluta* and *Euxesta annonae*

Zelus longipes males and females adults showed a type II functional response to *E. stigmatias*, *E. eluta* and *E. annonae* (Fig. 3-3). In functional response of male *Z.*

longipes to *Euxesta* spp., the handling time (T_h) ranged from 1 to 1.5 h while female *Z. longipes* handled *Euxesta* spp. within the time range of 0.67 to 0.97 h (Table 3-7). The attack rate constant (a) in both the cases of male and female *Z. longipes* ranged from 0.05 to 0.08.

Discussion

Sweet corn provides a breeding substrate for ulidiid flies. Females prefer to lay eggs inside newly emerged silks at the tip of the corn ear. Oviposition decreases significantly as corn silk ages (Seal et al. 1996). In the present study, corn-infesting Ulidiidae abundance was very low before silking, which may be due to the lack of proper egg laying location. As the plant proceeded from R1 to R3 stage the abundance of both corn-infesting Ulidiidae and *Z. longipes* was found to increase significantly. This result is in agreement with Seal et al. (1996) who mentioned that the density of *E. stigmatias* continues to increase until three week after anthesis. The increasing predator density due to increasing prey number has been supported by Rogers (1972) in the past, which may account for the higher abundance of *Z. longipes* with approaching corn development (R1 stage to R3 stage).

Throughout the sampling period, prey-predator density was found to be abundant on tassel at 1700 h EST. At 0900-1300 h EST the prey-predator density was mostly varied on different parts of plants except the tassel. This can be supported by the observation made by Seal et al. (1996) who reported that *E. stigmatias* showed peak oviposition behavior during early morning hours from 0900 to 1300 h EST. This is the time when fully gravid females aggregate around lower and middle regions of corn plants in order to oviposit inside the silk channels. They further observed variation in

diel pattern of mating behavior, with most mating taking place in the evening near the tassel.

Corn-infesting Ulidiidae and *Z. longipes* showed aggregated as well as random pattern of distribution during the R1 stage of corn development. The occurrence of corn-infesting Ulidiidae was observed at the onset of tassel emergence (vegetative stage) but the number was low. The adults of *Z. longipes* were observed two weeks after corn planting, but again their abundance was low. During the R1 stage, the corn-infesting Ulidiidae started visiting the corn plants more frequently and started establishing itself. At this time its distribution was more random. Occurrence of corn-infesting Ulidiidae changed the micro-ecosystem of a corn plant, affecting distribution of other arthropods such as *Z. longipes*. Rogers (1972) mentioned that predators adopt a random search strategy to find its prey, and search is independent of prey distribution. They further suggested that random attack strategy of a predator is a function of host density rather than host distribution.

During the R2 and R3 stages of corn development, the pattern of distribution was aggregated for both the flies and their predator, *Z. longipes*. By this time both the pest and the predator were well established in the field. Later in the season, with the increase in population density of corn-infesting Ulidiidae, the population tends to be aggregated, and this further resulted in similar population structure of its predator *Z. longipes*. This observation was in agreement with the previous study done by Hassel (1978), who reported that at high-densities many predators have shown an aggregated distribution.

Zelus longipes exhibited a type II functional response to all three *Euxesta* spp. tested (Fig. 3-4). Hassel et al. (1977) suggested that a generalist predator shows a type III functional response, as the population of generalist predators is independent of host densities. This occurs because a generalist predator can easily switch from one extinct host type to another. However, in our lab experiment *Z. longipes* showed a type II response because the experiment was a no-choice type, with only one prey type irrespective of different *Euxesta* spp. Thus, the predator did not have the choice of changing to different prey type.

The other factor tested in this experiment was predator sex. It was observed that male *Z. longipes* took longer handling time as compare to the females. This may be due to the difference in the size of the predators, as males are smaller than females (Hart 1986, Kalsi and Seal 2011). As has been already mentioned if the size of predator is small, the time to handle its prey increases and the ability to search new prey decreases. Future research is suggested in a corn field under environmental conditions to better ascertain the potential of *Z. longipes* as a predator in an agro-ecosystem.

Table 3-1. Taylor's power law, Iwao's patchiness regression, Index of dispersion and Lloyd's index of patchiness parameters for distribution of corn-infesting Ulidiidae sampled in a cornfield.

R1 stage (0900 h EST)								
Plot sizes (ha)	Taylor's power law			Iwao's patchiness regression			Index of dispersion	Lloyd's index of patchiness
	a	b	r ²	α	β	r ²	ID	
0.60	-0.11	3.51 AGG	0.98	-2.30	3.09 AGG	0.97	1.87 AGG	1.87 AGG
0.30	-.043	1.31 AGG	0.91	0.387	1.54 AGG	0.92	1.91 AGG	1.92 AGG
0.15	-0.03	1.14 AGG	0.82	-0.247	1.22 AGG	0.75	1.98 AGG	1.98 AGG
R1 stage (1300 h EST)								
0.60	-.23	0.67 RAN	0.98	0.56	0.69 RAN	0.96	0.63 RAN	0.67 RAN
0.30	-.13	0.33 RAN	0.92	0.34	0.48 RAN	0.91	0.76 RAN	0.78 RAN
0.15	-.12	0.28 RAN	0.67	0.88	0.36 RAN	0.66	0.85 RAN	0.95 RAN
R1 stage (1700 h EST)								
0.60	038	2.89 AGG	0.97	075	2.98 AGG	0.98	1.50 AGG	1.51 AGG
0.30	0.17	1.90 AGG	0.79	0.66	1.83 AGG	0.85	1.47 AGG	1.47 AGG
0.15	0.13	1.15 AGG	0.71	0.67	1.85 AGG	0.73	1.51 AGG	1.49 AGG

AGG, aggregated distribution, *b* significantly >1 ($P \leq 0.05$); REG, regular distribution, *b* significantly < 1 ($P \leq 0.05$); RAN, random distribution, *b* not significantly different from 1 ($P > 0.05$).

Table 3-2. Taylor's power law, Iwao's patchiness regression, Index of dispersion and Lloyd's index of patchiness parameters for distribution of corn-infesting Ulidiidae sampled in a corn field.

R2 stage (0900 h EST)								
Plot sizes (ha)	Taylor's power law			Iwao's patchiness regression			Index of dispersion	Lloyd's index of patchiness
	a	b	r ²	α	β	r ²	ID	
0.60	0.69	1.63 AGG	0.90	1.70	1.45 AGG	0.91	1.06 AGG	1.05 AGG
0.30	0.72	1.73 AGG	0.71	1.56	1.76 AGG	0.80	1.05 AGG	1.06 AGG
0.15	0.56	1.56 AGG	0.75	1.17	1.59 AGG	0.75	1.01 AGG	1.06 AGG
R2 stage (1300 h EST)								
0.60	0.17	2.4 AGG	0.98	-1.75	3.23 AGG	0.97	1.76 AGG	1.65 AGG
0.30	0.19	1.50 AGG	0.97	-0.18	1.73 AGG	0.98	1.63 AGG	1.55 AGG
0.15	0.18	1.39 AGG	0.68	0.51	1.18 AGG	0.58	1.72 AGG	1.63 AGG
R2 stage (1700 h EST)								
0.60	-0.36	5.54 AGG	0.99	-5.93	5.90 AGG	0.99	1.4 AGG	1.31 AGG
0.30	-0.12	3.48 AGG	0.65	-2.42	3.22 AGG	0.61	1.45 AGG	1.34 AGG
0.15	0.11	1.40 AGG	0.61	-0.13	1.48 AGG	0.60	1.48 AGG	1.37 AGG

AGG, aggregated distribution, *b* significantly >1 ($P \leq 0.05$); REG, regular distribution, *b* significantly < 1 ($P \leq 0.05$); RAN, random distribution, *b* not significantly different from 1 ($P > 0.05$).

Table 3-3. Taylor's power law, Iwao's patchiness regression, Index of dispersion and Lloyd's index of patchiness parameters for distribution of corn-infesting Ulidiidae sampled in corn field.

R3 stage (0900 h EST)								
Plot sizes (ha)	Taylor's power law			Iwao's patchiness regression			Index of dispersion	Lloyd's index of patchiness
	a	b	r ²	α	β	r ²	ID	
0.60	-2.60	4.18 AGG	0.96	-2.64	1.4 AGG	0.93	1.77 AGG	1.96 AGG
0.30	-2.13	3.47 AGG	0.91	-1.217	1.15 AGG	0.90	1.70 AGG	1.95 AGG
0.15	-1.60	2.42 AGG	0.97	-1.034	1.08 AGG	0.95	1.42 AGG	1.89 AGG
R3 stage (1300 h EST)								
0.60	0.77	5.93 AGG	0.93	5.81	5.96 AGG	0.92	1.0 AGG	1.04 AGG
0.30	4.21	4.57 AGG	0.85	5.78	4.12 AGG	0.68	1.06 AGG	1.02 AGG
0.15	2.81	2.80 AGG	0.79	5.96	2.47 AGG	0.57	1.14 AGG	1.06 AGG
R3 stage (1700 h EST)								
0.60	0.76	2.79 AGG	0.96	0.55	2.78 AGG	0.95	2.12 AGG	1.32 AGG
0.30	0.24	1.06 AGG	0.67	0.74	1.05 AGG	0.83	1.94 AGG	1.28 AGG
0.15	0.53	0.46 AGG	0.58	2.12	0.73 AGG	0.54	2.12 AGG	1.39 AGG

AGG, aggregated distribution, *b* significantly >1 ($P \leq 0.05$); REG, regular distribution, *b* significantly < 1 ($P \leq 0.05$); RAN, random distribution, *b* not significantly different from 1 ($P > 0.05$).

Table 3-4. Taylor's power law, Iwao's patchiness regression, Index of dispersion and Lloyd's index of patchiness parameters for distribution of *Z. longipes adults* sampled in a corn field.

R1 stage (0900 h EST)								
Plot sizes	Taylor's power law			Iwao's patchiness regression			Index of dispersion	Lloyd's index of patchiness
(ha)	a	b	r ²	α	β	r ²	ID	
0.60	-.18	0.48 RAN	1.0	0.487	0.83 RAN	0.99	0.96 RAN	0.93 RAN
0.30	-.23	0.65 RAN	0.71	0.91	0.60 RAN	0.78	0.84 RAN	0.81 RAN
0.15	-.14	0.71 RAN	0.74	0.34	0.73 RAN	0.76	0.95 RAN	0.99 RAN
R1 stage (1300 h EST)								
0.60	-0.86	2.65 AGG	0.75	4.13	5.78 AGG	0.91	1.17 AGG	1.45 AGG
0.30	-.24	1.07 AGG	0.85	1.19	1.75 AGG	0.83	1.17 AGG	1.34 AGG
0.15	-.99	0.88 AGG	0.76	-0.28	1.58 AGG	0.72	1.06 AGG	1.03 AGG
R1 stage (1700 h EST)								
0.60	-.48	0.89 RAN	0.83	0.23	0.86 RAN	0.89	0.82 RAN	0.56 RAN
0.30	-.46	0.85 RAN	0.76	0.27	0.79 RAN	0.76	0.86 RAN	0.65 RAN
0.15	-.192	0.72 RAN	0.75	0.07	0.60 RAN	0.7	0.90 RAN	0.76 RAN

AGG, aggregated distribution, *b* significantly >1 ($P \leq 0.05$); REG, regular distribution, *b* significantly < 1 ($P \leq 0.05$); RAN, random distribution, *b* not significantly different from 1 ($P > 0.05$).

Table 3-5. Taylor's power law, Iwao's patchiness regression, Index of dispersion and Lloyd's index of patchiness parameters for distribution of *Z. longipes adults* sampled in a corn field.

R2 stage (0900 h EST)								
Plot sizes	Taylor's power law			Iwao's patchiness regression			Index of dispersion	Lloyd's index of patchiness
(ha)	a	b	r ²	α	β	r ²	ID	
0.60	0.42	1.38 AGG	0.98	0.27	2.4 AGG	0.99	2.15 AGG	2.96 AGG
0.30	0.35	1.47 AGG	0.99	0.01	2.06 AGG	0.94	1.67 AGG	1.82 AGG
0.15	0.29	1.37 AGG	0.85	0.48	1.37 AGG	0.74	1.74 AGG	2.27 AGG
R2 stage (1300 h EST)								
0.60	0.22	1.66 AGG	0.97	-0.60	2.30 AGG	0.96	1.15 AGG	1.24 AGG
0.30	0.13	1.31 AGG	0.98	-0.24	1.62 AGG	0.98	1.18 AGG	1.27 AGG
0.15	0.07	1.08 AGG	0.87	0.13	1.02 AGG	0.68	1.14 AGG	1.24 AGG
R2 stage (1700 h EST)								
0.60	0.24	2.06 AGG	0.96	-1.09	2.83 AGG	0.98	1.44 AGG	1.47 AGG
0.30	0.02	1.04 AGG	0.83	0.022	1.10 AGG	0.74	1.12 AGG	1.35 AGG
0.15	-0.01	1.10 AGG	0.75	-0.05	1.13 AGG	0.79	1.04 AGG	1.07 AGG

AGG, aggregated distribution, *b* significantly >1 ($P \leq 0.05$); REG, regular distribution, *b* significantly < 1 ($P \leq 0.05$); RAN, random distribution, *b* not significantly different from 1 ($P > 0.05$).

Table 3-6. Taylor's power law, Iwao's patchiness regression, Index of dispersion and Lloyd's index of patchiness parameters for distribution of *Z. longipes adults* sampled in a corn field during R3 stage at different time intervals.

R3 stage (0900 h EST)								
Plot sizes (Hectare)	Taylor's power law			Iwao's patchiness regression			Index of dispersion	Lloyd's index of patchiness
	a	b	r ²	α	β	r ²	ID	
0.60	0.01	1.27 AGG	0.99	-0.17	1.20 AGG	0.99	1.15 AGG	1.09 AGG
0.30	0.10	2.79 AGG	0.99	-1.97	3.27 AGG	0.99	1.04 AGG	1.12 AGG
0.15	0.08	1.97 AGG	0.79	-0.77	2.06 AGG	0.59	1.20 AGG	1.19 AGG
R3 stage (1300 h EST)								
0.60	0.10	2.58 AGG	0.99	-1.75	3.02 AGG	0.98	1.32 AGG	1.28 AGG
0.30	-0.04	1.5 AGG	0.97	-0.51	1.62 AGG	0.99	1.34 AGG	1.27 AGG
0.15	0.1	0.44 AGG	0.12	0.76	1.02 AGG	0.57	1.31 AGG	1.16 AGG
R3 stage (1700 h EST)								
0.60	0.17	1.43 AGG	0.98	-0.10	1.58 AGG	0.99	1.59 AGG	1.49 AGG
0.30	0.12	1.87 AGG	0.99	-0.77	2.1 AGG	0.98	1.53 AGG	1.37 AGG
0.15	0.15	1.59 AGG	0.83	-0.57	2.01 AGG	0.63	1.63 AGG	1.41 AGG

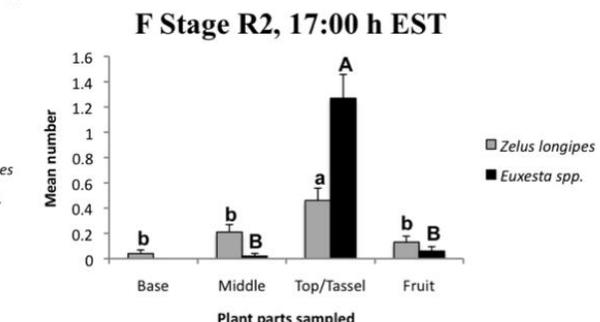
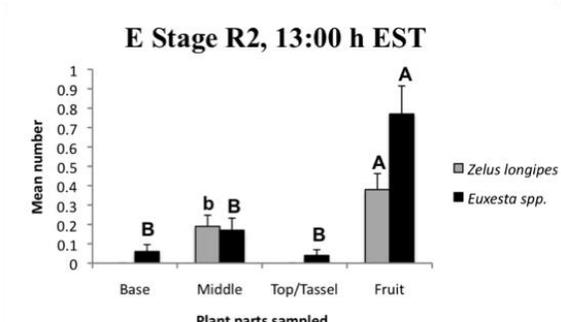
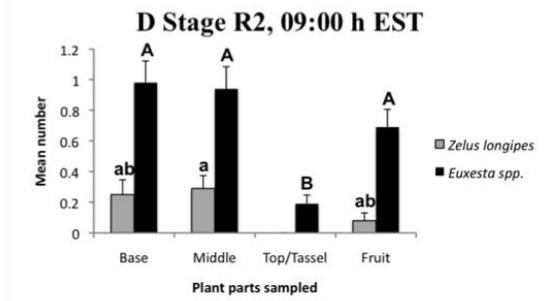
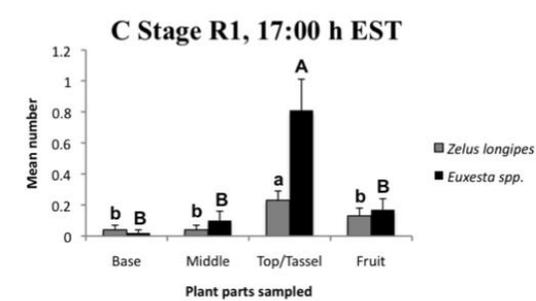
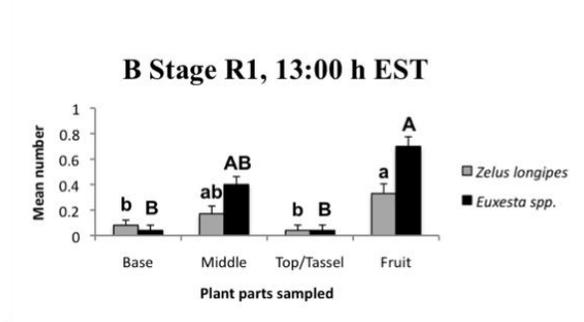
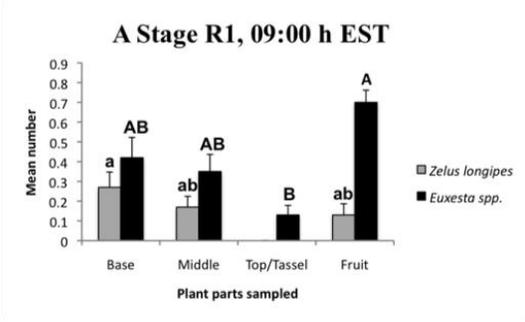
AGG, aggregated distribution, *b* significantly >1 ($P \leq 0.05$); REG, regular distribution, *b* significantly < 1 ($P \leq 0.05$); RAN, random distribution, *b* not significantly different from 1 ($P > 0.05$).

Table 3-7. Parameters (means ± S.E) estimated by random predator equation, indicating functional response of *Zelus longipes* (male and female) to densities of *Euxesta stigmatias*, *Euxesta eluta* and *Euxesta annonae* adults.

<i>Zelus longipes</i> Male			
Corn-infesting Ulidiidae	Functional Type	Handling time T _h (h)	Attack constant (h ⁻¹)
<i>Euxesta stigmatias</i>	II	1.12 ± 2.25	0.07 ± 0.03
<i>Euxesta eluta</i>	II	1.0 ± 1.23	0.06 ± 0.02
<i>Euxesta annonae</i>	II	1.39 ± 1.27	0.07 ± 0.02
<i>Zelus longipes</i> Female			
<i>Euxesta stigmatias</i>	II	0.97 ± 1.25	0.06 ± 0.02
<i>Euxesta eluta</i>	II	0.67 ± 1.81	0.05 ± 0.03
<i>Euxesta annonae</i>	II	0.82 ± 1.36	0.05 ± 0.02



Figure 3-1. *Zelus longipes* female feeding on *Euxesta stigmatias* in sweet corn field.



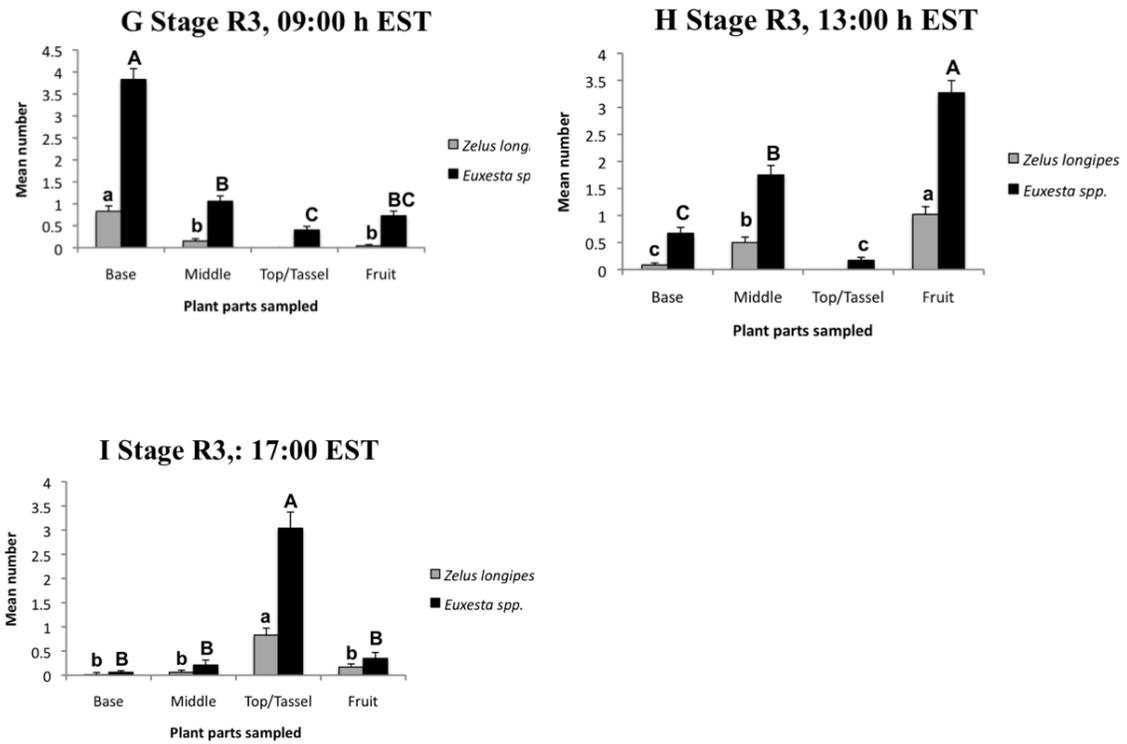


Figure 3-2. Mean number of *Z. longipes* and corn-infesting Ulidiidae adults per time interval in various plant parts sampled in sweet corn field during R1, R2 and R3 stage (a, b, c indicates significant difference in mean number of *Z. longipes* and A, B and C indicates significant difference in mean number of Corn-infesting Ulidiidae (here *Euxesta* spp.) collected from various plant parts using ANOVA (at $\alpha = 0.05$).

A) *Z. longipes* : F = 4.13; df = (3,192); Pr < 0.072; *Euxesta* spp: F = 3.32; df = (3,192); Pr < 0.021 B) *Z. longipes* : F=5.19; df=(3,192); Pr < 0.018; *Euxesta* spp: F = 13.17; df = (3,192); Pr < 0.001 C) *Z. longipes* : F = 4.07; df = (3,192); Pr < 0.021; *Euxesta* spp: F =15.30 ; df = (3,192); Pr < .0001. D) *Z. longipes* : F = 4.02; df = (3,192); Pr < 0.0084; *Euxesta* spp: F = 9.23; df = (3,192); Pr < 0.0001 E) *Z. longipes* : F=14.09; df=(3,192); Pr < 0.0001; *Euxesta* spp: F = 18.54; df = (3,192); Pr < 0.0001 F) *Z. longipes* : F = 7.9; df = (3,192); Pr < 0.0001; *Euxesta* spp: F =41.94; df = (3,192); Pr < .0001. G) *Z. longipes* : F = 32.29; df = (3,192); Pr < 0.0001; *Euxesta* spp: F = 105.9; df = (3,192); Pr < 0.001 H) *Z. longipes* : F = 27.15 ; df=(3,192); Pr < 0.0001; *Euxesta* spp: F = 78.96; df = (3,192); Pr < 0.001 I) *Z. longipes* : F = 18.46; df = (3,192); Pr < 0.0001; *Euxesta* spp: F =58.53 ; df = (3,192); Pr < .0001.

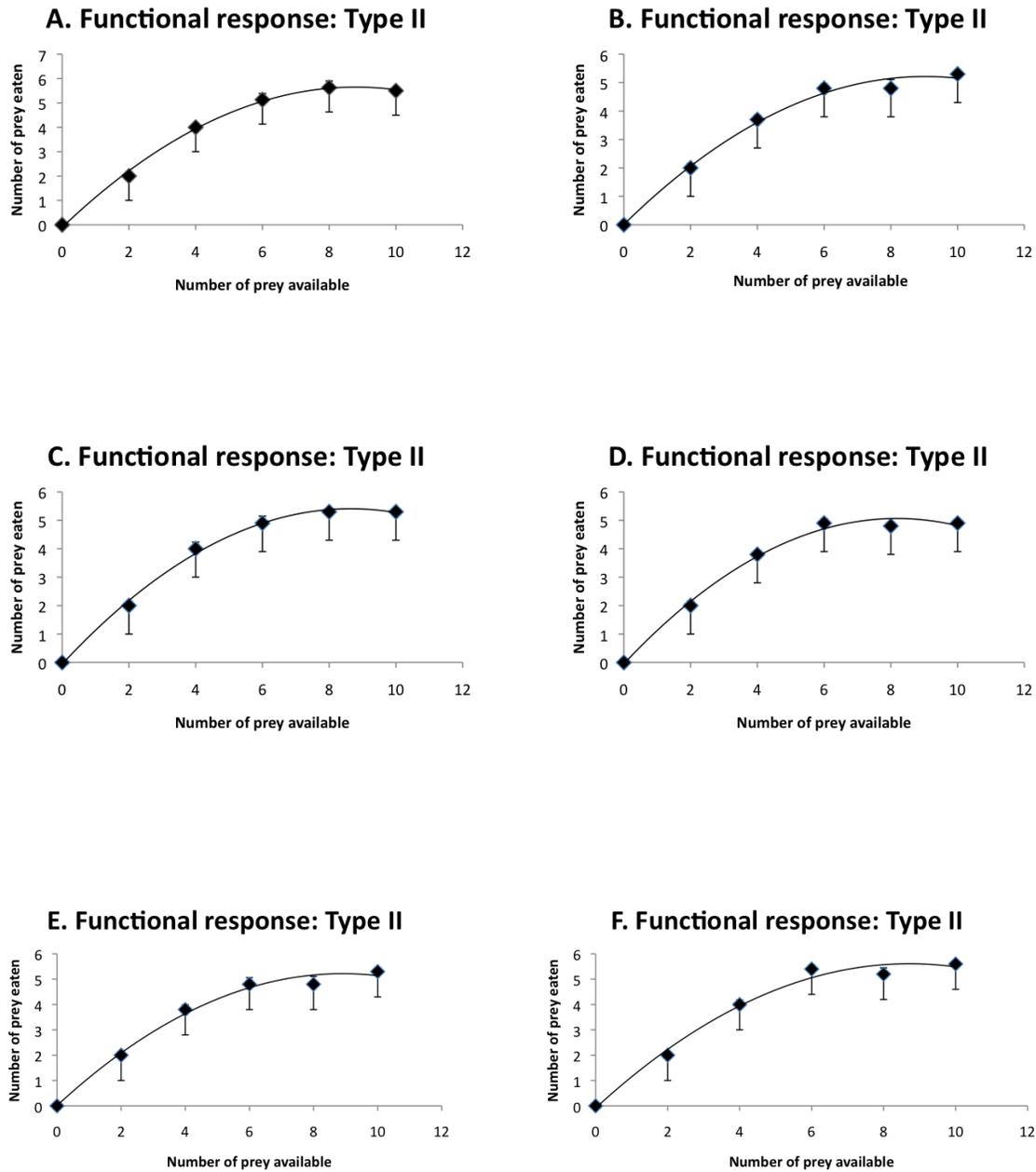


Figure 3-3. Type II functional response of male *Zelus longipes* to *Euxesta stigmatias* (A), *Euxesta eluta* (B) *Euxesta annonae* (C) and type II functional response female *Zelus longipes* to *Euxesta stigmatias* (D), *Euxesta eluta* (E) *Euxesta annonae* (F). The graph represents mean number of prey eaten v/s mean number of initial prey available.



Figure 3-4. Adult male, *Z. longipes* feeding on *Euxesta annonae* adult in lab experiment.

CHAPTER 4 CONCLUSIONS

The four species of Ulidiidae (Diptera), *Euxesta stigmatias*, *Euxesta eluta*, *Euxesta annonae* and *Chaetopsis massyla*, were found to infest sweet corn in southern Florida during the present study. The corn plant injury due to larval feeding includes rotting and clipping of silk, pollination disruption, poor kernel set, hollowing of kernel, feeding through entire corn ear and rotting of ear due to fungal infection. At the peak level of larval injury, the yield reduction could reach to 100%. Even after the application of insecticides, significant injury is known to occur to the corn plant. Severe larval infestation usually makes corn unmarketable. Growers apply insecticides multiple times a week to control adult flies. Such application of insecticides makes the management of this pest costly. Thus, the demand for a sound integrated pest management program comprising chemical insecticides and bio-control agents seem to be a viable alternative for growers for corn-infesting Ulidiidae. Such program needs detail information about biology of pests and their natural enemies.

My research dealt with surveying sweet corn fields for natural predator which feed on different life stages of the corn-infesting Ulidiidae found in the sweet corn field in Homestead, and measuring the potential of these natural predators. Abundance and diversity of different arthropods residing in corn ears along with the eggs and larvae of Ulidiidae flies were reported. The study was replicated through spring, summer and fall 2010. Each season sampling was done at three different reproductive stages of corn ear development (i.e., silking, blister and milk stage). The various arthropod found in sweet corn ear were *O. insidiosus*, unidentified thrips, unidentified mites, of unidentified

species of Staphylinidae larvae, larvae of *Chrysoperal carnea*, and adults and larvae of *Lobiopa insularis* and *Carpophilus lugubris*. Among these arthropods the most abundant predatory arthropod found in corn at silking stage was *O. insidiosus*. The occurrence of *Orius insidiosus* in corn ear silk coincided with the occurrence of Ulidiidae eggs. In the laboratory studies different aged nymphs and adults of *O. insidiosus* were found to feed on the eggs and all larval instars of *E. stigmatias*, *E. eluta* and *E. annonae*. Similarly, Staphylinidae larvae were also found to feed on the eggs and larvae of *Euxesta* spp.

Spatial distribution of these predatory arthropods in relation to eggs and larvae of corn-infesting Ulidiidae was investigated. In majority of the samplings, both the pest and predator were found to be aggregated in corn fields and in few cases they were found to be randomly distributed. In the laboratory experiment, *O. insidiosus* displayed type III functional response to the 24 h old eggs of *E. stigmatias*, *E. eluta* and *E. annonae*. The handling time and attack rate was also measured.

Information is available on natural enemies feeding on the eggs, larvae and pupae of corn infesting ulidiid, but there are no reports of a natural enemy feeding on adult flies. Effort was made to find if there were any natural enemies that feed on different stages corn infesting ulidiids. The study was conducted in fall 2010 to identify potential predators of adult pest flies in a sweet corn field in Homestead, Florida. The adults of *Zelus longipes* were found feeding on the adult flies of *E. stigmatias*, *E. eluta*, *E. annonae* and *C. massyla* in the sweet corn fields. Further studies were conducted to find within corn plant distribution and spatio-temporal distribution of both prey and

predator in the sweet corn field. *Zelus longipes* started visiting the field after two weeks of corn planting while corn-infesting Ulidiidae were observed around tassel maturity (6 or 7th wk after corn planting). It was observed that the mean number of both the Ulidiidae adults and *Z. longipes* continued to increase from silking stage to milk stage. Throughout the sampling period, the density of both insects followed the same pattern of within corn plant distribution. The density of corn-infesting Ulidiidae and *Z. longipes* was higher on base leaves (present on lower three collar bands of stem), middle leaves (on collar band around the corn ear) and fruits (corn ear) at 0900 and 1300 h EST. whereas the density of prey and predator both was higher on top or tassel (portion above the corn ear) at 1300 h EST. The pattern of distribution of corn-infesting Ulidiidae and *Z. longipes* was random or aggregated during the silking stage but at later stages (blister and milk stage) their distribution was aggregated. *Zelus longipes* adults (both male and female) displayed type II functional response to the adults of *E. stigmatias*, *E. eluta*, and *E. annonae* in the laboratory experiment. The male *Z. longipes* was found to take longer handling time as compare to the female adults.

The spatial distribution studies were conducted to understand the predator-prey dynamics in the corn field. The action potential of these pests is yet to be established, so the information gained on the distribution of their population and predator can help in more targeted management of the Ulidiidae corn pest i.e., precision integrated pest management. Furthermore combining the spatial distribution data of the natural enemy with various physical and environmental factors will help to better understand their ecological needs. Ultimately this research would help in using beneficial insects in

management of corn infesting Ulidiidae in sweet corn. The use of chemical insecticides will be continued to control *Euxesta* spp. until the establishment of effective biological control. Therefore, the spatial distribution pattern of pest and predator will help to reduce use of insecticides by site-specific application. Secondly, the time specific spray of these chemicals will promote the natural enemy survival. Future study should also include the testing of these insecticides on survival rate of the natural enemy on Ulidiidae pest of corn.

The functional response helps to understand if the predator is efficient in regulating the pest population i.e., how predator would react to higher or lower density of the pest. Ideally in a functional response study at a higher prey density, the predator should display increased prey consumption. This produces a type III functional response with a sigmoid curve. Such type of functional response mostly occurs in a field as predator has greater chances of switching over preys. Thus, field studies involving functional response of potential predators *O. insidiosus* and *Z. longipes* to Ulidiidae corn pest is suggested. This will give an idea about how the predator reacts to different prey options in the field, helping in developing more efficient biocontrol program.

LIST OF REFERENCES

AgMRC (Agriculture Marketing and Resource Center). 2010.

http://www.agmrc.org/commodities__products/grains__oilseeds/corn/sweet_corn.cfm

Albajes, R., C. Lopez, and X. Pons. 2003. Predatory fauna in cornfields and response to imidacloprid seed treatment. *Journal of Economic Entomology* 96: 1805–1813.

Allen, E. J., and B. A. Foote. 1967. Biology and immature stages of three species of Otitidae (Diptera) which have saprophagous larvae. *Annals of the Entomological Society of America* 60: 826–836.

Allen, E. J., and B. A. Foote. 1975. Biology and immature stages of *Tritoxa incurva* (Diptera: Otitidae). *Proceedings of the Entomological Society of Washington* 77: 247–257.

Allen, E. J., and B. A. Foote. 1992. Biology and immature stages of *Chaetopsis massyla* (Diptera: Otitidae), a secondary invader of herbaceous stems of wetland monocots. *Proceedings of Entomological Society of Washington* 94: 320–328.

Andow, D. A., and S. J. Risch. 1985. Predation in diversified agroecosystems: relations between a coccinellid predator *Coleomegilla maculata* and its food. *Journal of Applied Ecology* 22: 357–372.

Andow, D. A. 1990. Characterization of Predation on Egg Masses of *Ostrinia nubilalis* (Lepidoptera: Pyralidae). *Annals of the Entomological Society of America*. 83: 482–486.

Anonymous. 2008. Florida Cooperative Agricultural Pest Survey Program. Quarterly report No. 2-2008. Division of Plant Industry, Florida Department of Agriculture and Consumer Services, Gainesville, FL.

App, B. A. 1938. *Euxesta stigmatias* Loew, an Otitid fly infesting ear corn in Puerto Rico. *Journal of Agriculture of the University of Puerto Rico* 23: 181–187.

Ashley, J. L. 2003. Toxicity of selected acaricides on *Tetranychus urticae* (Tetranychidae: Acari) and *Orius insidiosus* Say (Hemiptera: Anthocoridae) life stages and predation studies with *Orius insidiosus*. M. S. Thesis. Virginia Polytechnic Instituted and State University.

Asin, L., and X. Pons. 1999. Effects of soil insecticide treatments on maize aphids and aphid predators in Catalonia. *Crop Protection* 18: 389–395.

Andow, D. A. 1990. Characterization of Predation on Egg Masses of *Ostrinia nubilalis* (Lepidoptera: Pyralidae). *Annals of the Entomological Society of America* 83: 482–486.

App, B. A. 1938. *Euxesta stigmatias* Loew, an otitid fly infesting ear corn in Puerto Rico. Journal of Agriculture of University of Puerto Rico 23: 18–187.

Baez, I., S. R. Reitz., and J. E. Funderburk. 2004. Predation by *Orius insidiosus* (Heteroptera: Anthocoridae) on life stages and species of *Frankliniella* flower thrips (Thysanoptera: Thripidae) in pepper flowers. Environmental Entomology 33: 662–670.

Báez, J. C. R, G. C. García, J. I. V. Hernández , E. L. V. Montoya, E N Pérez, D. B Armenta and M. M Ocampo. 2010. Búsqueda de enemigos naturales asociados de los estigmas *Euxesta* spp. (Diptera: Otitidae) En Maiz Blanco En Guasave, Sinaloa, Mexico.

Bailey, W. K. 1940. Experiments in controlling corn ear pests in Puerto Rico. Puerto Rico Experiment Station, circular no. 23, USDA, Mayaguez, P. R.

Balog, A., J. Kiss, D. A. Szenasi, and V. Marko. 2009. Rove beetle (Coleoptera: Staphylinidae) communities in transgenic Bt (MON810) and near isogenic maize. Crop Protection 29: 567–571.

Balog, A., and V. Marko. 2008. Chemical disturbances effects on community structure of rove beetles (Coleoptera: Staphylinidae) in Hungarian agricultural fields. North- West. Journal of Zoology 3: 67–74.

Barber, G. W. 1936. *Orius insidiosus* (Say), an important natural enemy of the corn earworm. USDA Technical Bulletin 504. Environmental Entomology 22: 1192–1200.

Barber, G. W. 1939. Injury to sweet corn by *Euxesta stigmatias* Loew in southern Florida. Journal of Economic Entomology 32: 879–880.

Bean, B., and C. Patrick. 2011. Corn development and key growth stages. Texas A & M, Agricultural Research and Extension Center. Amarillo.

Blanton, F. S. 1938. Some dipterous insects reared from narcissus bulbs. Journal of Economic Entomology. 31: 113–116.

Boiteau, G., J. R. Bradley and J. W. Van Duyn. 1979. Bean leaf beetle: micro-spatial patterns and sequential sampling of field populations. Environmental Entomology. 8: 1139–1144.

Brodeur, J. 2006. The challenge of assessing efficacy of biocontrol agents against insect pests. Canada's Bulletin on Ecological Pest Management.

- Brunel, O., and J. Rull. 2010.** The natural history and unusual mating behavior of *Euxesta bilimeki* (Diptera: Ulidiidae). *Annals of the Entomological Society of America* 103: 111–119.
- Bush, L., T. J. Kring, and J. R. Roberson. 1993.** Suitability of greenbugs, cotton aphids, *Heliothes virescens* eggs for development and reproduction of *Orius insidiosus*. *Entomologia Experimentalis et Applicata* 67: 217–222.
- Carrel, J. E. 2001.** Response of predaceous arthropods to chemically defended larvae of the pyralid moth *Uresiphita reversalis* (Guenée) (Lepidoptera: Pyralidae). *Journal of the Kansas Entomological Society* 74: 128–135.
- Cisneros, J. J and J. H. Rosenheim. 1997.** Ontogenic change of prey preference in the generalist predator *Zelus renardii* and its influence on predator-prey interactions. *Ecological Entomology* 22: 399–407.
- Cividanes, F. J., J. S. Barbosa, S. Ide, N.W. Perioto, and R.I R. Lara. 2009.** Faunistic analysis of Carabidae and Staphylinidae (Coleoptera) in five agroecosystems in northeastern São Paulo state, Brazil. *Pesquisa Agropecuária Brasileira*. 44: 954–958
- Coderre, D., E. Lucas, and I. Gagne. 1995.** The occurrence of *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) in Canada. *Canadian Entomologist* 127: 609–611.
- Cogni R, A.V.L, Freitas, and F. A, Filho, 2000.** Influence of prey size on predation success by *Zelus longipes* L. (Hemiptera: Reduviidae). *Journal of Applied Entomology* 126: 74–78.
- Cohen, A. C. 1990.** Feeding adaptations of some predatory heteropterans . *Annals of Entomological Society of America* 83: 1215–1223.
- Cohen, A. C and Tang, R. 1997.** Relative prey weight influences handling time and biomass extraction *Sinea confusa* and *Zelus renardii* (Heteroptera : Reduviidae) *Environmental entomology* 26: 559–565.
- Coll, M., and D. G. Bottrell. 1991.** Microhabitat and resource selection of the European corn borer (Lepidoptera: Pyralidae) and its natural enemies in Maryland field corn. *Environmental Entomology* 20: 526–533.
- Coll, M., and D. G. Bottrell. 1992.** Mortality of European corn borer larvae by natural enemies in different corn microhabitats. *Biological Control* 2: 95–103.
- Coll, M and L. R. Ridgeway. 1995.** Functional and numerical response of *Orius insidiosus* (Heteroptera: Anthocoridae) to its prey in different vegetable crops. *Annals of Entomological Society of America* 88: 732–738.

- Corey, D. 1994.** Field, molecular and laboratory observations of *Orius insidiosus* (Hemiptera: Anthocoridae), a predator in corn. M. S. Thesis, Kansas State University.
- Corey, D., S. Kambhampati, and G. Wilde. 1998.** Electrophoretic analysis of *Orius insidiosus* (Hemiptera: Anthocoridae) feeding habits in field corn. *Journal of Kansas Entomological Society* 71: 11–17.
- Cortez, M. E. 2008.** Recomendaciones para el control de gusano cogollero y mosquita pinta en maíz, en primavera-verano. *Panorama Agropecuario, Los Mochis, Sinaloa, México* 193:16–17.
- Curran, C. H. 1935.** New American Diptera. *The American Museum of Natural History*. 812 :1-24.
- Daly, T., and D. G. Buntin. 2005.** Effects of *Bacillus thuringiensis* transgenic corn for Lepidopteran control on nontarget arthropods. *Environmental Entomology* 34: 1292–1301.
- Diaz-Fleischer, F., and M. Aluja. 2000.** Behavior of tephritid flies: a historical perspective, pp. 39–72. In M. Aluja and A. L. Norrbom (eds.), *Fruit flies (Tephritidae): phylogeny and evolution behavior*. CRC, Boca Raton, FL.
- Dicke, F. F., and J. L. Jarvis. 1962.** The habits and seasonal abundance of *Orius insidiosus* (Say) (Hemiptera- Heteroptera: Anthocoridae) on corn. *Journal of the Kansas Entomological Society* 35: 339–344.
- Duffie, W. D., M. J. Sullivan, and S. G. Turnipseed. 1998.** Predator mortality in cotton from different insecticide classes, pp. 1111–1112. In *Proceedings, Beltwide Cotton Conference, 5–9 January, 1998, San Diego, CA*.
- Eckert, J., I. Schuphan, L. A. Hothorn, and A. Gathmann. 2006.** Arthropods on maize ears for detecting impacts of Bt maize on nontarget organisms. *Environmental Entomology* 35: 554–560.
- Evans, D. C., and E. Zambrano. 1991.** Insect damage in maize of highland Ecuador and its significance in small farm pest management. *Tropical Pest Management* 37: 409–414.
- Evenhuis, N. L. 1997.** New records, synonymies, and range extension of two-winged flies (Diptera) from the Hawaiian Islands, pp. 29–32. In *Records of the Hawaiian biological survey for 1996, part 2: Notes Bishop Museum Occasional Papers*. Vol. 49.

Everly, R.T. 1938. Spiders and insects found associated with sweet corn with notes on the food habits of some species. I. Arachnida and Coleoptera. Ohio. Journal of Science 38: 136–148.

Ewert, M. A., and H. C. Chiang. 1966. Dispersal of three species of coccinellids in corn fields. Canadian Entomologist 98: 999–1003.

Fantinou, A. A., D. C. Perdikis, and C. S. Chatzoglou. 2003. Development of immature stages of *Sesamia nonagrioides* (Lepidoptera: Noctuidae) under alternating and constant temperatures. Environmental Entomology 32: 1337–1342.

Fisher, E. 1996. Two new insect pests of corn in California. New pest/disease Advisory, 31 December 1996. State of California, Department of Food and Agriculture, Division of Plant Industry.

Fox, T.B., D.A. Landis, F.F. Cardoso, and C.D. DiFonzo. 2004. Predators suppress *Aphis glycines* Matsumura population growth in soybean. Environmental Entomology 33: 608–618.

Franca, F. H., and P. T. D. Vecchia. 1986. Damages caused by *Euxesta stigmatias* on carrot roots in commercial seed field. Pesquisa Agropecuária Brasileira, Brasília 21: 789–791.

Frías, D. L. 1978. Estudios ecológicos en *Euxesta eluta* y *Euxesta annonae* (Diptera: Ottitidae). Agriculture technology. Chile. 38: 110–114.

Funderburk, J., J. Stavisky, and S. Olson. 2000. Predation of *Frankliniella occidentalis* (Thysanoptera: Thripidae) in field peppers by *Orius insidiosus* (Hemiptera: Anthocoridae). Environmental Entomology 29: 376–382.

Gould, F. 1998. Sustainability of transgenic insecticidal cultivars: integrating pest genetics and ecology. Annual Review of Entomology 43: 701–726.

Goyal, G. 2010. Morphology, biology and distribution of corn-infesting Ulidiidae. PhD Dissertation. University of Florida, Gainesville.

Goyal, G., G. S. Nuessly, D. R. Seal, J. L. Capinera, G. J. Steck, and K. J. Boote. 2010. New report of *Chaetopsis massyla* (Diptera: Ulidiidae) as a primary pest of corn in Florida. Florida Entomologist. 93 :198–202.

Goyal, G., G. S. Nuessly, D. R. Seal, J. L. Capinera, G. J. Steck, and K. J. Boote. 2011. Corn-infesting picture winged flies (Diptera: Ulidiidae) and their distribution in Florida. Florida Entomologist 94: 35–47.

Greve L. 1998. Family Otitidae. In Papp L. & Darvas B. (eds): Contributions to a Manual of Palaearctic Diptera. Higher Brachycera. Science Herald, Budapest 3: 185–192.

Hall DG. 2008. Biological control of *Diaphorina citri*. *Conciver*.
<http://www.conciver.com/huanglongbingYPSilidoAsiatico/Memor%C3%ADa8%apdf>

Hansen, R. 2011. Agricultural marketing resource center.
http://www.agmrc.org/commodities__products/grains__oilseeds/corn_grain/sweet_corn_profile.cfm

Harper, A. M. 1962. Life history of the sugarbeet root maggot in southern Alberta. *Canadian Entomologist* 94: 1334–1340.

Hart, E. R. 1986. Genus *Zelus* Fabricius in the United States, Canada, and Northern Mexico (Hemiptera: Reduviidae). *Annals of the Entomological Society of America* 79: 535–548.

Hassell, M. P. 1978. The dynamics of arthropod predator-prey systems. Princeton University Press, New Jersey.

Hassell, M. P. 1980. Foraging strategies, population models and biological control: a case study. *Journal of Animal Ecology*, 49, 603–628.

Hassell, M. P, J. H, Lawton and J. R, Beddington. 1977. Sigmoid functional responses by invertebrate predators and parasitoids. *Journal of Animal Ecology*.46: 249–262.

Hayslip, N. C. 1951. Corn-silk fly control on sweet corn. University of Florida Agriculture Experimental Station. Circular 41: 1–6.

Hoffmann, M. P., M. S. Orfanedes, L. H. Pedersen, J. J. Kirkwyland, E. R. Hoebeke, and R. Ayyappath. 1997. Survey of lady beetles (Coleoptera: Coccinellidae) in sweet corn using yellow sticky cards. *Journal of Entomological Science* 32: 358–369.

Holling, C. S. 1959. Some characteristics of simple types of predation and parasitism. *Canadian Entomologist*: 91:385–398.

Holling, C. S. 1963. An experimental component analysis of population processes. *Memoirs of the Entomological Society of Canada*. 32: 22–32.

Holling, C.S. 1966. The functional response of invertebrate predators to prey densities. *Memoirs of the American Entomological Society*: 48:1–86.

Hokkanen, H.M.T., and C. H. Wearing. 1994. The safe and rational deployment of *Bacillus thuringiensis* genes in crop plants: conclusions and recommendations of OECD workshop on ecological implications of transgenic crops containing Bt toxin genes. *Biocontrol Science and Technology* 4: 399–403.

Hoy, C. W., J. Feldman, F. Gould, G. G. Kennedy, G. Reed, and J. A. Wyman. 1998. Naturally occurring biological controls in genetically engineered crops, pp. 185–205. In R. Barbosa (ed.), *Conservation Biological Control*. Academic, New York.

Illingworth, J. F. 1929. Pests of pineapple in Hawaii. *Proceedings of the Hawaiian Entomological Society* 7: 254–256.

Isenhour, D. J. and N. L. Martson. 1981. Season cycles of *O. insidiosus* in Missouri soyabeans and corn. *Journal of Kansas Entomological Society*. 54:129–142.

Isenhour, D. J., and K. V. Yeargan. 1981. Effect of temperature on the development of *Orius insidiosus* with notes on laboratory rearing and a key to the nymphal stages. *Annals of the Entomological Society of America* 74: 114–116.

Isenhour, D. J., R. C. Layton, and B. R. Wiseman. 1990. Potential of adult *Orius insidiosus* as predator of the fall armyworm, *Spodoptera frugiperda*. *Entomophaga* 35: 269–275.

Ives, A. R., R. Kareiva, and R. Perry. 1993. Response of a predator to variation in prey density at three hierarchical scales of lady beetles feeding on aphids. *Ecology* 74: 1929–1938.

Iwao, S. 1968. A new regression model for analyzing the aggregation pattern of animal populations. *Researches on Population Ecology* 4: 35–46.

Jafari, R., and S. Goldasteh. 2009. Functional response of *Hippodamia variegata* (Goeze) (Coleoptera: Coccinellidae) on *Aphis fabae* (Scopoli) (Homoptera: Aphididae) in laboratory conditions. *Acta Entomologica Serbica*. 14: 93–100.

Jasinski, J. R., J. B. Eisley, C. E. Young, J. Kovach, and H. Wilson. 2003. Select nontarget arthropod abundance in transgenic and non-transgenic field crops in Ohio. *Environmental Entomology* 32: 407–413.

Jepson, P. C., B. A. Croft, and G. E. Pratt. 1994. Test systems to determine the ecological risks posed by toxin release from *Bacillus thuringiensis* genes in crop plants. *Molecular Ecology* 3: 81–89.

Jervis, M. A., and M. J. W. Copland. 1996. Insect natural enemies; Practical approaches to their study and evaluation, pp. 63-161. In M.A. Jervis and N. Kidd (eds.), *The insects: structure and function*, Chapman & Hall, London.

Jindřich, R. 2006. Checklist of Diptera of the Czech Republic and Slovakia. Department of Entomology, Silesian Museum.

<http://zoology.fns.uniba.sk/diptera2009/families/ulidiidae.htm>

Juliano, S. A. 2001. Non-linear curve fitting: predation and functional response curves. Design and analyses of ecological experiments. 2nd edition. (eds S.M. Scheiner and J. Gurevitch) pp. 178–196. Chapman and Hall, New York.

Kalsi, M. and D. R. Seal. 2011. Featured Creatures. Milkweed assassin bug. *Zelus longipes* Linnaeus.

http://entnemdept.ufl.edu/creatures/beneficial/bugs/zelus_longipes.htm

Kameneva, E. P. 2004. New records of picture-winged flies (Diptera: Ulidiidae) of Central America. *Studia Dipterologica* 10: 609–652.

Kameneva, E. P. 2005. A new genus and species of tribe Lipsanini (Dipter: Ulidiidae) from Central America. *Vestnik Zoologii* 39: 97–101.

Kameneva, E. P. 2006. East Asian and Papuan species of the genus *Herina* Robineau Desvoidy (Diptera, Ulidiidae, Otitinae). *Instrumenta Biodiversitatis* 7: 15–59.

Kameneva, E. P. 2007. A new species of *Hernia* (Diptera: Ulidiidae) from Switzerland, with a key to European species and notes on nomenclature and distribution. *Vestnik Zoologii* 41: 405–421.

Kameneva, E. P., and L. Greve. 2004. Fauna Europaea: Ulidiidae. Fauna Europaea: Diptera Cyclorrhapha. Fauna Europaea version 1.1. Ed. T. Pape.

<http://www.faunaeur.org>

Kawai, A. 1976. Analysis of the aggregation behavior in the larvae of *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae) to prey colony. *Research Population of Ecology (Kyoto)* 18: 123–134.

Kazmer D.J and M.I J. Brewer. 2009. Biological types of biological control.

http://wiki.bugwood.org/HPIPM:Biological_Types_of_Biological_Control

Kimman, Z. B., and K. V. Yeargan. 1985. Development and reproduction of the predator *Orius insidiosus* (Hemiptera: Anthocoridae) reared on diets of selected plant material and arthropod prey. *Annals of the Entomological Society of America* 78: 464–467.

Knuston, A. E., and F. E. Gilstrap. Predator and Parasites of southwestern corn borer (Lepidoptera: Pyralidae) in Texas corn. *Journal of the Entomological Society.* 62: 511–520.

Korneyev, V. A. 2000. Phylogenetic relationships among the Families of the Superfamily Tephritoidea, pp. 3–27. In M. Aluja and A. L. Norrbom (eds.), *Fruit flies (Tephritidae): phylogeny and evolution of behavior.* CRC, Boca Raton, FL.

Krebs, J. R and Davies, N. B. 1993. An introduction to behavioral ecology. Chapter.5. Managing time and energy. Oxford: Blackwell Science.

Lloyd, M. 1967. Mean crowding. *Journal of Animal Ecology* 36: 1–30.

Livdahl, T. P., and A. E. Steven. 1983. Statistical difficulties in the analysis of functional predator response. *Canadian Entomology* 115: 1365–1370.

Lundgren, J. G., and J. K. Fergen. 2006. The oviposition behavior of the predator *Orius insidiosus*: acceptability and preference for different plants. *Bio Control* 51: 217–227.

McAlpine, J. F. 1989. Manual of Nearctic Diptera. Monograph 32. Agriculture Canada, Ottawa, ON, Canada.

Merrill, L. S., Jr. 1951. Diptera reared from Michigan onions growing from seeds. *Journal of Economic Entomology.* 14: 1015–1015.

Morista, M. 1962. l_o - index, a measure of dispersion of individuals. *Researches on Population Ecology* 4: 1–7.

Mossler, M. A. 2008. Crop profiles for sweet corn in Florida. Publication #CIR1233. <http://edis.ifas.ufl.edu/pi034>

Murdoch, W. W. 1969. Switching in general predators: experiments on predator specificity and stability of prey populations. *Ecological Monographs* 39: 335–354.

Murdoch, W. W., and A. Oaten. 1975. Predation and population stability. *Advances in Ecological Research* 9: 1–131.

Musser, F. R., J. P. Nyrop, and A. M. Shelton. 2004. Survey of predators and sampling method comparison in sweet corn. *Journal of Economic Entomology* 97: 136–144.

Nault, B. A., and G. G. Kennedy. 2000. Seasonal changes in habitat preference by *Coleomegilla maculata*: implications for Colorado potato beetle management in potato. *Biological Control* 17: 164–173.

Nuessly, G. S., and J. L. Capinera. 2010. Featured Creatures. *Euxesta stigmatias* Loew (Insecta: Diptera: Ulidiidae).
http://entnemdept.ufl.edu/creatures/field/cornsilk_fly.htm

Nuessly, G. S., K. Pernezney, P. Stansley, R. Sprenkel and R. Lentini. 2010. Field corn insect identification guide. University of Florida.
<http://erec.ifas.ufl.edu/fciig/index.htm>

Nuessly, G. S., and J. L. Capinera. 2001. Online Publication. Featured Creatures. Entomology and Nematology Department, Institute of Food and Agriculture Sciences, University of Florida
http://entnemdept.ufl.edu/creatures/field/cornsilk_fly.htm

Nuessly, G. S., and M. Hentz. 2002. Evaluation of insecticides for control of fall armyworm in pre ear-stage sweet corn, 2000. *Arthropod Management Tests* 27: E34. Entomological Society of America,
http://entsoc.org/home?ip_login_no_cache=3489a43619412201c94e5f58c52b6320

Nuessly G. S., and M. G. Hentz. 2004. Contact and leaf residue activity of insecticides against the sweet corn pest *Euxesta stigmatias* (Diptera: Otitidae). *Journal of Economic Entomology* 97: 496–502.

Nuessly, G. S., B. T. Scully, M. G. Heintz, R. Beiriger, M. E. Snook, and N. W. Widstrom. 2007. Resistance to *Spodoptera frugiperda* (Lepidoptera: Noctuidae) and *Euxesta stigmatias* (Diptera: Otitidae) in sweet corn derived from exogenous and endogenous genetic systems. *Journal of Economic Entomology* 100: 1887–1895.

Obrycki, J. J., J. E. Losey, O. R. Taylor, and L. C. H. Jesse. 2001. Transgenic insecticidal corn: beyond insecticidal toxicity to ecological complexity. *BioScience* 51: 353–361.

Painter, R.H. 1955. Insects on corn and teosinte in Guatemala. *Journal of Economic Entomology* 48: 36–42.

Pilcher, C. D., M. E. Rice., and J. J. Obrycki. 2005. Impact of transgenic *Bacillus thuringiensis* corn and crop phenology on five nontarget arthropods. *Environmental Entomology* 34: 1302–1316.

Ramachandran, S., J. Funderburk, J. Stavisky, and S. Olson. 2001. Population abundance and movement of *Frankliniella* species and *Orius insidiosus* in field pepper. *Agricultural and Forest Entomology* 3: 1–10.

Reid, C. D. 1991. Ability of *Orius insidiosus* to search for, find and attack European corn borer and corn earworm eggs on corn. *Journal of Economic Entomology* 84: 83–86.

Ritchie, S. W., and J. J. Hanway. 1984. How a corn plant develops. Iowa State University Cooperative Extension Service. Report number 48.

Rogers, D. 1972. Random search and insect populations models. *Journal of animal ecology* 41: 369–383.

Rutledge, C.E., R.J. O’Neil, T.B. Fox, and D.A. Landis. 2004. Soybean aphid predators and their use in integrated pest management. *Annals of the Entomological Society of America* 97: 240–248.

Sabelis, M. W., and P. C. J. Van Rijn. 1997. Predation by mites and insects, pp. 25–354. In T. Lewis (ed.), *Thrips as crop pests*. CAB International, Wallingford, UK.

SAS Institute. 2003. SAS® System for Windows, version 9.1. SAS Institute, Cary, NC.

Schauber, E. M., R. S. Ostfeld, and C. G. Jones. 2004. Type 3 functional response of mice to gypsy moth pupae: is it stabilizing? *Oikos* 107: 592–602.

Seal, D. R., and R. K. Jansson. 1989. Biology and management of corn-silk fly, *Euxestastigmatis* Loew (Diptera: Otitidae), on sweet corn in southern Florida. *Proceedings of the Florida State Horticultural Society* 102: 370–373.

Seal, D.R., and R. K. Jansson. 1993. Oviposition and development of *Euxesta stigmatis* (Diptera: Otitidae). *Environmental Entomology* 22: 88–92.

Seal, D.R., R. K. Jansson, and K. Bondari. 1995. Bionomics of *Euxesta stigmatis* (Diptera: Otitidae) on sweet corn. *Environmental Entomology* 24: 91–922.

Seal, D.R., R. K. Jansson, and K. Bondari. 1996. Abundance and reproduction of *Euxesta stigmatis* (Diptera: Otitidae) on sweet corn in different environmental conditions. *Florida Entomologist* 79: 413–422.

Seal, D. R. 2001. Control of the corn silk fly using various insecticides, 2000. *Arthropod Management Tests* 26: E31. Entomological Society of America, <http://www.entsoc.org/Protected/AMT/AMT26/INDEX.ASP>.

- Severin, H. H. P., and W. J. Hartung. 1912.** Will the Mediterranean fruit fly (*Ceratitis capitata* Wied.) breed in bananas under artificial and field conditions? *Journal of Economic Entomology* 6: 443–451.
- Sigsgaard, L., and P. Esbjerg. 1997.** Cage experiments on *Orius tantillus* predation of *Helicoverpa armigera*. *Entomologia Experimentalis et Applicata* 82: 311–318.
- Silvie, P. J., H. P. Aberlenc, C. Duverger, J.M. Bérenger, R. Cardozo, V. Gomez. 2007.** *Harmonia axyridis* no Paraguai e novos predadores identificados no cultivo do algodoeiro (*Harmonia axyridis* in Paraguay and new predators identified in cotton crop). In proceedings, Simposio de Controle Biológico. 30 June–4 July 2007, Brasilia Brésil.
- Shrestha, R. M., and M. N. Parajulee. 2004.** Functional response of selected cotton arthropod predators to bollworm eggs in the laboratory. Beltwide cotton conferences, Jan 5–9, 2004, San Antonio, TX.
- Solomon, M.E. 1949.** The natural control of animal populations. *Journal of Animal Ecology* 18: 1–35.
- Southwood, T. R. E. 1978.** *Ecological methods*. 2 Ed. Chapman & Hall, London.
- Sterling, W.L., K.M. El-Zik and L.T. Wilson. 1989.** Biological control of pest populations, pp.159–189. *In* Integrated Pest Management Systems and Cotton Production. John Wiley and Sons, New York.
- Stern, V. 1981.** Environmental control of insects using trap crops, sanitation, prevention, and harvesting, pp 199–207. *In* D. Pimentel (ed.) *CRC Handbook of Pest Management in Agriculture*, Vol. 1. CRC Press, Boca Raton, Florida.
- Steyskal, G. C. 1952.** Ulidiinae (Diptera, Otitidae) of Australian regions. Occasional papers of Bernice P. Bishop Museum. Vol. XX 15.
- Steyskal, G. C. 1961.** The genera of Platystoniidae and Otitidae known to occur in America north of Mexico (Diptera, Acalyptratae). *Annals of Entomological Society of America*. 54: 401–410.
- Steyskal, G. C. 1968.** Family Otitida (Ortalidae: including Pterocallidae, Ulidiidae). A Catalogue of the Diptera of the Americas South of the United States. Departamento de Zoologia, Secretaria de Agricultura, Sao Paulo, Brasil. 54: 1–31.
- Steyskal, G. C. 1971.** A new Central American species of *Zacompsia* Coquillett, with a key to the described species (Diptera: Otitidae). *Proceedings of the Entomological Society of Washington* 73: 247–248.

Sutherland, W. J. .1983. Aggregation and the ideal free distribution. *Journal of Animal Ecology*. 52:821–828.

Taylor, L. R. 1961. Aggregation, variance and the mean. *Nature (London)* 189: 732–735.

Taylor, L. R. 1984. Assessing and interpreting the spatial distributions of insect populations. *Annual Review of Entomology* 29: 321–357.

Thomas, C.F.G., L. Parkinson, G.J.K. Griffiths, A.F. Garcia, and E.J.P. Marshall. 2001. Aggregation and temporal stability of carabid beetle distributions in field and hedgerow habitats. *Journal of Applied Ecology*. 38:100–116.

Thompson, J.D. 1975. Towards a predator-prey model incorporating age structure. The effects of predator and prey size on predation of *Daphnia magna* by *Ischnura elegans*. *Journal of Animal Ecology* 44: 907–916.

Thompson, F. C. 2006. Classification Notes, In N. L. Evenhuis, T. Pape, A. C. Pont, and F. C. Thompson [eds]. *Biosystematic Database of World Diptera*. <http://www.sel.barc.usda.gov/Diptera/names/FamClass.htm>

Tillman, P. G., and J. E. Mulrooney. 2000. Effect of selected insecticides on the natural enemies *Coleomegilla maculata* and *Hippodamia convergens* (Coleoptera: Coccinellidae), *Geocoris punctipes* (Hemiptera: Lygaeidae), and *Bracon mellitor*, *Cardiochiles nigriceps*, and *Cotesia marginiventris* (Hymenoptera: Braconidae) in cotton. *Journal of Economic Entomology* 93: 1638–1643.

Unigaro, P.A. 1958. Biología del predator *Zelus longipes* linneo (Hemiptera: Reduviidae) en el vale Cauca. *Revista facultad nacional de agronomia*. Medellin.

(USDA) U. S. Department of Agriculture. 2011. Vegetable summary 2010.

(USDA) U. S. Department of Agriculture. 2010. National Agriculture Statistics Service (NASS). USDA.

(USDA) U. S. Department of Agriculture. 2010. Economic Research Service (NASS). USDA.

Van Zwaluwenburg, R. H. 1917. Report of the entomologist. Puerto Rico Agriculture Experiment Station. 31–34.

- van den Meiracker, R. A. F., and P. M. J. Ramakers. 1991.** Biological control of the western flower thrips *Frankliniella occidentalis* in sweet pepper with the anthocorid predator *Orius insidiosus*. Mededelingen van de Faculteit Landbouwwetenschappen Universiteit Gent 56: 241–249.
- Walter, E. V., and G. P. Wene. 1951.** Tests of insecticides to control larvae of *Euxesta stigmatias* and *Megaselia scalaris*. Journal of Economic Entomology 44: 998–999.
- Way, M. J., and H. F. van Emden. 2000.** Integrated pest management in practice pathway toward successful application. Crop Protection 19: 81–103.
- Wheeler, A. G., Jr., and C. A. Stoops. 1996.** Status and spread of the Palearctic lady beetles *Hippodamia variegata* and *Propylea quatuordecimpunctata* (Coleoptera: Coccinellidae) in Pennsylvania, 1993-1995. Entomological News 107: 291–298.
- Wiedenmann, R.N and R.J.O'Neil 1991.** Searching behavior and time budgets of the predator *Podisus maculiventris* Entomologia Experimentalis et Applicata 6: 83–93
- Wilson, M. L. 2010.** Differential responses of odor-mediated predators to density and distribution characteristics of prey patches. 95th ESA annual meeting. 1st August to 6th August. Pittsburgh, PA.
- Wulp, F. M. 1903.** Biologia centrali-americana. Insecta, Diptera. pp 396–399. Vol. III. http://books.google.com/books?id=IQIQAAAAYAAJ&pg=PA399&lpg=PA399&dq=euxesta+stigmatias+metallic+green&source=bl&ots=rrSkW7ghAS&sig=6uadrqmjlphoHIC63ta5mQts6eE&hl=en&ei=z7kKTrH2BsWEtgf2hax3&sa=X&oi=book_result&ct=result&resnum=3&ved=0CCMQ6AEwAg#v=onepage&q=euxesta%20stigmatias%20&f=false
- Xiao, C. L., J. J. Hao and K. V. Subbarao. 1997.** Spatial patterns of microsclerotia of *Verticillium dahliae* in soil and *Verticillium* wilt of cauliflower. Phytopathology 87 :325–331.
- Yoon, J. S., M. T. Mathew, and R. E. Holman. 1983.** Biology of *Euxesta quaternaria* Loew (Diptera: Otitidae). Entomological News 94: 122–126.

BIOGRAPHICAL SKETCH

Megha Kalsi was born and brought up in New Delhi, India. She received her bachelor's degree in botany with honors, from University of Delhi, India in 2004. In 2006, she received a master's degree in biotechnology from Hemwati Nandan Bahuguna Garhwal University, India and was among top ranked students. Her master's research focused on "estimation of total serum IgE and molecular characterization of fungal antigens" at Allergy and Immunology Section, Institute of Genomics & Integrative Biology (CSIR), Delhi under the guidance of Dr. A. B. Singh. After completing her master's degree, she was appointed as the Assist. Lecturer in the same college she graduated from. She worked there for six months (2006-2007).

In spring 2009, she was enrolled at University of Florida for pursuing her master's degree in entomology under the supervision of Dr. Dakhshina R. Seal. Her research focused on potential predators of corn-infesting Ulidiidae in sweet corn field, Homestead: a report on their distribution and functional response. She found two predators feeding on different life stages of these corn pest flies. During her master's program, she received various travel grants and prizes for student paper competitions. In fall 2011, she will begin her PhD program at University of Kentucky, Lexington. She will be specializing in area of 'molecular insect physiology'.