

**THE POTENTIAL ROLE OF HETEROPTERAN PREDATORS - *GEOCORIS PUNCTIPES* (SAY), *G.*  
*ULIGINOSUS* (SAY) (GEOCORIDAE) AND  
*ORIOUS INSIDIOSUS* (SAY) (ANTHOCORIDAE) IN WARM - SEASON TURFGRASS**

by

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(Under the direction of S. KRISTINE BRAMAN)

**ABSTRACT**

Occurrence, abundance, predatory potential and residual effect of insecticides on the heteropteran predators, big-eyed bugs *Geocoris punctipes* (Say), *G. uliginosus* (Say) and the minute pirate bug, *Orius insidiosus* (Say) were studied in different turfgrass taxa. Evaluation of sweep and vacuum samples collected from 20 residential lawns, revealed a significant influence of grass taxa on abundance of all predatory heteropterans. None of the predatory heteropterans were affected by turfgrass density. Anthocorids increased with increasing turfgrass height and all stages of mirids were more often collected as weed density increased. Anthocorids were most abundant in St. Augustinegrass and showed a strong correlation with the abundance of chinch bugs. Male *G. punctipes* killed significantly more fall armyworm, *Spodoptera frugiperda* (J. E. Smith) neonates on bermudagrass and seashore paspalum than on zoysiagrass cultivars, while, *Orius* demonstrated significant predation on zoysiagrass and bermudagrass cultivars. Fall armyworm mortality was highest on 'Cavalier' and least on 'Sea Isle 1' and their mortality occurred in the following order: zoysiagrass > seashore paspalum > bermudagrass in the field when different densities of *Orius* were released. In both pesticide assessment trials, reduced concentrations of chlorpyrifos were toxic to *G. uliginosus* and *G. punctipes* as compared to

controls. Different concentrations of both spinosad and halofenozide failed to influence ( $P > 0.05$ ) the survival of big-eyed bugs in tube trials for one and three days after exposure.

INDEX WORDS: Predatory heteroptera, big-eyed bug, *Geocoris punctipes*, *G. uliginosus*, Insidious flower bug, *Orius insidiosus*, turfgrass, chlorpyrifos, spinosad, halofenozide

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**CHAPTER 1**  
**INTRODUCTION AND LITERATURE REVIEW**



Turfgrasses are unique and ubiquitous components of urban landscapes. They support a diverse arthropod community, which include herbivores, omnivores and carnivores. It is well understood that natural enemies in low maintenance turf play an important part in preventing pest outbreaks (Potter and Braman 1991). However, most urban landscapes especially home lawns, recreational and commercial turfs are intensively managed posing many challenges for conservation of natural enemies. Use of chemical agents as a main strategy for pest control has raised socio-economic and environmental challenges for pest management programs in the turfgrass industry (Potter and Braman 1991). These issues could be addressed by judicious integration of pragmatic pest management approaches such as utilization of host plant resistance, incorporation or enhancing of specific or general natural enemies populations, and treatment with selective chemical agents. Implementation of an integrated approach requires more detailed study on the tritrophic relationship between different host-turf 'taxa', their specific herbivores and the natural enemies. Consideration of tritrophic interactions becomes more important when non-selective pesticides affect non-target invertebrates as well as target pests in turfgrass (Braman et al. 2004a, Stewart and Braman 2001).

As Coll et al. (1997) stated, "In most studies of tritrophic interactions, the effect of plants on predators is confounded with changes in prey and predator behaviors after an encounter event". The goal of the proposed research was to acquire knowledge to facilitate implementation of host plant resistance, conservation of natural enemies and alternative pesticide technologies in turfgrass production, recreation and maintenance industries. The primary goal was to furnish additional information to build definite complementary strategies. Previous research revealed the opportunity to give added emphasis on augmentative and

conservation biological control in turf management programs (Braman et al. 2000b, 2003, 2004b).

My research focused on the possibility of biocontrol solutions for pests using known predatory heteropterans such as big-eyed bugs, *Geocoris spp.* and minute pirate bugs, *Orius spp.* Yeargan (1998) determined relative abundance of predatory heteropterans primarily *Orius*, *Nabis* and *Geocoris* species, at about 40-80% in soybean, 72% in alfalfa, 46% in cotton, and 2-12% in wheat out of total predator complex. Predatory mirids are observed to be most common in tree crops such as apples and pecans, while predatory pentatomids and reduviids are also reported in North American cropping systems (Yeargan 1998). Beneficial heteropterans (*Geocoris spp.* and *Orius spp.*) are commonly found in residential turf and occasionally mistaken for phytophagous insects like chinch bug, *Blissus insularis* (Barber) (Dunbar 1971).

Out of 240 *Geocoris* species described all over the world, 20 species occur in the United States (Dunbar 1971). Among them, *Geocoris punctipes* (Say), *G. bullatus* (Say), *G. pallens* (Stål), *G. uliginosus* (Say) and *G. floridanus* (Blatchley) occur very commonly in cultivated crops. The predatory potential of these heteropterans is less understood and, consequently, they are underutilized in turfgrass management. Greater emphasis on studies of selective insecticides and their residual effects on beneficial arthropods, especially big-eyed bug and minute pirate bug should be encouraged. Simultaneously, utilization of host plant resistance coupled with beneficial arthropods such as heteropterans should be optimized in turfgrass management. This research documented the natural occurrence and abundance of predatory Heteroptera and associated prey diversity in residential turf. The predatory potential of *G. punctipes*, *G. uliginosus* and *O. insidiosus* (Say) on fall armyworm, *Spodoptera frugiperda* (J E Smith) in

different turfgrass types was evaluated, along with the possible effects of non-target applications of insecticides.

### **Biology and Performance of Big-eyed Bugs**

Big-eyed bugs, *Geocoris spp.*, are common, omnivorous, generalist predators that attack aphids, lepidopteran eggs, and other pests on various crops in the United States (Champlain and Scholdt 1966, Lawrence and Watson 1979, Atim and Graham 1984). Usually, the adult big-eyed bug overwinters in plant residues or cracks in the soil to escape cold winter months (Dunbar 1971). They engage in active mating during spring season. Females are normally bigger than males, and the aggressive male bugs inspect the female by beating their antennae and subsequently, climb on the female extending its genitalia for mating. The mating period may last from 45 minutes to three hours. Mating pairs do not fly when they are copulating. Instead, they move together where the bigger female leads (Dunbar 1972). Dunbar (1972) observed that males start mating when they are three to five-days-old and females mate from two to five days after attaining sexual maturity. Usually, males mate at least ten times per week. Female big-eyed bugs laid eggs continuously up to 30 days after a single mating (Dunbar 1972). Adults live approximately one month and lay up to 300-400 fertile eggs, which are deposited singly either on leaves or on stems. Naranjo (1987), through cage experiments, showed that 77.5% of *G. punctipes* eggs were laid on the mesh screen lid area of the cage surface rather than on the plant surface. It was observed that big-eyed bugs choose the undersides of leaves and stems for oviposition rather than the upper surface of leaves, petioles or apex (Naranjo 1987). The nymphs emerge in approximately one week and the nymph undergoes five instars, with each instar requiring 4-6 days, and taking 2-4 weeks to reach adulthood (Dunbar 1971). Marques (2000) reported that female *G. punctipes* produced a sex pheromone, (*E*)-2-octenyl acetate,

which proved effective in attracting males. However, pheromone bait in the field needs more study as females are rarely in a stationary state so that males are attracted to a point for mating (Marques 2000).

Immature insects and adults can kill at least 12 prey items per day (Hagler and Cohen 1991). Hagler and Naranjo (1994) suggested that predator quantification is not very easy, due to their cryptic nature in field. Crocker et al. (1975) examined the feeding efficiency of *G. punctipes* on soybean looper, *Pseudoplusia includens* (Walker), in laboratory experiments and concluded that temperature, sex and developmental stage affected their predation rate. Adult males and nymphs ate more eggs at 35°C, whereas adult females fed more at 30°C. Fifth instar females consumed significantly more eggs than their male counterparts at 35°C, clearly indicating behavioral difference between sexes (Crocker et al. 1975). The predatory ability of big-eyed bugs was significantly greater when they were fourth and fifth instar nymphs compared to other instars (Crocker et al. 1975, Chiravathanapong and Pitre 1980). At the same time, predatory ability decreased as the prey size increased.

Braman et al. (1985) demonstrated that developmental rates of *G. uliginosus* could vary from one geographical area to another. This study established the relationship between development and temperature and derived a temperature threshold and the mean thermal unit requirements to predict the generation time in Kentucky and Texas populations of *G. uliginosus*. Cave and Gaylor (1988b) demonstrated that *G. punctipes* successfully emerged when they were reared between 18-35°C with 90% survival reported at 85% relative humidity. Hutchison and Pitre (1982) evaluated diurnal activity of *G. punctipes* and observed maximum activity during noontime in cotton. Pfannenstiel and Yeargan (2002) noted that 100% predatory activity took place during daytime after noon when lepidopteran eggs of *Helicoverpa zea* (Boddie) were

monitored for predation in soybean and sweet corn fields. Mack et al. (1988) showed that the total body water loss of *G. punctipes* was directly proportional to a period of desiccation and recorded 80% and 69% mortality for adults and nymphs respectively within 24 hours.

*Geocoris punctipes* can be mass-produced on beef-artificial diet, which is as nutritional as tobacco budworm eggs (Cohen 1985). Lopez et al. (1987) observed that fresh *Heliothis spp.* eggs are better than fresh or frozen *Sitotroga cerealella* (Olivier) eggs when the authors examined the fecundity, egg viability and mortality rates of *G. punctipes* for two generations. Hagler and Cohen (1990) determined the digestibility of consumed food under different temperature regimes when they incorporated rabbit IgG antigen (0-8.3 $\mu$ g) in food. They observed that antigen retention was discernable for 24-48 hours over a temperature range of 10-25°C. They could not detect rabbit IgG antigen after either 72 hours or when the temperature regime increased beyond 25°C. This allowed them to determine the food retention and assimilation rate in the gut by *G. punctipes* relative to time and different temperatures. Hagler et al. (1994) showed that enzyme-linked immunosorbent assay (ELISA) tests showed that 60% of *G. punctipes* had fed on the common cotton pest pink bollworm, *Pectinophora gossypiella* (Saunders), when specific monoclonal antibody (S3D6-H2-H11) was incorporated into these lepidopteran eggs in laboratory trials. These data were considered as a source of valuable information to predict predatory activity in field situations (Hagler et al. 1994). Naranjo and Hagler (2000) developed an improved, relatively accurate predation model from the data they obtained from the immunoassays, predator density and predator functional response of *G. punctipes* to ascertain the total prey attacked. Jackson (1991) suggested the use of elemental markers such as rubidium in diet or plant parts to determine and study dispersal, survival, and abundance of *G. punctipes* in different agro-ecosystems. Zeng and Cohen (2000) reported that

amylolytic and proteolytic activity in the digestive system of insects could further help to comprehend their food habits. Lower  $\alpha$ -amylases and moderate proteases were found in *G. punctipes* salivary glands. The data obtained by Zeng and Cohen (2000) supported the hypothesis that predators will possess smaller quantities of starch-digesting enzymes than proteases in their digestive systems because *G. punctipes* is omnivorous and facultative plant feeder.

### **Big-eyed bugs: Occurrence and Abundance as a Potential Predator**

Big-eyed bugs were predominantly reported from mid-May to early October (Eubanks and Denno 1999) in Maryland, and as early as April in the Southern parts of the United States (Cave and Gaylor 1988b, Buschman 1984). Observations by Eubanks and Denno (1999) showed that big-eyed bugs complete three generations per year. They occur in a variety of cropping systems such as cotton, corn, tobacco, alfalfa, soybean, radish, strawberries, grape vineyards, turfgrasses and peanuts in the United States (Crocker and Whitcomb 1980, Readio and Sweet 1982, Bisabri-Ershadi and Ehler 1981, Jubb et al 1979, Lynch and Garner 1980, Pfannenstiel and Yeorgan 1998). *Geocoris spp.* were also found in weed flora associated with cultivated crops like clover and knotweed (Martin et al. 1981, Bugg et al. 1987). Reports suggest that *Geocoris spp.* feed on a wide range of prey, which include insect eggs, spider mites, plant bugs, leafhoppers, aphids, and various lepidopteran larvae (Dunbar 1971). Pfannenstiel and Yeorgan (1998) observed the abundance of *G. punctipes* during early to mid-July and later by in August, in tobacco, corn, soybean and tomato. Tamaki et al. (1981) noted that *G. bullatus* showed plant preference when various densities of potential prey such as green peach aphid, *Myzus persicae* (Sulzer) were released on broccoli, radish and sugar beet. Big-eyed bugs fed on fewer aphids when exposed to broccoli than on other crops in greenhouse (Tamaki et al. 1981).

*Geocoris spp.* and *S. frugiperda* were found in the insect samples collected from cotton fields in Southern Alabama and South Carolina (Moar et al. 2002).

*Geocoris uliginosus* has been reported from turfgrass and shown to prey on the lepidopteran pest *S. frugiperda* (Braman et al. 2002b) and western yellow-striped armyworm, *Spodoptera praefica* (Grote) in alfalfa (Bisabri-Ershadi and Ehler 1981). Marti and Hamm (1985), demonstrated that mortality of *G. punctipes* individuals was less significantly affected when the bugs were fed on fall armyworm, *S. frugiperda* larvae infected with microsporidia *Vairimorpha spp.*, compared to healthy fall armyworms. McPherson et al. (1982) reported the occurrence and abundance of big-eyed bugs, *Geocoris spp.* in conventional and double-cropped soybean fields in Eastern Virginia. McCarty et al. (1980) also reported abundance of *G. uliginosus* and *G. punctipes* in soybean during a study using <sup>32</sup>P-labeled lepidopteran eggs. Reed et al. (1984) also claimed *G. punctipes* to be an effective predator in soybean based on their studies with lepidopteran eggs and noctuid larvae in field cages. McDaniel and Sterling (1979) reported predation by adults and nymphs of *G. uliginosus* and *G. punctipes* when exposed to <sup>32</sup>P-labeled eggs of *H. virescens* in cotton fields. Occurrence of geocorids was correlated with growing crop stages and associated insect prey abundance of velvetbean caterpillar, *Anticarsia gemmatalis* (Hübner) when Buschman et al. (1984) studied the effect of row spacing in soybeans. In cotton, natural populations of *G. punctipes* and *G. uliginosus* were observed feeding on cotton leafworm, *Alabama argillacea* (Hübner) eggs and first larvae (Gravena and Sterling 1983). Lopez et al. (1976) determined that *G. punctipes* was a more effective predator feeding on first instar larvae of *H. virescens* than on eggs and other larval instars, while Orphanides (1971) showed more predation on pink bollworm, *P. gossypiella*, eggs

than first instar larvae. They also effectively feed on eggs of *Heliothis virescens* (Fabricius) and early-instar lepidopteran larvae (Chiravathanapong and Pitre 1980).

Reinert (1978) reported a natural enemy complex for Southern chinch bug, *Blissus insularis* (Barber), on St. Augustinegrass, *Stenotaphrum secundatum* (Walt. Kuntze), in Florida, where the predatory bugs *G. uliginosus* and *G. bullatus* and other predators and parasitoids were abundant. Medal et al. (1995) observed that the first, second and third instars of threecornered alfalfa hopper, *Spissistilus festinus* (Say), were consumed at 100, 90 and 60%, respectively, when exposed to adults of *G. punctipes*. *Geocoris punctipes* prey consumption rate and prey preference for *S. festinus* did not vary when early larval instars of soybean looper, *P. includens* were offered (Medal et al. 1997). In a field cage evaluation of predators of *P. includens* (Noctuidae), *G. punctipes* and *G. uliginosus* were found in the predator complex (Richman et al. 1980). In strawberry ecosystems, *G. punctipes* was among the generalist predators preying on melon aphid *Aphis gossypii* (Glover), the twospotted spider mite, *Tetranychus urticae* (Koch), *Frankliniella* spp. and sap beetles, *Carpophius* spp. (Rondon et al. 2003. UFL IFAS, HS923 <http://edis.ifas.ufl.edu/HS180>). McCutcheon (2002) determined that consumption of eggs of tobacco budworm, *H. virescens*, and first instar larvae of the hooded beetle, *Notoxus monodon* (F.), was 76.5% and 32.5%, respectively, when respective eggs and larvae were exposed to *G. punctipes* adults in a 1200 ml container for 24 hours. The authors also noted significantly higher prey consumption at 48 and 72 hours. Rondon et al. (2004) observed that third instar *G. punctipes* preferred feeding on *T. urticae* (Wilson et al. 1991) with 69% feeding rate compared to a 27% feeding rate on cotton aphid, *A. gossypii* in one hour. It was also noted that *G. punctipes* (third instar nymphs) had less handling time on twospotted spider mite than on cotton aphid (Rondon et al. 2004). Wyman et al. (1979) reported 6.4% predation on twospotted spider



mite by *G. punctipes*. Waddill and Shepard (1974) determined a significant rate of predation by *G. punctipes* on Mexican bean beetle, *Epilachna varivestis* (Mulsant), eggs (~3.1 eggs) and first instars (~3.2 grubs). However, a decreased fecundity rate of 56% was noticed when *G. punctipes* fed on *E. varivestis* (Waddill and Shepard 1974). High predation of *G. punctipes* was noted on larvae and pupae of bandedwing whitefly, *Trialeurodes abutilonea* (Haldeman) (Watve and Clower 1976). Citrus growing areas in Florida also reported significant predatory activity by *G. floridanus* nymphs on neonate larvae of root weevil, *Diaprepes abbreviatus* (L.) (Stuart et al. 2003). *Geocoris punctipes*, longevity increased by four-fold when fed on pests other than on the aphids (Eubanks and Denno 2000b). Nutritional quality and prey mobility were important criteria for prey selection used by *G. punctipes* (Eubanks and Denno 2000b).

### **Big-eyed bugs as Plant Feeder**

Big-eyed bugs are polyphagous, feeding on seeds, as well as other insect predators and pests (Eubanks and Denno 1999). *Geocoris punctipes* has shown nutritional flexibility when availability of prey density declines, instead, feeding on plant parts such as pods, leaves, seeds and nectars on lima beans (Eubanks and Denno 1999) and on turfgrass (Dunbar 1971), exploiting more than one trophic level as complementary food resources, in experiments conducted on lima beans (Eubanks and Denno 1999). Eubanks and Denno (2000a) observed that the plant quality and quantity differences had little effect on prey suppression by *G. punctipes* in separate field studies on lima beans. This finding disproved the hypothesis that big-eyed bug preference and prey consumption declines when the quality and quantity of desired plant parts declines (Eubanks and Denno 2000a). Naranjo and Stimac (1985) noted that *G. punctipes* were unable to reach sexual maturity and exhibited reduced oviposition and fecundity when adults fed on soybean parts alone. However, plant parts provided sufficient moisture for survival, although

longevity and reproductive rates of big-eyed bugs were reduced. None of the nymphs raised on plant diet reached adulthood (Naranjo and Stimac 1985). Dunbar (1971) reported that *G. bullatus* on bentgrass, fed on 'Merion' blue grass and ryegrass, sometimes inflicted plant injury.

Abundance of *G. punctipes* reaches peak in nectaried cotton (Agnew et al. 1982), and its prey consumption intensified on increased of phytophagous species, in turn protecting the crop from destruction (Bisabri-Ershadi and Ehler 1981). Stone et al. (1984) demonstrated direct correlation of *G. punctipes* abundance with cotton square density and lower leaf soluble protein. Tillman and Mullinix (2003) reported that *G. punctipes* fed on plants regardless of prey availability. Trials were conducted to compare the prey preference when predators were provided with cotton aphid, *A. gossypii*, and *Helicoverpa zea* (Boddie) first instar larvae and eggs. *Geocoris punctipes* preferred first instar larvae of *H. zea* to other prey items. This study also contradicts the occurrence of big-eyed bugs on the upper half (anterior regions of plant) of the cotton plants. Authors noted that big-eyed bugs were observed most frequently on the lower half of cotton plant thereby sheltering the bugs from the daytime heat (Stone et al. 1984). A study by Cospers et al. (1983) in cotton reported that *G. punctipes* persisted on leaves and terminals during early and mid season respectively until fruit structures appeared on plants.

Geocorid occurrence was comparatively higher on the common knotweed, *Polygonum aviculare* L., than on weeds such as pigweed or common purslane. Common knotweed flowers produce nectaries at ground level attracting predatory insects including big-eyed bugs. Though nectaries contributed to the longevity of geocorids, experiments with and without nectaries were not significantly different from each other on knotweed (Bugg et al. 1987). Bugg et al. (1987) determined that big-eyed bug occurrence was consistently higher on knotweed when it was grown in combination with radish, *Raphanus sativus* L., and bell pepper, *Capsicum annuum* L.,

than on alfalfa, *Medicago sativa* L. These studies proved that knotweed was a better host refugia plant harboring more beneficial arthropods than hay alfalfa, by increasing the overall longevity of *G. punctipes* (Bugg et al. 1987). It was a more effective predator and suppressed *Trichoplusia ni* (Hübner) and *Helicoverpa zea* compared to *Chrysopa carnea* (Stephens) in soybean (Barry 1974). Large populations of *Geocoris spp.* could be harbored by planting refuge crops such as sunflower plants, around the growing area (Tamaki and Weeks 1972). Braman et al. (2002) reported increased occurrence of big-eyed bugs in turfgrass grown adjacent to wildflowers. In separate studies, *G. uliginosus* persisted in turfgrass and effectively preyed on the larvae of *S. frugiperda* (Braman et al. 2003). Braman et al. (2002) reported that growing floral plantings might be useful in providing refugia for beneficial insects when insecticides were applied to suppress turfgrass pests. Tillman et al. (2004) noted that *G. punctipes* density was higher in cotton fields where crimson clover, *Trifolium michelianum* (Savi), was planted the previous year.

The big-eyed bug's occurrence and predation were significantly enhanced with cover cropping in cantaloupe especially with subterranean clover mulches rather than clovers such as crimson clover and 'Vantage' vetch. This encouraged a higher rate of fall armyworm egg feeding by *G. punctipes* on cantaloupe leaves (Bugg et al. 1991). Gross et al. (1985) determined that the general predators *G. punctipes* and *Coleomegilla maculata* (De Geer) responded positively to larval homogenates in whorl-stage corn. These aqueous larval homogenates were prepared from selected larvae of fifth-instar corn earworms, and sixth-instar fall armyworms maintained on corn, soy flour and milk solid diet in the laboratory. A higher response of big-eyed bugs was noted within one hour, and up to four times after eight hours of larval homogenate application of 1.0 larval equivalent than in control plots. They also observed that *G.*

*punctipes* did not feed on the larval homogenates, instead they were considered as stimuli for host seeking (Gross et al. 1985).

### **Functional Response and Behavioral Studies**

Ables et al. (1978) showed that *G. punctipes* response to alternate prey, *H. virescens* eggs in the absence of the primary prey, cotton aphid, and was density dependent on increase of prey density. Functional response of *O. insidiosus* on consumption of *Heliothis* eggs was comparatively less (Ables et al. 1978). In field cage experiments, Hutchinson and Pitre (1983) demonstrated the functional response of *G. punctipes* feeding on *H. virescens* eggs and found that there is no differences in the number of eggs consumed regardless of predator density increase. However, predation rate per individual big-eyed bug increased when prey quantity was higher (Hutchinson and Pitre 1983).

Losey and Denno (1998) observed that pea aphid, *Acyrtosiphon pisum* (Harris), adopted a defensive strategy of 'drop off' behavior from the plant in response to disturbance. Losey and Denno (1998) found that pea aphid 'drop off' tendency doubled (14%) from alfalfa foliage with *G. punctipes* and *O. insidiosus* exposure compared to no predator (7%). Tillman and Mullinix (2003) noted that geocorids performed in a stop-and-go fashion. They make a salutatory move, stop and scan, if they find any prey, they immediately change to attack mode. Authors stated that they are attracted more to mobile prey, such as small sized larvae rather than stationary prey like eggs. *Geocoris punctipes* feed on more *Helicoverpa zea* eggs as its density increases (Tillman and Mullinix 2003). Nuessly and Sterling (1994) reported *Geocoris spp.* were more effective in predation on the upper half of the cotton when *Helicoverpa* eggs were placed on different plant parts to find the predator preference. Olmstead and Denno (1993) stated that

tortoise beetles *Charidotella bicolor* (F.) and *Deloyala guttata* (Oliv.) possessed shields that provided effective protection against predatory bugs like geocorids and minute pirate bugs.

### **Natural Enemies of Big-eyed Bugs**

Frequently, geocorids fall victim to parasitoids and predators, thus, it becomes important to evaluate the adverse impact on its predatory efficiency (Cave and Gaylor 1989). Those parasitoids observed were tachinid nymphal parasitoids, *Hyalomya aldrichii* (Townsend), scelionid egg parasitoid, *Telenomus reynoldsi* (Gordh and Coker) on *G. pallens* and *G. punctipes* (Atim and Graham, 1983), scelionid egg parasitoid, *T. reynoldsi*, and egg parasitoids, *Trichogramma pretiosum* (Riley) on *G. uliginosus* and *G. punctipes* (Cave and Gaylor 1988a). Cave and Gaylor (1988a) reported 7-30% parasitization of *Geocoris spp.* eggs by *T. reynoldsi* where as *T. pretiosum* parasitized only <1% during a two year study in cotton and soybean. Longevity of female adult *T. reynoldsi* ranged from 12-16 days under temperature regimes of 20, 25, 28 and 32°C. The fertility of the parasitoids was higher at 28°C when the adult female age ranged from one to six days. In an attempt to control codling moths, *Cydia pomonella* (L.), in walnuts, *Trichogramma platneri* (Nagarkatti) inundation was widely implemented (Mansefield and Mills 2002). Mansefield and Mills (2002) observed that female *T. platneri* did not attempt oviposition on *G. punctipes* eggs when they were evaluating the possibility of any deleterious effect of inundation on other natural populations of beneficial insects.

Another heteropteran *Nabis alternatus* (Parshley) was reported to feed on geocorids (Atim and Graham 1984). In field trials, Roach (1987) reported that the spider *Phidippus audax* (Hentz) clearly attacked and consumed by *G. punctipes* when their prey preference among other common insects was compared. Rosenheim (2005) reported the presence of strong intraguild predation by geocorids on *Orius tristicolor* (White) during his study in cotton growing areas in

California. The author suggested one possible reason for failure in population abundance of big-eyed bugs could be due to intraguild predator and big-eyed bug itself, fed by bigger predators such as *Chrysoperla spp.* (Rosenheim 2005).

### **Effects of *Bt*-Toxins on Big-eyed bugs**

The plant-feeding tendency was also examined in a transgenic cropping system where the plants were embedded with  $\delta$ -endotoxins. Studies by Armer et al. (2000) showed no effect of these  $\delta$ -endotoxins on the longevity of *G. punctipes* as a generalist predator in the potato growing system feeding on aphids, spider mites, loopers and psyllids other than lepidopterans. Ali and Watson (1982) demonstrated the compatible use of *Bacillus thuringiensis* (Berliner) (abbreviated as *Bt*) product ‘Dipel’ with big-eyed bug densities in both laboratory and field studies to control tobacco budworm, *H. virescens*, in cotton with remarkable predation and low risk of direct or indirect effect on the heteropterans. However, when Herbert and Harper (1986) tested topical application ( $LD_{50}$  0.250  $\mu$ g per insect) of beta-exotoxin on fourth-instar nymphs and adults, they noted high mortality on nymphs during immature stages or molting, but no toxic effect on adults. *G. punctipes* did not show as signs of toxicity in tactile (perceptible by touch) studies. Exponential curves indicated reduction in the adult longevity with increased exposure interval while *G. punctipes* were feeding on the beta-exotoxin intoxicated *Heliothis zea* larvae (Herbert and Harper 1986). Ponsard (2002) observed mild reduction of 27% in *G. punctipes* survival when he examined its longevity in studies on *Bt*-transgenic cotton (expressing Cry1Ac *Bt*-toxin) and two other non-transgenic crops in both laboratory and field trials.

### **Impact of Host Resistance on Geocorids**

In laboratory studies, when six turfgrass were compared (‘Sea Isle 1’ and ‘561-79’ seashore paspalum, *Paspalum vaginatum* [Swartz]; ‘TifSport’ and ‘TifEagle’ bermudagrass,

*Cynodon dactylon* [L] x *C. transvaalensis* [Burt-Davy]; and ‘Cavalier’ and ‘Palisades’ zoysiagrass *Zoysia japonica* [Von Steudel] and *Z. matrella* [L] Merrill) maximum predation on *S. frugiperda* was observed on the resistant ‘Cavalier’ zoysiagrass by a low number of *G. uliginosus*. These studies also showed that there was a weight difference of 7- fold on 10-day old *S. frugiperda* between those feeding on the resistant or susceptible turfgrass cultivars. *Spodoptera frugiperda* developed more slowly on the resistant turfgrass and hence spent more time in a size range prone to predation by *G. uliginosus* (Braman et al. 2003). Field studies revealed however, that maximum predation on *S. frugiperda* larvae by low numbers of *G. uliginosus* occurred on ‘Sea Isle I’ and ‘561-79’ seashore paspalum (Braman et al. 2003). It was also reported that predation was not adversely affected by the resistant turfgrass species (Braman et al. 2003). Barbour et al. (1997) reported that susceptible and resistant lines of tomato, *Lycopersicon esculentum* (Mill), did not affect the predatory performance and occurrence of *G. punctipes*. Accession no. PI 134417 and Bc2 showed improved resistance to first instar larvae of tobacco hornworm, *Manduca sexta* (L.), corn earworm, *H. zea* and *H. virescens* compared to ‘Better Boy’ and its F1 hybrid (Barbour et al. 1997, Barbour et al. 1993). However, earlier studies showed more effective predation of *H. zea* eggs by *G. punctipes* on the resistant (presence of trichomes) lines than on susceptible lines (Barbour et al. 1993).

Rogers and Sullivan (1986) observed that *G. punctipes* nymphs preying on velvetbean caterpillar, *Anticarsia gemmatilis* (Hübner), reared on pest-resistant soybean genotypes, such as PI 171451 and PI 229358, experienced increased nymphal mortality. In addition, the predator responded with increased nymphal development time when preying on a host that had been reared on pest-resistant genotypes. This indicates that antibiosis effects may persist to the third trophic level when *G. punctipes* preys on a lepidopteran pest reared on the pest-resistant soybean

genotypes. Rogers and Sullivan (1987) reported no significant difference in nymphal development (increase in fresh weight) of *G. punctipes* on soybean, when the nymphs were provided both pest-resistant and pest-susceptible genotypes (attached and detached leaves).

### **Biology and Distribution of Minute Pirate Bug, *Orius insidiosus*.**

Minute pirate bug or insidious flower bug, *O. insidiosus*, is a common, generalist predator reported in various agro-ecosystems such as vineyards, sunflower, cotton, soybean, corn, sorghum, alfalfa, apple and tomato (Jubb et al. 1979, Lynch and Garner 1980, McDaniel and Sterling 1979, Pfannenstiel and Yeargan 1998, Al-Deeb 2001). Pfannenstiel and Yeargan (1998) recorded *O. insidiosus* on tomato, soybean, corn and tobacco from June to August, but mostly during vegetative phase of soybean and before flowering in corn when tobacco, corn, soybean, and tomato was grown in separate trial plots. They suggested that *O. insidiosus* colonization and occurrence might have been affected by periodic occurrence and abundance of prey (Aphids or thrips) and crop 'taxa' (Pfannenstiel and Yeargan 1998). Tillman et al. (2004) noted a higher density of *O. insidiosus* in legume cover crops, although lesser populations were noticed on the crimson clover in cotton fields.

Elkassabany et al. (1996) reported seasonal fluctuation of pirate bug in grass weeds, corn, sorghum, cotton and soybean. They observed higher *O. insidiosus* abundance either during higher availability of prey species or during flowering stages of crops. *Orius insidiosus* population increases from early-mid May to early September in Southwestern Arkansas. Knutson and Gilstap (1989) reported two-generations of *O. insidiosus* abundance per year on irrigated corn in Texas. Yeargan (1998) reported that *O. insidiosus* plays important role by constituting 70-80% of predator complex in corn growing areas of Texas. Isenhour and Yeargan (1981) reported shorter generations for *O. insidiosus* up to 20 days under 25°C. First generation



increase of *O. insidiosus* was noted during whorl stage, while second generation increase were observed during the post-tassel stage of corn (Knutson and Gilstap 1989). Lower larval survival of Southwestern corn borer, *Diatraea grandiosella* (Dyar), was observed when *O. insidiosus* adults were included in the cage study (Knutson and Gilstap 1989).

*O. insidiosus* preferred bean foliage as an oviposition site compared to pepper and tomato and did not prefer to oviposit on corn foliage (Coll 1996). Adult *O. insidiosus* had higher longevity when fed with bean rather than other food sources and a moderate reproduction rate was recorded on beans, tomato and pepper with no eggs on corn. Coll (1996) also suggested the importance of partial dependence of minute pirate bugs on plant nutrients for their developmental success. Norton et al. (2001) reported that predation by *O. insidiosus* was less on the beneficial mites, *Amblyseius andersoni* (Chant) and *Orthotydeus lambi* (Baker) with leaf domatia (small mass of hair or invagination present on the leaf) than when these domatia was blocked with tar.

### **Potential Prey of Minute Pirate Bugs**

Isenhour et al. (1990) reported heavy consumption of fall armyworm eggs by *O. insidiosus* adults. Trials demonstrated 100% feeding on these eggs by *Orius* within 30 minutes. Uninterrupted feeding of up to 3-12 minutes was noticed as predators moved from egg to egg. Significant feeding on one or two day old first instar larvae of fall armyworm was greater than that on three-day-old larvae. *O. insidiosus* demonstrated a type-II functional response where predatory activity increases at decreasing rate, reaching an asymptote at higher prey densities. Male and female adult *O. insidiosus* preying on eggs and first instar larvae were not significantly different in the laboratory trials (Isenhour et al. 1990). Pfannenstiel and Yeargan (2002) noted that 85% of the predatory activity by *O. insidiosus* took place during the daytime when

lepidopteran eggs of *Helicoverpa zea* were monitored for feeding in soybean and sweet corn fields. Clements and Yeargan (1997) reported active feeding of eggs and first instar larvae of green cloverworm, *Plathypena scabra* (F.), by fourth instar and adult *O. insidiosus* on soybean. Eigenbrode et al. (1995) demonstrated diamondback moth, *Plutella xylostella* (L.), survival was significantly reduced on glossy leaves of cabbage with addition of a generalist predator, *O. insidiosus*, as compared to normal wax-cabbage both in greenhouse and field studies. Jacobson and Kring (1994) observed higher consumption of *Helicoverpa* eggs and neonate larvae than other instars by fourth instars and adults of *O. insidiosus* in laboratory trials. They noticed a lower predatory activity when neonate density increased continuously while holding egg density in constant. However, when egg density increased, predation by adult *O. insidiosus* increased (Jacobson and Kring 1994). Reed (1991) observed that as *O. insidiosus* density increased, the mortality of *Helicoverpa* eggs also increased. Musser and Shelton (2003) reported consumption of an average 2-3 eggs per day of the lepidopteran, *Ostrinia nubilalis* (Hübner), by *O. insidiosus* when alternate food source (pollen, aphids or combination of pollen and aphids) was absent. Egg consumption was lower when alternate food was provided.

Rondon et al. (2004) observed that third instar *O. insidiosus* preferred feeding on twospotted spider mite, *T. urticae* (25% feeding rate) compared with the cotton aphid, *A. gossypii*, (5% feeding rate) during one hour exposure periods. It was also noted that *O. insidiosus* (third instar nymphs) had shorter handling times on twospotted spider mite compared with cotton aphid (Rondon et al. 2004). High predatory activity was noted when *O. insidiosus* fed on eggs, larvae, and pupae of bandedwing whitefly, *Trialeurodes abutilonea* (Haldeman) (Watve and Clower 1976). Baez et al. (2004) reported that flower thrips, *Frankliniella occidentalis* (Pergande) and *F. tritici* (Fitch), larvae were significantly preyed upon than adults

by *O. insidiosus* on pepper flower. More dramatic prey movement was noticed with the presence of *Orius* than during their absence. They also reported a lower predation rate as compared to other studies on glass and filter paper substrates. This study did not show any significant prey preference between thrips species (Baez et al. 2004). Isenhour and Yeargan (1981) reported that *O. insidiosus* predatory activity decreased with an increase in prey density of the soybean thrip, *Sericothrips variabilis* (Beach), in soybean. McCaffrey and Horsburgh (1986) found that *O. insidiosus* preyed on the European red mite, *Pononychus ulmi* (Koch), demonstrating both type-two or three functional response curves fit the data obtained.

*O. insidiosus* was actively involved in predation when they were exposed to  $^{32}P$ -labels of *H. virescens* (McDaniel and Sterling 1979). Ponsard (2002) observed a mild reduction of 28% in *O. tristicolor* survival when he examined its longevity on *Bt*-transgenic cotton (expressing Cry1Ac *Bt*-toxin) and two other non-transgenic crops in both the laboratory and the field.

### **Insecticide Effects on Heteroptera: Big-eyed Bugs and Minute Pirate Bugs**

Elzen (2001) suggested the likelihood of resurgence and secondary pest outbreaks following a reduction in beneficial arthropods such as *Geocoris spp.* due to chemical pesticide treatments. DeBach and Bartlett (1951) reported adverse effects of chemical pesticides on natural enemy populations through direct toxicity, repellent action, and through removal of the beneficial arthropod prey or hosts. Graves et al. (1978) did not find evidence of resistance of *G. punctipes* and *O. insidiosus* to commonly used pesticides in cotton such as azinphosmethyl, carbaryl, dimethoate, DDT, malathion, methyl parathion, monocrotophos, toxaphene and combination of toxaphene and DDT. Carbaryl was the least toxic pesticide of those tested with 1.355 mg and 0.00366% concentration required to kill 50% of big-eyed bugs and minute pirate bugs, respectively. This finding also suggested that organophosphates were more toxic to both

heteropterans (Graves et al. 1978, McCutcheon and DuRant 1999). Tillman and Mulrooney (1997) suggested that residual toxicity of malathion is more severe up to 48 hours on *G. punctipes* than cyfluthrin. Fipronil showed more persistence in residual toxicity (even after 48 hours) on natural enemies, but showed more selectivity towards boll weevil, *Anthonomus grandis* (Boheman) (Tillman and Mulrooney 1997). Tillman and Mulrooney (2001) reported increasing *G. punctipes* mortality through 48 hours after ultra-low volume treatment of malathion on cotton leaves. Other pesticides such as cyfluthrin and fipronil also proved toxic to *G. punctipes* even in ultra-low volume treatment (Tillman and Mulrooney 2001).

Naranjo et al. (2002, 2004) observed reduction in the *G. punctipes* and *G. pallens* population in cotton growing areas where insecticide and insect growth regulators were used. McCutcheon and DuRant (1999) suggested that organophosphates (acephate, profenofos and sulprofos) and combined formulations such as acephate+ amitraz (an ovicide, formamidine amitraz), profenofos+amitraz and cyhalothrin (parathyroid) were toxic to the generalist predators *G. punctipes* and *G. pallens* in field cage studies when predators were exposed to residue of cotton (48 hours post-treatment with these pesticides) for 4 hours. Profenofos+amitraz and acephate+ amitraz caused mortality of 86.4% and 72.8% respectively. Carbamates (thiodicarb or methomyl) and *B. thuringiensis* subsp. *kurstaki* combined with amitraz were less toxic to predators. Cyhalothrin reduced big-eyed bug survival by 89.7% after 48 hours post treatment on cotton (McCutcheon and DuRant, 1999).

*Geocoris punctipes* was susceptible to various pesticides when residual studies were conducted on soybean foliage, paper and grass. Mortality of *G. punctipes* was as high as 100% (chlorfenapyr and methyl parathion) and as low as 21.9% (thiodicarb) when these pesticides were applied to soybean leaves (Boyd and Boethel 1998a). Spinosad was more toxic than

thiodicarb as it demonstrated higher mortality rates (Boyd and Boethel 1998b). Boyd and Boethel (1998a) also suggested that pyrethroid, permethrin and methyl parathion were more lethal to predacious heteropterans than chemicals such as emamectin benzoate, spinosad and imidacloprid on treated foliage of soybean. Emamectin benzoate caused less toxicity to geocorids compared to imidacloprid and spinosad (Boyd and Boethel 1998b). Other selective chemicals such as methoxyfenozide and indoxacarb were reported to have lower mortality than  $\lambda$ -cyhalothrin and acephate on heteropterans such as geocorids when tested for residual effects on soybean (Baur et al. 2003). Cockfield and Potter (1983) determined that the impact of bendiocarb and trichlorfon were mild and temporary but chlorpyrifos and isofenphos had severe impact on predatory arthropods in turfgrass system. Pesticide treatments with chlorpyrifos (0.56 AI/ha), cypermethrin (0.06 AI/ha) and esfenvalerate (0.06 AI/ha) dramatically reduced the *G. punctipes* population in soybean, while thiodicarb and methomyl were less deleterious to *G. punctipes* and more effective in suppressing velvetbean caterpillar, *A. gemmatalis* (Chandler and Sumner 1993). Ross and Brown (1982) found the larvicidal activity, interfering with the growth of *S. frugiperda* after application of the insecticide NMH (nitromethylene heterocycle) and SD 52618 by incorporation in artificial diet. Isenhour and Todd (1984) determined that the insecticide SD 52618 and other insecticides had no ovicidal or adult mortality effects on *G. punctipes* ensuring continuing predation on surviving lepidopteran pests on soybean.

Imidacloprid, tebufenozide, methoxyfenozide and spinosad were significantly less toxic to male *G. punctipes* than chlorfenapyr, endosulfan, and fipronil (Elzen 2001, Elzen and Elzen 1999, Elzen et al. 1988). Spinosad, tebufenozide, and azinphos-methyl were significantly less toxic to female *G. punctipes* than fipronil and endosulfan. These studies also showed that *Helicoverpa zea* egg consumption by *G. punctipes*, was greatly reduced in malathion,

endosulfan, fipronil, azinphos-methyl, and imidacloprid treatments compared with the control. Tebufenozide and lower doses of spinosad, however, were not different from the control. Elzen and Elzen (1999) demonstrated, that chlorfenapyr had an intermediate toxicity to big-eyed bugs. It not only increased fecundity by 30% but also significantly increased egg feeding capability of *Geocoris spp.* compared with the control. Azinphos-methyl, imidacloprid and spinosad at the recommended rate was less toxic to *O. insidiosus* than profenofos and malathion (Elzen et al. 1998). Elzen et al. (1998) also suggested that fipronil was comparatively less toxic to *O. insidiosus* than to *G. punctipes*. Tillman et al. (2003) observed that residual toxicity of oxamyl was lower than dicrotophos, fipronil,  $\lambda$ -cyhalothrin and acephate. Toxicity studies also showed that imidacloprid (70% mortality) was less severe than oxamyl (45% mortality) to *G. punctipes* (Tillman et al. 2003). Terry et al. (1993) reported that insecticides reduced predatory arthropods and predation on *S. frugiperda* pupae in turfgrass. Walker and Turnipseed (1976) reported that under field conditions, the insecticidal treatments of methyl parathion, carbaryl, and methomyl resulted in no significant changes in predatory activity, reproductive potential, and longevity of *Geocoris spp.* Tillman et al. (2001) examined toxicity through plant residue, tarsal contact and treated eggs a soluble concentrate formulation of an oxidiazine insecticide, indoxacarb on *G. punctipes*. They found that treated *Heliothis* eggs were toxic to female big-eyed bugs. Tarsal contact toxicity of indoxacarb was not as severe on the geocorid, however, they observed occurrence of indoxacarb residues on the leaf surface or waxy cuticle of the cotton plant. Direct ingestion was more severe under high humidity conditions. (Tillman et al. 2001). Tillman and Mulrooney (2002) observed that  $\lambda$ -cyhalothrin was a highly toxic insecticide showing direct and residual effect on *G. punctipes* compared to S-1812, which was selectively toxic (at higher rates) to specific insects.

Badji et al. (2004) reported the abundance of *O. insidiosus* populations as secondary predators correlated to *S. frugiperda* abundance in a maize growing area, where deltamethrin was regularly used to control the pest. Bostonian and Akalach (2004) observed that S-kinoprene was the least toxic pesticide while dimethoate and abamectin were the most toxic chemicals among others (indoxacarb, endosulfan and insecticidal soap). Toxicity of indoxacarb on *O. insidiosus* became more apparent from the seventh day after treatment in a greenhouse study by Bostonian and Akalach (2004). Pietrantonio and Benedict (1999) demonstrated residual toxicity effects of tebufenozide, spinosad and chlorfenapyr on *O. insidiosus* and found that chlorfenapyr caused more *O. insidiosus* mortality than tebufenozide and spinosad by 52% at 2 hours and 44% after 24 hours. There was no significant difference in *Orius* mortality between tebufenozide and spinosad treatment after 2 and 24 hours (Pietrantonio and Benedict 1999). Petri dish experiments showed severe toxicity (high mortality) on male, female and nymphs of *O. insidiosus* when spinosad, imidacloprid and indoxacarb were tested compared to field and greenhouse experiments (Stuebaker and Kring 2003). Stuebaker and Kring (2003) reported 95-100% of mortality *O. insidiosus* using  $\lambda$ -cyhalothrin and 50-100% mortality using fipronil, emamectin benzoate and abamectin in petri-dish, greenhouse and field trials.

Al-Deeb et al. (2001) found that fipronil and thiamethoxam were less toxic to *O. insidiosus* adults than imidacloprid. Studies showed pesticides such as ethyl parathion, permethrin, chlorpyrifos and cyfluthrin caused more severe adult mortality than carbofuran and  $\lambda$ -cyhalothrin on corn and sorghum. General results showed more severe mortality rates on seed treatments than on leaves of sorghum and corn (Al-Deeb 2001). In citrus, Michaud and Grant (2003) reported higher toxicity for carbaryl, methidathion, bifenthrin and fenpropathrin than Z-

cypermethrin and indoxacarb when exposing second instar *O. insidiosus* to treated leaves after 24 hours.

### **Role of Insect Growth Regulators and Viruses**

Bull et al. (1973) showed that *G. punctipes* performance was hampered by apparent morphological deformities when topical treatments of different juvenile hormone analogues (1 µg/insect and 5 µg/insect) were applied. James (2004) observed the nymphal development and survival when a chitin synthesis inhibitor, buprofezin insecticide was directly applied in laboratory trials. He observed severe mortality (up to 85%) as nymphs failed to undergo complete ecdysis, thus, failing to reach adulthood. At the same time, he noticed 100% emergence in spite of buprofezin treatment. All immature individuals of *O. tristicolor* survived and successfully developed to adulthood (James 2004). Another chitin synthesis inhibitor, diflubenzuron was considered as a promising chemical controlling cotton pests including boll weevils population (Keever et al. 1977). Studies were conducted to determine its impact on beneficials such as *G. punctipes* and *O. insidiosus*, and significant differences in the ratio of adults to nymphs were observed, indicating a discrepancy in the reproduction rate when treated and untreated areas were compared. Nevertheless, it was also noted that adult populations quickly returned to normal in the treated areas in cotton (Keever et al. 1977).

Johansen and Eves (1972) observed the impact of trichlorfon sprays on beneficial arthropods, including *G. pallens* and *G. bullatus*, and found no toxic effect with treatments in alfalfa. Morrison et al. (1979) examined the effect of soil-applied pesticides such as aldicarb, carbofuran, ethoprop, fensulfothion and phorate on corn earworm and beneficial insects in soybean. They found that nymphs and adults of *O. insidiosus* were greatly reduced in aldicarb treated plots compared to those treated with other pesticides. Genetically engineered or normal



baculoviruses are used as biopesticides in cotton for control of lepidopteran pests (Li et al. 1999). Li et al. (1999) studied the impact of recombinant viruses (four AcNPVs and one HzNPV) and AcNPVs and HzNPV wild type each) on *G. punctipes* and other beneficial insects and concluded that none of them had significant differences in food consumption, fecundity, mobility or survival when compared to untreated ones (Li et al. 1999).

### **Effect of Herbicides**

The herbicides acifluorfen and bentazon were examined for residual effects on the production of viable eggs by *G. punctipes* in soybean in greenhouse and field trials. Both experiments suggested an absence of any residual effect of these herbicides on oviposition or survival of adult big-eyed bugs (Farlow and Pitre 1983). Toxaphene, widely used as a herbicide to control the common soybean weed, sickle pod, *Cassia obtusifolia* L., was studied to find the impact on the beneficial insects in North Carolina. Reports suggested that there was a reduced effect of this chemical on the beneficial insect populations including *G. punctipes* and *O. insidiosus*. Toxaphene treated plots succeeded in reducing thrips, (*Seriothrips variabilis* Beach) but higher populations of *Helicoverpa zea* were observed when compared to control plots (Huckaba et al. 1983). Contrastingly, Isenhour et al. (1985) reported a significant reduction in *G. punctipes* populations in soybean growing areas in South Georgia due to toxaphene application. Other results indicate no significant evidence of any toxic effects, such as higher mortality or reduced female fecundity when nymphs and adults *G. punctipes* were exposed to 'Roundup' (transgenic) soybean leaves or direct treatment of glyphosate herbicide (Jackson and Pitre 2004a). Nevertheless, Jackson and Pitre (2004b) reported a mild reduction of *G. punctipes* populations for a period of less than three weeks when 'Roundup ready' treated plots were compared to control plots. This reduction could have occurred due to immediate reduction of

weed flora in soybean plots (Jackson and Pitre 2004b). When dinoseb, diuron and MSMA (monosodiummethanearsonate) herbicides were directly applied to cotton, *G. punctipes* and *O. insidiosus* populations quickly re-established after a temporary reduction (Stam et al. 1978).

### **Biology and Distribution of Fall Armyworm**

Fall armyworm, *S. frugiperda*, is a sporadic pest in the southern United States especially Florida, Georgia, Texas and Gulf coast (Sparks 1979, Brandenburg, 2002). It overwinters in southern Texas, Southern Florida and the Caribbean (Sparks 1979), as it lacks any mechanism for diapause. Migration starts during the spring in the Southern states (Johnson 1987). Generally, two to three generations occur in the South and one generation in Northern regions. The warm season grasses attacked by *S. frugiperda* include bermudagrass, St. Augustinegrass and others. Cool-season turfgrasses infested by fall armyworm are bluegrass, ryegrass, fine fescues and bentgrass. Nagoshi and Meagher (2004) reported the population dynamics of *S. frugiperda*, with higher numbers occurring during fall and spring periods rather than in summer months in agricultural fields and turfgrass sod farms.

Fall armyworm adults are nocturnal (Sparks 1979) in behavior and their activity starts when dusk falls. Adult females emit pheromones to attract males for mating. The temperature and wind velocity determine male response to pheromones and flight direction respectively. Adults lay eggs on the turfgrass and on other vegetation as well as windowpanes, buildings, flags, signs and shed etc on golf courses. Johnson (1987) reported that a fall armyworm deposits clusters of 900-1000 eggs/female, which are covered by scales (Sparks 1979). Fall armyworms have a relatively short generation time of 30 days and good dispersal ability, making it a successful colonizing species. It is redistributed over most of the Eastern USA each growing season. Eggs emerge in 7-10 days; the caterpillars feed on the leaves, stems, and stolons for 2-4

weeks depending on the temperature. The damage begins from edges of turf to the center of the field. Caterpillars pupate in soil for about 2 weeks (Brandenburg, N. Carolina State University, Ground maintenance, July 2002).

Hobollah et al. (2004) reported on the occurrence and direct control potential of parasitoids and predators of the fall armyworm on maize in Mexico. The herbivore-induced volatile emissions in maize plants may help to increase the effectiveness of natural enemies, which use these volatiles to locate their prey (Hobollah et al. 2004). Molina-Ochoa et al. (2003) reported the pathogens and parasitic nematodes associated with populations of fall armyworm larvae in Mexico. Williams et al. (1997) pointed out *S. frugiperda* as an important pest of maize. Canas and O'Neil (1998) showed the natural enemy abundance, concentration and impact of treated maize fields on *S. frugiperda* populations in Honduras. Terry et al. (1993) reported that insecticides such as carbaryl, cyfluthrin, and isazofos, affects predation of *S. frugiperda* pupae in turf. Predators in turf systems other than heteropterans include ground beetles (Carabidae), rove beetle (Staphylinidae), spiders (Araneae) and ants (Formicidae) (Braman and Pendley 1993a, 1993b, 2002b, 2000c).

### **Resistant Turf Taxa: Performance of Fall Armyworm**

Braman et al. (2000a) identified potential resistance in zoysiagrass, (*Zoysia spp.*) 'Cavalier', 'Emerald', 'DALZ8501', 'DALZ8508', 'Royal', and 'Palisides'. At the same time, different selections of paspalum such as 561-79, Temple-2, PI-509021, and PI-509022 showed reduction of fall armyworm developmental periods. Braman et al. (2002a) reported endophyte effects in grasses on fall armyworm. Relative resistance studies on cool-season grasses with and without endophyte were also compared with warm season grasses that do not have endophytes. The cool-season grass, 'Dawson' E+ showed the larval and pupal weight difference of *S.*

*frugiperda*, on endophyte-infected grass is evident on most of the turfgrass species. This and other studies have also illustrated significant variation in the resistance conferred depending factors such as genotype of the endophyte, host genotype, interaction of host and the endophyte, soil PH, soil fertility, presence of allelochemicals and temperature.

Braman et al. (2000a, 2002a) reported the *S. frugiperda* showed varying degrees of resistance to different turfgrass species such as seashore paspalum ('Sea Isle I' and '561-79'), bermudagrass ('TifSport' and 'TifEagle') and zoysiagrass ('Cavalier' and 'Palisades').

Shortman et al. (2002) reported that zoysiagrass ('Emerald'), *Z. japonica* and bermudagrass ('Tifway') and seashore paspalum ('Sea Isle 2000') were tolerant to twolined spittle bug, *Prosapia bicincta* (Say). *Geocoris uliginosus* occurs in susceptible and pest-resistant turfgrasses (Reinert 1978), preying on *S. frugiperda* larvae (Braman 2003).

### **Research Objectives**

Beneficial arthropods such as heteropterans, big-eyed bugs (*G. punctipes* and *G. uliginosus*), minute pirate bugs (Anthocoridae), damsel bugs (Nabidae) and predaceous whitemarked fleahoppers (Miridae) were often collected in bermudagrass, zoysiagrass, and centipedegrass (Braman et al. 2002b, Braman and Pendley 1993a, Braman et al. 2003). Davis and Smitley (1990b) had reported the occurrence of big-eyed bug, *G. bullatus* and other predators such as Formicidae, Nabidae, Reduviidae and Carabidae individuals in fine fescue (*Festuca rubra* L.) and Kentucky bluegrass (*P. pratensis* L.) through transect sampling from residential lawns in Michigan. Nevertheless, not much study was done on occurrence and abundance of heteropteran predators and their prey groups influenced by turf attributes such as different turf taxa, grass density, height and weed density on warm-season turfgrasses. Our comparative study of predatory heteropterans in different turf 'taxa' in residential settings

addressed the following objectives: to determine the 1) occurrence and abundance of predatory heteropterans and other arthropods, 2) influence of turf taxa, grass density, height, and weed density, and 3) comparative effectiveness between sweeping and vacuum sampling techniques for quantification of hemipterans in turf.

The fact that attributes of turfgrass especially plant resistance have influenced phytophagous insects such as fall armyworm in turf, which directly or indirectly influenced occurrence and predatory efficiency of heteropteran predators especially big-eyed bugs in managed turf (Braman et al. 2003, Braman and Duncan 2000a). Further studies are needed to understand the influence of turf taxa on predatory heteropterans such as *G. uliginosus* and *G. punctipes* (Heteroptera: Geocoridae). The major objective behind this study was 1) to determine the predatory potential of *G. uliginosus* and *G. punctipes* in different turfgrass taxa, and 2) evaluate the relative predatory performance of these heteropterans at different densities on neonates of fall armyworm, *S. frugiperda*.

Braman et al. (2004a) previously demonstrated the mortality rate of fall armyworm neonate and third instar larvae when mediated by varying levels of resistant turfgrass types and six-dose concentrations of three pesticides (chlorpyrifos, spinosad, and halofenozide). Resistant ‘Cavalier’ reported maximum mortality of fall armyworm first instar larvae on lower rates of halofenozide in laboratory and no surviving larvae in the field experiments. Survival of first instar larvae of fall armyworm was lower on ‘Cavalier’ zoysiagrass compared to bermudagrass and seashore paspalum when these grass taxa were exposed to lower rates of chlorpyrifos. However, survival of fall armyworms was higher on bermudagrass and seashore paspalum than when spinosad was used in a separate experiment. These studies focused on the contributing factors such as different mode of action of pesticides, varied levels of resistance and rate of

phytophagosity shown by fall armyworm (Braman et al. 2004a). Most of the studies conducted were on predator, *G. punctipes* with organophosphate and spinosad pesticides on field crops and few studies have been done on turfgrass systems. Studies were rarely conducted on the residual activity of pesticides influencing *G. punctipes*, *G. uliginosus* and *O. insidiosus* predation, either directly or indirectly on different turfgrass taxa. Hence, this study intends to integrate the direct and indirect effects with exposure of different levels of pesticides (chlorpyrifos, spinosad, and halofenozide) seeking survival of *G. uliginosus* and *G. punctipes* when mediated by different turfgrass taxa.

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**CHAPTER 2**  
**OCCURRENCE AND ABUNDANCE OF PREDATORY HETEROPTERA IN WARM-SEASON**  
**RESIDENTIAL TURFGRASS <sup>1</sup>**

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**ABSTRACT** Residential turfgrasses were sampled from May to July, 2005, in Georgia. Sweep and vacuum samples were collected from 20 residential lawns on three dates. The occurrence and abundance of predatory heteropterans and other arthropods were evaluated based on plant parameters such as turf taxon, density, height, and weed density. Grass taxon significantly influenced abundance of all predatory heteropterans in residential settings. However, Formicidae and Aphididae were not influenced by turf taxa. None of the predatory heteropterans were affected by turfgrass density. Numbers of anthocorids were significantly greater with an increase in turfgrass height and all stages of mirids more often collected as weed density increased. Anthocorids were most abundant in St. Augustinegrass and were strongly correlated with the abundance of chinch bugs. Predaceous mirids were more abundant in zoysiagrass than any other grass taxon, while geocorids were well represented in all turf taxa. Abundance of heteropterans captured was affected by sampling method except adult Geocoridae and adult Miridae. Vacuum samples collected significantly more individuals from diverse arthropod groups, including heteropterans, than sweep samples in residential turfgrass. Adults and especially nymphs of hemipterans were more numerous in the vacuum samples.

**KEYWORDS:** Predatory Heteroptera, Hemiptera, turfgrass, sweep sampling, vacuum sampling

The turfgrass system is inhibited by a diverse beneficial arthropod fauna including indigenous natural enemies (Reinert 1978) that regulates and naturally prevents pest outbreaks in the turfgrass systems (López and Potter 2000, Potter and Braman 1991). Various surveys have reported the occurrence, abundance and incidence of prey suppression by different predators and parasitoids in warm and cool season turf (Rogers and Potter 2004, Frank and Shrewsbury 2004, Potter and Braman 1991). Major soil dwelling predators recorded were rove beetles (Staphylinidae), ground beetles (Carabidae), spiders (Araneae) and ants (Formicidae) in different

turf taxa in the United States (Jo and Smitley 2003, Braman et al. 2002). Abundance of predaceous ants (*Pheidole spp.* and *Solenopsis spp.*), rove beetles and spiders were observed in pitfall traps in Kentucky bluegrass (*Poa pratensis* L.) (Cockfield and Potter 1984, Terry et al. 1993). Predaceous ants, *Lasius neoniger* Emery were abundant around of all collar and consumed 99% of black cutworm, *Agrotis ipsilon* Hufnagel eggs (Lepidoptera: Noctuidae) than 62% egg consumption on greens regions of golf courses with creeping bentgrass (López and Potter 2000). While other study showed *Solenopsis molesta* Say was responsible for 83% of Japanese beetle (Coleoptera: Scarabaeidae) egg removal in Kentucky bluegrass (Zenger and Gibb 2001).

Predatory heteropterans, big-eyed bugs (*Geocoris punctipes* Say and *G. uliginosus* Say), insidious flower bug (Anthocoridae), damsel bugs (Nabidae) and predaceous whitemarked fleahoppers (Miridae) were often collected in bermudagrass, zoysiagrass, and centipedegrass (Braman et al. 2002, Braman and Pendley 1993a, Braman et al. 2003). Davis and Smitley (1990b) reported the occurrence of the big-eyed bug, *Geocoris bullatus* (Say) and other predators, such as Formicidae, Nabidae, Reduviidae and Carabidae, in fine fescue (*Festuca rubra* L.) and Kentucky bluegrass (*P. pratensis*) in transect samples from residential lawns in Michigan. Predaceous nabids also were collected from Kentucky bluegrass pitfall samples (Cockfield and Potter 1985, Terry et al. 1993). Predatory heteropterans including the big-eyed bugs (*G. uliginosus* and *G. punctipes*) and predaceous mirids (*Spanagonicus albofasciatus* Reuter) were represented in turfgrasses with varying resistance to fall armyworm, *Spodoptera frugiperda* (J E Smith) (Braman et al. 2003, Braman et al. 2002).

Crocker and Whitcomb (1980) reported that *Geocoris spp.* behave differently when they are studied in the laboratory rather than in field conditions. Predation by *G. uliginosus* was

greater on a resistant zoysiagrass in laboratory studies where an extended developmental period rendered prey vulnerable to predation for an extended period. In the field, substantial predator induced reductions in fall armyworms were also realized in susceptible grasses (Braman et al. 2003). Davis and Smitley (1990b) suggested that turfgrass species structured the insect communities and modified the abundance of certain insect fauna. These studies have highlighted the need to evaluate the influence of plant mediated effects on the biology and behavior of predatory Heteroptera (Braman et al. 2003).

Urban landscapes, including residential turf are often intensely managed systems. Habitat structural complexity can be critical by directly or indirectly influencing the arthropod community (Shrewsbury and Raupp 2006). Turf maintenance activities have various effects on predators. Predators such as rove beetles, ground beetles, ants and spiders may quickly recover from periodic suppression by chemical pest management efforts in residential settings (Braman et al. (2000). However, occurrence and abundance of the predator community showed severe differences in high and low intensely maintained bluegrass and tall fescue (Cockfield and Potter 1985). Jo and Smitley (2003) observed that the abundance of carabids and staphylinids were not affected by mowing height in bluegrass. Ground dwelling big-eyed bugs, *G. uliginosus*, often observed in turf, also occur in wild flowers adjacent to turf, where they provide refuge and protection from insecticide treatments (Braman et al. 2002).

Davis and Smitley (1990b) observed a positive correlation between grass thatch thickness and occurrence of predators, including *G. bullatus*, formicids, nabids, reduviids, carabids and spiders, in fine fescue and Kentucky bluegrass. Turfgrass thatch thickness, dry weight of grass clippings and grass taxa may influence insect abundance. Thatch was positively correlated with abundance of chinch bug (*Blissus leucopterus hirtus* Montandon) (Davis and Smitley 1990b) and

indirectly provides protection from potential predators and pesticide applied to turf (Davis and Smitley 1990a). In other study, Koppenhöfer et al. (2003) tested for indirect effects of endophyte-infected tall fescue on soil-dwelling predators using pitfall samples and observed no difference in their activity.

Predaceous staphylinids are reported from home lawns and occasionally feed on alternate food sources such as earthworms, collembolans and pest species in turf systems (Vavrek and Niemczyk 1990). *Geocoris bullatus* attacks early stages of chinch bugs (Davis and Smitley 1990b). Braman et al. (2003) observed significant predatory activity of big-eyed bugs, preying on early larval stages and eggs of lepidopteran pests of turfgrass. Crocker and Whitcomb (1980) reported 17, 11 and 19 insect prey taxa of *G. bullatus*, *G. punctipes* and *G. uliginosus*, respectively, and also reported 67 species of minute (0.25-8.7 mm long) prey belonging to Arachnida and Diplopoda.

Previous studies showed different levels of occurrence and abundance of beneficial fauna, especially predatory Heteroptera, among turfgrasses with varying levels of resistance to fall armyworm, *S. frugiperda*. Bermudagrass and seashore paspalum supported more predatory heteropterans than did zoysiagrasses (Braman et al. 2003). Conservation biological control efforts will be aided by an in-depth understanding of insect-plant interactions in turfgrass. Our objective was to determine the influence of turf taxa, grass density, height, and weed density on occurrence and abundance of predatory Heteroptera. A secondary objective was to compare the effectiveness between sweeping and vacuum sampling techniques for quantification of hemipterans in turf.



## Materials and Methods

### Selection of residential lawns for sampling

Employees of the Griffin Campus, University of Georgia, Griffin, Georgia volunteered their lawns for our study. Twenty residential lawns were selected within Spalding County representing varying turfgrass taxa, with sufficient sampling area and proximity to the station. Three monthly visits to each site were conducted between 25 May to 26 July, 2005. All samples were collected during peak insect activity between 1000-1200 hours and 1400-1700 hours. Lawns were maintained by the homeowners, not by commercial landscape professionals. No insecticides were applied but two of the homeowners applied 'Atrazine' and 'imazapyr' herbicide for broadleaf weed control. Lawns sampled were two with common bermudagrass *Cynodon dactylon* (L.), nine with centipedegrass *Eremochloa ophiuroides* Munro Hack, six with St. Augustinegrass *Stenotaphrum secundatum* [Walt.] Kuntze, and three with zoysiagrass, *Zoysia spp.* lawns.

### Sample collection procedures

Two main insect collection techniques were used: sweep and vacuum sampling. Sampling methods were focused on quantification particularly of hemipterans. Previous studies indicated that *G. uliginosus* was more often collected in turf than *G. punctipes*, which is a common inhabitant of flowers in the landscape (Braman et al. 2002). Samples were collected from a 9.1 by 9.1 m area from each residential lawn. This area was further subdivided into quadrants of 4.6 by 4.6 m. Twenty-five sweeps were collected along a diagonal in each quadrant and vacuum samples were collected from twenty random suction using a 'Vortis' vacuum sampler (Burkhard manufacturing Co., Ltd, Herefordshire, England) from each quadrant. The 'Vortis' vacuum sampler covered 0.2 m<sup>2</sup> per suction, thus four square meters were sampled per

quadrant with air throughput of  $10.5 \text{ m}^3$  per minute. The standard sweep net used (Ward's, Rochester, NY) had an opening of  $0.03 \text{ m}^2$ , net occupied  $0.024 \text{ m}^3$  and a handle length of 0.92 m. Sweep samples in plastic bags and suction samples in plastic cups were temporarily stored overnight at  $4^\circ\text{C}$  to kill the sampled arthropods. Samples were cleaned, labeled, and stored in ethanol (70%), and subsequently, arthropods were quantified based on taxonomic classification.

### **Environmental parameters considered for the study**

This study investigated the influence of plant parameters on the occurrence and abundance of turf arthropods. Grass taxa, leaf density, height and weed taxa and density were recorded. Grass density was assessed using a plastic strip of 8.5 cm long, 6.5 cm breadth and 1 mm thickness and  $2.5 \text{ cm}^2$  incision in the center. This plastic strip was placed on the grass canopy and the number of leaves passing through the  $2.5 \text{ cm}^2$  area were counted. Grass density was randomly measured from each quadrant and an average was computed from each lawn on three dates of sampling separately. Grass height was recorded from each lawn on each date. Weed density was assessed by counting the number of weeds on a 13.1 m diagonal transect across the 9.1 by 9.1 m plot. The weed taxa along this transect was identified and recorded for evaluation. The level of shade in the lawn was recorded as sunny, partially shady and shady. The building structure, perennial woody plants, trees, and herbaceous annual flowering plants, were sketched for evaluation. This information was also related to insect diversity and abundance at each residential lawn.

### **Statistical analysis**

Data were transformed as the square root of the insect count plus 0.5. Grass density, grass height and weed density were designated as covariates. Analysis was done using the Proc mix procedure of SAS (SAS Institute 2003), mixed model with covariate, and mean separation

was accomplished using ‘least square means.’ Relationship among various groups of insects was assessed using the correlation procedure of SAS.

Diversity of arthropod communities inhabiting the different lawn taxa were assessed using Simpson’s diversity index ( $D$ ) (Magurran 1988, Siemann et al. 1997). We calculated diversity based on families rather than species, separating for each grass taxon. The total arthropods were grouped into heteropteran predators, other predators, and herbivores and detritivores as collected from four grass taxa observed in the residential turfs to see their diversity. Separate diversity indexes were calculated for each of the three-dates of sample collections.

Proportion of families (total individuals per family ‘ $i$ ’) relative to the sum of the total numbers of individuals from all families ( $pi$ ) were calculated and squared. The squared proportions for all the families were summed and the reciprocal was calculated.

$$D = \frac{1}{\sum_i p_i^2}$$

Simpson’s  $D$  is proportional to equitability for taxon richness ( $S$ ) (sum of families from each category, where at least one individual from each family is collected). Therefore, if equitability increases, richness also increases for a particular community. Simpson’s equitability ( $E_D$ ) otherwise called evenness can be calculated by taking the total of the maximum possible families assumed to be present in a turfgrass system. Equitability ( $E_D$ ) values fall between 0 and 1 and maximum evenness occurs if the value is 1 for:

$$E_D = \frac{D}{S}$$

## Results

### **Arthropod Fauna Collected by Sweep and Vacuum Sampling Methods from Residential Lawns**

A total of 504 samples were drawn from 20 residential lawns (Table 2.1). Samples were sorted into various order and family taxa under a compound microscope. A total of 333,278 arthropods were identified, of which 24,699 and 308,579 were sampled by sweep and vacuum sample methods, respectively. Vacuum sampling was more effective than sweep sampling. Arthropods in vacuum samples represented 92% of the total individuals collected. Order Hemiptera comprised 12% of the total arthropods. Seventy three percent of total number of Hemiptera collected were from vacuum samples. Most (92.3%) of the heteropterans were collected in vacuum samples, where 86.6% were nymphs and 13.4% adults. Eight percent of all heteropterans that were collected in sweep samples, 80.7% were adults. Of predatory heteropterans, 89% were collected by vacuum sampling method (Table 2.1). The vacuum method collected relatively more nymphs than adult Hemiptera, while sweeps collected mostly adults (Fig. 2.4).

### **Occurrence and Abundance of Heteroptera Including Predatory Heteroptera Influenced by Grass Parameters and Sampling Method**

All taxonomic groups were analyzed by grass taxon, height, and density and weed density. All arthropod taxa were significantly different among turf taxa (Table 2.2 a) except Formicidae ( $F = 1.14$ ;  $df = 4, 475$ ;  $P = 0.33$ ) and Aphididae ( $F = 2.12$ ;  $df = 4, 479$ ;  $P = 0.07$ ; Table 2.2 b and c). Heteropterans were consistently collected from each grass taxon (Fig 2.1 A and B). Families represented in samples included Anthocoridae, Geocoridae, Blissidae, Miridae, Nabidae, Pentatomidae, Alydidae, Reduviidae and Tingidae. Miridae, Anthocoridae,

Geocoridae and Blissidae were the most numerous. Total Heteroptera (all families together) were significantly different among grass taxon ( $F = 11.22$ ;  $df = 4, 479$ ;  $P < 0.0001$ ; Table 2.2a), sampling method ( $F = 24.36$ ;  $df = 1, 479$ ;  $P < 0.0001$ ), grass height ( $F = 13.94$ ;  $df = 1, 479$ ;  $P = 0.0002$ ), and density ( $F = 5.32$ ;  $df = 1, 479$ ;  $P < 0.0215$ ) but, were not affected by date ( $F = 2.53$ ;  $df = 2, 479$ ;  $P = 0.0806$ ) or weed density ( $F = 2.73$ ;  $df = 1, 479$ ;  $P = 0.0991$ ). Predatory Heteroptera, which included Geocoridae, Anthocoridae, Miridae, Nabidae and Pentatomidae, were recorded from all grass taxa, with Geocoridae, Anthocoridae and Miridae the most abundant (Fig. 2.1 C and D). Predatory Heteroptera (all families together) were also significantly influenced by grass taxa ( $F = 10.32$ ;  $df = 4, 479$ ;  $P < 0.0001$ ), sampling method ( $F = 24.84$ ;  $df = 1, 479$ ;  $P < 0.0001$ ), sampling date ( $F = 3.98$ ;  $df = 2, 479$ ;  $P < 0.0193$ ), grass height ( $F = 4.60$ ;  $df = 1, 479$ ;  $P < 0.0325$ ) and weed density ( $F = 10.15$ ;  $df = 1, 479$ ;  $P < 0.0015$ ), but not by grass density ( $F = 1.92$ ;  $df = 1, 479$ ;  $P < 0.1661$ ; Table 2.2a).

Grass taxon (when all grass taxon considered) significantly influenced abundance of all individual heteropterans which included total Geocoridae ( $F = 4.55$ ;  $df = 4, 479$ ;  $P = 0.0013$ ), adult Geocoridae ( $F = 2.52$ ;  $df = 4, 476$ ;  $P = 0.0403$ ), nymphal Geocoridae ( $F = 3.34$ ;  $df = 4, 476$ ;  $P = 0.0103$ ), total Anthocoridae ( $F = 11.29$ ;  $df = 4, 479$ ;  $P < 0.0001$ ), adult Anthocoridae ( $F = 6.73$ ;  $df = 4, 479$ ;  $P < 0.0001$ ), nymphal Anthocoridae ( $F = 9.40$ ;  $df = 4, 479$ ;  $P < 0.0001$ ), total Miridae ( $F = 16.72$ ;  $df = 4, 479$ ;  $P < 0.0001$ ), adult Miridae ( $F = 19.78$ ;  $df = 4, 479$ ;  $P < 0.0001$ ) and nymphal Miridae ( $F = 14.01$ ;  $df = 4, 479$ ;  $P < 0.0001$ ) when both the sample methods were considered.

In vacuum samples, most heteropterans were collected from St. Augustinegrass (mean =  $33.7 \pm 25.8$ ) followed by zoysiagrass (mean =  $17.3 \pm 11.6$ ). Abundance of total Blissidae ( $F = 12.41$ ;  $df = 4, 479$ ;  $P < 0.0001$ ), adult Blissidae ( $F = 11.45$ ;  $df = 4, 479$ ;  $P < 0.0001$ ) and

nymphal Blissidae ( $F = 8.82$ ;  $df = 4, 478$ ;  $P < 0.0001$ ) differed significantly among grass taxa. Predatory Heteroptera were more abundant on zoysiagrass (mean =  $16.78 \pm 11.3$  in vacuum sample and mean =  $1.9 \pm 1.2$  in sweep samples; Fig. 2.1 C and D) in both sample methods, followed by St. Augustinegrass (mean =  $9.5 \pm 11.3$  in vacuum sample and mean =  $0.3 \pm 0.1$  in sweep sample; Table 2.3a). Predatory Heteroptera abundance correlated positively and significantly with Blissidae ( $r = 0.4629$ ;  $P < 0.0001$ ) and Delphacidae ( $r = 0.4545$ ;  $P < 0.0001$ ; Fig. 2.1 C and D vs. 2.3 A, B, C, and D).

Anthocoridae were more abundant on St. Augustinegrass (mean =  $8.2 \pm 4.8$  in vacuum samples and mean =  $0.1 \pm 0.1$  in sweep samples; Fig. 2.2 A and B) than other grass taxa in the study. Anthocoridae were significantly associated with Blissidae ( $r = 0.6719$ ;  $P < 0.0001$ ) and Delphacidae ( $r = 0.8839$ ;  $P < 0.0001$ ; Fig. 2.2 A and B VS Fig. 2.3). Both Blissidae (mean =  $24.2 \pm 21.2$  in vacuum sample and mean =  $1.1 \pm 0.7$  in sweep samples) and Delphacidae (mean =  $108.3 \pm 49.2$  in vacuum samples and mean =  $48.7 \pm 23.7$ ) were more abundant in St. Augustinegrass than any other grasses (Fig. 2.3). Miridae were abundant in the zoysiagrass (mean =  $2.8 \pm 2.0$  sweep samples, mean =  $15.0 \pm 10.4$  vacuum samples; Fig. 2.2 E and F). Geocorids occurred in all grass taxa (Fig. 2.2 C and D).

Vacuum sampling collected significantly more individuals than sweep netting for all heteropterans including total Geocoridae ( $F = 47.39$ ;  $df = 1, 479$ ;  $P < 0.0001$ ), nymphal Geocoridae ( $F = 44.06$ ;  $df = 1, 476$ ;  $P < 0.0001$ ), total Anthocoridae ( $F = 8.01$ ;  $df = 1, 479$ ;  $P = 0.0048$ ), adult Anthocoridae ( $F = 6.75$ ;  $df = 1, 479$ ;  $P < 0.0097$ ), nymphal Anthocoridae ( $F = 6.70$ ;  $df = 1, 479$ ;  $P = 0.0100$ ), total Miridae ( $F = 4.25$ ;  $df = 1, 479$ ;  $P = 0.0397$ ), and nymphal Miridae ( $F = 4.37$ ;  $df = 1, 479$ ;  $P = 0.0371$ ), adult Blissidae ( $F = 6.03$ ;  $df = 1, 478$ ;  $P = 0.0144$ ),

nymphal Blissidae ( $F = 6.28$ ;  $df = 1, 478$ ;  $P = 0.0125$ ) except for adult Geocoridae ( $F = 3.38$ ;  $df = 1, 476$ ;  $P = 0.0665$ ) and adult Miridae ( $F = 0.40$ ;  $df = 1, 479$ ;  $P = 0.5277$ ). Abundance of all heteropterans varied significantly among sampling dates except for Anthocoridae (Table 2.2 a and b; Fig. 2.4).

### **Abundance of Other Hemipterans Influenced by Grass Taxa and Sampling Method**

Other hemipterans were also collected from all of the grass taxa. Vacuum samples collected more individuals compared to the sweep samples (Table 2.3a). Both of the life stages of Hemiptera were collected by the vacuum sample method. Sweep samples collected relatively more adults than nymphal stages of Hemiptera. The major families were Cicadellidae, Delphacidae, Membracidae, Aphididae and Cercopidae, with Cicadellidae and Delphacidae being collected most often. Total number of Cicadellidae ( $F = 5.25$ ;  $df = 4, 473$ ;  $P = 0.0004$ ), adult Cicadellidae ( $F = 8.95$ ;  $df = 4, 473$ ;  $P < 0.0001$ ) and nymphal Cicadellidae ( $F = 2.88$ ;  $df = 4, 474$ ;  $P = 0.0224$ ), total Delphacidae ( $F = 27.44$ ;  $df = 4, 473$ ;  $P < 0.0001$ ), adult Delphacidae ( $F = 39.02$ ;  $df = 4, 474$ ;  $P < 0.0001$ ) and nymphal Delphacidae ( $F = 15.19$ ;  $df = 4, 476$ ;  $P < 0.0001$ ) were significantly different among grass taxa (Table 2.2b). Grass taxon ( $F = 10.61$ ;  $df = 4, 476$ ;  $P < 0.0001$ ) significantly affected Cercopidae abundance. Cercopids were collected from all grass taxa except zoysiagrass, and they were frequently collected ( $F = 6.86$ ;  $df = 1, 476$ ;  $P = 0.0091$ ) in vacuum samples (Table 2.2b). Sampling method had a significant effect on capture number of adult Cicadellidae ( $F = 15.0$ ;  $df = 1, 473$ ;  $P = 0.0001$ ), nymphal Cicadellidae ( $F = 58.08$ ;  $df = 1, 474$ ;  $P < 0.0001$ ), and nymphal Delphacidae ( $F = 10.18$ ;  $df = 1, 476$ ;  $P = 0.0015$ ), but not on adult Delphacidae ( $F = 2.93$ ;  $df = 1, 474$ ;  $P = 0.0876$ ; Table 2.2b and Fig. 2.4).

### **Abundance of Other Predatory Arthropods (excluding Hemiptera) and Parasitoids**

Adult rove beetles ( $F = 2.88$ ;  $df = 4, 477$ ;  $P = 0.0225$ ) and spiders ( $F = 2.76$ ;  $df = 4, 470$ ;  $P = 0.0272$ ), were also influenced by grass taxon. Vacuum samples collected more adult Staphylinidae and spiders than sweep samples ( $F = 91.61$ ;  $df = 1, 477$ ;  $P < 0.0001$ ;  $F = 233.79$ ;  $df = 1, 470$ ;  $P < 0.0001$ ; Table 2.2c). Staphylinidae and spiders were most abundant in St. Augustinegrass (Table 2.3b). Vacuum samples collected significantly more ants than sweeping ( $F = 225.65$ ;  $df = 1, 475$ ;  $P < 0.0001$ ). Formicids were equally collected from all grass taxa (Braman et al. 2003). Parasitic hymenopteran abundance was significantly affected by grass taxon ( $F = 8.43$ ;  $df = 4, 475$ ;  $P < 0.0001$ ), sampling methods ( $F = 101.83$ ;  $df = 1, 475$ ;  $P < 0.0001$ ) and date ( $F = 8.37$ ;  $df = 2, 475$ ;  $P = 0.0003$ ). Hymenopterans were abundant in St. Augustinegrass (Table 2.2c and 2.3b).

### **Evaluation of Other Non-Predatory Arthropods**

Potential prey items, in addition to hemipterans collected in samples, included Collembola, Thysanoptera, Dipterans and Acari. Collembolan occurrence and abundance were significantly influenced by grass taxa (sminthurids,  $F = 5.64$ ;  $df = 4, 470$ ;  $P = 0.0002$  and other Collembola  $F = 4.47$ ;  $df = 4, 473$ ;  $P = 0.0015$ ), sampling method (sminthurids,  $F = 149.96$ ;  $df = 1, 470$ ;  $P < 0.0001$  and other Collembola,  $F = 433.88$ ;  $df = 1, 473$ ;  $P < 0.0001$ ) and date of sampling (Table 2.2c).

Thrips and mites could be potential prey items for predatory heteropterans. Thrips (excluding Phlaeothripidae) ( $F = 5.97$ ;  $df = 4, 475$ ;  $P = 0.0001$ ) and Phlaeothripidae ( $F = 2.68$ ;  $df = 4, 478$ ;  $P = 0.0310$ ; Table 2.2a) were significantly different with turf taxa (Table 2.2c). Number of thrips (excluding Phlaeothripidae) were abundant in the sweep samples from St.



Augustinegrass (mean =  $22.5 \pm 20.9$ ) and vacuum samples from zoysiagrass (mean =  $12 \pm 5.175$ ) and Phlaeothripidae were in all turf taxa (Table 2.3b). Mites were collected from all turf taxa and were abundant in the vacuum samples. Some of the predaceous and parasitic dipterans species were also in samples but, their role in pest management is unknown. Grass taxa ( $F = 3.96$ ;  $df = 4, 470$ ;  $P = 0.0036$ ) and sample method ( $F = 4.06$ ;  $df = 1, 470$ ;  $P = 0.0445$ ) were significant for dipterans (Table 2.2c). Coleopterans, excluding staphylinids were found in all turfgrass taxa ( $F = 5.85$ ;  $df = 4, 473$ ;  $P = 0.0001$ ; Table 2.2a and 2.3b). Mites ( $F = 269.43$ ;  $df = 1, 470$ ;  $P < 0.0001$ ), thrips ( $F = 5.80$ ;  $df = 1, 473$ ;  $P = 0.0164$ ) and dipterans ( $F = 4.06$ ;  $df = 1, 470$ ;  $P = 0.0445$ ) were more effectively sampled-with the vacuum samples (Table 2.3b).

### **Effect of Grass Height and Density on Arthropods Abundance**

Anthocoridae ( $F = 16.80$ ;  $df = 1, 479$ ;  $P < 0.0001$ ), Blissidae ( $F = 20.34$ ;  $df = 1, 479$ ;  $P < 0.0001$ ), Cicadellidae ( $F = 72.24$ ;  $df = 1, 473$ ;  $P < 0.0001$ ), Delphacidae ( $F = 88.97$ ;  $df = 1, 473$ ;  $P < 0.0001$ ), Formicidae ( $F = 24.31$ ;  $df = 1, 475$ ;  $P < 0.0001$ ), Hymenoptera (excluding ants) ( $F = 60.23$ ;  $df = 1, 475$ ;  $P < 0.0001$ ), Diptera ( $F = 19.47$ ;  $df = 1, 470$ ;  $P < 0.0001$ ), adult Staphylinidae ( $F = 7.40$ ;  $df = 1, 477$ ;  $P = 0.0068$ ), non-sminthurid Collembola ( $F = 8.99$ ;  $df = 1, 473$ ;  $P = 0.0029$ ), mites ( $F = 6.48$ ;  $df = 1, 470$ ;  $P = 0.0112$ ) and spiders ( $F = 28.72$ ;  $df = 1, 470$ ;  $P < 0.0001$ ) were positively affected by increase in grass height (Table 2.2c). Grass height was an important parameter positively affecting Anthocoridae ( $F = 21.26$ ;  $df = 135, 479$ ;  $P < 0.0001$ ), Blissidae ( $F = 21.44$ ;  $df = 135, 479$ ;  $P < 0.0001$ ) and Delphacidae ( $F = 57.94$ ;  $df = 132, 479$ ;  $P < 0.0001$ ) in St. Augustinegrass (Fig. 5). Grass height did not influence Miridae ( $F = 0.11$ ;  $df = 1, 479$ ;  $P = 0.7383$ ) or Geocoridae ( $F = 0.42$ ;  $df = 1, 479$ ;  $P = 0.5175$ ; Table 2.2a).

Grass density was not a significant determinant for any of the predatory heteropterans. However, grass density was significant for Blissidae ( $F = 7.30$ ;  $df = 1, 479$ ;  $P = 0.0072$ ),

Delphacidae ( $F = 5.40$ ;  $df = 1, 473$ ;  $P = 0.0206$ ), Sminthuridae ( $F = 22.74$ ;  $df = 1, 470$ ;  $P < 0.0001$ ), other Collembola ( $F = 4.36$ ;  $df = 1, 473$ ;  $P = 0.0372$ ), Thripidae ( $F = 9.59$ ;  $df = 1, 475$ ;  $P = 0.0021$ ), and Phlaeothripidae ( $F = 4.79$ ;  $df = 1, 478$ ;  $P = 0.0291$ ; Table 2.2a, b and c).

### **Effect of Weeds on Abundance of Predatory and Non-Predatory Arthropods**

The major broadleaf weed species included yellow woodsorrel (*Oxalis spp.*), plantain (*Plantago spp.*), common lespedeza [*Lespedeza striata* (Thunb.) H. & A], ground ivy (*Glechoma hederacea* L.), dandelion (*Taraxacum officinale* Weber), hop clover (*Trifolium dubium* Sibth.), violet (*Viola spp.*), annual bluegrass (*Poa annua* L.), chickweed (*Drymaria cordata* L.) Willd. ex Roem. and Schult.), white clover (*T. repens* L.), hawksbeard [*Youngia japonica* (L.) DC.] and grassy weeds such as bermudagrass (*Cynodon dactylon* L.) and Southern crabgrass (*Digitaria ciliaris* (Retz) Koel).

Total Miridae ( $F = 10.44$ ;  $df = 1, 479$ ;  $P = 0.0013$ ), adult Miridae ( $F = 13.75$ ;  $df = 1, 479$ ;  $P = 0.0002$ ), nymphal Miridae ( $F = 9.73$ ;  $df = 1, 479$ ;  $P = 0.0019$ ), total Geocoridae ( $F = 9.35$ ;  $df = 1, 479$ ;  $P = 0.0024$ ) and nymphal Geocoridae ( $F = 9.19$ ;  $df = 1, 476$ ;  $P = 0.0006$ ) increased with increasing weed density. Geocorid nymphs were more numerous than adults. Other arthropod groups positively influenced by weed density included nymphal Cicadellidae ( $F = 8.44$ ;  $df = 1, 474$ ;  $P = 0.0038$ ), Cercopidae ( $F = 4.02$ ;  $df = 1, 476$ ;  $P = 0.0455$ ), mites ( $F = 5.01$ ;  $df = 1, 470$ ;  $P = 0.0257$ ), Thripidae ( $F = 38.32$ ;  $df = 1, 475$ ;  $P < 0.0001$ ), Phlaeothripidae ( $F = 10.04$ ;  $df = 1, 478$ ;  $P = 0.0016$ ), and Sminthuridae ( $F = 8.85$ ;  $df = 1, 470$ ;  $P = 0.0031$ ; Table 2.2b and 2.2c).

### **Evaluation of Diversity, Richness and Evenness in Residential Turf**

Simpson's diversity index ( $D$ ) showed the St. Augustinegrass had maximum diversity of 4.397 followed by centipedegrass and zoysiagrass (Table 2.4a). Over the season, maximum

evenness of predators occurred in St. Augustinegrass (0.73 and 0.88) compared with other turfgrass taxa. The category, herbivores and detritivores had lower evenness during the entire sampling period (Table 2.4a). The Simpson's index for the first date showed that richness and evenness of heteropteran predators were fairly similar on centipedegrass, St. Augustinegrass and zoysiagrass (Table 2.4b). The indices for heteropteran predators progressively increased with the second and third date of sampling on, St. Augustinegrass and zoysiagrass (Table 2.4c and 2.4d).

### **Discussion**

Genetic variation of plant species is a factor that could reflect either directly or indirectly on diversity and abundance of arthropod community in an ecosystem (Fritz 1992). Johnson and Agrawal (2005) illustrated that plant genotype and its variation could more directly influence herbivorous and omnivorous arthropods than obligate predators since, they are more directly exposed to plant defense. Our study showed that occurrence and abundance of all arthropod groups were influenced by turfgrass taxa, except the ants and aphids in residential settings. Abundance of predatory Heteroptera followed the pattern zoysiagrass > St. Augustinegrass > centipedegrass > bermudagrass (Fig. 2.1 C and D); Major contributing predatory Heteroptera in our study were mirids. In contrast, previous field plot studies reported a greater abundance of predatory heteropterans on bermudagrass and seashore seashore paspalum than on zoysiagrasses (Braman et al. 2003). This disparity in abundance of predaceous heteropterans between our study and Braman et al. (2003) may be because of varied physical and ecological settings of different residential turfs as compared to experiment plots or may be due to occurrence of alternate prey items in some of the residential turf at the time of sampling. Our study showed that mirids, primarily *Spanogonicus albofasciatus* (Reuter), were most abundant in zoysiagrass.

These mirids fed mainly on lepidopteran pests (*Heliothis zea* Boddie and *Pseudoplusia includens* Walker) in soybean (Neal et al. 1972). In our study, mirids increased with increasing weed density in the residential lawns. They might have benefited from weeds in zoysia, as supplemental nutritional source or presence of alternate prey items in zoysiagrass when target prey were not available. Some mirids are known to be phytophagous and predaceous in agroeco-systems, depending on the specific time, crop stage and location. Some studies have suggested that mirid nymphs often feed on spider mite eggs and adults, bollworm eggs and larvae, lygus bug eggs and all stages of banded whitefly (Butler 1965, Butler and Stoner 1965) on weed species in cotton growing areas (Stoner and Bottger 1965) but their diets have rarely been explored in turfgrass. Stoner and Bottger (1965) also indicate phytophagous tendencies of mirids when in high numbers on cotton and reported that pest control measures are inevitable during seedling stages of cotton. More predation studies are required in warm-season turfs as few published data are available.

In addition, a good correlation of predatory heteropterans was observed with planthopper (Delphacidae) and chinch bug (Blissidae) abundance. This observation was supported by earlier studies, which indicated a significant correlation of planthopper abundance in seashore paspalum and bermudagrass with predatory Heteroptera (Braman et al. 2003). Predatory Heteroptera (primarily anthocorids) were abundant on St. Augustinegrass in our study (Fig. 2.2 A and B). Lower numbers of anthocorids were regularly captured in pitfall traps on centipedegrass (Braman and Pendley 1993a). Their abundance was related with increase of chinch bugs and planthoppers (Fig. 2.3). Few predatory studies have been conducted with anthocorids in turf grasses. On the other hand, chinch bugs are serious turf pests in the Southern United States, especially on St. Augustinegrass whereas planthoppers are often considered more as a nuisance

in residential turf than as potential pest species (Potter and Braman 1991). This positive correlation did not indicate any predatory relationship between anthocorids and blissids from the data in St. Augustinegrass. However, *Orius insidiosus* (Say) adults were reported heavily consume of eggs of fall armyworm, *S. frugiperda* (Isenhour et al. 1990), and *Helicoverpa zea* (Boddie) in soybean and sweet corn fields (Pfannenstiel and Yeargan 1998), and eggs and first instar larvae of green cloverworm, *Plathypena scabra* (F.), in soybean (Clements and Yeargan 1997).

*Geocoris punctipes* are considered foliage dwellers in vegetables and field crops (Eubanks and Denno 1999, Cospers et al. 1983) and on turfgrass (Dunbar 1971), but *G. uliginosus* predominantly inhabits in the soil surface of turf as often recorded in samples (Braman et al 2003). Previous field studies have suggested that big-eyed bugs were more abundant in seashore paspalum and bermudagrass than in zoysiagrass (Braman et al. 2003), but in the residential lawns, they were relatively more abundant on centipedegrass. Braman et al. (2002) reported increased occurrence of big-eyed bugs in turfgrass grown adjacent to wildflowers. Braman et al. (2003) demonstrated significant predation by *G. uliginosus* on neonates of the fall armyworm, *S. frugiperda*, in seashore paspalum. Geocoridae have shown nutritional flexibility when availability of prey density declines, instead feeding on plant parts such as pods, leaves, seeds and nectars (Eubanks and Denno 1999, Dunbar 1971).

Both nymphal and adult hemipterans showed a tendency to aggregate around a food resource, at certain prime locations in the lawn (Table 2.3a and b). Vacuum samplers create a consistent suction pressure so that even small immatures of Anthocoridae, Geocoridae, Blissidae, Miridae, Delphacidae and Cicadellidae were collected (Fig. 2.4). This partially explains why the vacuum sampling technique was more effective over sweep net in sampling all

stages of hemipterans (Fig. 2.3). Although occurrence of heteroperans such as reduviids and pentatomids were rarely reported in turf, the chance of sampling arthropods with greater body mass is rather challenging with vacuum sampler. Small sized arthropods (hymenopteran parasitoids and dipterans) were sampled in greater numbers in vacuum samples as compared to sweep net. In this study, vacuumed arthropods included greater numbers of both adult and immature stages of Aranaea, Acari, Collembolla, Thysanoptera (adults and nymphs), Hemiptera, Hymenoptera (adults), Diptera (adults and larvae), Lepidoptera (larvae) and Coleoptera (adults and grubs) (Table 2.3b) than did sweep samples. This result was consistent with Buffington and Redak (1998), who reported higher densities of various taxonomic groups with greater diversity, abundance and richness in vacuum samples when compared to sweep samples.

Most of the residential lawns were surrounded by complex physical structures such as buildings, perennial woody trees and annual flowering plants. These structures sustain a diverse arthropod fauna by providing conditions for oviposition, larval development, and winter diapause (Potter and Braman 1991). Frank and Shrewsbury (2004) observed higher numbers of staphylinids in turf with conservation strips rather than without them and thus suggested that those sites provide ample food and refuge for the generalist predators. Rove beetles were most abundant in St. Augustinegrass (higher biomass generation than other grass taxa) in the current study, which may be because of indirect effect of thicker thatch formation in this variety than in other grass taxa. Also other studies have shown that flowering and foliage plants close to turfgrass attracted more beneficial arthropods such as *Geocoris spp.* and *Orius spp.*, to the vicinity (Braman et al. 2002, Shrewsbury et al. 2004). Predators such as staphylinids were reported to feed on alternate prey items when their regular prey density declined in turf systems (Vavrek and Niemczyk 1990). Non-pest arthropods, including springtails and planthoppers are

hardly considered in the turfgrass system as a potential alternate prey item (Braman et al. 2002). Frank and Shrewsbury (2004) considered the possibility of Collembola and leafhoppers as potential prey items for ground-dwelling, generalist predators in turf.

Low mowing height (2.5 cm or less) normally provide conditions for grassy weeds, such as crabgrass and bermudagrass to grow rapidly, therefore if grass mowed at an optimum height of 5-6 cm is advisable (Busey 2003). Arthropod fauna in St. Augustinegrass lawns were influenced by the mowing height in our study, which were maintained at a mowing height ranging from 3.8-12.9 cm. Our study showed that abundance of minute pirate bugs, chinch bugs and planthoppers (Delphacidae) increased with increase in grass height (Fig. 2.5) in St. Augustinegrass. Mowing height ranging from 5-7.6 cm is optimum for proper chinch bug management in St. Augustinegrass (McCarty 1994). The increase in minute pirate bugs may be in response to abundance of chinch bugs or planthoppers, or increase in mowing height may help by providing refuge or favorable microclimatic conditions for more predators in turf. Smitley et al. (1998) also found greater diversity in ground-dwelling predatory beetles in golf rough (tall grass) regions than in green (shorter grass). The mowing interval may vary from lawn to lawn in residential settings and also might have affected the arthropod build up in turfgrass. More studies are required to ascertain anthocorid-blissid relationship in other grass taxa.

Most of the residential lawns (60 %) were exposed to partial sunlight, increasing the possibility of high moisture retention in certain locations of turf. This may indirectly favor soil dwelling fauna such as collembolans (Frank and Shrewsbury 2004) and mites. Braman et al. (2000) also observed increased arthropod number in the shady turf with higher moisture content than areas fully exposed to sunlight. Collembolan density was also higher where there were larger patches of weed flora in some residential lawns. Frank and Shrewsbury (2004) suggested

the likelihood that vegetation near the turf grass could supply pollens to the turf area and indirectly benefit the collembolans. Weedy plants and perennial trees adjacent to turf could be a source of pollen for the collembolans and indirectly benefit the predaceous community in the turfgrass system.

Occurrence and abundance of predaceous ants were reported from several studies in different turfgrass. Predaceous formicids (*Solenopsis spp.*) were abundant and regularly collected in several studies in turfgrass (Cockfield and Potter 1984, Terry et al. 1993) and were consistently reported from centipede grass in pitfall traps (Braman et al. 1993b). In this study, ants were abundant on all turfgrasses throughout the season. López and Potter (2000) suggested predaceous ants, *L. neoniger*, actively preyed on black cutworm, *Agrotis ipsilon* (Hufnagel), eggs in high percentages [greens (65.5%), collars (71.8%) and roughs (69.2%)] in golf courses with bentgrass and Kentucky bluegrass. Parasitic hymenopterans are important agents in regulating pest outbreak in turfgrass (Braman et al. 2004). Abundance of hymenopterans (other than formicids) was highest in St. Augustine grass in our study. Braman et al. (2004) reported highest parasitization of fall armyworm on 'Sea Isle 1' seashore paspalum than on hybrid bermudagrass and zoysiagrass cultivars by *Aleiodes laphygmae* Viereck (Braconidae) in field studies. However, whether parasitoid abundance resulted in greater parasitism of chinch bugs or planthopper in infested turfs was not evaluated in this study. Although presence of flowering weed stand did not influence hymenopteran (excluding ants) abundance, high mowing height influenced their abundance in this grass. Elaborate studies are lacking in these areas in turfgrass systems. Spiders were abundant in zoysiagrass (Braman et al. 2003) but were collected more frequently from St. Augustine grass. Increase in grass height markedly increased their abundance.



Mites were collected in large numbers from different turfgrasses. Oribatid mites were also sampled from pitfall samples in centipedegrass (Braman et al. 1993b). Twoline spittlebugs were not abundant in centipedegrass in our study, but they were present in all grass taxa studied except in zoysiagrass. This result was consistent with Braman et al. (2002) as lower number of these bugs developed on zoysiagrass. Their low numbers observed in our study may be due to late development of adults during the season.

Our study indicated the presence of predatory heteropterans in different turfgrass systems and their occurrence was strongly influenced by turfgrass taxa. Occurrence and abundance of Anthocoridae opened up opportunity towards further study as potential biological control agents in turf. More studies are also needed to understand how the plant, including resistant plants, helps to structure the arthropod community and predatory efficiency on turf pests. Hence, our study indicate more efforts towards adoption of judicious management strategies for effective conservation of predatory heteropterans in turfgrass ecosystems.

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Figure 2.1. Number of Heteroptera and predaceous heteropterans (mean  $\pm$  SE) sampled (N = 504) from different residential lawns comprising bermudagrass, centipedegrass, St. Augustinegrass, and zoysiagrass. Sweep samples (SS) include twenty-five sweeps per quadrant and vacuum samples (VS) sampled from twenty suctions (four-square meter) per quadrant. A. Total Heteroptera (SS), B. Total Heteroptera (VS); C. Predaceous heteroptera (SS), and D. Predaceous heteroptera (VS).

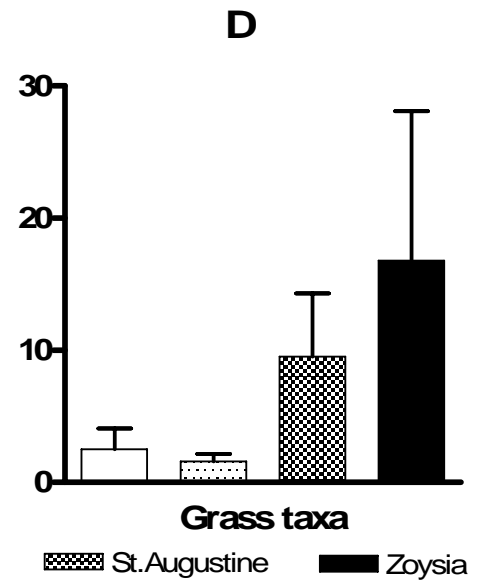
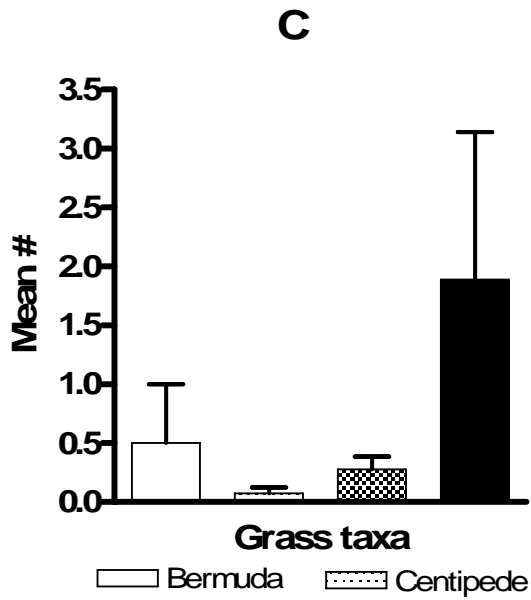
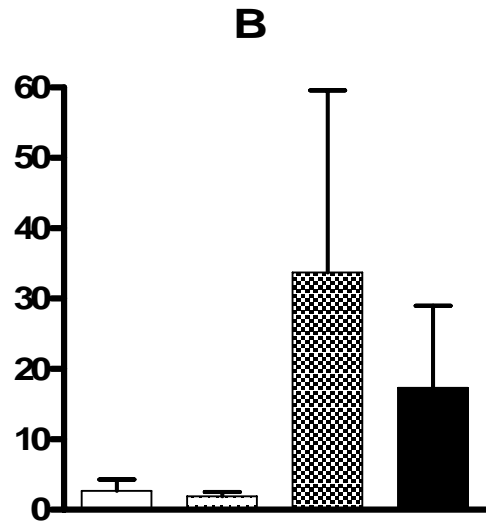
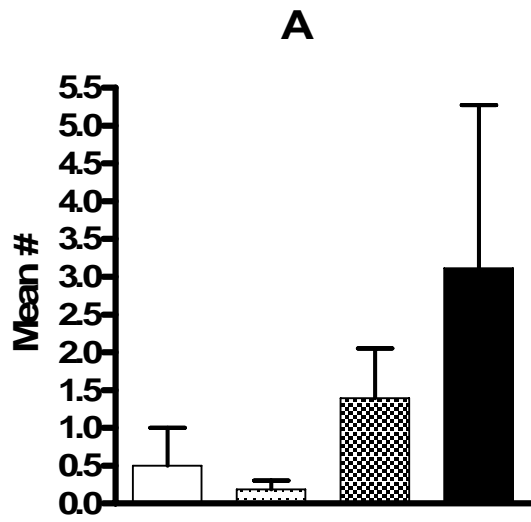


Figure 2.2. Number of predaceous heteropterans (mean  $\pm$  SE) sampled (N = 504) from different residential lawns comprising bermudagrass, centipedegrass, St. Augustinegrass, and zoysiagrass. Sweep samples (SS) include twenty-five sweeps per quadrant and vacuum samples (VS) sampled from twenty suction (4 square meter) per quadrant. A. Anthocoridae (SS), B. Anthocoridae (VS); C. Geocoridae (SS), D. Geocoridae (VS); E. Miridae (SS), F. Miridae (VS).

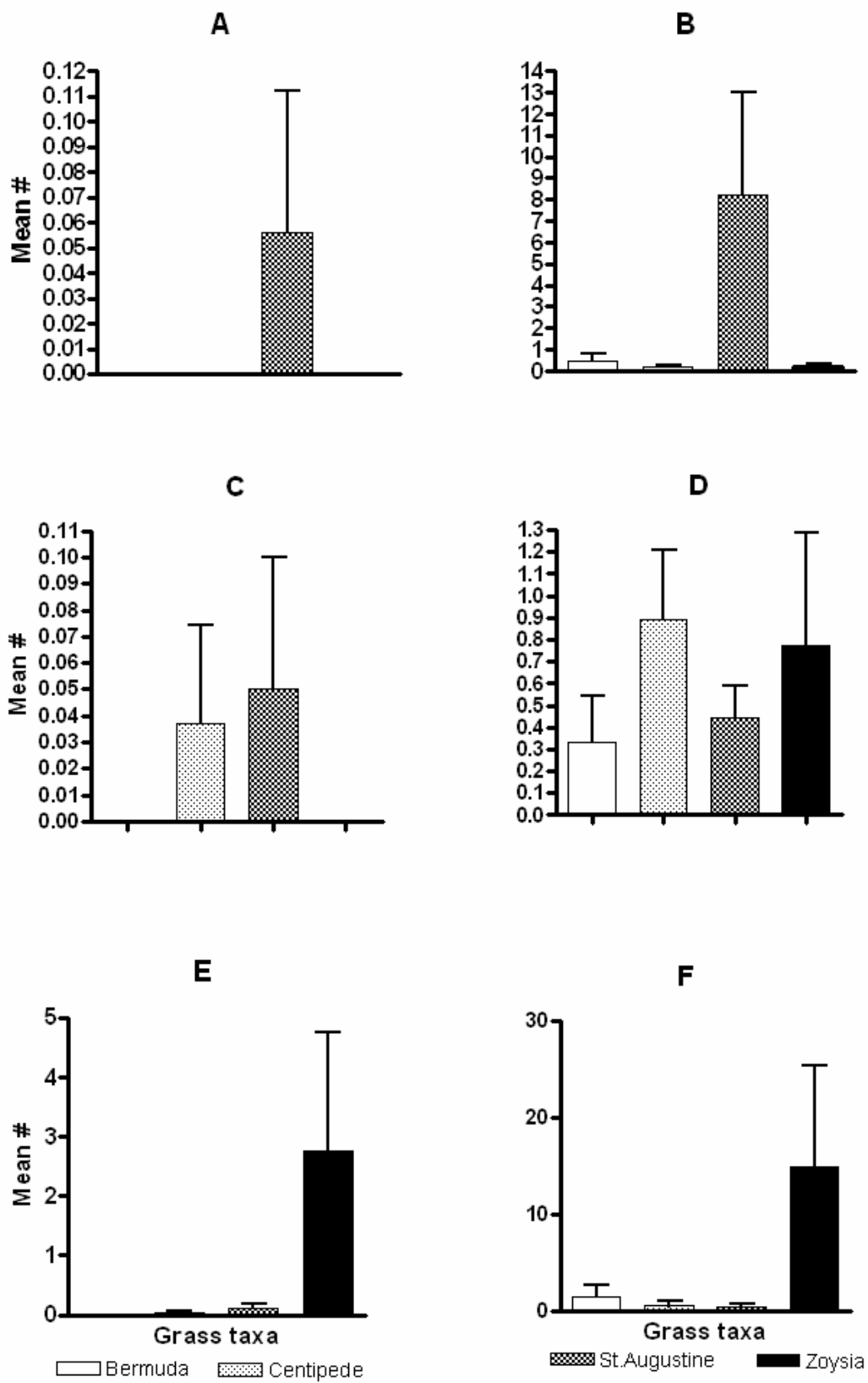




Figure 2.3. Number of delphacids and blissids (mean  $\pm$  SE) sampled (N = 504) from different residential lawns comprising bermudagrass, centipedegrass, St. Augustinegrass, and zoysiagrass. Sweep samples (SS) include twenty-five sweeps per quadrant and vacuum samples (VS) sampled from twenty suction per quadrant. A. Delphacidae (SS), B. Delphacidae (VS); C. Blissidae (SS), D. Blissidae (VS). Anthocoridae were significantly associated with Blissidae ( $r = 0.6719$ ;  $P < 0.0001$ ) and Delphacidae ( $r = 0.8839$ ;  $P < 0.0001$ ).

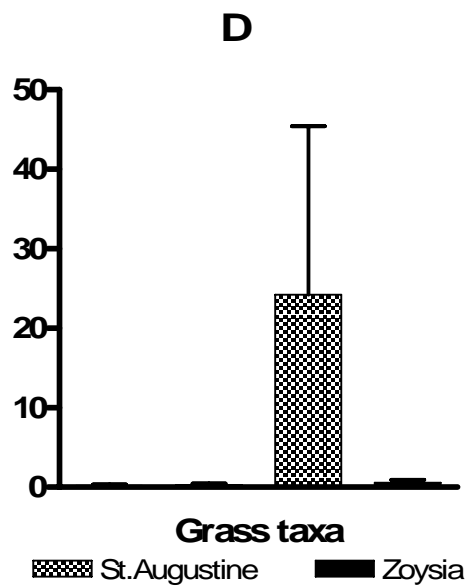
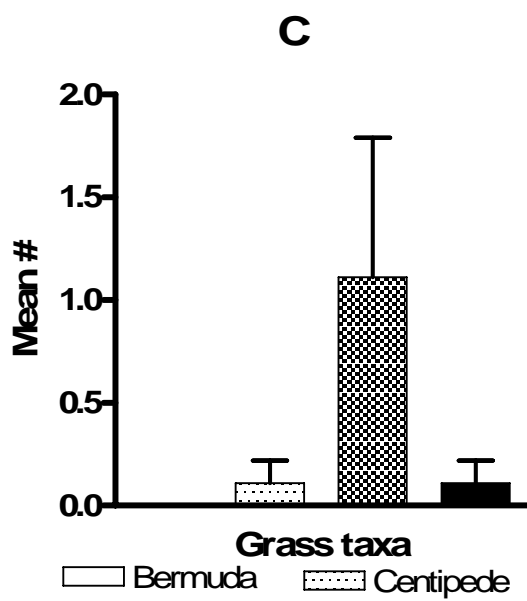
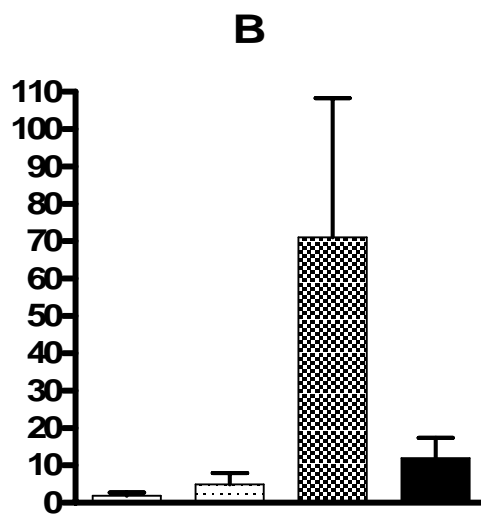
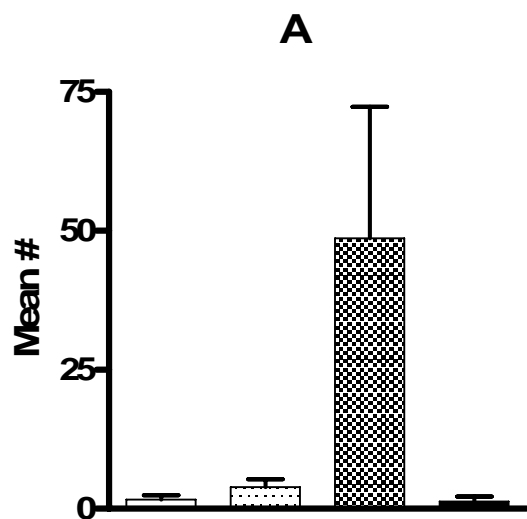
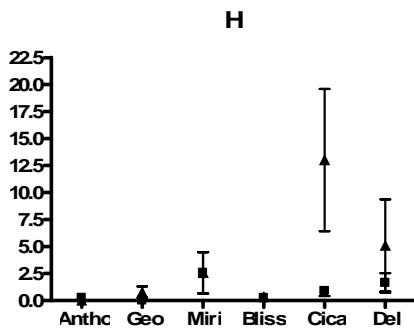
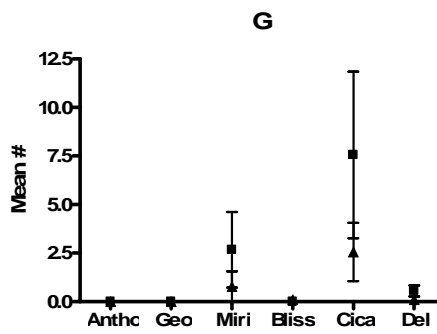
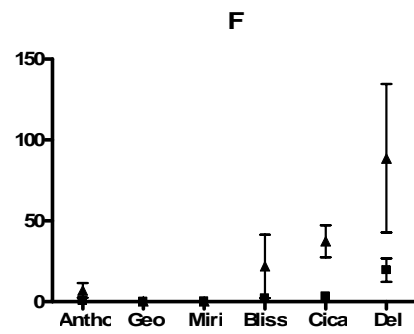
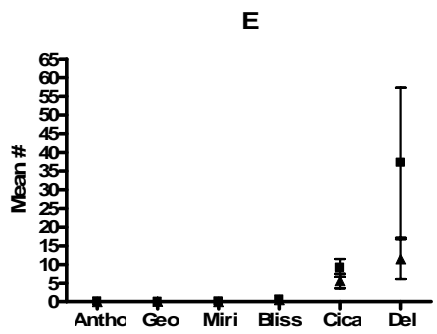
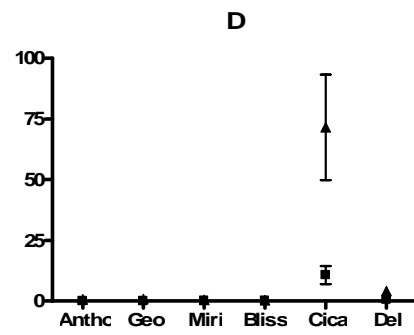
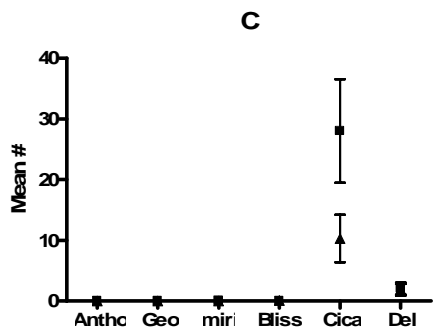
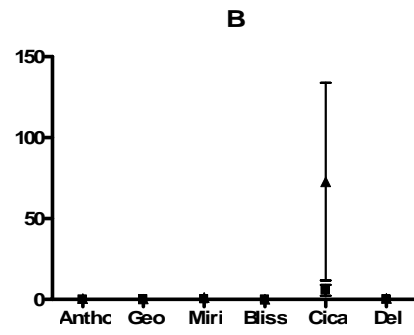
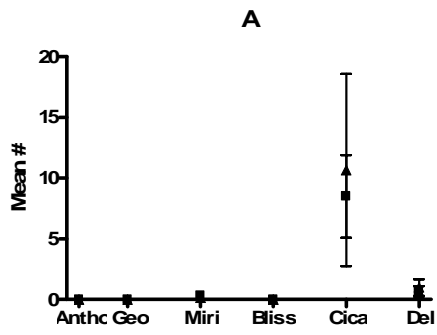


Figure 2.4. Number of adults and nymphs of hemipterans sampled (N = 504) by sweep (A, C, E and G) and vacuum sampling (B, D, F and H) methods from bermudagrass (A and B), centipedegrass (C and D), St. Augustinegrass (E and F), and zoysiagrass (G and H) in residential settings. Anthocoridae (Antho), Geocoridae (Geo), Miridae (Miri), Blissidae (Bliss), Cicadellidae (Cica) and Delphacidae (Del).



■ Adults      ▲ Nymphs

■ Adults      ▲ Nymphs

Figure 2.5. Relationship between grass height and abundance of Anthocoridae, Blissidae and Delphacidae in St. Augustinegrass over three dates of sampling. Grass height is significantly affected abundance of different with Anthocoridae ( $F = 21.26$ ;  $df = 135$ ;  $P < 0.0001$ ), Blissidae ( $F = 21.44$ ;  $df = 135$ ;  $P < 0.0001$ ) and Delphacidae ( $F = 57.94$ ;  $df = 132$ ;  $P < 0.0001$ ).

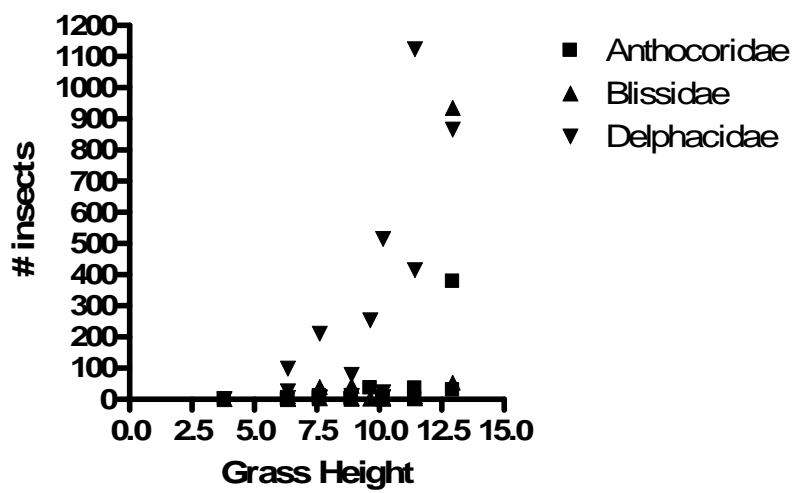


Table 2.1. The total arthropods sampled separated by method, sex and stage of development.

| <b>Insect group</b>          | <b>Method</b> | <b>Stage of development</b> | <b>Arthropod count</b> |
|------------------------------|---------------|-----------------------------|------------------------|
| <b>Total Arthropod</b>       | Both methods  | All                         | 333,278                |
|                              | Sweep         | All                         | 24,699                 |
|                              | Vacuum        | All                         | 308,579                |
| <b>Hemiptera</b>             | Both methods  | All                         | 39,874                 |
|                              | Sweep         | All                         | 10,410                 |
|                              | Vacuum        | All                         | 29,464                 |
|                              | Both methods  | All                         | 2,844                  |
|                              | Sweep         | All                         | 218                    |
|                              | Vacuum        | All                         | 2,626                  |
| <b>Heteroptera</b>           | Both methods  | Adults                      | 526                    |
|                              | Both methods  | Nymphs                      | 2,318                  |
|                              | Sweep         | Adults                      | 176                    |
|                              | Sweep         | Nymphs                      | 42                     |
|                              | Vacuum        | Adults                      | 350                    |
|                              | Vacuum        | Nymphs                      | 2,276                  |
|                              | Both methods  | All                         | 1562                   |
| <b>Predatory Heteroptera</b> | Sweep         | All                         | 169                    |
|                              | Vacuum        | All                         | 1,393                  |

Table 2.2(a). Level of significance for abundance of predatory heteropterans sampled (N = 504), in relation to method, date, turf attributes and weed attribute.

| Attribute           | Heteroptera | Predatory Heteroptera | Geocoridae total | Geocoridae adults | Geocoridae nymphs | Anthocoridae total | Anthocoridae adults | Anthocoridae nymphs | Miridae total | Miridae adults | Miridae nymphs |
|---------------------|-------------|-----------------------|------------------|-------------------|-------------------|--------------------|---------------------|---------------------|---------------|----------------|----------------|
| Grass taxa          | ***         | ***                   | **               | *                 | **                | ***                | ***                 | ***                 | ***           | ***            | ***            |
| Sampling method     | ***         | ***                   | ***              | NS                | ***               | **                 | **                  | **                  | *             | NS             | *              |
| Date                | NS          | *                     | **               | *                 | ***               | NS                 | NS                  | NS                  | ***           | **             | *              |
| Grass Height        | ***         | *                     | NS               | NS                | NS                | ***                | ***                 | ***                 | NS            | NS             | NS             |
| Grass Density       | **          | NS                    | NS               | NS                | NS                | NS                 | NS                  | NS                  | NS            | NS             | NS             |
| Weeds               | NS          | **                    | **               | NS                | **                | NS                 | NS                  | NS                  | **            | ***            | **             |
| Grass taxa X method | **          | *                     | NS               | *                 | *                 | ***                | **                  | ***                 | NS            | NS             | NS             |
| Grass taxa X date   | *           | NS                    | NS               | NS                | NS                | NS                 | NS                  | *                   | **            | **             | **             |
| Method X date       | *           | *                     | ***              | NS                | ***               | *                  | *                   | **                  | NS            | NS             | NS             |

Notations NS = not significant.

Significant different \* $P < 0.05$ ; \*\* $P < 0.01$ ; \*\*\* $P < 0.001$ .



Table 2.2(b). The abundance of other hemipterans sampled (N = 504), showing relationship with sampling method, date, turf attributes and weed attribute.

| Attribute        | Blissidae<br>total | Blissidae<br>adult | Blissidae<br>nymph | Cicadellidae<br>total | Cicadellidae<br>adult | Cicadellidae<br>nymph | Delphacidae<br>total | Delphacidae<br>adult | Delphacidae<br>nymph | Aphididae | Cercopidae |
|------------------|--------------------|--------------------|--------------------|-----------------------|-----------------------|-----------------------|----------------------|----------------------|----------------------|-----------|------------|
| Grass<br>taxa    | ***                | ***                | ***                | ***                   | ***                   | *                     | ***                  | ***                  | ***                  | NS        | ***        |
| Method           | **                 | **                 | **                 | ***                   | ***                   | ***                   | NS                   | NS                   | **                   | *         | **         |
| Date             | NS                 | NS                 | NS                 | ***                   | NS                    | ***                   | NS                   | NS                   | NS                   | **        | **         |
| Grass<br>height  | ***                | ***                | ***                | ***                   | ***                   | ***                   | ***                  | ***                  | ***                  | NS        | ***        |
| Grass<br>density | **                 | **                 | *                  | NS                    | NS                    | NS                    | *                    | **                   | NS                   | NS        | NS         |
| Weeds<br>density | NS                 | NS                 | NS                 | **                    | NS                    | **                    | NS                   | NS                   | NS                   | NS        | *          |
| Taxa X<br>method | ***                | ***                | ***                | NS                    | *                     | NS                    | *                    | NS                   | ***                  | NS        | NS         |
| Taxa X<br>date   | NS                 | NS                 | NS                 | **                    | **                    | **                    | ***                  | ***                  | ***                  | NS        | **         |
| Method X<br>date | NS                 | NS                 | NS                 | *                     | *                     | **                    | NS                   | NS                   | ***                  | *         | NS         |

Notations NS = not significant;

Significant different \* $P < 0.05$ ; \*\* $P < 0.01$ ; \*\*\* $P < 0.001$ .

Table 2.2(c). The abundance of arthropod sampled (N = 504), showing relationship with sampling method, date, turf attributes and weed attribute.

| Attribute                | Mites | Diptera | Hymenop. | Formicidae | Coleoptera | Staphylinid.<br>adult | Staphylinid.<br>grub | Spider | Sminthurid. | Other<br>Collembola | Phleothripid. | Thripid. |
|--------------------------|-------|---------|----------|------------|------------|-----------------------|----------------------|--------|-------------|---------------------|---------------|----------|
| <b>Grass<br/>taxa</b>    | *     | **      | ***      | NS         | ***        | *                     | ***                  | *      | ***         | ***                 | *             | ***      |
| <b>Method</b>            | ***   | *       | ***      | ***        | ***        | ***                   | ***                  | ***    | ***         | ***                 | ***           | *        |
| <b>Date</b>              | ***   | ***     | ***      | NS         | **         | ***                   | ***                  | NS     | ***         | **                  | NS            | ***      |
| <b>Grass<br/>height</b>  | *     | ***     | ***      | ***        | *          | **                    | NS                   | ***    | NS          | **                  | NS            | NS       |
| <b>Grass<br/>density</b> | NS    | NS      | NS       | NS         | NS         | NS                    | NS                   | NS     | ***         | *                   | *             | **       |
| <b>Weeds<br/>density</b> | *     | NS      | NS       | NS         | NS         | NS                    | NS                   | NS     | ***         | NS                  | **            | ***      |
| <b>Taxa X<br/>method</b> | ***   | NS      | *        | *          | ***        | ***                   | ***                  | *      | **          | ***                 | *             | NS       |
| <b>Taxa X<br/>date</b>   | *     | *       | **       | **         | NS         | NS                    | *                    | *      | NS          | *                   | **            | ***      |
| <b>Method<br/>X date</b> | NS    | **      | NS       | NS         | *          | ***                   | *                    | NS     | ***         | ***                 | NS            | NS       |

Notations NS = not significant;

Significant different \* $P < 0.05$ ; \*\* $P < 0.01$ ; \*\*\* $P < 0.001$ .

Table 2.3(a). Overall mean  $\pm$  SEM number of heteropterans collected (N = 504) from sweep and vacuum samples from twenty residential lawns influenced by turfgrass taxa during May-July, 2005.

|                           | Bermudagrass      |                   | Centipedegrass    |                   | St. Augustinegrass |                    | Zoysiagrass      |                   |
|---------------------------|-------------------|-------------------|-------------------|-------------------|--------------------|--------------------|------------------|-------------------|
|                           | Sweep             | Vacuum            | Sweep             | Vacuum            | Sweep              | Vacuum             | Sweep            | Vacuum            |
| <b>Hemiptera</b>          | 28.83 $\pm$ 10.07 | 82.83 $\pm$ 63.25 | 44.63 $\pm$ 12.94 | 91.04 $\pm$ 25.34 | 69.94 $\pm$ 28.09  | 176.20 $\pm$ 77.34 | 14.10 $\pm$ 7.18 | 38.10 $\pm$ 17.59 |
| <b>Heteroptera</b>        | 0.50 $\pm$ 0.50   | 2.67 $\pm$ 1.61   | 0.18 $\pm$ 0.12   | 1.96 $\pm$ 0.59   | 1.39 $\pm$ 0.66    | 33.72 $\pm$ 25.85  | 3.10 $\pm$ 2.16  | 17.33 $\pm$ 11.62 |
| <b>Other Hemiptera</b>    | 23.30 $\pm$ 9.64  | 80.17 $\pm$ 61.73 | 44.44 $\pm$ 12.94 | 89.07 $\pm$ 25.25 | 68.56 $\pm$ 27.45  | 150.9 $\pm$ 56.96  | 11.0 $\pm$ 5.1   | 23.37 $\pm$ 10.4  |
| <b>Anthocoridae Total</b> | 0.0 $\pm$ 0.0     | 0.50 $\pm$ 0.34   | 0.0 $\pm$ 0.0     | 0.22 $\pm$ 0.08   | 0.06 $\pm$ 0.06    | 8.20 $\pm$ 4.79    | 0.0 $\pm$ 0.0    | 0.22 $\pm$ 0.15   |
| <b>Anthocoridae Adult</b> | 0.0 $\pm$ 0.0     | 0.0 $\pm$ 0.0     | 0.0 $\pm$ 0.0     | 0.04 $\pm$ 0.04   | 0.06 $\pm$ 0.06    | 0.67 $\pm$ 0.31    | 0.0 $\pm$ 0.0    | 0.22 $\pm$ 0.15   |
| <b>Anthocoridae Nymph</b> | 0.0 $\pm$ 0.0     | 0.5 $\pm$ 0.34    | 0.0 $\pm$ 0.0     | 0.07 $\pm$ 0.05   | 0.0 $\pm$ 0.0      | 7.17 $\pm$ 4.58    | 0.0 $\pm$ 0.0    | 0.0 $\pm$ 0.0     |
| <b>Geocoridae Total</b>   | 0.0 $\pm$ 0.0     | 0.33 $\pm$ 0.21   | 0.04 $\pm$ 0.04   | 0.88 $\pm$ 0.32   | 0.06 $\pm$ 0.06    | 0.44 $\pm$ 0.145   | 0.0 $\pm$ 0.0    | 0.78 $\pm$ 0.52   |
| <b>Geocoridae Adult</b>   | 0.0 $\pm$ 0.0     | 0.17 $\pm$ 0.17   | 0.0 $\pm$ 0.0     | 0.0 $\pm$ 0.0     | 0.0 $\pm$ 0.0      | 0.06 $\pm$ 0.06    | 0.0 $\pm$ 0.0    | 0.0 $\pm$ 0.0     |
| <b>Geocoridae Nymph</b>   | 0.0 $\pm$ 0.0     | 0.33 $\pm$ 0.21   | 0.0 $\pm$ 0.0     | 0.88 $\pm$ 0.32   | 0.06 $\pm$ 0.06    | 0.39 $\pm$ 0.14    | 0.0 $\pm$ 0.0    | 0.78 $\pm$ 0.52   |
| <b>Miridae Total</b>      | 0.0 $\pm$ 0.0     | 1.5 $\pm$ 1.31    | 0.04 $\pm$ 0.04   | 0.56 $\pm$ 0.48   | 0.11 $\pm$ 0.08    | 0.44 $\pm$ 0.34    | 2.78 $\pm$ 1.98  | 15.0 $\pm$ 10.43  |
| <b>Miridae Adult</b>      | 0.33 $\pm$ 0.33   | 0.17 $\pm$ 0.17   | 0.04 $\pm$ 0.04   | 0.11 $\pm$ 0.08   | 0.11 $\pm$ 0.08    | 0.17 $\pm$ 0.09    | 2.67 $\pm$ 1.95  | 2.56 $\pm$ 1.92   |
| <b>Miridae Nymph</b>      | 0.17 $\pm$ 0.17   | 1.33 $\pm$ 1.15   | 0.0 $\pm$ 0.0     | 0.48 $\pm$ 0.44   | 0.0 $\pm$ 0.0      | 0.33 $\pm$ 0.33    | 0.78 $\pm$ 0.78  | 12.44 $\pm$ 8.54  |
| <b>Blissidae Total</b>    | 0.0 $\pm$ 0.0     | 0.17 $\pm$ 0.17   | 0.10 $\pm$ 0.10   | 0.33 $\pm$ 0.13   | 1.11 $\pm$ 0.68    | 24.2 $\pm$ 21.2    | 0.10 $\pm$ 0.10  | 0.55 $\pm$ 0.37   |
| <b>Blissidae Adult</b>    | 0.0 $\pm$ 0.0     | 0.0 $\pm$ 0.0     | 0.0 $\pm$ 0.0     | 0.11 $\pm$ 0.08   | 0.61 $\pm$ 0.49    | 2.20 $\pm$ 1.68    | 0.0 $\pm$ 0.0    | 0.22 $\pm$ 0.22   |
| <b>Blissidae Nymph</b>    | 0.0 $\pm$ 0.0     | 0.17 $\pm$ 0.17   | 0.10 $\pm$ 0.10   | 0.39 $\pm$ 0.12   | 0.50 $\pm$ 0.50    | 22.0 $\pm$ 19.57   | 0.10 $\pm$ 0.10  | 0.33 $\pm$ 0.24   |

Table 2.3(b). Mean  $\pm$  SEM number of other arthropods collected from sweep and vacuum samples from twenty residential lawns in relations by turfgrass taxa.

|                            | Bermudagrass     |                     | Centipedegrass   |                    | St. Augustinegrass |                    | Zoysiagrass       |                     |
|----------------------------|------------------|---------------------|------------------|--------------------|--------------------|--------------------|-------------------|---------------------|
|                            | Sweep            | Vacuum              | Sweep            | Vacuum             | Sweep              | Vacuum             | Sweep             | Vacuum              |
| <b>Cicadellidae total</b>  | 15.83 $\pm$ 9.44 | 78.50 $\pm$ 61.66   | 38.3 $\pm$ 11.4  | 82.30 $\pm$ 24.23  | 14.72 $\pm$ 3.93   | 40.82 $\pm$ 10.18  | 10.10 $\pm$ 5.08  | 13.87 $\pm$ 6.70    |
| <b>Cicadellidae adult</b>  | 8.5 $\pm$ 3.4    | 5.67 $\pm$ 3.41     | 28 $\pm$ 8.5     | 10.74 $\pm$ 3.71   | 9.10 $\pm$ 2.53    | 3.35 $\pm$ 0.83    | 7.56 $\pm$ 4.28   | 0.87 $\pm$ 0.44     |
| <b>Cicadellidae nymph</b>  | 10.67 $\pm$ 7.92 | 72.83 $\pm$ 61.07   | 10.3 $\pm$ 3.93  | 71.59 $\pm$ 21.7   | 5.60 $\pm$ 1.95    | 37.47 $\pm$ 9.88   | 2.56 $\pm$ 1.50   | 13.0 $\pm$ 6.58     |
| <b>Delphacidae total</b>   | 1.67 $\pm$ 0.8   | 1.0 $\pm$ 0.68      | 3.92 $\pm$ 1.43  | 7.96 $\pm$ 3.60    | 48.67 $\pm$ 23.7   | 108.29 $\pm$ 49.17 | 1.30 $\pm$ 0.89   | 6.56 $\pm$ 5.02     |
| <b>Delphacidae adult</b>   | 0.67 $\pm$ 0.42  | 0.3 $\pm$ 0.3       | 2.10 $\pm$ 0.97  | 0.55 $\pm$ 0.31    | 37.22 $\pm$ 20.1   | 19.58 $\pm$ 7.19   | 0.56 $\pm$ 0.29   | 1.62 $\pm$ 0.90     |
| <b>Delphacidae nymph</b>   | 1.0 $\pm$ 0.68   | 0.67 $\pm$ 0.42     | 1.88 $\pm$ 0.97  | 4.2 $\pm$ 1.5      | 11.44 $\pm$ 5.33   | 88.70 $\pm$ 45.89  | 0.1 $\pm$ 0.1     | 5.10 $\pm$ 4.27     |
| <b>Cercopidae</b>          | 1.17 $\pm$ 0.83  | 0.17 $\pm$ 0.17     | 1.70 $\pm$ 0.59  | 0.40 $\pm$ 0.17    | 1.88 $\pm$ 0.78    | 0.33 $\pm$ 0.16    | 0.0 $\pm$ 0.0     | 0.0 $\pm$ 0.0       |
| <b>Sminthuridae</b>        | 17.0 $\pm$ 8.87  | 306.67 $\pm$ 0.17   | 5.07 $\pm$ 1.57  | 232.40 $\pm$ 55.68 | 7.67 $\pm$ 2.65    | 312.17 $\pm$ 78.75 | 14.3 $\pm$ 11.14  | 310.0 $\pm$ 117.07  |
| <b>Other Collembola</b>    | 6.0 $\pm$ 1.57   | 507.50 $\pm$ 180.63 | 6.67 $\pm$ 2.01  | 452.25 $\pm$ 69.90 | 6.61 $\pm$ 2.86    | 453.70 $\pm$ 95.61 | 3.60 $\pm$ 1.58   | 573.75 $\pm$ 164.23 |
| <b>Staphylinidae adult</b> | 0.0 $\pm$ 0.0    | 0.83 $\pm$ 0.54     | 0.04 $\pm$ 0.04  | 2.30 $\pm$ 0.53    | 0.11 $\pm$ 0.076   | 3.05 $\pm$ 0.87    | 0.1 $\pm$ 0.1     | 2.38 $\pm$ 0.865    |
| <b>Staphylinidae grub</b>  | 0.0 $\pm$ 0.0    | 1.67 $\pm$ 1.67     | 0.0 $\pm$ 0.0    | 3.40 $\pm$ 1.28    | 0.0 $\pm$ 0.0      | 7.67 $\pm$ 2.10    | 0.0 $\pm$ 0.0     | 2.25 $\pm$ 1.32     |
| <b>Formicidae</b>          | 1.0 $\pm$ 0.45   | 9.67 $\pm$ 3.05     | 0.7 $\pm$ 0.24   | 10.74 $\pm$ 2.37   | 0.77 $\pm$ 0.31    | 10.65 $\pm$ 1.85   | 1.47 $\pm$ 0.47   | 10.88 $\pm$ 4.38    |
| <b>Hymenoptera</b>         | 0.5 $\pm$ 1.5    | 6.80 $\pm$ 2.18     | 3.33 $\pm$ 0.42  | 11.55 $\pm$ 2.50   | 3.16 $\pm$ 0.82    | 29.89 $\pm$ 15.52  | 3.67 $\pm$ 1.85   | 10.25 $\pm$ 2.84    |
| <b>Spider</b>              | 4.0 $\pm$ 1.44   | 16.16 $\pm$ 4.1     | 0.67 $\pm$ 0.24  | 21.37 $\pm$ 3.65   | 1.27 $\pm$ 0.30    | 33.47 $\pm$ 8.75   | 1.22 $\pm$ 0.36   | 12.75 $\pm$ 4.10    |
| <b>Thripidae</b>           | 7.16 $\pm$ 5.68  | 2.83 $\pm$ 0.98     | 1.77 $\pm$ 0.48  | 4.33 $\pm$ 1.68    | 22.50 $\pm$ 20.92  | 6.35 $\pm$ 1.86    | 4.33 $\pm$ 2.11   | 12.0 $\pm$ 5.17     |
| <b>Phlaeothripidae</b>     | 0.0 $\pm$ 0.0    | 0.17 $\pm$ 0.17     | 0.07 $\pm$ 0.08  | 1.59 $\pm$ 1.10    | 0.38 $\pm$ 0.23    | 1.76 $\pm$ 0.98    | 0.1 $\pm$ 0.1     | 2.67 $\pm$ 1.46     |
| <b>Diptera</b>             | 17.16 $\pm$ 5.51 | 6.50 $\pm$ 3.87     | 15.30 $\pm$ 3.86 | 27.83 $\pm$ 7.47   | 20.20 $\pm$ 3.58   | 27.88 $\pm$ 5.71   | 7.67 $\pm$ 2.08   | 11.63 $\pm$ 4.44    |
| <b>Mite</b>                | 2.16 $\pm$ 0.87  | 119.30 $\pm$ 98.74  | 18.96 $\pm$ 8.88 | 409.0 $\pm$ 70.35  | 12.70 $\pm$ 3.27   | 595.82 $\pm$ 94.50 | 26.40 $\pm$ 19.07 | 139.43 $\pm$ 45.84  |
| <b>Coleoptera</b>          | 0.67 $\pm$ 0.49  | 2.0 $\pm$ 1.0       | 0.52 $\pm$ 0.14  | 3.15 $\pm$ 0.62    | 1.83 $\pm$ 1.20    | 4.47 $\pm$ 1.06    | 1.0 $\pm$ 0.5     | 5.38 $\pm$ 2.59     |

Table 2.4(a). Seasonal Simpson's diversity indices and evenness indices illustrating different categories of arthropods and major turfgrass taxa from vacuum samples collected from residential lawns during May to July 2005.

| Category   | Turfgrass taxa |                |                    |             |
|--|----------------|----------------|--------------------|-------------|
|  | Bermudagrass   | Centipedegrass | St. Augustinegrass | Zoysiagrass |
| <i>Simpson's Diversity index (D)</i>                     | 3.13           | 3.44           | 4.39               | 3.34        |
| <i>Simpson's Equitability (Evenness) (E<sub>D</sub>)</i> |                |                |                    |             |
| <i>Heteropteran Predators</i>                            | 0.52           | 0.57           | 0.73               | 0.56        |
| <i>Other Turf Predators</i>                              | 0.63           | 0.69           | 0.88               | 0.67        |
| <i>Herbivores and Detritivores</i>                       | 0.15           | 0.16           | 0.21               | 0.16        |
| <i>Total</i>   | 0.09           | 0.11           | 0.14               | 0.10        |

Table 2.4(b). Simpson's diversity indices and evenness indices illustrating different categories of arthropods and major turfgrass taxa from vacuum samples collected from residential lawns during first date, May 2005, of sampling.

| Category   | Turfgrass taxa |                |                    |             |
|--|----------------|----------------|--------------------|-------------|
|  | Bermudagrass   | Centipedegrass | St. Augustinegrass | Zoysiagrass |
| <i>Simpson's Diversity index (D)</i>                     | 2.24           | 3.21           | 3.13               | 3.44        |
| <i>Simpson's Equitability (Evenness) (E<sub>D</sub>)</i> |                |                |                    |             |
| <i>Heteropteran Predators</i>                            | 0.37           | 0.54           | 0.52               | 0.57        |
| <i>Other Turf Predators</i>                              | 0.45           | 0.64           | 0.63               | 0.69        |
| <i>Herbivores and Detritivores</i>                       | 0.15           | 0.21           | 0.20               | 0.23        |
| <i>Total</i>   | 0.09           | 0.12           | 0.12               | 0.13        |

Table 2.4(c). Simpson's diversity indices and evenness indices illustrating different categories of arthropods and major turfgrass taxa from vacuum samples collected from residential lawns during second date, June 2005 of sampling.

| Category   | Turfgrass taxa |                |                    |             |
|--|----------------|----------------|--------------------|-------------|
|  | Bermudagrass   | Centipedegrass | St. Augustinegrass | Zoysiagrass |
| <i>Simpson's Diversity index (D)</i>                     | 2.78           | 3.38           | 3.65               | 2.93        |
| <i>Simpson's Equitability (Evenness) (E<sub>D</sub>)</i> |                |                |                    |             |
| <i>Heteropteran Predators</i>                            | 0.46           | 0.56           | 0.61               | 0.49        |
| <i>Other Turf Predators</i>                              | 0.56           | 0.68           | 0.73               | 0.59        |
| <i>Herbivores and Detritivores</i>                       | 0.18           | 0.23           | 0.24               | 0.19        |
| <i>Total</i>   | 0.11           | 0.13           | 0.14               | 0.11        |

Table 2.4(d). Simpson's diversity indices and evenness indices illustrating different categories of arthropods and major turfgrass taxa from vacuum samples collected from residential lawns during third date, July 2006 of sampling.

| Category   | Turfgrass taxa |                |                    |             |
|--|----------------|----------------|--------------------|-------------|
|  | Bermudagrass   | Centipedegrass | St. Augustinegrass | Zoysiagrass |
| <i>Simpson's Diversity index (D)</i>                     | 2.29           | 4.13           | 6.08               | 3.48        |
| <i>Simpson's Equitability (Evenness) (E<sub>D</sub>)</i> |                |                |                    |             |
| <i>Heteropteran Predators</i>                            | 0.38           | 0.69           | 1.01               | 0.58        |
| <i>Other Turf Predators</i>                              | 0.46           | 0.83           | 1.21               | 0.69        |
| <i>Herbivores and Detrivores</i>                         | 0.15           | 0.28           | 0.40               | 0.23        |
| <i>Total</i>   | 0.09           | 0.16           | 0.23               | 0.13        |



**CHAPTER 3****PREDATORY POTENTIAL AND PERFORMANCE OF *GEOCORIS SPP.* AND *ORIOUS INSIDIOSUS* (SAY)****ON FALL ARMYWORM IN RESISTANT AND SUSCEPTIBLE TURF<sup>1</sup>**

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**ABSTRACT** Predatory potential and performance of the predaceous heteropterans, *Geocoris punctipes* (Say), *G. uliginosus* (Say) (Geocoridae), and *Orius insidiosus* (Say) (Anthocoridae), were evaluated using fall armyworm, *Spodoptera frugiperda* (J. E. Smith), as prey on different turfgrass taxa (resistant zoysiagrass, ‘Cavalier’ and ‘Palisades’, intermediate resistant bermudagrass, ‘TifSport’, and susceptible seashore paspalum, ‘Sea Isle 1’) through laboratory and field studies. In preliminary laboratory cup trials, *O. insidiosus* demonstrated high mortality on zoysiagrass and bermudagrass cultivars. Greater mortality of fall armyworm was noted on ‘Cavalier’ when no predator was introduced. Male *G. punctipes* killed significantly more fall armyworms on bermudagrass and seashore paspalum than on zoysiagrass in cup trials. While, female *G. punctipes* fed more on fall armyworm larvae on seashore paspalum and bermudagrass than males. Grass taxon did not influence predation by male or female *G. uliginosus* in short duration cup trials. In both laboratory pot and field trials, significant predation was observed on different grass taxa by various *Orius* densities on fall armyworm neonates. In laboratory pot trials, few or no survivors (of 20 initial fall armyworm larvae) were observed on ‘Cavalier’ at all predator densities greater than zero. Fall armyworm mortality was highest on ‘Cavalier’ and least on ‘Sea Isle 1’; however, mortality did not differ on ‘TifSport’ and ‘Sea Isle 1’. In a field experiment, few or no live fall armyworms were recovered from ‘Cavalier’, while an increase in *Orius* density did not significantly affect mortality on ‘Palisades’ zoysiagrass. Mortality of fall armyworms occurred in the following order: zoysiagrass> seashore paspalum>bermudagrass. *Orius* predation on fall armyworm in bermudagrass and seashore paspalum was not different.

**KEYWORDS:** Big-eyed bug, *Geocoris uliginosus*, *Geocoris punctipes*, Insidious flower bug, *Orius insidiosus*, turfgrass, fall armyworm

Predator-prey interactions are often complex in managed turfgrass systems (Potter and Braman 1991). Big-eyed bugs, *Geocoris* spp., are common generalist predators, occurring from April onwards in the Southern United States (Cave and Gaylor 1988, Buschman 1984). *Geocoris uliginosus* (Say) frequently inhabits turfgrass systems (Reinert 1978, Braman et al. 2003). Furthermore, Reinert (1978) reported that the predatory bugs *G. uliginosus* and *Geocoris bullatus* (Say) were abundant in association with southern chinch bug, *Blissus insularis* (Barber), on St. Augustinegrass, *Stenotaphrum secundatum* (Walt. Kuntze) in Florida.

Although insidious flower bugs, *Orius insidiosus* (Say), are commonly collected from turfgrasses (Braman et al. 2003), few studies have evaluated their role in turfgrass systems. They are widely reported as a common, generalist heteropteran predators in various agro-ecosystems, such as vineyards, sunflower, cotton, soybean, corn, sorghum, alfalfa, apple and tomato (Jubb et al. 1979, Lynch and Garner 1980, McDaniel and Sterling 1979, Pfannenstiel and Yeargan 1998, Al-Deeb 2001). Pfannenstiel and Yeargan (1998) observed *O. insidiosus* on tomato, soybean, corn and tobacco from June to August, increasing during the vegetative phase of soybean and before flowering in corn, when tobacco, corn, soybean and tomato was grown in separate trial plots. They suggested that insect colonization and occurrence might have been affected by periodic occurrence and abundance of prey (aphids or thrips) and crop 'taxa' (Pfannenstiel and Yeargan 1998). Tillman et al. (2004) noted a higher density of *O. insidiosus* in legume cover crops, although lower populations were noticed on the crimson clover in cotton fields.

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith) is considered a sporadic pest in the southeastern United States (Braman et al. 2002). Moths migrate northward annually often-causing severe damage (Potter and Braman 1991). Braman et al. (2000b, 2002a) demonstrated varying degrees of resistance to fall armyworm larvae among turfgrass taxa, such as seashore

paspalum ('Sea Isle 1' and '561-79'), *Paspalum vaginatum* Swartz, bermudagrass ('TifSport' and 'TifEagle'), *Cynodon dactylon* [L] x *C. transvaalensis* [Burt-Davy], 'Cavalier' and 'Palisades' zoysiagrass, *Zoysia japonica* von Steudel and *Z. matrella* [L] Merrill. Braman et al. (2000a) reported that zoysiagrass cultivars ('Cavalier', 'Emerald', 'DALZ8501', 'DALZ8508', 'Royal' and 'Palisades') were more resistant to first instar larvae of fall armyworm than seashore paspalum cultivars. Shortman et al. (2002) reported that zoysiagrass ('Emerald'), bermudagrass ('TifWay' *C. dactylon*), and seashore paspalum ('Sea Isle 2000') were tolerant to twoline spittlebug, *Prosapia bicincta* (Say).

Turfgrass attributes, including plant resistance, affect phytophagous insects such as fall armyworm in turf, and may directly or indirectly affect the occurrence and predatory efficiency of heteropteran predators in managed turf (Braman et al. 2003, Braman and Duncan 2000a). Indeed, *G. uliginosus* typically occurs in susceptible and pest-resistant turfgrasses, preying on *S. frugiperda* larvae (Reinert 1978, Braman et al. 2003). Previous studies have also shown that big-eyed bugs were abundant in different turfgrass samples (Braman et al. 2002a). Fifth instar big-eyed bugs at a density of two per cage significantly reduce fall armyworm numbers; often in susceptible grass than in resistant grasses (Braman et al. 2003) but nothing is known about the ability of *Orius* to reduce fall armyworm in turf. Anthocorids were well represented in different turfgrass types in residential turf and abundant in St. Augustinegrass (Shimat unpublished data). The purpose of our study was to advance the understanding of predatory behavior of heteropterans such as *O. insidiosus*, *G. uliginosus* and *G. punctipes* to pest management and conservation biological control in turfgrass. The specific objective of this study was to determine the predatory potential of *O. insidiosus*, *G. uliginosus* and *G. punctipes* in different turfgrass taxa and at different densities on neonates of fall armyworm.

## Materials and Methods

### Source of predators and prey insects

Predatory big-eyed bugs were field-collected from a mixed grassy patch including weed plants (primarily white clover, *Trifolium repens* L. and crimson clover, *Trifolium incarnatum* L.) in Spalding Co., GA, during May, June and July 2005. Sweep nets (Ward's Rochester, NY) and a 'Vortis' vacuum sampler (Burkhard manufacturing Co., Ltd, Herefordshire, England) were used to collect insects from the field. Big-eyed bugs (*G. uliginosus* and *G. punctipes*) were individually sorted and held in plastic petri dishes (11 cm diameter and 2.2 cm height, Pioneer plastics, KY). Male and female pairs were held in petri dishes in the laboratory at 24 °C and 14:10 (L:D) photoperiod and provided with frozen lepidopteran eggs of *Ephestia kuehniella* Zeller (Beneficial insectary, Redding, CA) and *S. frugiperda* (USDA, Tifton, GA), green bean sections, a moist paper towel and a small section of cheese cloth as an oviposition site. Moist paper towel helped to maintain an optimal humidity while beans also provided moisture and nutrition for the bugs. Moisture was maintained inside the dish throughout the rearing period. Clean petri dishes were replaced every three days. Insidious flower bugs, *O. insidiosus* were obtained as 'Oriline' from Syngenta Bioline, Little Clacton, Essex, England. The fall armyworm colony was initiated with eggs obtained from the USDA/ARS Crop Protection and Management Research Unit (Tifton, GA).

### Procurement of turfgrass and maintenance in the greenhouse for the study

Grass taxa were the resistant turf cultivars 'Cavalier' (zoysiagrass) and 'Palisades' (zoysiagrass), intermediately resistant 'TifSport' (bermudagrass) and susceptible 'Sea Isle 1' (seashore seashore paspalum). Grasses were grown in granular calcinated clay (Turface, Applied Industrial Materials, Corp., Deerfield, IL) in a greenhouse. Pots were watered daily and

fertilized once per week with a solution containing 250 ppm NPK (Peters 20-20-20, Scotts-Sierra Horticultural Products Corp., Maryville, OH). Grasses were sheared weekly and maintained at 8 cm height.

### **Experiment 1: Experiments in small arenas with two species of big-eyed bug and insidious flower bug in a growth chamber**

The objective was to determine the predatory potential of big-eyed bug and insidious flower bug when exposed to one-day-old fall armyworms. The susceptible 'Sea Isle 1' (seashore seashore paspalum), intermediate resistant 'TifSport' (bermudagrass), and resistant 'Cavalier' (zoysiagrass), were used because they demonstrated different levels of host resistance to fall armyworm, and may differentially affect predation (Braman et al. 2000a). A single 32 ml plastic cup (Jetware, Jet Plastica Industries, Inc. Hotfield, Pennsylvania 19440) had an inner mouth diameter of 4 cm. All cup experiments were conducted using a completely randomized design with eleven replications per grass taxa. An experimental unit consisted of a cup containing a single species of adult predator (big-eyed bug or insidious flower bug), five one-day-old fall armyworm larvae of and a small quantity (~ fifteen leaves) of the turfgrasses under the study. After introduction of predators and prey, cups were maintained under uniform conditions 27°C, 80% relative humidity and 14:10 (L:D) photoperiod in a growth chamber (Percival Environmental Chambers, Percival scientific Inc., Perry, IA) for 24 hours. Separate experiments were conducted with males, females, nymphs (third to fifth instar nymphs) and combinations of males and females of each species of big-eyed bug (*G. uliginosus* and *G. punctipes*) and insidious flower bug (*O. insidiosus*). After 24 hours, the total live fall armyworm larvae and predators were quantified for analysis.

## **Experiment 2: Laboratory pot experiments using two species of big-eyed bugs and insidious flower bug**

Two trials on potted turfgrasses were conducted with ‘Cavalier’ zoysiagrass, ‘TifSport’ bermudagrass, and ‘Sea Isle 1’ seashore paspalum. Pots were 15 cm in diameter (176.62 cm<sup>2</sup>) with as uniform a grass density as possible maintained. Twenty one-day-old fall armyworms were released onto each pot as prey items. Predator species were released at 0, 2, 4, 6, 8 or 10 individuals per pot, and pots were covered with 32-mesh nylon screen. Pots were arranged in a completely randomized design with four replications for each density per turfgrass taxa. During the first trial, ‘Cavalier’ and ‘Sea Isle 1’ were used, but ‘TifSport’ was added in the second trial. Separate experiments were conducted for each predator species. The turfgrass pots were caged with nylon plastic mesh immediately after release of specific insects in each pot, and pots randomized and maintained for four days in laboratory conditions (24 °C temperature and 14:10 (L:D) photoperiod). After the four-day period, all live fall armyworm were counted using intensive visual inspection of potted plants and quantified for analysis. The survival of predator was also noted after each experiment.

## **Experiment 3: Field cage experiments with using insidious flower bugs on varying turf taxa**

‘Cavalier’ (high resistance) zoysiagrass, ‘Palisades’ (zoysiagrass), ‘TifSport’ (intermediate resistant) bermudagrass and ‘Sea Isle1’ (susceptible) seashore paspalum were planted in the field at the Georgia Station Research and Education Garden in Griffin. Plots measured 25 m<sup>2</sup> and were arranged in a randomized complete block design with six replications.

One-day-old fall armyworm larvae (20 per cage) were released into six per grass taxa, 15.2 cm diameter Polyvinyl Chloride pipe 144 cages (181.36 cm<sup>2</sup>). These cages were pushed

into the turf in each plot. Special care was taken that at least 10 cm length of pipe was exposed above soil level so that screens could be taped over the outside of the cages. Insidious flower bugs, *O. insidiosus*, were introduced at the same time as the armyworms in varying densities (0, 2, 4, 6, 8, or 10 per cage) to each cage. Cages were covered with nylon mesh (Sheer knee-highs, 'Great fit', comfort brand, that fits 8 1/2-11, Sock Shoppe, Griffin, GA) after insects were released into the cages. After five days, cages with turf plugs were removed from the field intact, taken from the field and were intensively examined in the laboratory for remaining live larvae. Survival of the predators were accounted after experiment.

**Statistical analysis** Data were obtained as live fall armyworm per grass taxon in each experiment. Data were subjected to analysis of variance using the PROC GLM procedure in SAS (SAS institute, 2003); means separation was accomplished using Fisher's protected Least Significant Difference Test. Orthogonal contrasts were used to examine the influence of the three turf species on predator and at varying predator density-induced reductions in larval survival. In order to remove the effect of plant resistance from the combined effect of plant resistance and predation, the difference in surviving big-eyed bugs in no predator treatment (out of five big-eyed bugs introduced) on each turfgrass taxa were added to respective predator treatment trials within each turfgrass taxa, in the small arena experiments.

## Results

### **Experiment 1: Experiments in small arenas with two species of big-eyed bug and insidious flower bug in a growth chamber**

Turfgrass taxa significantly influenced predation by *Orius* ( $F = 11.67$ ;  $df = 2$ ;  $P = 0.0002$ ; Table 3.1a). Heavy predation by *Orius* was observed on 'TifSport' bermudagrass (mean survival =  $0.18 \pm 0.4$  out of five initial larvae) followed by 'Cavalier' zoysiagrass (mean survival



=  $0.45 \pm 0.82$ ) when compared to treatments without predators on these turfgrasses as on ‘Sea Isle 1’ seashore paspalum (mean =  $4.27 \pm 0.64$ ), ‘TifSport’ (mean =  $4.81 \pm 0.40$ ) and ‘Cavalier’ (mean =  $2.72 \pm 1.73$ ) ( $F = 10.78$ ;  $df = 2$ ;  $P = 0.0003$ ; Fig. 3.1a). More larvae were recovered on seashore paspalum in the presence of predators (mean =  $2.27 \pm 1.67$ ) than on the other two grass taxa. In controls, number of fall armyworm recovered were not significantly different on ‘Sea Isle 1’ and ‘TifSport’ but differed significantly from ‘Cavalier’ ( $F = 10.78$ ;  $df = 2$ ;  $P = 0.0003$ ). Mortality ( $F = 22.57$ ;  $df = 2$ ;  $P < 0.0001$ ) was highest on the bermudagrass (mean survival =  $0.37 \pm 0.40$ ) compared with that on the susceptible seashore paspalum cultivar and zoysiagrass when the mortality due to grass resistance is removed from combined effect (predation and grass resistance; Table 3.1b). Predation was not significantly different between ‘Sea Isle 1’ (mean survival =  $2.87 \pm 1.45$ ) and ‘Cavalier’ (mean survival =  $2.54 \pm 0.65$ ).

Predation by both male ( $F = 0.04$ ;  $df = 2$ ;  $P = 0.9577$ ) and female ( $F = 2.02$ ;  $df = 2$ ;  $P = 0.1574$ ) *G. uliginosus* was not significantly different among grass taxa (Table 3.1a, Fig. 3.1b). However, fall armyworm mortality with these predators present was significantly higher compared to controls where no predators were introduced. Predatory performance of *G. uliginosus* on ‘Sea Isle 1’ and ‘TifSport’ was similar (Table 3.1a). Lower numbers of live fall armyworms were recovered on zoysiagrass (Fig. 3.1b) from small arenas where females of *G. uliginosus* were introduced (mean =  $0.25 \pm 0.70$ ) as compared to controls (mean =  $2.72 \pm 1.73$ ). Armyworm survival in arenas with male *G. uliginosus* was similar in all grasses and lower when compared to controls without predators (Fig. 3.1b). On removal of mortality due to cultivar’s resistance, highest predation by male *G. uliginosus* ( $F = 4.32$ ;  $df = 2$ ;  $P = 0.0225$ ) was noted on ‘TifSport’ (mean =  $1.62 \pm 1.59$ ) followed by ‘Sea Isle 1’ (mean =  $2.35 \pm 1.62$ ) and ‘Cavalier’

(mean =  $3.47 \pm 1.24$ ); however, predation by females was not influenced by turf taxa ( $F = 1.95$ ;  $df = 2$ ;  $P = 0.1678$ ; Table 3.1b).

Results showed that nymphs of *G. punctipes* preyed similarly on fall armyworm larvae on all grass taxa ( $F = 0.80$ ;  $df = 2$ ;  $P = 0.4603$ ; Table 1a, Fig. 3.1c). This result was not different when the data were corrected to eliminate the cultivar resistance factor causing larval survival ( $F = 2.94$ ;  $df = 2$ ;  $P = 0.0682$ , Table 3.1b). When female *G. punctipes* ( $F = 2.88$ ;  $df = 2$ ;  $P = 0.0716$ ) were introduced to arenas of ‘Sea Isle 1’ and ‘TifSport’ there were no surviving fall armyworms, which was similar to the results observed for resistant ‘Cavalier’ (Table 3.1a) with few survivors (mean =  $0.72 \pm 1.42$ ). However, highest predation was noted on ‘TifSport’ (mean =  $0.19 \pm 0.00$ ) when effect of resistance factor was removed (Table 3.1b). Predation by males of *G. punctipes* was significantly influenced by turf taxa ( $F = 4.14$ ;  $df = 2$ ;  $P = 0.0259$ ), with less predation occurring on ‘Cavalier’ (mean =  $2.45 \pm 1.86$  surviving larvae/5 initial larvae) than on the other two grasses where 82-86% mortality occurred. This observation was similar on mortality rate when the resistance effect was removed ( $F = 14.97$ ;  $df = 2$ ;  $P < 0.0001$ ) with higher predation on ‘TifSport’ (mean survival =  $1.09 \pm 1.57$ ) and ‘Sea Isle 1’ (mean survival =  $1.45 \pm 1.10$ ) compared to ‘Cavalier’ (mean survival =  $3.95 \pm 1.26$ ). When unsorted (either male or female) *G. punctipes* were introduced, mortality of fall armyworm was not significant with any of the grass taxa ( $F = 3.10$ ;  $df = 2$ ;  $P = 0.0598$ ) but, effective predation (reduction compared to controls with no predators) was observed on all cultivars. Predation was in the order of, seashore paspalum > bermudagrass > zoysiagrass for male and female *G. punctipes*. At the same time, no significant influence of turfgrass taxa was observed ( $F = 2.55$ ;  $df = 2$ ;  $P = 0.0952$ ) when mortality due to resistance factor was removed on combined *G. punctipes* predation (Table 3.1b).

## Experiment 2: Laboratory pot experiments using two species of big-eyed bugs and insidious flower bug

In the first trial, few armyworm larvae survived on ‘Cavalier’ at all densities of *Orius* (sex ratio was 1:1) except when no predators were added (mean =  $1.5 \pm 0.57$ ) ( $F = 13.13$ ;  $df = 5$ ;  $P < 0.0001$ ). Significant mortality of one-day-old fall armyworm larvae was noticed (mean survival =  $4.75 \pm 2.22$ ), when *Orius* density was two, compared to no predator trial on seashore paspalum (mean =  $12.75 \pm 4.57$ ) ( $F = 10.42$ ;  $df = 5$ ;  $P < 0.0001$ ; Table 3.2a). Increasing the *Orius* density did not significantly increase fall armyworm mortality in ‘Sea Isle 1’ seashore paspalum. Predation by *Orius* was significantly affected by grass taxa (‘Cavalier’ vs. ‘Sea Isle 1’;  $F = 51.78$ ;  $df = 1$ ;  $P < 0.0001$ ; Fig. 3.2a).

In the second pot experiment, predatory performance of *Orius* on ‘Cavalier’ was similar to that observed in the first experiment, with no surviving fall armyworm larvae other than in the no predator control (mean =  $0.25 \pm 0.5$ ). Grass taxa significantly influenced ( $F = 28.63$ ;  $df = 2$ ;  $P < 0.0001$ ) predation on neonates. However, ‘TifSport’ and ‘Sea Isle 1’ were not significantly different (Table 3.2). There was no significant ( $F = 1.00$ ;  $df = 5$ ;  $P = 0.4457$ ) predator density influence on larval mortality when ‘Cavalier’ was the host plant. In contrast, an increase in the *Orius* density did significantly increase predation on ‘TifSport’ ( $F = 49.16$ ;  $df = 5$ ;  $P < 0.0001$ ) and ‘Sea Isle 1’ ( $F = 17.87$ ;  $df = 5$ ;  $P < 0.0001$ ). Predation by *Orius* was observed starting from an initial density of two predators on ‘TifSport’ (mean =  $2.75 \pm 1.5$ ) and ‘Sea Isle 1’ (mean =  $1.25 \pm 1.89$ ) causing a more than 50% reduction in fall armyworms compared to the no predator (‘TifSport’, mean =  $8.25 \pm 0.95$  and ‘Sea Isle 1’, mean =  $11.0 \pm 3.36$ ). When *Orius* densities reached eight and ten per pot, no fall armyworms survived on any of these turfgrasses (Fig. 3.2b).

### Experiment 3: Field cage experiments using insidious flower bugs on varying turf taxa

Grass taxa ( $F = 5.88$ ;  $df = 3$ ;  $P = 0.0037$ ) and *Orius* density ( $F = 3.70$ ;  $df = 5$ ;  $P = 0.0127$ ) significantly impacted fall armyworm survival. No fall armyworms survived on the ‘Cavalier’ ( $F = 1.0$ ;  $df = 5$ ;  $P = 0.4346$ ) on introduction of *Orius* (Table 3.3, Fig. 3.3). ‘Palisades’ zoysiagrass, was slightly less resistant, but no predator density effect was apparent ( $F = 0.64$ ;  $df = 5$ ;  $P = 0.6738$ ). Numbers of live fall armyworm larvae recovered on ‘TifSport’ bermudagrass were significantly different ( $F = 2.58$ ;  $df = 5$ ;  $P = 0.0469$ ) with lower numbers of fall armyworm recovered when *Orius* density was two (mean =  $5.66 \pm 4.54$ ) than when no predators were introduced (mean =  $2.5 \pm 2.58$ ; Table 3.3, Fig. 3.3). Reduced survival of fall armyworms was observed when *Orius* density was six or more individuals per enclosure (Fig. 3.3). In contrast with the second pot experiment, larvae did survive on ‘Sea Isle 1’ even at the higher *Orius* densities of eight and ten. Number of larvae recovered from ‘Sea Isle 1’ was unaffected by with *Orius* density ( $F = 0.64$ ;  $df = 5$ ;  $P = 0.6738$ ).

### Discussion

Big-eyed bugs feed on a wide range of prey, including insect eggs, spider mites, plant bugs, leafhoppers, aphids, and various lepidopteran larvae (Dunbar 1971). Their predatory behavior substantial contributes to suppression of various pest species, thereby playing a very important role in pest management in different ecosystems (Crocker and Whitcomb 1980). In small arenas on grass clippings, predation by *G. uliginosus* was significant compared to no-predator controls, but was not influenced by turf taxa. Predation by *G. punctipes* males was influenced by grass taxa, with higher predation occurring on the bermudagrass and seashore paspalum than on zoysiagrass. Female *G. punctipes* consumed more fall armyworm larvae than males on all turfgrasses, but predation was lower on the resistant zoysiagrass compared to

susceptible grass taxa. However, lower numbers of live fall armyworm were recovered from resistant zoysiagrass when no predators were introduced than from no-predator controls of seashore paspalum and bermudagrass. Previous studies (Braman et al. 2003) have shown mortality of *S. frugiperda* was observed on the resistant 'Cavalier' zoysiagrass by a low number of *G. uliginosus* when six turfgrass were compared ('Sea Isle 1' and '561-79', seashore paspalum; 'TifSport' and 'TifEagle' bermudagrass; and 'Cavalier' and 'Palisades' zoysiagrass) in laboratory studies. These studies also showed that there was a 7-fold weight difference of 10-day old *S. frugiperda* feeding on the resistant compared to those fed on susceptible turfgrass cultivars. *Spodoptera frugiperda* developed slower on the resistant turfgrass and hence spent more time in a size range prone to predation by *G. uliginosus* (Braman et al. 2003).

One-day-old fall armyworms were heavily preyed upon on bermudagrass and zoysiagrass by insidious flower bugs when they were released in small containers under uniform conditions. In laboratory studies, few or no surviving fall armyworms were observed on resistant zoysiagrass when *Orius* were introduced at different densities. Isenhour et al. (1990) noted more effective feeding on neonates of fall armyworm than on three-day-old larvae. Isenhour et al. (1990) previously determined that predation by adult male and female *O. insidiosus* on eggs and first instar larvae of fall armyworm did differ significantly in laboratory trials.

Results obtained from laboratory studies did not translate directly to the field, where we observed inconsistent mortality of fall armyworm. However, mortality of fall armyworm larvae was effective in bermudagrass and seashore paspalum compared to zoysiagrass cultivars as compared to no predator density. Previous studies conducted in the same plots has demonstrated a positive correlation of big-eyed bugs and insidious flower bugs with chinch bugs and leafhoppers on seashore paspalum and bermudagrass collected from vacuum samples (Braman

et al. 2003). In addition, our recent survey of residential turf showed occurrence and abundance of insidious flower bugs was associated with abundance of chinch bugs and delphacids (Shimat, unpublished data).

This study showed (Table 3.1b) that predators are very important in reducing survival of fall armyworm larvae on seashore paspalum and bermudagrass cultivars. Results also showed that predation was not prominent on resistant grass cultivar ('Cavalier' and 'TifSport') in enhancing mortality of fall armyworm larvae. Also Braman et al. (2000a) showed that lower numbers of herbivore (*S. frugiperda*) survived on resistant zoysiagrass. *Orius* demonstrated significant predation on fall armyworm larvae in both laboratory and field study. Occurrence of *Orius* was well reported at different grass taxa from recent residential survey and also demonstrated significant predation on lepidopteran larvae in laboratory studies. Laboratory studies did not directly translate to the field results probably because presence of alternate prey and predators in field. Thus, *Orius* should be evaluated further as potential bio-control agent in turf. More studies are also required focusing on the predatory efficiency of *Orius* on other potential prey items such as chinch bugs and mites should be conducted in turf.

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Figure 3.1a. Mean number of live fall armyworm larvae recovered after 24 hours in laboratory experiments when *Orius insidiosus* were introduced as predators on different turfgrass cultivars. Different letters denote significant difference ( $P < 0.05$ ) between mean survival of fall armyworm in different grass taxa, by Fisher's protected least significant difference test.

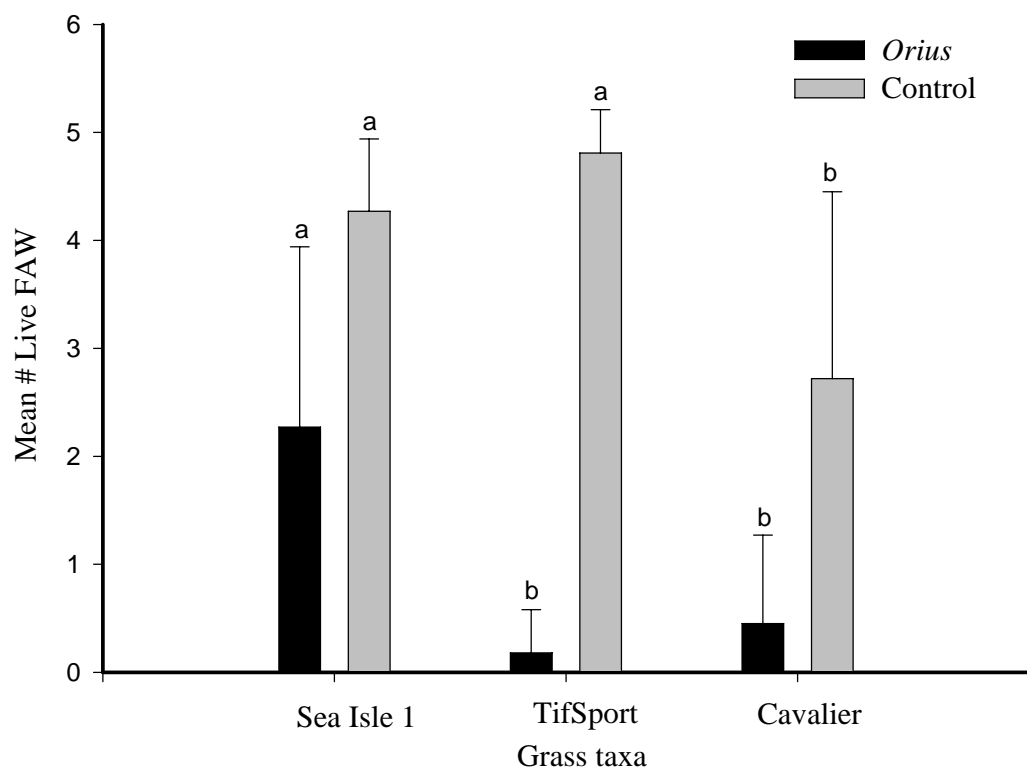


Figure 3.1b. Mean number of live fall armyworm larvae recovered after 24 hours in laboratory experiments when males and females of *Geocoris uliginosus* on different turfgrass cultivars. Different letters denote significant difference ( $P < 0.05$ ) between mean survival of fall armyworm in different grass taxa, by Fisher's protected least significant difference test.

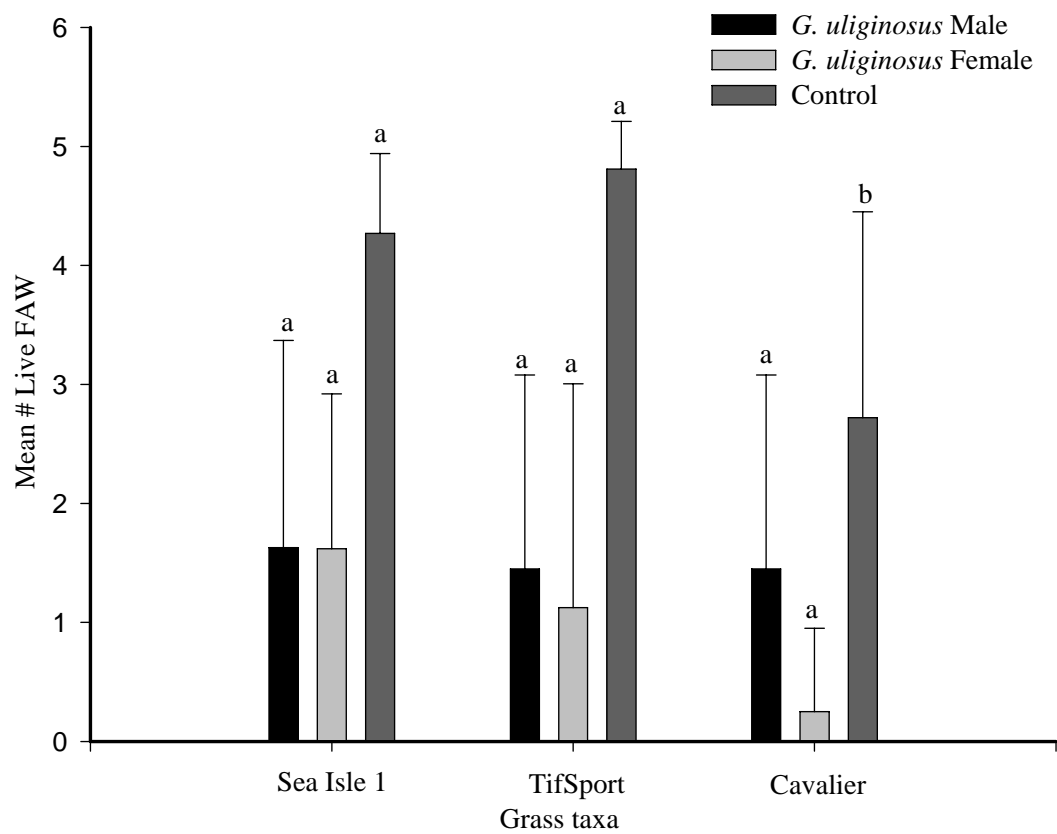


Figure 3.1c. Mean number of live fall armyworm larvae recovered after 24 hours in the laboratory experiments when males, females and nymphs of *Geocoris punctipes* were introduced as predators on different turfgrass cultivars. Different letters denote significant difference ( $P < 0.05$ ) between mean survival of fall armyworm in different grass taxa, by Fisher's protected least significant difference test.

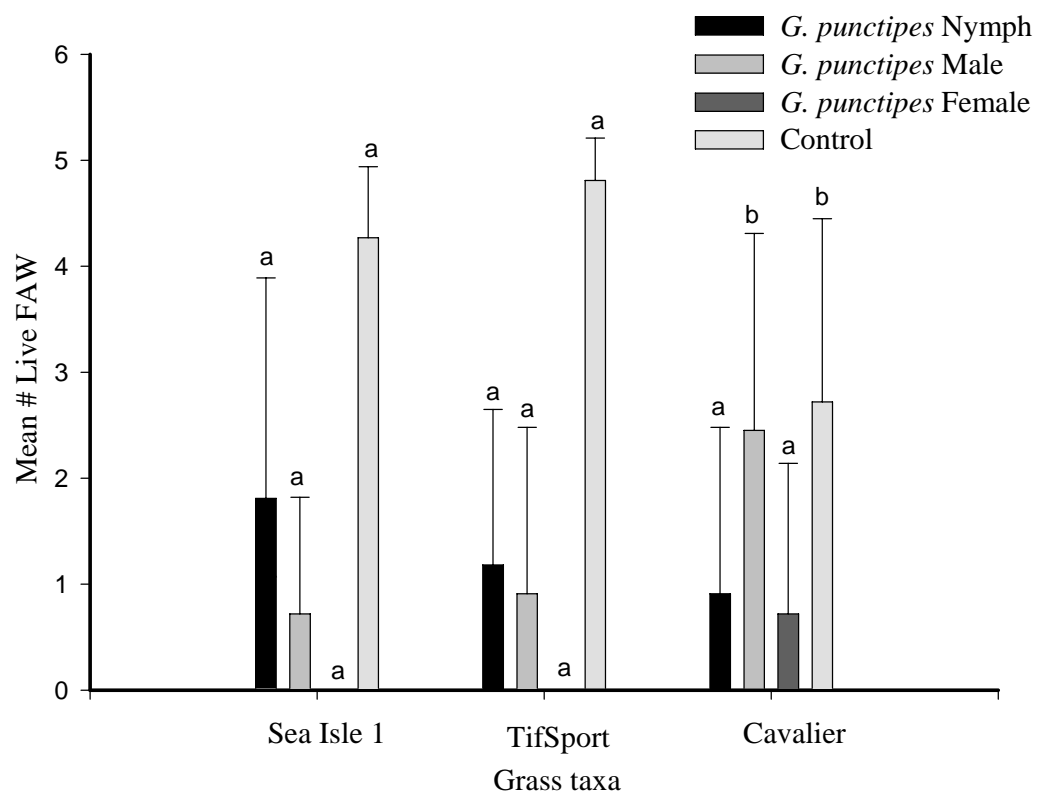


Figure 3.2a. Mean number of live fall armyworm larvae recovered after four days in the laboratory experiments when *Orius insidiosus* were introduced as predators on different turfgrass cultivars at different densities. Letters in upper caps denote mean survival of fall armyworm significantly different ( $P < 0.05$ ) between grass taxa and letter in small caps denote mean survival of fall armyworm significantly different within different *O. insidiosus* density by Fisher's protected least significant difference test.

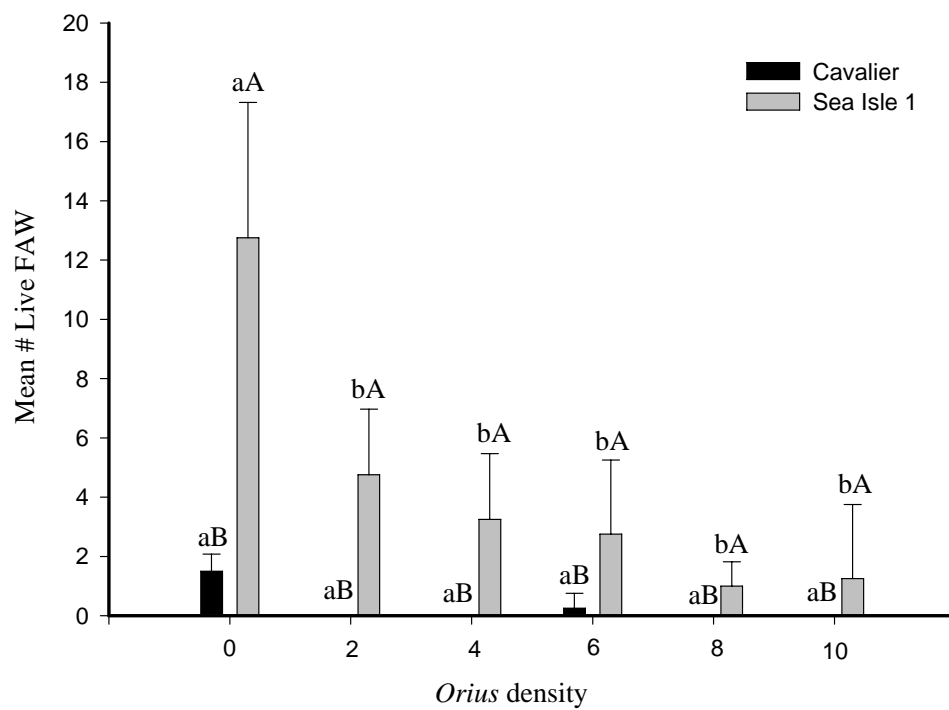




Figure 3.2b. Mean number of live fall armyworm larvae recovered after four days in the laboratory experiments when *Orius insidiosus* were introduced as predators on different turfgrass cultivars at different densities. Letters in upper caps denote mean survival of fall armyworm significantly different ( $P < 0.05$ ) between grass taxa and letter in small caps denote mean survival of fall armyworm significantly different within different *O. insidiosus* density by Fisher's protected least significant difference test.

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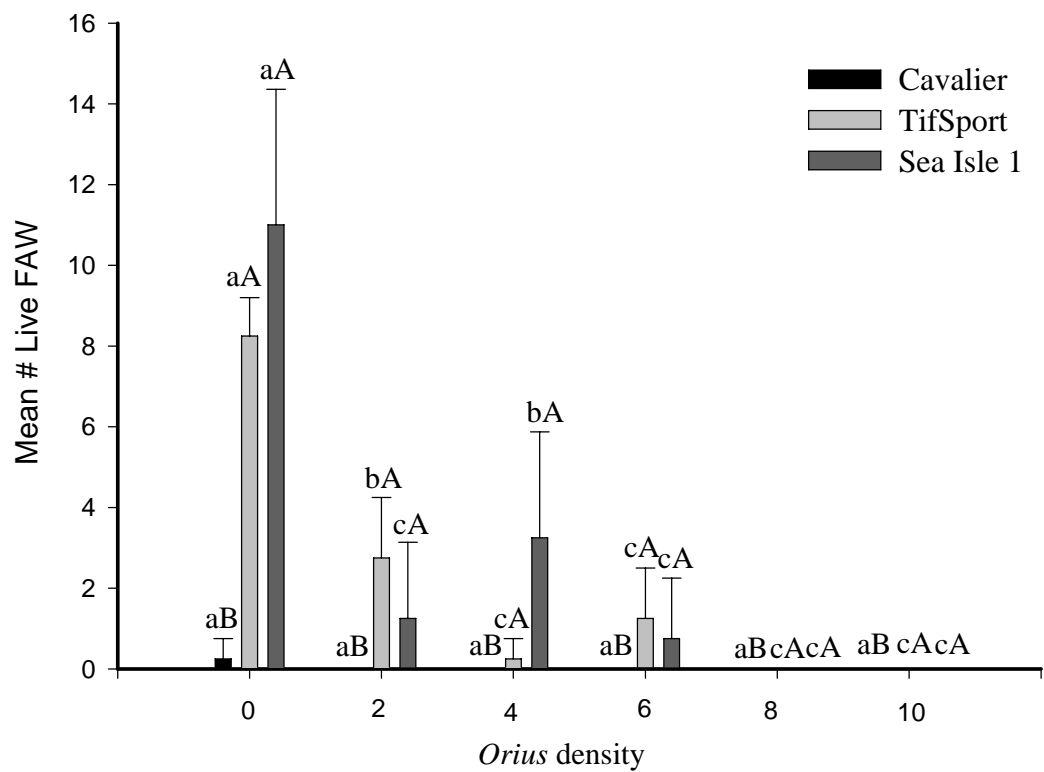


Figure 3.3. Mean number of live fall armyworm larvae recovered after five days in the field experiment when *Orius insidiosus* were introduced as predators on different turfgrass cultivars at different densities. Letters in upper caps denote mean survival of fall armyworm significantly different ( $P < 0.05$ ) between grass taxa and letter in small caps denote mean survival of fall armyworm significantly different within different *O. insidiosus* density by Fisher's protected least significant difference test.

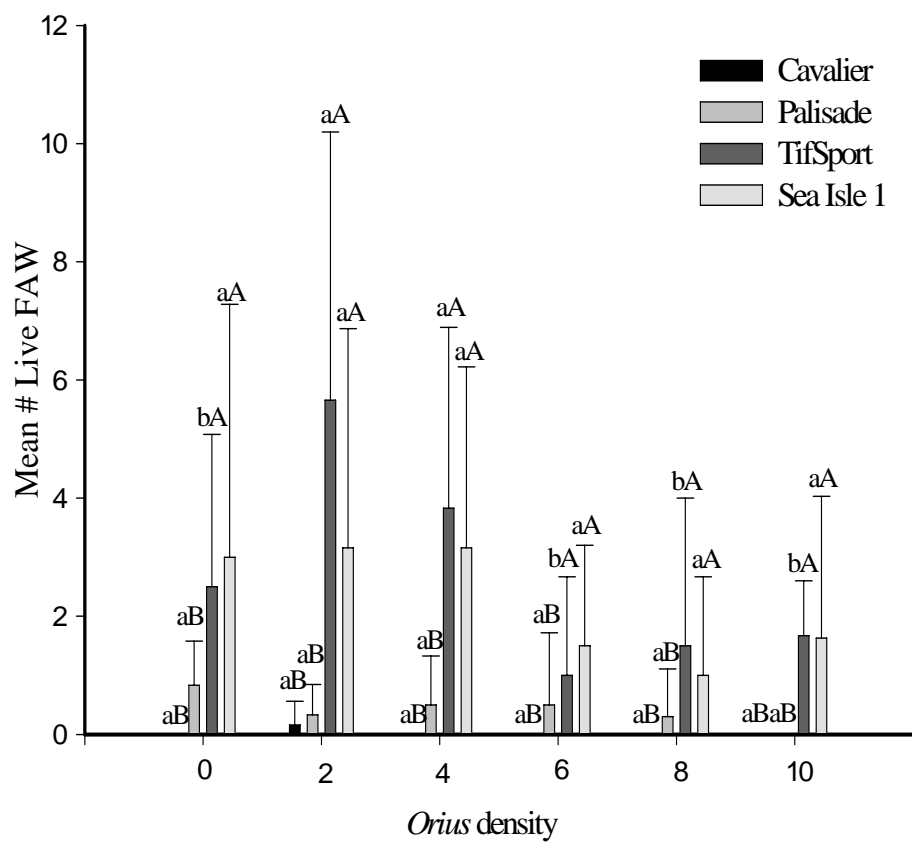


Table 3.1a. Mean number of live fall armyworm larvae recovered after 24 hours in laboratory experiments when male, female and nymph *G. punctipes*, *G. uliginosus* or *O. insidiosus* were introduced as predators on different turfgrass cultivars. Five one-day-old fall armyworms were introduced per cage initially.

| Heteroptera                  | 'Sea Isle 1' seashore seashore paspalum | 'TifSport' bermudagrass | 'Cavalier' zoysiagrass | <i>F value</i> | <i>P value</i> |
|------------------------------|---|-------------------------|------------------------|----------------|----------------|
| <i>Orius</i> combined        | 2.27 ±1.67 a                            | 0.18 ±0.40 b            | 0.45 ±0.82 b           | 11.67          | 0.0002*        |
| <i>G. uliginosus</i> male    | 1.63 ±1.74 a                            | 1.45 ±1.63 a            | 1.45 ±1.63 a           | 0.04           | 0.9577         |
| <i>G. uliginosus</i> female  | 1.62 ±1.30a                             | 1.12 ±1.88 a            | 0.25 ±0.7 a            | 2.02           | 0.1574         |
| <i>G. punctipes</i> Nymphs   | 1.81 ±2.08 a                            | 1.18 ±1.47 a            | 0.90 ±1.57 a           | 0.80           | 0.4603         |
| <i>G. punctipes</i> male     | 0.72 ±1.10 a                            | 0.91 ±1.57 a            | 2.45 ±1.86 b           | 4.14           | 0.0250*        |
| <i>G. punctipes</i> female   | 0 ±0 a                                  | 0 ±0 a                  | 0.72 ±1.42 a           | 2.88           | 0.0716         |
| <i>G. punctipes</i> combined | 1.09 ±1.44 a                            | 2.90 ±1.97 a            | 1.36 ±2.06 a           | 3.10           | 0.0598         |
| Control                      | 4.27 ±0.64 a                            | 4.81 ±0.40 a            | 2.72 ±1.73 b           | 10.78          | 0.0003*        |

Means within each row followed by the same letter are not significantly different by Fisher's protected least significant difference test. \* Mean survival of fall armyworm significantly different ( $P < 0.05$ ) if letters are different within each row by Fisher's protected least significant difference test.

Table 3.1b. Mean number is live fall armyworm larvae recovered after 24 hours in the laboratory cups experiments when males, females and nymphs of *G. punctipes*, *G. uliginosus*, *O. insidiosus* were introduced as predators on different turfgrass cultivars and after removal of mortality caused by the effect of resistance. Five one-day-old fall armyworms were introduced per cage initially.

| Heteroptera                  | 'Sea Isle 1' seashore seashore paspalum | 'TifSport' bermudagrass | 'Cavalier' zoysiagrass | <i>F</i> value | <i>P</i> value |
|------------------------------|---|-------------------------|------------------------|----------------|----------------|
| <i>Orius</i> combined        | 2.87±1.45 a                             | 0.37±0.40 b             | 2.54±0.65 a            | 22.57          | < 0.0001*      |
| <i>G. uliginosus</i> male    | 2.35±1.62 ab                            | 1.62±1.59 a             | 3.47±1.24 b            | 4.32           | 0.0225*        |
| <i>G. uliginosus</i> female  | 2.35±1.30 a                             | 1.3±1.83 a              | 2.53±0.71 a            | 1.95           | 0.1678         |
| <i>G. punctipes</i> Nymphs   | 2.41±1.87 a                             | 1.42±1.54 a             | 2.98±1.04 a            | 2.94           | 0.0682         |
| <i>G. punctipes</i> male     | 1.45±1.10 a                             | 1.09±1.57 a             | 3.95±1.26 b            | 14.97          | < 0.0001*      |
| <i>G. punctipes</i> female   | 0.73±0.00 a                             | 0.19±0.00 b             | 2.61±0.84 c            | 75.12          | < 0.0001*      |
| <i>G. punctipes</i> combined | 1.82±1.44 a                             | 3.04±1.91 a             | 3.20±1.29 a            | 2.55           | 0.0952         |
| Control                      | 4.27±0.64 a                             | 4.81±0.40 a             | 2.72±1.73 b            | 10.78          | 0.0003*        |

Means within each row followed by the same letter are not significantly different by Fisher's protected least significant difference test. \* Mean survival of fall armyworm significantly different ( $P < 0.05$ ) if letters are different within each row by Fisher's protected least significant difference test.

Table 3.2. Mean number of live fall armyworm larvae recovered after four days in the laboratory experiments when *Orius* were introduced as predators on different turfgrass cultivars at different densities. Twenty one-day-old fall armyworms were introduced per cage initially.

| Density   | Expt:1                      |  | Expt: 2                     |                              |  |
|-----------|-----------------------------|--|-----------------------------|------------------------------|--|
|           | ‘Cavalier’<br>(zoysiagrass) | ‘Sea Isle 1’<br>(seashore<br>paspalum) | ‘Cavalier’<br>(zoysiagrass) | ‘TifSport’<br>(bermudagrass) | ‘Sea Isle 1’<br>(seashore<br>paspalum) |
| <b>0</b>  | 1.50±0.57 aA                | 12.75±4.57 aB                          | 0.25±0.50 aA                | 8.25±0.95 aB                 | 11.00±3.36 aB                          |
| <b>2</b>  | 0±0 bA                      | 4.75±2.22 bB                           | 0±0 aA                      | 2.75±1.5 bB                  | 1.25±1.89 cB                           |
| <b>4</b>  | 0±0 bA                      | 3.25±2.22 bB                           | 0±0 aA                      | 0.25±0.5 cB                  | 3.25±2.62 bB                           |
| <b>6</b>  | 0.25±0.50 bA                | 2.75±2.5 bB                            | 0±0 aA                      | 1.25±1.25 cB                 | 0.75±1.50 cB                           |
| <b>8</b>  | 0±0 bA                      | 1.0±0.82 bB                            | 0±0 aA                      | 0±0 cB                       | 0±0 cB                                 |
| <b>10</b> | 0±0 bA                      | 1.25±2.5 bB                            | 0±0 aA                      | 0±0 cB                       | 0±0 cB                                 |

Not significantly different ( $P > 0.05$ ) indicated as same small alphabetic letters between different *Orius* densities within each turfgrass cultivars (each column) and same capital alphabetic letter between different turfgrass cultivars (between column) by Fisher’s protected least significant difference test within each experiment. Exp: 1 and Expt: 2 denotes two separate cage experiments done in the laboratory.

Table 3.3. Mean number of live fall armyworm larvae recovered after five days in the field from each *Orius* density on different turfgrass cultivars. Twenty one-day-old fall armyworms were introduced per cage initially.

| Density   | 'Cavalier'<br>(zoysiagrass) | 'Palisade'<br>(zoysiagrass) | 'TifSport'<br>(bermudagrass) | 'Sea Isle 1' (seashore<br>seashore paspalum) |
|-----------|-----------------------------|-----------------------------|------------------------------|--|
| <b>0</b>  | 0±0 aA                      | 0.83±0.75 aA                | 2.50±2.58 bB                 | 3.00±4.28 aB                                 |
| <b>2</b>  | 0.16±0.40 aA                | 0.33±0.52 aA                | 5.66±4.54 aB                 | 3.16±3.71 aB                                 |
| <b>4</b>  | 0±0 aA                      | 0.50±0.83 aA                | 3.83±3.06 bB                 | 3.16±3.06 aB                                 |
| <b>6</b>  | 0±0 aA                      | 0.50±1.22 aA                | 1.00±1.67 bB                 | 1.50±1.70 aB                                 |
| <b>8</b>  | 0±0 aA                      | 0.30±0.81 aA                | 1.5±2.5 bB                   | 1.00±1.67 aB                                 |
| <b>10</b> | 0±0 aA                      | 0±0 aA                      | 1.67±0.93 bB                 | 1.67±2.40 aB                                 |

Not significantly different ( $P > 0.05$ ) indicated as same small alphabetic letters between different *Orius* densities within each turfgrass cultivars (each column) and same capital alphabetic letter between different turfgrass cultivars (between column) by Fisher's protected least significant difference test.



**CHAPTER 4****DIRECT EFFECTS OF CHLORPYRIFOS, SPINOSAD AND HALOFENOZIDE ON BIG-EYED BUGS****(*GEOCORIS SPP.*: GEOCORIDAE)<sup>1</sup>**

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**ABSTRACT** Petri dish without turfgrass and conetainer with turfgrass experiments were conducted with two species of Geocoridae, *Geocoris uliginosus* (Say) and *G. punctipes* (Say). Seven concentrations of chlorpyrifos ('Dursban 50 WP'), halofenozide ('Mach 2 E') and spinosad ('Conserve SC') were applied to petri dish without turfgrass or conetainer with turfgrass. Survival percentage of geocorids were recorded on one, three days after treatment. In the petri dish experiment, reduced concentrations of chlorpyrifos were toxic to *G. uliginosus* and *G. punctipes* as compared to the control (no pesticide applied). Big-eyed bug survival was significantly influenced by geocorid species and age (third to fifth-instar nymphs) on one and three days post application of chlorpyrifos. Survival of big-eyed bugs was influenced by spinosad concentrations on one, three, while none of concentrations of halofenozide were toxic to big-eyed bugs. In the conetainer experiment, three turfgrass taxa ('Cavalier' zoysiagrass, 'Sea Isle 1' seashore paspalum, and 'TifSport' bermudagrass) were exposed to the same pesticide concentrations as above. Survival of both species of geocorids was affected by a chlorpyrifos concentration of 0.05 g in 400 ml water (second concentration) on 'TifSport' bermudagrass, between the second and third (0.1 g in 400 ml water) concentration on 'Sea Isle 1' seashore paspalum and between the third and fourth (0.2 g in 400 ml water) concentration on 'Cavalier' zoysiagrass for one and three after chlorpyrifos application. Differential survival of geocorid species was not influenced by chlorpyrifos applications. However, a higher survival percentage was observed in the 'Cavalier' zoysiagrass as compared to 'Sea Isle 1' seashore paspalum and 'TifSport' bermudagrass at different concentrations of chlorpyrifos by one and three days after application. Different concentrations of both spinosad and halofenozide failed to influence ( $P > 0.05$ ) the survival of big-eyed bugs in the conetainer experiments for one and three after application regardless of turf genotype.

**KEYWORDS** Big-eyed bug, Geocorids, *Geocoris uliginosus*, *G. punctipes*, chlorpyrifos, spinosad, halofenozide

Chemical pesticides are widely used to manage pest in different agro-ecosystems. Dhaliwal and Arora (2001) suggested that increased use of selective pesticides could have a negative impact on specific non-target fauna (the parasitoids and predators) and that might increase the risk of target pest resurgence and an outbreak of secondary pests. There are many reports of 'secondary pest' outbreaks in different cropping systems (Dhaliwal and Arora 2001). The varying interactions between herbivores and host-plant resistance also could determine the effectiveness of selective insecticides on target pests (Braman et al. 2004). Few studies have evaluated the effect of these pesticides on the extrinsic resistance offered by the natural enemies. Integrated pest management (IPM) in urban landscapes be more fully implemented through incorporation of host-plant resistance (different kind and degree), judicious use of commercial pesticides and productive implementation of biological control strategy. More potential pesticide assessment studies are needed to identify the compatibility and resultant interactive effects of integrated pest management approaches (Braman et al. 2004, Verkerk and Wright 1996, Thomas 1999).

Big-eyed bugs, *Geocoris spp.* are common, omnivorous, generalist predators that attack aphids, lepidopterans, and other pests on various crops in United States (Champlain and Scholdt 1966, Lawrence and Watson 1979, Atim and Graham 1984). Usually, the adult big-eyed bug overwinters in plant residues or cracks in soil to escape cold winter months (Dunbar 1971). They engage in active mating during the spring season. Female big-eyed bugs laid eggs continuously up to 30 days after single mating (Dunbar 1972). The adult big-eyed bugs live approximately one month and lay up to 300-400 fertile eggs, which are deposited singly either on leaves or on stems. The nymphs emerge in approximately one week and the nymph undergoes five nymphal

instars, with each instar requiring 4-6 days, and take 2-4 weeks to reach adulthood (Dunbar 1971). Immature insects and adults can kill at least 12 prey per day (Hagler and Cohen 1991). Hagler and Naranjo (1994) suggested that predator quantification is not very easy, due to their cryptic nature in field. *G. uliginosus* persisted in turfgrass and effectively preyed on the larvae of *S. frugiperda* (Braman et al. 2002a, Braman et al. 2003). Braman et al. (2002a) reported that growing floral plantings might be useful in providing refugia for beneficial insects when insecticides were applied to suppress turfgrass pests. *G. punctipes* has revealed nutritional flexibility when availability of prey density declines, instead, feeding on plant parts such as pods, leaves, seeds and nectars and on turfgrass (Eubanks and Denno 1999, Dunbar 1971)

Studies have been conducted to evaluate impact of different pesticides on the natural enemy complex in turfgrass systems. Braman et al. (1997) reported that insecticides such as chlorpyrifos, acephate and carbaryl were widely used by commercial lawn care firms and in sod production (Oetting et al. 1994, Braman et al. 2002b). In an attempt to examine the effects of isofenphos on non-target invertebrates, such as predaceous Acari and staphylinids, in residential lawns, Vavrek and Niemczyk (1990) observed short-term reductions of predator populations in treated lawns. Terry et al. (1993) determined that isazofos residual activity on larval stages of carabids and adults of staphylinids remained between the 1-3 weeks post application. Residual insecticidal activity of isazofos, carbaryl and cyfluthrin on spiders persisted for 2-5 weeks after application on Kentucky bluegrass (Terry et al. 1993). Cockfield and Potter (1984) showed a significant reduction in predation on pyralid eggs when turf was treated with chlorpyrifos at one and three weeks after application compared to eggs in untreated turfgrass. This finding was coupled with marked reduction in formicids and spiders numbers around the same time interval after pesticide application (Cockfield and Potter 1984). Studies have shown that direct exposure

(topical application) and ingestion of treated food by halofenozide (2.24 kg AI per ha) inflicted no mortality on the ground beetle, *Harpalus pennsylvanicus* (DeGeer) compared to bendiocarb (4.48 kg AI per ha) and imidacloprid (0.336 kg AI per ha) treatments (Kunkel et al. 2001). Halofenozide (2.24 kg AI per ha) also had no residual effects on ground beetles with irrigated and non-irrigated Kentucky bluegrass. Elzen (2001) observed that imidacloprid, tebufenozide, and spinosad were less toxic to male *G. punctipes* than were chlorfenapyr, endosulfan, and fipronil. Spinosad, tebufenozide, and azinphos-methyl were significantly less toxic to female *G. punctipes* than fipronil, and endosulfan. These studies also showed that consumption of prey (eggs of *Helicoverpa zea* Boddie) was greatly reduced in malathion, endosulfan, fipronil, azinphos-methyl, and imidacloprid treatments compared with the control, tebufenozide, and lower doses of spinosad which were not different (eggs consumption) from the control.

Braman et al. (2004) previously demonstrated the mortality rate of fall armyworm, *Spodoptera frugiperda* (J. E. Smith), neonates and third instar larvae when mediated by varying levels of resistant turfgrass taxa and six concentrations of three pesticides (chlorpyrifos, spinosad, and halofenozide). On 'Cavalier' zoysiagrass, maximum mortality of first-instar fall armyworm larvae was noticed with lower rates of halofenozide were applied in the greenhouse but no surviving larvae were recovered in field experiments. Survival of first-instar larvae of fall armyworms was lower on 'Cavalier' zoysiagrass compared to bermudagrass and seashore paspalum when these grass taxa were exposed to lower rates of chlorpyrifos. However, in a separate experiment, survival of fall armyworm was higher on bermudagrass and seashore paspalum when spinosad was used. Factors contributing to the differential response included different modes of action of pesticides, varied levels and modes action of plant resistance and rate of feeding shown by fall armyworm (Braman et al. 2004).

The present study was designed to determine the survival of two species of big-eyed bugs, *G. uliginosus* and *G. punctipes* when exposed to seven-concentrations of chlorpyrifos, spinosad and halofenozide mediated directly and when by different turfgrass taxa. These pesticides have prove toxic to fall armyworm larvae under reduced concentrations under various conditions (Braman et al. 2004). Therefore, effects of these pesticides on the beneficial arthropods including heteropteran predators become more important in implementation of effective pest management in turfgrass. Some published data is available for big-eyed bugs (*G. punctipes*) concerning organophosphate and spinosad exposure, while, no published information is available on their effects on *G. uliginosus* and no data exists on either species when mediated by resistant turfgrass.

## Materials and Methods

### Insects and Plant Source

Field-collected nymphs and the F<sub>1</sub> progeny of field-collected *G. uliginosus* and *G. punctipes* adults were used in the laboratory experiments. *G. uliginosus* and *G. punctipes* were collected from stands of mixed grasses in Spalding Co., GA, during April, May and June 2006. A 'Vortis' vacuum sampler (Burkhard manufacturing Co., Ltd, Herefordshire, England) was used to collect big-eyed bugs from the field. Male and female pairs were held in petri dishes in the laboratory at 24 °C and 14:10 (L:D) photoperiod and provided with eggs of *Ephesia kuehniella* Zeller (Beneficial insectary, Redding, CA) and *S. frugiperda* (USDA, Tifton, GA) a moist paper towel, green beans sections and a small section of cheesecloth as an oviposition site.

The turfgrasses included were fall armyworm resistant turf cultivar, 'Cavalier' zoysiagrass (*Zoysia japonica* von Steudel and *Z. matrella* L. Merrill), intermediate resistant cultivar, 'TifSport' bermudagrass (*Cynodon dactylon* L. x *C. transvaalensis* Burt-Davy and

susceptible cultivar ‘Sea Isle 1’ seashore paspalum (*Paspalum vaginatum* Swartz). These grasses were grown in pots (14.8 diameter) filled with granular calcinated clay (Turface, Applied Industrial Materials, Corp., Deerfield, IL) medium maintained in the greenhouse. Pots were watered daily and fertilized once per week with a solution containing 250 ppm NPK (Peters 20-20-20, Scotts-Sierra Horticultural Products Corp., Maryville, OH). These grasses were sheared weekly and maintained at 8 cm height.

### **Direct toxicity of insecticide concentrations on survival of big-eyed bugs in laboratory petri dish studies**

Three insecticides were used: chlorpyrifos (‘Dursban 50W’, Dow AgroSciences, Indianapolis, IN), halofenozide (‘Mach 2’, Dow AgroSciences, Indianapolis, IN) and spinosad (‘Conserve’, Dow AgroSciences, Indianapolis, IN) for laboratory experiments. The recommended rate of ‘Mach 2’ (emulsion) is 0.0005 liter per square meter (119.8 ppm per square meter), ‘Conserve’ (soluble concentrate) at 0.083 mille liter per square meter (9.94 ppm per meter) to 0.416 mille liter per square meter (49.85 ppm per square meter) and ‘Dursban’ (wetable powder) at 0.24 gram per square meter (119.0 ppm per square meter). Seven concentrations of each insecticide were examined to evaluate the direct toxicity on the predators, *G. uliginosus* and *G. punctipes*. The concentrations were in ml-formulated product to 400 ml distilled water: ‘Mach 2’ (halofenozide) as 0.00, 0.001, 0.010, 0.100, 0.500, 1.000, and 2.000 ml; ‘Conserve’ (spinosad) as 0.00, 0.000375, 0.0005625, 0.00075, 0.00375, 0.0375 and 0.375 ml, and wettable powder gram-formulated product of ‘Dursban’ (chlorpyrifos) to 400 ml distilled water as 0.00, 0.05, 0.10, 0.20, 0.30, 0.40 and 0.50 g. Previous results indicate that fall armyworm control was significantly greater on the resistant ‘Cavalier’ zoysiagrass than on susceptible ‘Sea Isle 1’ seashore paspalum at the 0.03 (17.97 ppm) and 0.09 ml 53.91 ppm)

concentrations of chlorpyrifos or the 0.001 (0.559 ppm), 0.01 (5.99 ppm) and 0.1 ml (59.9 ppm) concentration of halofenozide at seven days after treatment (Braman et al. 2004). A sub-unit consists of a single individual of either nymph or adult *G. uliginosus* or *G. punctipes*) aspirated into a disposable plastic petri dish of 8.4 cm diameter (100 x 15 mm petri dish, polystyrene disposable sterilized, VMR International Batavia, IL 60510). A treatment replicate consisted of three such sub-units per pesticide concentration. Pesticide concentrations were prepared (as mentioned above) and applied to these petri dishes at the rate of approximately 0.84 liter per square meter using a CO<sub>2</sub> powered backpack sprayer with a Meter Jet Gun (Spray Systems Co., Wheaton, IL). Big-eyed bugs were transferred to these treated petri dishes, and provided with a uniform quantity of *E. kuehniella* eggs (30-40 frozen eggs) and moistened paper towel as nutritional and moisture sources, respectively. This experiment consisted of two replications using adult *G. uliginosus*, two replications using adult *G. punctipes*, two replication using fifth-instar nymphs of *G. punctipes*, one replication with third through fifth-instar nymphs of *G. punctipes*, and two replications of third through fifth-instar nymphs of *G. punctipes* per each pesticide concentration. Big-eyed bugs were observed for survival after one and three after treatment.

### **Residual toxicity of insecticide concentrations on survival of big-eyed bugs in laboratory conetainer experiment**

Turfgrass sprigs (6-7 cm) of resistant turf cultivar ‘Cavalier’ zoysiagrass, intermediate resistant cultivar ‘TifSport’ bermudagrass and the susceptible cultivar ‘Sea Isle 1’ seashore paspalum were transplanted to plastic conetainers (‘Cone containers’) of 4 cm mouth diameter and 20.4 cm long (Stuewe & Sons Inc., Corvallis, OR 97333) and filled with soil media (‘Sun gro’, metro mix 300 series, Sun gro Horticulture Distribution Inc., Bellevue, WA). These newly



transplanted turfgrass sprigs were retained for one week to overcome transplanting shock and to be established in the greenhouse conditions. These containers were watered daily and weak sprigs were replanted after 2-3 days to maintain a uniform grass stand. The same pesticides and their concentrations (mentioned above) were applied at the rate of approximately 2.48 liters per square meter using a CO<sub>2</sub> powered backpack sprayer with a Meter Jet Gun on these turfgrasses in containers. The experiment was a randomized complete block design with five replicates per pesticide concentration per turfgrass cultivar. Each replicate consisted of three plastic containers of turfgrass cultivar. Single individuals, either nymphs (nymphs between third to fifth instar) or adults of *G. uliginosus* or *G. punctipes* was released per plastic container and immediately sealed by a paper sleeve (Milk check filters, Kleen test products, Milwaukee, WI 53201). Out of the total five replications, three replications with *G. uliginosus*, two replications with *G. punctipes* and one replication with combination of *G. uliginosus* and *G. punctipes*, were released. Survival of big-eyed bugs was noted after one and three days of post-treatment as number of live big-eyed bugs were observed from each replication.

**Statistical analysis** Data were obtained as live big-eyed bug from each experiment after one and three days after pesticide application. Data were subjected to analysis of variance using the PROC GLM procedure in SAS (SAS institute, 2003); means separation was accomplished using Fisher's protected Least Significant Difference Test. Orthogonal contrasts were used to examine the influence of the three turf species on survival of predator, their species and age.

## Results

### Direct toxicity of insecticide concentrations on survival of big-eyed bugs in laboratory petri dish studies

Results from the petri dish studies show that chlorpyrifos was more toxic to adults and nymphs of big-eyed bugs causing higher mortality as compared to spinosad and halofenozide (Table 4.1) at one ( $F = 260.0$ ;  $df = 6, 28$ ;  $P < 0.0001$ ) and three ( $F = 320.89$ ;  $df = 6, 28$ ;  $P < 0.0001$ ) days post treatment. Significant mortality occurred in the second lowest concentration (62.5 ppm) of chlorpyrifos as compared to the control. However, geocorids (*G. uliginosus* and *G. punctipes*) were significantly different after one ( $F = 28.57$ ;  $df = 1, 28$ ;  $P < 0.0001$ ) and three ( $F = 53.4$ ;  $df = 1, 28$ ;  $P < 0.0001$ ) days of chlorpyrifos application. *Geocoris uliginosus* did not survive on all concentrations of chlorpyrifos except in the control treatment. While, *Geocoris punctipes* was significantly different beginning from initial concentration of chlorpyrifos on day one ( $F = 30.02$ ;  $df = 6, 39$ ;  $P < 0.0001$ ) and three ( $F = 175.50$ ;  $df = 6, 39$ ;  $P < 0.0001$ ) of exposure. Different ages (adult, fifth instar nymphs, and nymphs less than fifth instar) of geocorids were also significantly influenced after one ( $F = 10.48$ ;  $df = 3, 28$ ;  $P < 0.0001$ ) and three ( $F = 4.57$ ;  $df = 3, 28$ ;  $P = 0.01$ ) days of chlorpyrifos application.

Spinosad concentration significantly affected big-eyed bug survival with lowest numbers recovered on one ( $F = 6.72$ ;  $df = 6, 28$ ;  $P = 0.002$ , mean =  $2.4 \pm 0.9$ ) and three ( $F = 6.61$ ;  $df = 6, 28$ ;  $P = 0.002$ , mean =  $1.1 \pm 0.9$ ) days after application of 0.375 ml in 400ml water (112.3 ppm); Table 4.1 and Table 4.2). Even though there was no significant difference between survival of geocorid species after spinosad application (Table 4.1), highest concentration (112.3 ppm) was significantly different for *G. punctipes* on one (mean =  $2.43 \pm 0.88$ ) and three (mean =  $1.29 \pm 0.93$ ) days after spinosad exposure. However, predator age significantly affected mortality after

one ( $F = 14.54$ ;  $df = 3, 28$ ;  $P < 0.0001$ ) days of exposure to spinosad. Adult *Geocoris punctipes* were significantly different ( $F = 3.82$ ;  $df = 3, 39$ ;  $P = 0.0171$ ) from fifth and younger instar nymphs on one day of exposure. When halofenozide was applied, none of the concentrations significantly affected mortality of big-eyed bugs (Table 4.2). Geocorid species was significantly affected ( $F = 6.26$ ;  $df = 6, 28$ ;  $P = 0.0188$ ) with halofenozide application. There was no mortality on *G. punctipes* after one day of halofenozide exposure but, after third day, highest concentration (1198 ppm) was significantly different ( $F = 2.69$ ;  $df = 6, 39$ ;  $P < 0.0277$ ) on *G. punctipes* as compared to the control. At the same time, *G. uliginosus* was not significantly different with exposure to halofenozide concentrations. Different age of big-eyed bugs especially, *G. punctipes* did not influence mortality at any concentration of halofenozide (Table 4.1).

#### **Residual toxicity of pesticide concentrations on survival of big-eyed bugs in laboratory conetainer experiment**

All concentrations of chlorpyrifos were toxic to big-eyed bug on all turfgrasses considered in this study (Table 4.3) after one ( $F = 38.98$ ;  $df = 6, 66$ ;  $P < 0.0001$ ) and three ( $F = 40.81$ ;  $df = 6, 66$ ;  $P < 0.0001$ ) day after treatment. Significant difference in survival of big-eyed bugs was observed on 0.10g in 400ml water (125 ppm) after first day (mean =  $1.6 \pm 0.9$ ) and 0.20g in 400 ml water (250 ppm) after third (mean =  $0.2 \pm 0.5$ ) day of application as compared to the control on 'Cavalier' zoysiagrass (Table 4.4). Survival of big-eyed bugs was influenced significantly by 0.10g in 400ml (125 ppm) water after first (mean =  $0.4 \pm 0.6$ ) and 0.05g in 400ml (62 ppm) water after third (mean =  $1.6 \pm 0.9$ ) days of exposure to chlorpyrifos 'Sea Isle 1' seashore paspalum. On 'TifSport' bermudagrass, a significant difference in the big-eyed bug

survival was noted at 0.05g in 400ml water (62.5 ppm) after one (mean =  $1.4 \pm 0.9$ ) and three (mean =  $0.8 \pm 0.8$ ) days of exposure (Table 4.4).

Geocorid species was not significantly different ( $F = 0.57$ ;  $df = 2, 66$ ;  $P = 0.5701$ ), *G. uliginosus* was significantly different ( $F = 22.05$ ;  $df = 6, 54$ ;  $P < 0.0001$ ) in mortality beginning from exposure to initial chlorpyrifos concentration after one day of exposure, instead *G. punctipes* was significantly different ( $F = 12.55$ ;  $df = 6, 12$ ;  $P = 0.0001$ ) in mortality between sixth concentration (500 ppm) and the control. Geocorid species was significantly different in survival after three ( $F = 3.29$ ;  $df = 2, 66$ ;  $P = 0.0433$ ) days after chlorpyrifos exposure with *G. uliginosus* ( $F = 26.83$ ;  $df = 6, 54$ ;  $P < 0.0001$ ) and *G. punctipes* ( $F = 7.37$ ;  $df = 6, 12$ ;  $P = 0.0018$ ) significantly different in mortality beginning from initial concentrations. Among turfgrasses, ‘Cavalier’ zoysiagrass significantly influenced big-eyed bug survival as compared to ‘Sea Isle 1’ seashore paspalum and ‘TifSport’ bermudagrass after day one ( $F = 5.03$ ;  $df = 2, 66$ ;  $P = 0.0092$ ) and three ( $F = 4.19$ ;  $df = 2, 66$ ;  $P = 0.0194$ ) of chlorpyrifos application with high survivors. Survival of *G. uliginosus* was significantly different ( $F = 4.27$ ;  $df = 2, 54$ ;  $P = 0.0189$ ) after one and ( $F = 4.23$ ;  $df = 2, 54$ ;  $P = 0.0197$ ) three of chlorpyrifos application between ‘Cavalier’ zoysiagrass and other two turfgrass (‘Sea Isle 1’ seashore paspalum and ‘TifSport’ bermudagrass). However, *G. punctipes* did not differ significantly between various turfgrasses.

Different concentrations of spinosad and halofenozide on turfgrass failed to influence ( $P > 0.05$ ) the survival of big-eyed bugs after one and three days after application (Table 4.3, 4.5 and 4.6) in the container experiments. Turfgrass taxa (‘Cavalier’ zoysiagrass, ‘TifSport’ bermudagrass and ‘Sea Isle 1’ seashore paspalum) did not significantly affect survival of big-eyed bugs. However, effect on geocorid species were noticed after three ( $F = 8.01$ ;  $df = 2, 66$ ;  $P$

= 0.0008) days when spinosad were applied, while, no effect of halofenozide application showed on geocorid species (Table 4.3).

### Discussion

Survival of big-eyed bugs was exposed to three pesticides commonly used by the turfgrass industry for management of lepidopteran pests assessed. Braman et al. (2004) previously demonstrated the mortality rate of *S. frugiperda* neonate and third instar larvae when mediated by varying levels of resistant turfgrass taxa and six-concentrations of three pesticides (chlorpyrifos, spinosad and halofenozide). This study attempted to reveal their effect on survival of a heteropteran predator is related to turfgrass cultivars. The only organophosphate pesticide used in these trials was chlorpyrifos, an acetylcholinesterase inhibitor that can cause insect mortality through contact and oral intake. Spinosad consist of two metabolites-spinosyn A and D-derived from the actinomycete soil bacterium, *Saccharopolyspora spinosa* (Mertz and Yao 1990, sp. nov.). These metabolites cause contact and ingestion poisoning through interrupting nicotinic acetylcholine receptors and GABA (gamma aminobutyric acid) receptors in insects. While, halofenozide is a systemic pesticide causing premature molting due to the presence of molting accelerator diacylhydrazine work along with 20-hydroxyecdysone (steroidal hormone) in molting process (Braman et al. 2004). Therefore they are slower acting giving rise to mortality in nymphs causing sub-lethal effects.

Chlorpyrifos was more toxic to big-eyed bugs as compared to spinosad and halofenozide in both the trials. Susceptibility of big-eyed bugs was greatly influenced by the lowest chlorpyrifos concentration (62.5 ppm) when mediated by 'TifSport' bermudagrass after first and third and by seashore paspalum after the third day post application, and trials without turfgrass on all days after application. Previous study showed significant reduction of live fall armyworm

was observed beginning from 0.030 ml of chlorpyrifos in 400 ml water (17.97 ppm) on zoysiagrass and seashore paspalum on seven and fourteen days after treatment. The fresh and dry weights of zoysiagrasses ('Cavalier' and 'Palisades') were also significantly different compared to other non-treated turfgrass indicating fall armyworm larvae fed on grass at lower rate compared to the control. All the turfgrasses showed significant negative effect on survival of fall armyworm from chlorpyrifos concentration 0.090 (53.91 ppm), 0.270 (161.73 ppm) and 0.810 ml (485.19 ppm) per 400 ml water on 3, 7 and 14 day after treatment (Braman et al. 2004). However, this study showed relatively higher survival of big-eyed bugs until on 0.1 g chlorpyrifos in 400 ml water (125 ppm) on 'Cavalier' zoysiagrass than on other grasses on first and third day of exposure. Braman et al. (2004) showed that spinosad treatments with 0.00075, 0.00375, 0.0375 and 0.375 ml per 400ml water or 0.225 ppm, 1.123 ppm, 11.23 ppm and 112.3 ppm, respectively, was significantly different for recovery of live fall armyworm on all grass taxa after 7 and 14 days of exposure. Bermudagrass ('TifEagle') significantly reduced for fall armyworm survival at 0.000375 ml per 400 ml water after 14 day of application and this result was positively correlated with the significant reduction in the dry weight in the bermudagrass. In contrast, big-eyed bug survival was not influenced by most of these concentrations except on 0.375 ml of spinosad in 400 ml water (112.3 ppm) when regardless of turfgrass taxa on first and third day after application (Table 4.2 and 4.5).

Previous study also showed that halofenozide was effective against fall armyworm on bermudagrass ('TifSport') with higher mortality of fall armyworm beginning from initial concentration of 0.001, 0.010, and 0.100 ml in 400 ml water or 0.599 ppm, 5.99 ppm and 59.9 ppm after 7 day than 14 day of application with no significant difference compared to control. This result was not significantly correlated with green and dry weight of 'TifSport'.

Halofenozide at 1.0 ml per 400ml (599 ppm) water effective by reduced fall armyworm numbers after seven and fourteen day of treatment for all grasses. Contrastingly, big-eyed bug survival was not influenced by most of these concentrations except 2.0 ml of halofenozide in 400 ml water when not mediated by any of the turfgrass on third day after application (Table 4.2 and 4.6). These results suggest that both spinosad and halofenozide are less toxic to big-eyed bugs than to fall armyworm, increasing the probability of their contribution in providing effective extrinsic resistance in turfgrass pests. In other studies, Terry et al. (1993) showed that cyfluthrin, carbaryl and isazofos, failed to reduce predation by soil dwelling arthropods on pupae of fall armyworm, *S. frugiperda* in Kentucky bluegrass, and Cisneros et al. (2002), observed that spinosad was relatively safe to general predators such as *Aleochara bilineata* Gyllenhal (Staphylinidae) and *Chrysoperla carnea* (Stephens) (Chrysopidae) but, moderately toxic to earwig, *Doru taeniatum* (Dohrn). These predators are often correlated to presence of *S. frugiperda* in maize growing areas (Cisneros et al. 2002). Insidiosus flower bugs, *Orius insidiosus* (Say) and predaceous mirids, *Spanagonicus albofasciatus* Reuter are potential heteropteran predators other than geocorids in turfgrass (Braman et al. 2003, Shimat, unpublished data). Studies have shown that spinosad was less harmful to *O. insidiosus* adults (Pietrantonio and Benedict 1999), when bioassay of foliar application (cotton leaves) of spinosad at the rate of 0.099 Kg (AI) per ha were tested (Elzen et al. 1998). Fecundity of *O. insidiosus* was higher ( $58.7 \pm 9.1d$ ) on spinosad treatment (0.099 Kg AI per ha) compared to other treatments: imidacloprid, tebufenozide, chlorfenapyr, endosulfan, fipronil, azinphos-methyl, profenofos, cyfluthrin, and malathion ULV and control (Elzen 2001). More studies are needed to assess the effect of pesticides on anthocorids and predaceous mirids in turfgrass.

Rogers and Sullivan (1986) observed that *G. punctipes* nymphs preying on velvetbean caterpillar, *Anticarsia gemmatalis* (Hübner) reared on pest-resistant soybean genotypes such as PI 171451 and PI 229358, experienced increased nymphal mortality. In addition, the predator responded with increased nymphal development time when preying on a host that had been reared on pest-resistant genotypes. This indicates that antibiosis effects may persist to the third trophic level when the predator, *G. punctipes* preys on a lepidopteran pest reared on the pest-resistant soybean genotypes. Braman et al. (2004) reported that *S. frugiperda* developed slower on the resistant turfgrass and hence spent more time in a size range prone to predation by *G. uliginosus* and predation was not adversely affected by the resistant turfgrass species. Field studies revealed, however, that maximum predation on *S. frugiperda* larvae by low numbers of *G. uliginosus* occurred on 'Sea Isle 1' and '561-79' susceptible seashore paspalum (Braman et al. 2003). Application of lower concentrations of spinosad and halofenozide was effective in causing significant mortality of neonates and third instar larvae of fall armyworms (Braman et al. 2004). Our study showed that lower concentrations of spinosad and halofenozide had no influence of heteropteran predators (big-eyed bugs) ensuring biological control as well. Indirect effect of pesticide (spinosad and halofenozide) through consumption of treated prey could be less toxic since the direct exposure with or without turfgrasses have produced insignificant mortality. Hence, integration of host plant resistance, biological control and application of lower concentrations of spinosad and halofenozide pesticides could be productive in pest management, especially with fall armyworm larvae in turfgrass systems. Our study also indicates that the use of chlorpyrifos for lepidopteran pest control increases the risk of mortality of heteropteran predators in turfgrass. More studies are needed to assess the impact of chlorpyrifos on big-eyed bugs when they were fed on treated fall armyworm larvae. Our study also suggests the need for



research assessing the impact of pesticides on younger nymphs (younger than third instar) of big-eyed bugs.

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Table 4.1. Statistical analysis of live big-eyed bugs recovered when petri dishes was exposed to concentrations of ‘Dursban’ (chlorpyrifos), ‘Conserve’ (spinosad) and ‘Mach 2’ (halofenozide).

| Source         | 1-Day post application |    |          | 3-Day post applications |    |          |
|----------------|------------------------|----|----------|-------------------------|----|----------|
|                | <i>F</i>               | df | <i>P</i> | <i>F</i>                | df | <i>P</i> |
| Chlorpyrifos   |                        |    |          |                         |    |          |
| Dose           | 260.00                 | 6  | <0.0001  | 320.90                  | 6  | <0.0001  |
| Species        | 28.57                  | 1  | <0.0001  | 53.40                   | 1  | <0.0001  |
| Age            | 10.48                  | 3  | <0.0001  | 4.57                    | 3  | 0.0100   |
| Dose x species | 12.57                  | 6  | <0.0001  | 53.40                   | 6  | <0.0001  |
| Dose x age     | 15.81                  | 18 | <0.0001  | 4.57                    | 18 | 0.0002   |
| Spinosad       |                        |    |          |                         |    |          |
| Dose           | 6.72                   | 6  | 0.0020   | 6.61                    | 6  | 0.0020   |
| Species        | 3.05                   | 1  | 0.0918   | 3.48                    | 1  | 0.0727   |
| Age            | 14.54                  | 3  | <0.0001  | 1.05                    | 3  | 0.3853   |
| Dose x species | 6.55                   | 6  | 0.0020   | 0.85                    | 6  | 0.5458   |
| Dose x age     | 7.72                   | 18 | <0.0001  | 1.14                    | 18 | 0.3683   |
| Halofenozide   |                        |    |          |                         |    |          |
| Dose           | 0.74                   | 6  | 0.6214   | 3.39                    | 6  | 0.0141   |
| Species        | 6.22                   | 1  | 0.0188   | 11.81                   | 1  | 0.0019   |
| Age            | 0.00                   | 3  | 1.0000   | 0.58                    | 3  | 0.6324   |
| Dose x species | 2.59                   | 6  | 0.0399   | 1.37                    | 6  | 0.2616   |
| Dose x age     | 0.00                   | 18 | 1.0000   | 0.38                    | 18 | 0.9818   |

Table 4.2. Mean number of live big-eyed bugs recovered after one and three days after pesticide application of concentrations of chlorpyrifos, halofenozide and spinosad on petri dishes.

| 'Dursban 50W' chloropyrifos |         | 1-Day post application                                 | 3-Day post application |
|-----------------------------|---------|--|------------------------|
| g/ 400 ml water             | ppm     | Mean number of surviving big-eyed bugs per replication |                        |
| 0.00                        | 0.0     | 2.7±0.5  | 2.1±1.1                |
| 0.05                        | 62.5    | 1.0±1.3*   | 0.0±0.0*               |
| 0.10                        | 125.0   | 0.0±0.0*   | 0.0±0.0*               |
| 0.20                        | 250.0   | 0.0±0.0*   | 0.0±0.0*               |
| 0.30                        | 375.0   | 0.0±0.0*   | 0.0±0.0*               |
| 0.40                        | 500.0   | 0.0±0.0*   | 0.0±0.0*               |
| 0.50                        | 625.0   | 0.0±0.0*   | 0.0±0.0*               |
| 'Conserve 1 SC' spinosad    |         | 1-Day post application                                 | 3-Day post application |
| ml/ 400 ml water            | ppm     | Mean number of surviving big-eyed bugs per replication |                        |
| 0.000                       | 0.00    | 3.0±0.0  | 2.6±0.5                |
| 0.000375                    | 0.11    | 2.9±0.3  | 2.8±0.4                |
| 0.000563                    | 0.17    | 2.7±0.7  | 2.6±0.5                |
| 0.00075                     | 0.23    | 2.8±0.4  | 2.4±0.9                |
| 0.00375                     | 1.12    | 2.8±0.3  | 2.6±0.5                |
| 0.0375                      | 11.23   | 3.0±0.0  | 2.3±0.9                |
| 0.375                       | 112.30  | 2.4±0.9*   | 1.1±0.9*               |
| 'Mach 2 E' halofenozide     |         | 1-Day post application                                 | 3-Day post application |
| ml/ 400 ml water            | ppm     | Mean number of surviving big-eyed bugs per replication |                        |
| 0.000                       | 0.00    | 2.8±0.3  | 2.8±0.3                |
| 0.001                       | 0.59    | 3.0±0.0  | 2.8±0.3                |
| 0.010                       | 5.99    | 3.0±0.0  | 2.8±0.4                |
| 0.100                       | 59.90   | 2.8±0.3  | 2.8±0.7                |
| 0.500                       | 299.50  | 3.0±0.0  | 2.8±0.1                |
| 1.000                       | 599.00  | 3.0±0.0  | 2.8±0.1                |
| 2.000                       | 1198.00 | 3.0±0.0  | 1.9±0.9*               |

\* denotes significant difference in big-eyed survival as compared to control ( $P < 0.05$ ).

Table 4.3. Statistical analysis of live big-eyed bugs recovered when three turfgrass cultivars were exposure to reduced concentrations of 'Dursban' (chlorpyrifos), 'Conserve' (spinosad) and 'Mach 2' (halofenozide) in conetainer experiment.

| Source               | 1-Day post application |    |          | 3-Day post applications |    |          |
|----------------------|------------------------|----|----------|-------------------------|----|----------|
|                      | <i>F</i>               | df | <i>P</i> | <i>F</i>                | df | <i>P</i> |
| Chlorpyrifos         |                        |    |          |                         |    |          |
| Dose                 | 38.98                  | 6  | <0.0001  | 40.81                   | 6  | <0.0001  |
| Grass taxa           | 5.03                   | 2  | 0.0092   | 4.19                    | 2  | 0.0194   |
| Species              | 0.57                   | 2  | 0.5701   | 3.29                    | 2  | 0.0433   |
| Dose x grass taxa    | 1.64                   | 12 | 0.1017   | 2.05                    | 12 | 0.0331   |
| Grass taxa x species | 0.86                   | 4  | 0.4941   | 1.71                    | 4  | 0.1583   |
| Dose x species       | 1.17                   | 12 | 0.3248   | 1.11                    | 12 | 0.3654   |
| Spinosad             |                        |    |          |                         |    |          |
| Dose                 | 0.30                   | 6  | 0.9340   | 1.94                    | 6  | 0.0865   |
| Grass taxa           | 0.23                   | 2  | 0.7383   | 1.33                    | 2  | 0.3281   |
| Species              | 0.10                   | 2  | 0.9046   | 8.01                    | 2  | 0.0008   |
| Dose x grass taxa    | 1.28                   | 12 | 0.2510   | 1.22                    | 12 | 0.2886   |
| Grass taxa x species | 1.08                   | 4  | 0.3736   | 0.52                    | 4  | 0.7233   |
| Dose x species       | 0.98                   | 12 | 0.4774   | 2.03                    | 12 | 0.0348   |
| Halofenozide         |                        |    |          |                         |    |          |
| Dose                 | 1.09                   | 6  | 0.3787   | 1.32                    | 6  | 0.2589   |
| Grass taxa           | 1.54                   | 2  | 0.2224   | 0.17                    | 2  | 0.8428   |
| Species              | 1.66                   | 2  | 0.1973   | 0.50                    | 2  | 0.6059   |
| Dose x grass taxa    | 1.14                   | 12 | 0.3481   | 0.69                    | 12 | 0.7567   |
| Grass taxa x species | 1.56                   | 4  | 0.6889   | 1.36                    | 4  | 0.2591   |
| Dose x species       | 1.56                   | 12 | 0.1448   | 1.12                    | 12 | 0.3626   |

Table 4.4. Mean number of live big-eyed bugs recovered after one and third days after pesticide application of concentrations of chlorpyrifos on different turfgrasses in conetainer experiment.

| ‘Dursban W’ chlorpyrifos concentrations in gram formulation per 400 ml of distilled water or in ppm |            |                 |                |                |                |                |                |
|---|------------|-----------------|----------------|----------------|----------------|----------------|----------------|
| Turf cultivar   | 0.00 (0.0) | 0.05 (62.5 ppm) | 0.10 (125 ppm) | 0.20 (250 ppm) | 0.30 (375 ppm) | 0.40 (500 ppm) | 0.50 (625 ppm) |
| Mean number of surviving big-eyed bugs per replication  |            |                 |                |                |                |                |                |
| 1-day post application  |            |                 |                |                |                |                |                |
| Cavalier  | 3.0±0.0    | 2.8±0.5         | 1.6±0.9*       | 0.4±0.6*       | 0.8±0.8*       | 0.8±0.8*       | 0.2±0.5*       |
| Sea Isle 1  | 2.8±0.4    | 2.0±1.0         | 0.4±0.6*       | 0.4±0.6*       | 0.2±0.4*       | 0.6±0.9*       | 0.2±0.5*       |
| TifSport  | 3.0±0.0    | 1.4±0.9*        | 1.6±1.1*       | 0.4±0.9*       | 0.0±0.0*       | 0.2±0.5*       | 0.0±0.0*       |
| 3-day post application  |            |                 |                |                |                |                |                |
| Cavalier  | 2.2±0.8    | 2.2±0.8         | 1.4±0.9        | 0.2±0.5*       | 0.4±0.9*       | 2.0±0.5*       | 0.0±0.0*       |
| Sea Isle 1  | 2.4±1.3    | 1.6±0.9*        | 0.2±0.5*       | 0.0±0.0*       | 0.0±0.0*       | 0.0±0.0*       | 0.0±0.0*       |
| TifSport  | 2.8±0.5    | 0.8±0.8*        | 0.4±0.6*       | 0.0±0.0*       | 0.0±0.0*       | 0.2±0.5*       | 0.0±0.0*       |

\* denotes significant difference in big-eyed survival as compared to control ( $P < 0.05$ ).

Table 4.5. Mean number of live big-eyed bugs recovered after one and third after pesticide application of reduced concentrations of spinosad on different turfgrasses in conetainer experiment.

| ‘Conserve’ spinosad concentrations in ml-formulation per 400 ml of distilled water or in ppm |          |                     |                     |                    |                    |                    |                   |
|--|----------|---------------------|---------------------|--------------------|--------------------|--------------------|-------------------|
| Turf cultivar  | 0.000    | 0.000375 (0.11 ppm) | 0.000563 (0.17 ppm) | 0.00075 (0.23 ppm) | 0.00375 (1.12 ppm) | 0.0375 (11.23 ppm) | 0.375 (112.3 ppm) |
| Mean number of surviving big-eyed bugs per replication                                       |          |                     |                     |                    |                    |                    |                   |
| 1-day post application   |          |                     |                     |                    |                    |                    |                   |
| Cavalier   | 2.6±0.6  | 3.0±0.0             | 2.8±0.4             | 3.0±0.0            | 3.0±0.0            | 3.0±0.0            | 3.0±0.0           |
| Sea Isle 1   | 3.0±0.0  | 2.8±0.5             | 2.8±0.4             | 2.8±0.4            | 3.0±0.0            | 2.8±0.5            | 3.0±0.0           |
| TifSport   | 3.0±0.0  | 3.0±0.0             | 2.8±0.5             | 3.0±0.0            | 2.6±0.9            | 3.0±0.0            | 2.6±0.6           |
| 3-day post application   |          |                     |                     |                    |                    |                    |                   |
| Cavalier   | 1.8±1.1  | 1.8±0.8             | 2.2±1.3             | 1.6±0.0            | 2.8±0.4            | 2.8±0.4            | 2.8±0.6           |
| Sea Isle 1   | 2.4±0.54 | 2.4±0.6             | 2.0±1.0             | 2.4±0.6            | 2.8±0.4            | 2.0±1.2            | 2.6±0.5           |
| TifSport   | 2.0±0.7  | 2.2±0.8             | 2.6±0.5             | 2.6±0.9            | 2.6±0.9            | 3.0±0.0            | 2.4±0.6           |



Table 4.6. Mean number of live big-eyed bugs recovered after one and third days after pesticide application of reduced concentrations of halofenozide on different turfgrasses in conetainer experiment.

| Turf cultivar  | 'Mach 2' halofenozide concentrations in ml-formulation per 400 ml of distilled water |                  |                  |                   |                   |                    |                     |
|--|--|------------------|------------------|-------------------|-------------------|--------------------|---------------------|
|  | 0.000  | 0.001 (0.59 ppm) | 0.010 (5.99 ppm) | 0.100 (59.90 ppm) | 0.500(299.50 ppm) | 1.000 (599.00 ppm) | 2.000 (1198.00 ppm) |
| Mean number of surviving big-eyed bugs per replication |  |                  |                  |                   |                   |                    |                     |
| 1-day post application                                 |  |                  |                  |                   |                   |                    |                     |
| Cavalier   | 2.8±0.5  | 3.0±0.0          | 2.8±0.4          | 2.8±0.5           | 2.4±0.9           | 2.4±0.5            | 2.8±0.5             |
| Sea Isle 1   | 3.0±0.0  | 2.6±0.5          | 3.0±0.0          | 2.6±0.5           | 2.8±0.5           | 2.8±0.4            | 2.8±0.5             |
| TifSport   | 3.0±0.0  | 2.8±0.5          | 2.2±0.8          | 2.4±0.9           | 2.2±1.3           | 3.0±0.0            | 2.4±0.5             |
| 3-day post application                                 |  |                  |                  |                   |                   |                    |                     |
| Cavalier   | 2.2±0.8  | 2.4±0.5          | 2.0±1.0          | 2.2±0.5           | 1.6±1.3           | 2.2±0.8            | 2.6±0.7             |
| Sea Isle 1   | 2.4±0.5  | 2.4±0.8          | 2.2±0.8          | 2.4±0.5           | 1.4±1.1           | 2.6±0.5            | 1.6±0.9             |
| TifSport   | 2.6±0.5  | 1.8±0.8          | 1.8±1.1          | 1.8±0.8           | 2.0±0.7           | 2.0±0.7            | 2.2±0.8             |

**CHAPTER 5**

**SUMMARY**

Occurrence and abundance of predatory heteropterans and other arthropods were analyzed based on plant attributes such as turf taxa, density, height, and weed density, from sweep and vacuum samples collected from 20 residential lawns during May to July 2005 in Georgia. Abundance of all predatory heteropterans was influenced by grass taxa. None of the predatory heteropterans were affected by turfgrass density. Numbers of anthocorids increased as mowing height of turfgrass increased. All stages of mirids were more often collected as weed density increased. Anthocorids were most abundant in St. Augustinegrass and showed strong correlation with the abundance of chinch bugs. Mirids were more abundant in zoysiagrass, while, occurrence of geocorids was noted from all turf taxa.

Predatory potential and performance of the predaceous heteropterans, *G. punctipes*, *G. uliginosus*, and *O. insidiosus*, were evaluated using neonates of fall armyworm as prey on different turfgrass taxa (resistant zoysiagrass, 'Cavalier' and 'Palisades', intermediate resistant bermudagrass, 'TifSport', and susceptible seashore paspalum, 'Sea Isle 1'). *Orius* demonstrated significant predation on zoysiagrass and bermudagrass cultivars. Male *G. punctipes* killed significantly more fall armyworm on bermudagrass and seashore paspalum than on zoysiagrass cultivars. Female *G. punctipes* fed more on larvae on seashore paspalum and bermudagrass than males. Grass taxa did not influence predation by male or female *G. uliginosus* in these short duration trials. In laboratory pot trials, few or no survivors (20 neonates of fall armyworm) were observed on 'Cavalier' at all *Orius* densities greater than zero. Grass taxa significantly influenced fall armyworm mortality. Mortality was highest on 'Cavalier' and least on 'Sea Isle 1'. However, 'TifSport' and 'Sea Isle 1' were not significantly different. In a field study, few or no live fall armyworms were recovered from 'Cavalier', while an increase in *Orius* density did

not significantly affect predation on 'Palisades' zoysiagrass. *Orius* predation on bermudagrass and seashore paspalum was similar but was significantly less on both zoysiagrass cultivars.

Reduced concentrations of chlorpyrifos were toxic to *G. uliginosus* and *G. punctipes* as compared to controls in petri dish trials. A significant difference in big-eyed bug survival was observed, with the highest concentration (0.375 ml/ 400ml water) of spinosad by one and three days after application. However, only the highest concentration was significantly different on big-eyed bugs, after third day of halofenozide application. In tube experiments, survival of both species of big-eyed bugs was affected by concentration (between 0.05-0.2g in 400 ml water) on bermudagrass, seashore paspalum, and zoysiagrass for one and three days after chlorpyrifos application. Both geocorid species responded similarly to chlorpyrifos applications. Different concentrations of both spinosad and halofenozide failed to influence the survival of big-eyed bugs in turfgrass tubes for one and three days after application.

Heteropteran predators are common and abundant inhabitants of residential turfgrass. Their occurrence and abundance was affected by plant parameters including grass taxa, grass height and weed density. *Orius insidiosus* and *Geocoris spp.*, represented in vacuum samples, were efficient predators of *Spodoptera frugiperda*, although turfgrass taxa and predator density influenced the extent of pest suppression in laboratory and field trials. Common turfgrass insecticides varied in their effect on *Geocoris spp.*, identifying potential chemical tools for incorporation into IPM strategies that include host plant resistance and conservation biological control. Future research should elaborate the role and potential of other heteropteran predators, such as *Orius spp.* that have not previously been considered important in turf pest management.