

DIFFERENTIAL PREDATION BY *Orius insidiosus* (Say) ON *Frankliniella occidentalis* (Pergande) AND *Frankliniella bispinosa* (Morgan) IN SWEET PEPPER

By

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Generalist predators can show preferences for certain prey. These preferences can either result from active choice by predators or by certain prey being more vulnerable to predation than others. Consequently, differential predation can alter the population dynamics of closely related prey species and ultimately community structure. I investigated interactions between the generalist predator *Orius insidiosus* (Say) and adults of two thrips species, *Frankliniella bispinosa* (Morgan) and *F. occidentalis* (Pergande). Specifically I investigated interspecific differences between these prey species that could affect predation by *O. insidiosus*. *O. insidiosus* were offered either *F. bispinosa* or *F. occidentalis* as prey in single species trials, but there were no significant differences in the number of prey captured. However, *O. insidiosus* encountered more *F. bispinosa* than *F. occidentalis*. In arenas with equal numbers of both thrips species, *O. insidiosus* had more encounters with and captures of *F. occidentalis* than of *F. bispinosa*.

In large arenas with two pepper plants, *O. insidiosus* preyed more on *F. occidentalis* than on *F. bispinosa*. These results indicate that *O. insidiosus* can prey on adults of both

thrips species, but that in mixed species groups, this predator preferentially captures *F. occidentalis*. *F. occidentalis* are much larger than *F. bispinosa*, the but it is the greater locomotion and movement of *F. bispinosa* that allow it to avoid interactions with *O. insidiosus* and evade predation better than *F. occidentalis*. Consequently, the observed preference of *O. insidiosus* for *F. occidentalis* is not exclusively a function of active selection by the predator but arises from inherent differences among prey. Because *F. occidentalis* is more vulnerable than *F. bispinosa* to predation by *O. insidiosus*, this differential predation can affect the temporal dynamics of these species, and allow populations of *F. bispinosa* to persist longer into the growing season than populations of *F. occidentalis*.

## INTRODUCTION

### **Life History**

Thrips are minute insects (between 1 to 4 mm) classified in the insect order Thysanoptera (fringed-wing bearers). They were first described in 1744 by De Geer who called them *Physapus*, however the genus was renamed *Thrips* in 1758 by Linnaeus. In 1836, the English entomologist Haliday raised the status of the thrips taxon to order and renamed them Thysanoptera, although the members of the order are still commonly referred to as thrips. A common vernacular name for thrips is "thunder flies," which comes from association of dispersal after springtime storms.

The order Thysanoptera is divided into two suborders: Tubulifera and Terebrantia and is further subdivided into eight families containing approximately 5000 described species (Mound 1997). Tubulifera and Terebrantia differ in respect to body, specifically abdominal shape, wing structure and number of larval instars (Tubulifera have an extra pupal stage). The seven families that make up Terebrantia are Uzelothripidae, Merothripidae, Aeolothripidae, Adiheterothripidae, Fauriellidae, Heterothripidae and Thripidae. Combined, these families account for about 1900 of the approximately 5000 known species. Phlaeothripidae, the sole family in the suborder Tubulifera, contains close to 3100 described species.

All thrips are believed to have evolved from a common ancestor along with

Heteroptera, Psocoptera, and Pthiraptera (Kristensen 1995). This early form led a detritivorous lifestyle and fed primarily on fluids of fungal hyphae and decaying organic matter. As a testament to the success of thrips in securing that niche, most thrips today are still saprophytic; although it is actually a reverted behavior in some species (Mound 1997).

Merothripidae, all 15 known species of which are fungus feeders, are thought to best resemble the ancestral form (Mound 1997). The only species found in Uzelothripidae is a fungus feeder as well. Many thrips species evolved in their food preferences and moved from feeding on senescing leaves to live leaves and eventually to other plant tissues. Some went beyond this to feeding on other arthropods found in those environments as well (Mound 1997). Although the majority of Heterothripidae and Adiheterothripidae are associated with flowers (the latter specifically with those of date palms [*Phoenix dactylifera* L.]) (Mound 1997). A new species of Heterothripidae (*Aulacothrips dictyotus* Hood) is the first reported parasitic thrips (Izzo et al. 2002). Members of Aeolothripidae contain trophic lifestyles that span from phytophagous to predaceous (Mound 1997). At least 45% of the species constituting Phlaeothripidae are fungal feeders with the remaining portion made up of predacious and phytophagous groups (including several specifically associated with flowers, trees, cereals or mosses). Members of Thripidae also run the gamut from plant feeding to predatory. The plants feeders show diversity in association with all types and parts of plants. Little is known about the natural history of Fauriellidae.

Within the phytophagous groups, there is wide variation in ecologies and diets can consist of several types of plant tissues (leaves, flowers, fruits, stems, pollen, etc.)

Several of these species are also omnivorous, feeding on both plants and arthropod prey (Wilson et al. 1996) and many species have been reported as crop pests (Mound 1997).

As the name suggests, the distinguishing characteristics of this insect order are the fringed wings. The cilia that make up the fringes laterally surround a chitinous rod (Moritz 1997). There are also numerous species that exhibit intraspecific variation in wingform and other species that have secondarily lost the wings altogether. Both macropterous and brachypterous thrips jump as a means of motility. This jumping is accomplished with specially evolved meso- and metacoxae, which are generally and advantageously folded under the body.

Most thrips reproduce sexually, but a majority of the sexual species are facultative and capable of asexual reproduction as well (Moritz 1997). Thrips exhibit all variations of parthenogenesis including arrhenotoky (most common), thelytoky and deuterotoky. Recent investigations reveal that the bacterial symbiont *Wolbachia* may play a significant role in reproductive rates (*Heliothrips haemorrhoidalis* (Bouché), *Hercinothrips femoralis* (Reuter) (Pintureau et al. 1999) and *Franklinothrips vespiformis* (Crawford) (Arakaki et al. 2001)), and in conjunction with temperature, determining sex ratios (discussed in Moritz 2002). Facultative parthenogenesis is a key adaptation associated with their successful *r*-strategy based life history. Although there is limited research on chemical mediation of sexual activity in Thysanoptera, within the species *Frankliniella occidentalis* (Pergande) a chemical substance produced by males has been shown to attract male and female conspecifics (Kirk and Hamilton 2004). But the most likely and well-studied aggregation cues for phytophagous thrips are visual and are theorized to be associated with particular plant parts (Matteson et al. 1992).

The Thysanopteran lifecycle is divided into six (or seven) stages: ovum, 1<sup>st</sup> and 2<sup>nd</sup> instars (larvae), prepupa, 1st pupa, 2nd pupa (in Tubulifera only) and adult.

Depending on temperature, the development from egg to adult lasts 10 d to 30 d on average, with the adult stage lasting about the same amount of time (Lewis 1997a).

The piercing-sucking feeding action of all thrips is accomplished with a uniquely evolved stylet consisting of three modified mouthparts (one mandible and two maxillae) that originate from the left side of the head (the mouthparts on the right side of the head have become vestigial or disappeared all together) (Moritz 1997). In some species, the hypopharynx may serve as a fourth stylet (Borden 1915). Feeding Thysanoptera generally accomplish their task by piercing the plant or pollen wall or the prey exoskeleton while releasing saliva (sometimes containing virus particles in infected individuals) into the puncture site (Hemming 1978). They then suck up the fluid puddles using the cibarial pump. In addition to potential severe dehydration of the plants, thrips feeding can result in “silvering” or “bronzing” of fruits and leaves (Bournier 1983). Further damage to plants by Terebrantain thrips to a host plant occurs when females oviposit on the fruits, flowers, stems and leaves (Salguero Navas et al. 1991). At high densities this type of damage will generally cause plants to grow malformed.

### **Thrips Ecology and Population Dynamics**

Patches of decomposing vegetation where developing fungi can be found, and where thrips origins are commonly believed to lie, are characterized by specific conditions that include brief existence of optimal conditions, rapid change and wide variation of environment from patch to patch (Kristensen 1995). These origins impart this group with several fitness-enhancing characteristics that were selected for.

The successful traits of the primitive thrips are now believed to be possessed by and give an advantage to the extant descendants. These traits include high vagility, a broad food range, high fecundity and regeneration rates, parthenogenesis, as well as gregarious and competitive breeding behavior (Mound 1997). These phenomena are better understood in phytophagous thrips, especially those associated with agricultural crops.

For thrips, there are several factors affecting the four standard categories (births, deaths, immigration and emigration (Turchin 1991, Thomas and Kunin 1999) used for measuring population trends for species. Included among the factors that most significantly control the dynamics of phytophagous thrips are type and condition of host plant, climate and weather, predation, parasitism, disease, ability to overwinter and human interactions (Kirk 1997).

### **Host Plant**

Interactions between thrips and their host plants can be influenced by the host's cultivar type (Fery and Schalk 1991, de Kogel et al. 1998), food quality and availability (Shibao 1997, Agrawal and Klein 2000), the host's age and phenotypic state (including flower color) (Ram and Mathur 1984, Stoddard 1986, Baqui and Kershaw 1993, de Kogel et al. 1997) and the ability of the host plant to recruit predators (Venzon et al. 1999, Agrawal et al. 2000, Norton et al. 2001, van Rijn et al. 2002).

Lab and field studies have shown differential suitability of crop species, varieties and non-crop plants (weeds) as host plants for many arthropods (Mansour et al. 1982, Appel and Martin 1992, Mound 1997, Beard and Walter 2001, Fogleman and Danielson 2001). This holds true for thrips. The differential spatial and temporal presence,

availability and quality of nutrients between different species of host plants affect thrips fitness. It is important to point out that while thrips may feed on a specific plant or group of plants, those plants may not be used or found suitable for oviposition and development of the larvae (Mound and Marullo 1996). In addition, many plants are used as a site where thrips can seek shelter until other flora appear that are more suitable for feeding, mating and/or development. Each species of phytophagous thrips seems to prefer a specific plant part for feeding, oviposition and/or congregation for mating (Palmer et al. 1991, Mound and Marullo 1996, Hansen et al. 2000), although they are usually able to derive nutrition from multiple tissue types on a plant. Studies on most *Frankliniella* species have shown that over 95% of the thrips on pepper plants in the field are located in flowers (Gerin et al. 1999, Hansen et al. 2000, Ramachandran 2001).

The use of multiple hosts contributes to predisposing flower thrips as crop pests, specifically in regards to generation, survival and persistence as well as dispersal and movement. Subsequently these behaviors enhance movement of thrips-vectored plant diseases. In agricultural ecosystems, this is relevant in that flower thrips, with their broad host range, are often able to find suitable hosts on the periphery of agricultural fields (Puche et al. 1995, Hobbs et al. 1996, Chatzivassiliou et al. 2001, Groves et al. 2001). In modern agricultural practice, a lack of attention to or understanding of how communities outside the designated cultivation area affect population movement and dynamics within the field has generally resulted in approaches to controlling pest populations that are myopic. In these cases, the portion of the environment considered when planning a control strategy is the cropping area, while the heavy impact from influences outside the tillage is ignored. In order to have a truly successful impact on lowering thrips numbers

in the field, one must consider the impact of the surrounding biotic systems. The use of alternative hosts by thrips coupled with their high rate of movement and good dispersal capabilities allow “weeds” to act as a reservoir of immigrating populations and vectored plant diseases (Mound 1997, Cossentine et al. 1999, Chatzivassiliou et al. 2001, Groves et al. 2001, Pearsall and Myers 2001). However timing is important as well; Weed control measures in the middle of a crop growth cycle can actually increase disease incidence in a cultivated crop (Eberwine 1995, 1998).

On a smaller level, the architecture of a host plant is a major factor in the ecology of a plant-dwelling arthropod species. Data reveal that many smaller organisms acquire a significant amount of protection from predation and adverse conditions by seeking refuge in small pockets of a more favorable environment, termed domatia (O'Dowd and Willson 1991, Agrawal 1997, Agrawal et al. 2000, Roda et al. 2000, Norton et al. 2001). Thrips are a characteristic example. They are shown to persist longer in sites where there are microclimates that enhance fitness. These domatia optimize one or a number of environmental factors, such as humidity and temperatures. Domatia include structures on plants such as small invaginations, crevices, tufts of hairs and arthropod-created structures on plants that exclude or repel predators. Localized sources of food, nutrient or water also fall into this grouping.

Experimentally, domatia have been shown to have significant effects on predation. They appear to serve primarily in harboring populations of smaller predators thereby increasing overall predation rates (Grostal and O'Dowd 1994, Agrawal 1997, Agrawal et al. 2000), although the size and trophic level of the organism(s) involved in the interaction appear to be relevant.

In some cases the presence of domatia can have the opposite effect (O'Dowd and Willson 1991, Roda et al. 2000, Norton et al. 2001). These pockets can serve to protect several arthropods (including thrips) from predation (Venzon 2000, Norton et al. 2001). Although there are few published studies involving thrips, *Orius insidiosus* (Say) (Heteroptera: Anthocoridae) and the effect of domatia, Agrawal et al. (2000) found that plants showed a positive correlation between domatia and numbers of predatory bugs (including *O. insidiosus*) and a negative correlation between domatia and phytophagous thrips. Conversely, Norton et al. (2001) demonstrated that *O. insidiosus* had less success preying on mites in crops with a greater level of domatia.

One obvious benefit of these shelters to thrips relates to their relatively small size: desiccation is a serious factor for smaller organisms. The high surface area to volume ratio of thrips results in a high rate of desiccation. This principle dictates that thrips are only able to make relatively short flights, require regular feedings of fluid and must seek protection from exposure when possible. These objectives can be accomplished by spending non-foraging time in low airflow/high humidity spots like domatia (O'Dowd and Willson 1991).

### **Abiotic Factors**

From 1932 to 1946, data for a population study were collected on *Thrips imaginis* Bagnall on roses in Adelaide, South Australia. The information gathered by Davidson and Andrewartha (1948) showed dramatic fluctuations in thrips numbers based on climate. This paper generated much study and debate on (leading to further study and illumination of) the complex ecology of thysanopteran population dynamics (Smith 1961, Varley et al. 1973).

Thrips populations are highly susceptible to changing climate. As indicated, arid conditions can have a significant impact on fitness, since thrips size makes them highly vulnerable to desiccation. Therefore drought could have a serious effect on thrips populations directly by decreasing humidity. While the small size of flower thrips can predispose them to rapid dehydration and desiccation in locations with arid ambient humidity, use of more humid microclimates found within 5 mm of leaf surfaces allows them persist (Shipp et al. 1996). The optimal relative humidity for thrips is between 70% and 90% (Kirk 1997). In phytophagous species one of the drought-related phenomena of greatest influence on thrips populations is a decrease of the nutritional value of the host plant through plant wilting. Withering of flowers (which reduces availability of sites for mating) and drying out of the soil (whereby decreasing success in pupation) are also impacts of drought that can affect thrips on a population level (Moritz 1997, Mound 1997). One strategy used by Terebrantians to combat desiccation of ova is to lay the eggs inside plant tissues (Mound 1997). Although Tubuliferans deposit ova on plant surfaces, this strategy is still beneficial because of the higher humidity of the microclimates in close proximity to the host plant surface. Of the post-ova eclosion stages, the pupae have the highest tolerance in low humidity environments, due to their lower rate of respiration (Kirk 1997).

Rain can impact thrips populations as well (Harris et al. 1936, North and Shelton 1986). Buhl (1937) reported as many as 95% of *Kakothrips pisivorus* (Westwood) were lost during a heavy rain event. In such cases, population densities generally rebound slowly. Many of the losses seem to be from drowning, but even more so from the ensuing rain-induced soil conditions that can trap larvae and adults or that prevent

successful eclosion by pupae (Moritz 1997). Those that are lost generally end up caked in the mud and are unable to escape.

Just as important as humidity is temperature. *Frankliniella occidentalis* is able to develop more rapidly with increasing temperatures until approximately 30°C, after which the developmental rate is hindered. Beyond a given temperature threshold, all thrips become impaired in their feeding, movement, development and behavior. Kirk (1997) recommends that degree-day models for thrips do not include temperatures above 35°C.

Winter with its associated cold temperatures is an event that needs to be endured by all organisms outside (and sometimes inside) the tropics. Several thrips species, including *F. occidentalis*, *Limothrips cerealium* (Haliday) and *Thrips palmi* Karny are able to survive air temperatures below freezing in all stages of development (Kirk 1997). In outdoor sites where leaf litter, soil and sometimes snow are available, many species can survive full winters and emerge to repopulate areas again when favorable temperatures return. Thrips may overwinter in either the pupal stage or the adult stage.

### **Natural Enemies**

Another measurably strong influence (though sometimes it is quite difficult to measure) is the pressure exerted on thrips populations by natural enemies. Predators, parasites and diseases have been shown to play a significant role in controlling thrips numbers in many trophic systems for several species.

Members of the predator guilds with the greatest impact include Heteroptera (primarily members of the Anthocoridae in the genus *Orius*, but also Lygaeidae, Pentatomidae, Reduviidae, Nabidae and Miridae), Acari (primarily the Phytoseiidae in the genus *Amblyseius*, but also Trombidiidae, Erythraeidae, Laelapidae, Pyemotidae and

Acarophenacidae), Chrysopidae, Coccinellidae, Diptera (primarily Syrphidae, but also Cecidomyiidae, Dolichopodidae, Chloropidae and Hypotidae), several Araneae and other Thysanoptera (Aeolothripidae, Phlaeothripidae and Thripidae) (Sabelis and van Rijn 1997). Other thrips predators that are known are some solitary wasps (*Spilomena* spp.) (Danks 1971), mantids (Mohandaniel et al. 1983), crickets (Ghabn 1948), some birds (Buhl 1937) and toads (Hamilton 1930).

Thrips parasitoids include mostly endoparasitic wasps (Loomans and van Lenteren 1995). All of these wasps are classified in the superfamily Chalcidoidea and most are in the family Eulophidae (larval parasites), Trichogrammatidae and Mymaridae (egg parasites). Many non-insect parasites can be found among the Nematoda. As in the case of *Thripinema nicklewoodii* (Siddiqi) and *Thripinema reniroai* (Reddy) and their relationship with thrips in the genus *Frankliniella*, the parasites decrease fecundity in the female thrips by damaging reproductive tissues (Nickle and Wood 1964, Funderburk et al. 2002, Stavisky et al. 2002).

Diseases too play a significant role in regulating thrips populations and, in some cases, can have the highest impact on thrips numbers (Dyadechko 1964, Butt and Brownbridge 1997). Prominent fungal pathogens include *Aspergillus*, *Entomophthora*, *Verticillium* and *Beauveria*. The last of these was recorded to have caused 100% mortality in cereal thrips (Dyadechko 1964). The same is true for some protozoan parasites in other thrips species (Raizada 1976).

Impacts on populations due to interspecific competition with other thrips species and/or arthropods undoubtedly occur. This is often most dramatic in cases of the introduction of non-native species. Several Acari and Heteroptera that share the same

niche as a thrips have been able to efficiently compete for limited resources and, in turn, have had a significant effect on thrips populations (Karban 1987, 1989; Janssen et al. 1998, Pallini et al. 1999). For example, flower dwelling thrips must compete with other sympatric species for the limited space provided in flowers (Kirk 1997). As expected, when Reitz and Trumble (2002) analyzed a number of studies they determined that interactions between more closely related species are characterized by a higher level of competitive displacement than those of less related organisms.

Intraspecific competition in thrips results in some unique adaptive behaviors, including fighting (for territory, mates and food resources) (Immaraju and Crespi 1986, Terry 1997), caste development (Kranz et al. 1999) and sexual dimorphism (Crespi 1986). Other phenomena in thrips increasing competitive ability include high levels of fecundity (Nugaliyadde and Heinrichs 1984, Malchau 1991, Kirk 1994), high levels of mating (Kawai 1987, Kawai and Kitamura 1987, 1990) and increased precision in dispersal timing and rates (Gopinathan et al. 1981, Crespi and Taylor 1990, Puche et al. 1995).

While larvae and pupae are limited in their movement, adult thrips are quite adept at dispersal. In macropterous thrips, cues such as increasing humidity, changes or disturbance to habitat and increased competition can be linked to flights of thrips and invasion of new habitats (Kirk 1997). Movements may be made by individuals at any time, but generally certain conditions (such as the aforementioned cues) result in a massive exodus. Species (Vierbergen 1996), sex (van de Wetering et al. 1998), climate (Pearsall and Myers 2001), density (Crespi and Taylor 1990) and host plant changes (Peters et al. 1996) are influential factors in dispersal behavior in thrips. Flying thrips

generally fly while remaining just above the vegetation and their movement is strongly influenced by prevailing wind currents (Lewis 1997b, Pearsall and Myers 2001).

Thrips have a propensity for enormous increase in population. A small number of colonists can multiply to reach massive numbers in days (Wang and Shipp 2001).

Appanah and Chan (1981) found lab-reared thrips to be at 30x their original numbers after 10 d. Basic exponential and logistic growth curves are used in modeling various populations, but exclude extenuating aspects, such as the above-mentioned impacts of predation and parasitism, competition, climatic phenomena, microhabitats and human interactions (including control methods). Two other significant attributes of flower thrips population growth are initial conditions (Schaffer and Kot 1985, Camilo and Willig 1995) and mate availability (a significant density-dependent factor) (Wang and Shipp 2001). Successfully incorporating all of these factors into a model of thrips population dynamics is still difficult, mainly due to the limited knowledge of their biology.

### **Flower thrips**

The highest-evolved Thysanoptera, the flower thrips (represented mainly by the genera *Frankliniella* and *Thrips*), are most often found in flowers as adults and larvae (Pearsall 2000, Hansen et al. 2003). They inhabit tropical and temperate areas throughout the world (Mound 1997). These species feed primarily on the contents of plants cells including fruits, leaves, inflorescence tissues and pollen. Several flower thrips are also facultative predators of other arthropods (Wilson et al. 1996, Agrawal and Klein 2000, Venzon et al. 2000)

Two major flower thrips species represented in Florida are the western flower thrips, *Frankliniella occidentalis* and the Florida flower thrips, *F. bispinosa* (Morgan). *F.*

*occidentalis* is an invasive species from the western US and is found throughout Florida. *F. bispinosa* is a native species found throughout Florida, with the greatest abundance in the south of the state (Childers and Brecht 1996, Hansen 2002). They share similar morphology and ecology and both are identified as pests of agriculture (Lewis 1997a). They inflict direct feeding damage to plants as well as being transmitters of plant disease.

The characteristic movement by flower thrips, coupled with their feeding behavior and a relatively broad host range, make them an effective and efficient vector for plant diseases. A number of thrips-vectored viruses have been reported. Some thrips-vectored viruses that have surfaced as notable problems in agriculture are impatiens necrotic spot virus (Deangelis et al. 1994), peanut yellow spot virus (Satyanarayana et al. 1998), groundnut ringspot virus (Wijkamp et al. 1995), tomato chlorotic spot virus and multiple strains of tomato spotted wilt virus (Palmer et al. 1991, Wijkamp et al. 1995, Latham and Jones 1998, Nagata 2002).

### **Tomato Spotted Wilt**

Tomato spotted wilt, first described in Australia in 1915 and discovered to have viral origins in 1930 (tomato spotted wilt virus), impacts a very large range of plants and has a tremendous impact on agriculture throughout the world. Tomato spotted wilt virus is the type species for the genus *Tospovirus* (family Bunyaviridae) and is known to infect over 1090 plant species in 85 families worldwide (Parrella et al. 2003). Susceptible vegetation includes peanuts, tomato, lettuce, potato, pepper, tobacco, peas, ornamentals and several other cultivated and non-cultivated plants (Murphy et al. 1995). Tomato spotted wilt is characterized by top distortion, stunted growth, necrotic and chlorotic

spots on leaves as well as mosaic, necrosis and chlorosis on stems and fruit. Infection in younger plants by the virus is often fatal (Nagata 2002).

The virus is solely transmitted by phytophagous thrips, is generally acquired only by larvae due to a barrier in the midgut of adult flower thrips. Although the larvae are physiologically capable of transmission, adults almost exclusively transmit the virus due to the fact that larval thrips generally have a lower titer of the virus and limited dispersal capabilities (Sherwood et al. 2000). The sheer number of susceptible hosts coupled with the innate dispersal characteristics of the thrips vector consequently results in potentially epidemic virus transmission rates (Ullman et al. 1997). Unchecked non-crop plants or “weeds” near or adjacent to the agricultural field can function as a virus and vector reservoir thereby increasing incidence of disease transmitted into that plot (Puche et al. 1995, Peters et al. 1996, Groves et al. 2001, Pearsall and Myers 2001).

For the complete inoculation/transmission cycle of the virus to occur in thrips, first instars must feed on an infected plant and ingest a sufficient amount of virus (Wijkamp et al. 1996). The mean acquisition period for *F. occidentalis* larvae was determined to be 67 min (Peters et al. 1996, Wijkamp et al. 1996). After the virus is ingested it passes through the midgut walls and begins replication in the larval midgut cells. A barrier that develops in the midgut of adult thrips prevents passage of viral particles and effective inoculation at this late stage (Ullman et al. 1997, Ohnishi et al. 2001).

Tomato spotted wilt virus generally survives development of the thrips through the 2nd instar, prepupal and pupal stages and comes to infect several organs throughout the thrips, including the salivary glands (Wijkamp et al. 1996). Additional evidence

suggests that larvae reared at a higher temperature are less effective transmitters than larvae reared at lower temps, due to the developmental rate of the thrips host outstripping the replication rate of the virus (Wijkamp and Peters 1993). Confirmation of tomato spotted wilt virus infection in thrips can be achieved using enzyme-linked immunosorbent assay (ELISA) (Ullman et al. 1997) or reverse transcriptase-polymerase chain reaction (RT-PCR) (Bandla et al. 1994).

As adults, infected thrips disseminate virus through their saliva to plants that they feed upon. Factors influencing the rate of tomato spotted wilt virus transmission include: concentration of virus in host plants and host plant suitability (Peters et al. 1996), the sex of the thrips vector (van de Wetering et al. 1998), vector movement and dispersal characteristics (Wijkamp and Peters 1993), amount of time spent probing by hosts on plants and transmission time (Wijkamp et al. 1996), and the presence or absence of virus in a host plant (*F. occidentalis* has been shown to prefer feeding on plants infected with tomato spotted wilt virus (Bautista et al. 1995)).

In Florida, four species in the genus *Frankliniella* have been established as vectors of TSWV, with *F. occidentalis* recognized as the most efficient vector. The other three are *F. bispinosa*, *F. fusca* (Hinds) and *F. schultzei* (Trybom). *F. schultzei* is found in northern Florida while *F. occidentalis*, *F. bispinosa* and *F. fusca* are found throughout Florida.

### **Thrips Management**

Traditional controls to prevent thrips infestation and virus epidemics have focused on regular applications of broad-spectrum, chemical insecticides. In retrospect, we have learned that this tactic decreases the number of natural enemies while exacerbating thrips

numbers and ultimately virus transmission rates (Etienne et al. 1990, Izawa et al. 2000). The failure in control by chemical insecticides is due in part to physiological characteristics in thrips that allow for resistance (Brødsgaard 1994). Other population characteristics that make chemical control unrealistic include thrips' high reproductive capacity, a relatively short transmission time and constant inundation by thrips colonizers from peripheral metapopulations (Diekmann et al. 1988). *F. occidentalis*, especially, shows enormous capabilities in developing resistance against several common classes of insecticides, including organophosphates, carbamates and pyrethroids (Immaraju et al. 1992, Brødsgaard 1994, Robb et al. 1995, Jensen 1998).

In addition to this evidence, knowledge that pesticides are innately toxic and have been recorded to bioaccumulate in several phyla of organisms (including vertebrates) (Honrubia et al. 1993, Nebeker et al. 1994, Albanis et al. 1996) is even further motivation to select a solution that is more effective, affordable, more target-specific while being as ecologically and temporally sustainable as possible. These revelations lead to The Food Quality Protection Act of 1996 (FQPA 1996).

With awareness of the hazards of chemical pesticides and the subsequent legislation, emphasis has been placed on developing sustainable agricultural practices and practical, holistic approaches to dealing with pest problems. The concept of "integrated pest management" and biological control had been introduced several decades previously, but only reached conventionality in the United States after being mandated by the FQPA (Wellings 1996). Out of concern for ecologically sustainable practices and in an effort to comply with the law, more growers turned to natural enemies and cultural control

practices to suppress or prevent pest outbreaks while maintaining, and even improving, profitability in some systems (Hara et al. 1990, Hoffmann et al. 1995).

### ***Orius insidiosus* (Say)**

Nymphs and adults of the insidious flower bug, *Orius insidiosus* (Heteroptera: Anthocoridae), prey on several species of thrips, whiteflies and mites, as well as the ova and young larvae of Lepidoptera (Sterling et al. 1989). Although natural enemies were not thought to have a significant impact on thrips numbers (Davidson and Andrewartha 1948, Butt and Brownbridge 1997, Loomans et al. 1997, Parker and Skinner 1997, Parrella and Lewis 1997), *Orius* species have proven and been accepted as effective controls of thrips populations in multiple agricultural and ornamental crops (Van de Viere and Degheele 1992, Coll and Ridgway 1995, Dissevelt et al. 1995, Glenister 1998, Funderburk et al. 2000, Ramachandran et al. 2001). *O. insidiosus* is currently being mass-reared for control of multiple arthropod pests in several agricultural systems (Glenister 1998).

*Orius* species are generally associated with flowers, which coincides with their major prey items: flower thrips. They use specific visual and volatile cues to locate suitable habitats and prey items (Reid and Lampman 1989, Teerling et al. 1993, Hénaut et al. 1999). Female *O. insidiosus* require 12.5 thrips per day in order to maintain sufficient levels of protein for egg production (Tommasini and Nicoli 1993). Ramachandran et al. (2001) show that *O. insidiosus* was capable of high levels of movement between plants and flowers meeting requirements to access sufficient numbers of thrips to support this demand. Funderburk et al. (2000) determined that unsupplemented populations of *O. insidiosus* were responsible for rapid suppression of

three key species of tomato spotted wilt virus -vectoring thrips in field peppers once predator:prey ratios reached 1:212. Eventually *F. occidentalis* populations in northern Florida were driven to virtual extinction within days of reaching a predator:prey ratio of 1:40. Persistence of *O. insidiosus* (Say) in the field in the absence of high numbers of prey prevents buildup and recovery of thrips populations. The survival of *O. insidiosus* populations with little prey is facilitated by the fact that this predator is able to survive in fields in the absence of thrips prey and complete a full lifecycle by feeding on pollen and plant fluids (Dissevelt et al. 1995, Richards and Schmidt 1996).

Domatia have a positive impact on populations of *Orius*. Agrawal (1997) found that numbers of *Orius* were positively correlated with abundance of domatia on plants. Eggs and nymphs were able to endure using these structures and were more likely to survive to adulthood on plants with these small sanctuaries. However, even in the presence of persistent plants, *O. insidiosus* diapauses in northern and central Florida from winter through early spring, which results in a subsequent, primavera eruption of thrips populations during this time (Toapanta et al. 1996, Ruberson et al. 2000). Another limitation to predation on thrips by *O. insidiosus* is the host plant. While predation occurs at higher levels on bean, pepper and corn, the physical and chemical properties of tomato plants limit movement of *O. insidiosus* and its efficacy as a predator of thrips (Coll and Ridgway 1995). The dense collection of glandular trichomes on the surface of tomato leaves significantly hinders the searching ability of *O. insidiosus* (Say).

### **Differential predation**

Behavioral differences in related species of arthropods can cause an overall predation pressure to bear more heavily on one or a few certain species (Chesson 1983,

McPeck 1990). Two main factors in this interaction influence predation: predator choice and passive selection (Pastorok 1981). These two aspects of the predator-prey relationship shape the overall dynamics of the outcomes. Active choice occurs when predators choose prey based on nutritional or energy versus payoff bases (Williams 1987, Lang and Gsödl 2001). Conversely, passive selection is a result of the prey's behaviors and characteristics. Potential prey may select habitat based on a lower probability of encountering a predator (Hanna and Wilson 1991; Cloutier and Johnson 1993) or may change the outcome by way of altered behavior during or after an encounter (Lang and Gsödl 2001). These differences in otherwise morphologically similar species can have broad implications for community structure and ecology.

Interspecific variation of prey can affect predation levels in any given trophic system. Honda and Luck (1995) found that *Aonidiella aurantii* (Maskell) was one of several species of scale insects that were preyed upon by the coccinellid *Rhyzobius lophanthae* (Blaisdell). It was determined that *A. aurantii* was preyed upon at a significantly lower level than the other sympatric scales due to behavioral differences that made it harder to capture and subdue. Likewise, Fritsche and Tamo (2000) found that *Orius albipennis* (Rueter) captured and consumed fewer *Megalurothrips sjostedti* (Trybom) than two other thrips species (*Ceratothripoides cameroni* (Priesner) and *Frankliniella schultzei*). The reason for the lighter predation on *M. sjostedti* was determined to be its high level of activity and movement.

The innate vagility of a species is a balance between factors affecting fitness of an insect. Slower rates of movement allow some species to more closely examine host plants and thereby determine the most favorable site (Byers 1996). Other, more actively

moving species may be less competitive in the absence of a predator guild, but are better able to escape from predators when they are present (Baez et al. 2004, Northfield et al. *unpublished data*). If host plant suitability is not significantly different across the habitat (as in the case of agricultural fields) and predators are present, increased activity and movement by a particular species may give it a competitive edge in colonization and establishment.

In general, my research will attempt to illuminate the predator-prey dynamics between *O. insidiosus* and two of its thrips prey, *F. occidentalis* and *F. bispinosa*. Specifically, I will attempt to determine if *O. insidiosus* preys on the two thrips species at different levels in single-species populations as well as in mixed-species populations and at the level of a single pepper flower habitat. I will also use a larger arena to determine if there is any differential predation between the two thrips prey when presented together on the whole-plant level.

## MATERIALS AND METHODS

### Thrips

When possible, wild, field collected *F. occidentalis* and *F. bispinosa* were used in the assays. Verification of thrips species was acquired from Dr. Joe Funderburk from the University of Florida's Department of Entomology. Voucher specimens were also deposited in the University of Florida Department of Entomology's insect collection. The thrips were collected from wild mustard (*Brassica kaber* DC.) and crepe myrtle (*Lagerstroemia indicia* L.) in Alachua and Marion Counties, Florida. Field collected thrips were housed in 100 cm<sup>3</sup> plastic, Gladware containers with a 5x8 cm ventilation hole in the lid covered with thrips screen (0.15 x 0.15 mm holes) until use in the assays. A 20cm<sup>2</sup> square of paper towel was used to line the bottom of the container. Pole beans (*Phaseolus vulgaris* L.) purchased from the local Winn Dixie supermarket were used as a food, a fluid source. The beans were scrubbed with Fit® Fruit and Vegetable Wash and rinsed in order to remove any residual insecticide. They were then lightly streaked with honey. Bee pollen was also offered as an alternative source of protein.

For those times when thrips were not available in the field, colonies were set up and maintained using field-captured individuals. Pole beans (*Phaseolus vulgaris* L.) of the same origin and that were handled the same way as for the field-collected thrips were used as a food, a fluid source and oviposition material. All lab-reared thrips used in these experiments were kept in the same 100 cm<sup>3</sup> plastic, Gladware

containers with a 5x8 cm ventilation hole in the lid covered with thrips screen (0.15 x0.15 mm holes) with a 20cm<sup>2</sup> square of paper towel lining the bottom.

All lab colonies were maintained in a Percival plant growth chamber at the University of Florida's Department of Entomology at a photoperiod of 14L:10D, 70-80%RH. All field-collected and lab-reared thrips used in the experiments were adults selected at random.

### **Predators**

When possible, *O. insidiosus* to be used in the assays were collected from crepe myrtle (*Lagerstroemia indicia* L.) blossoms in Alachua and Manatee Counties Florida. Verification of specimen identification was acquired from Dr. Joe Funderburk from the University of Florida's Department of Entomology. Voucher specimens were also deposited in the University of Florida Department of Entomology's insect collection. For those times when *O. insidiosus* were not available in the field, colonies were set up and maintained using field-captured individuals or were acquired from Entomos, Gainesville, Florida. Colonies maintained at the Entomology Department at University of Florida were given pole beans as oviposition material that were scrubbed with Fit Fruit and Vegetable Wash and rinsed in order to remove any residual insecticide. The colonies were maintained at 14L:10D and 70-80%RH in the same type containers as the thrips were reared in.

In order to provide nutrition and precondition them to recognizing thrips as a prey item, thrips from both *Frankliniella* species were added to all *O. insidiosus* colonies on a regular basis (every 5 days) when available. In order to maintain sufficient thrips numbers for experimentation, *Helicoverpa zea* (Boddie) ova and bee pollen were often

offered as a supplement in addition to thrips or as a substitute source of protein when thrips numbers were not high enough to use as food.

All *O. insidiosus* used in the tests were adults selected at random. Specimens used from lab colonies were all 3-5 d post eclosion.

### **Objective 1.1: Single Species Arena**

The arena was constructed from a polystyrene petri dish 15 cm in diameter and 3 cm in depth and given three ventilation holes and one entrance hole that were punched in the lid of the dish using a hot, metal cylinder 3.5 cm in diameter. The ventilation holes had thrips screen glued over them to prevent escape of the thrips and predator. The cap and upper 1 cm of a 0.2 mL flip-top Eppendorf vial was sliced off and glued into place using a hot glue gun so that the lower portion would sit in the entrance hole and the cap could be opened and closed as to allow for the introduction of thrips and predators. A screw cap from a 0.2 mL Eppendorf vial (to be used as a miniature floral pic) was glued approximately 5 cm off-center onto the base of the dish. A straight pin was poked into the mini-vase approximately 1 cm off the floor of the arena and a flip-top Eppendorf vial cap was glued to the apical end of the pin and deemed to be a landing for the introduced predators. The floral pic and the landing site were at the same distance from the center so that the single entrance could service both by simply rotating the arena lid.

A single, clean pepper flower (*Capsicum annuum* L. (cultivar Camelot)) was placed in the floral pic. The floral pic was filled with water to maintain turgidity in the flower. The requisite number and species of thrips were collected and counted from the colonies using a mouth aspirator. They were then chilled in the collecting container for 1.5 minutes (to facilitate easier handling) and then emptied into the entrance hole over the

flower. The arena containing the flower and the thrips was placed under dissecting microscope while lighted by an adjustable 150W fiber optic illuminator. The thrips were allowed to acclimate for 1 h before introduction of a predator.

A single species of thrips was used for each trial. Densities of 5, 10 and 20 thrips were added to the arena and a single predator was added after 1 h. The trial was carried out upon introduction of a predator. The lid of the arena was rotated so that the entrance was directly over the landing and the predator was dropped in. The recording time began once the predator left the landing and began walking on the pin towards the flower. Behavior was recorded for exactly 1h.

Observations were made with the aid of a dissecting microscope at 30x magnification. Occasionally observations had to be made without aid of the scope, when a predator disappeared from view the field of vision (i.e. under a petal). Five activities were recorded for each predator (Observer v 2.1, Noldus Information Technology, Sterling, VA) and included the number of encounters (directed, physical contact with a thrips), number of captures (time spent subduing a thrips), amount of time spent moving, the duration of feeding activity and the amount of time spent resting.

For each trial inflorescences were removed from greenhouse reared plants just before use. All inflorescences were cleaned of any existing insects and mites, using an aspirator and a fine-bristle paintbrush.

Fifteen replicates of each predator sex/prey species/prey density combination were recorded. Data were analyzed by a three-factor analysis of variance (ANOVA), sex, species of prey and density of prey being the three factors. Means for each species at all

treatments and treatment combinations were separated by least squares means *t*-tests. Untransformed means and their standard errors are presented.

### **Objective 1.2: Mixed Species Arena**

For Objective 1.2, a mixture of *F. occidentalis* and *F. bispinosa* were used at a fixed density of 10 thrips (5 *F. bispinosa* : 5 *F. occidentalis*), and similar experimental procedures were followed as in Objective 1.1. Likewise, the variables recorded in Objective 1.2 were the same as in Objective 1.1, but in addition, the species of thrips captured and/or encountered was recorded as well.

For each encounter I determined if the differences between prey species and the dependent variables were significantly different from zero and if there was predation variability between the two sexes of *O. insidiosus*. This was accomplished by fitting the data to an ANOVA with sex as the main effect and the intercept term and testing if the mean differences were significantly different from zero (PROC GLM, intercept option, SAS 1999).

Differences for dependent variables were calculated as *F. bispinosa* minus *F. occidentalis* in each replicate arena; therefore, negative values reflect greater values for *F. occidentalis* than for *F. bispinosa*. Data were checked for normality and homoscedasticity, and did not need transformation.

### **Objective 1.3: Whole Plant Arena**

Plexiglas cylinders, 15.5 cm in diameter and 36 cm in height, were used as arenas and four holes 10 cm in diameter were cut into the cylinders as ventilation. Two holes were placed at 1/3 distance from the top and two were placed at 2/3 distance from the top and covered with thrips screen that was secured with silicone caulk. A fifth hole, 4 cm in

diameter, was drilled 5 cm from the top and used to introduce predators. It was covered with a rubber stopper to prevent escape after the predator entered. The top of the cylinder was covered with thrips screen.

A pot containing two specimens of *Capsicum annuum* L. (cultivar Camelot) of roughly the same size, each with a single open flower at approximately the same height, was used as an experimental setting. Another pot with plants similar in height, size and placement of flower to each other and those in the experimental pot was used as a control (no predator). The same number of thrips was placed in the experimental and control arenas. The plants in all of the arenas were manicured as to prevent direct contact between the leaves and other plant parts.

Thrips were tested at four densities: 10, 20, 40 and 80 total thrips per arena in a 1:1 species ratio. A vial of the thrips used for each trial was placed directly under and touching one of the plants allowing the thrips to crawl out of the vial and onto the plant. The initial plant that the thrips were introduced to was deemed Plant A.

The cylinder was placed over both of the plants and the base was pushed approximately 5 cm into the soil as to prevent escape of the thrips and the predator by that direction. The thrips were allowed to acclimate for 4 h, after which a predator was introduced into the experimental arena.

Twenty-four hours after the introduction of the thrips, the flowers were sampled by placing them in vials containing 70 % isopropyl alcohol and labeled corresponding to its designation (Plant A Control, Plant A Experimental, Plant B Control or Plant B Experimental). The thrips were counted and recorded to species.

The remainder of each plant was lopped off at the base just above the soil line then chopped into small parts, and placed in a Ziploc bag with a corresponding label (Plant A Control, Plant A Experimental, Plant B Control and Plant B Experimental) and immediately doused with 70% isopropyl alcohol. Each plant was thoroughly agitated in the alcohol to remove thrips before the plant parts were taken out and carefully rinsed one more time using a wash bottle containing 70% isopropyl. The thrips present in the alcohol were then counted and recorded to species. Any live thrips remaining in the arenas were aspirated, identified to species and counted.

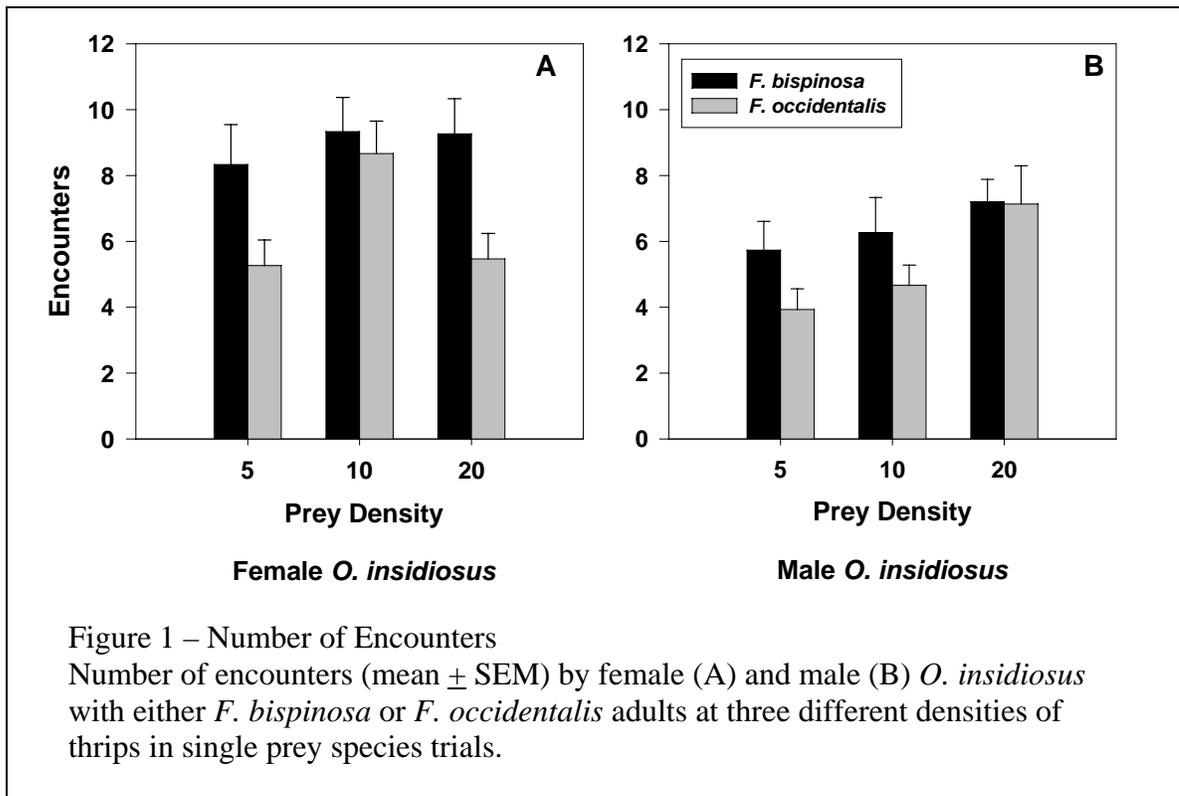
The control arenas were used to represent background mortality in the absence of any predatory influence. The difference in the number of thrips surviving between corresponding control and experimental arenas was presumed to be a result of predation by *O. insidiosus*. Differences between experimental and control arenas for numbers of each species were analyzed and compared.

Two factor ANOVAs using the number of surviving *F. occidentalis*, *F. bispinosa* and the difference between the two were carried out with density and predator treatments as factors. Specific comparisons were made using least squares means *t*-tests. Because there was no expectation of one species surviving better than the other species, two-tailed tests to test for interspecific differences in survivorship in the respective treatment were conducted. The hypothesis was that numbers of surviving thrips would be lower in the presence of the predator *O. insidiosus* than in its absence, so one-tailed tests to compare numbers of each species surviving in the control and experimental treatments at each density were used.

## RESULTS

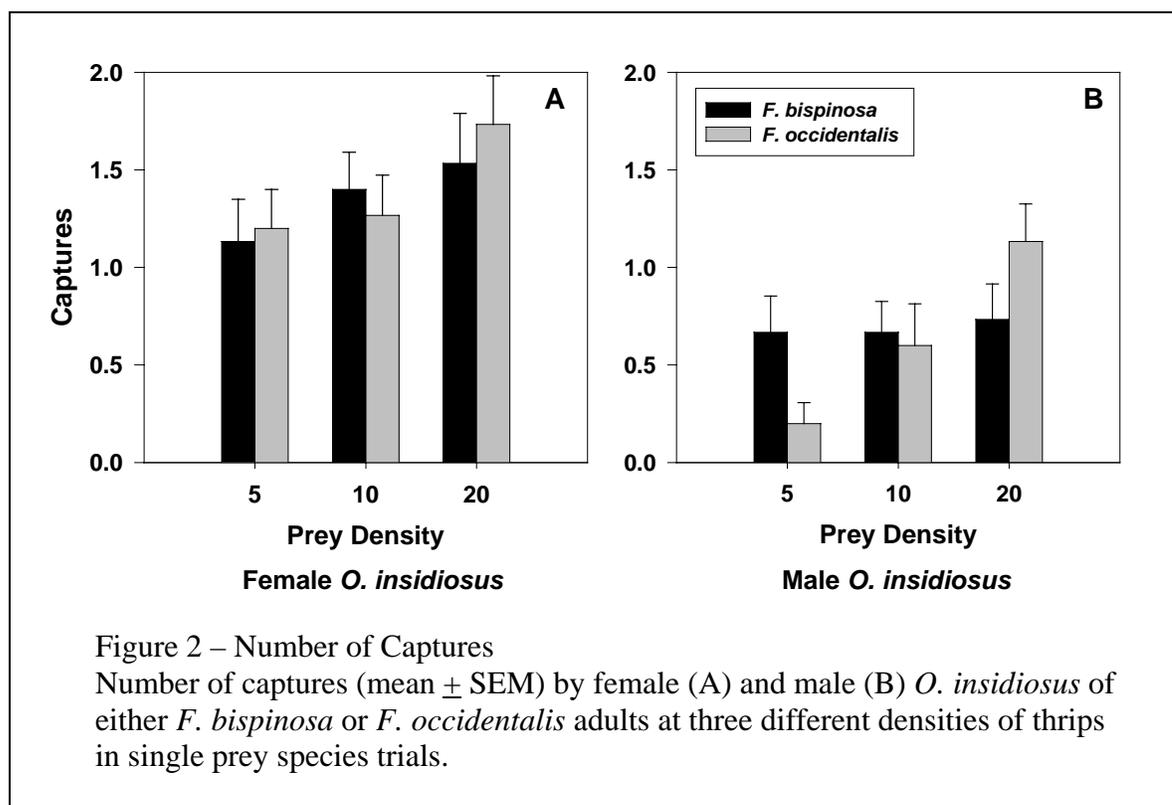
### Objective 1.1: Single Species Arenas

Both female and male *O. insidiosus* had significantly more encounters with *F. bispinosa* than with *F. occidentalis* ( $F = 10.59$ ,  $df = 1, 168$ ,  $P = 0.0014$ ; Fig. 1). There was also a significant difference between the sexes of *O. insidiosus* as females were significantly more likely to encounter prey than males ( $F = 12.42$ ,  $df = 1, 168$ ,  $P = 0.0005$ ). The interaction between sex and density was significant ( $F = 3.46$ ,  $df = 2, 168$ ,  $P = 0.0337$ ).

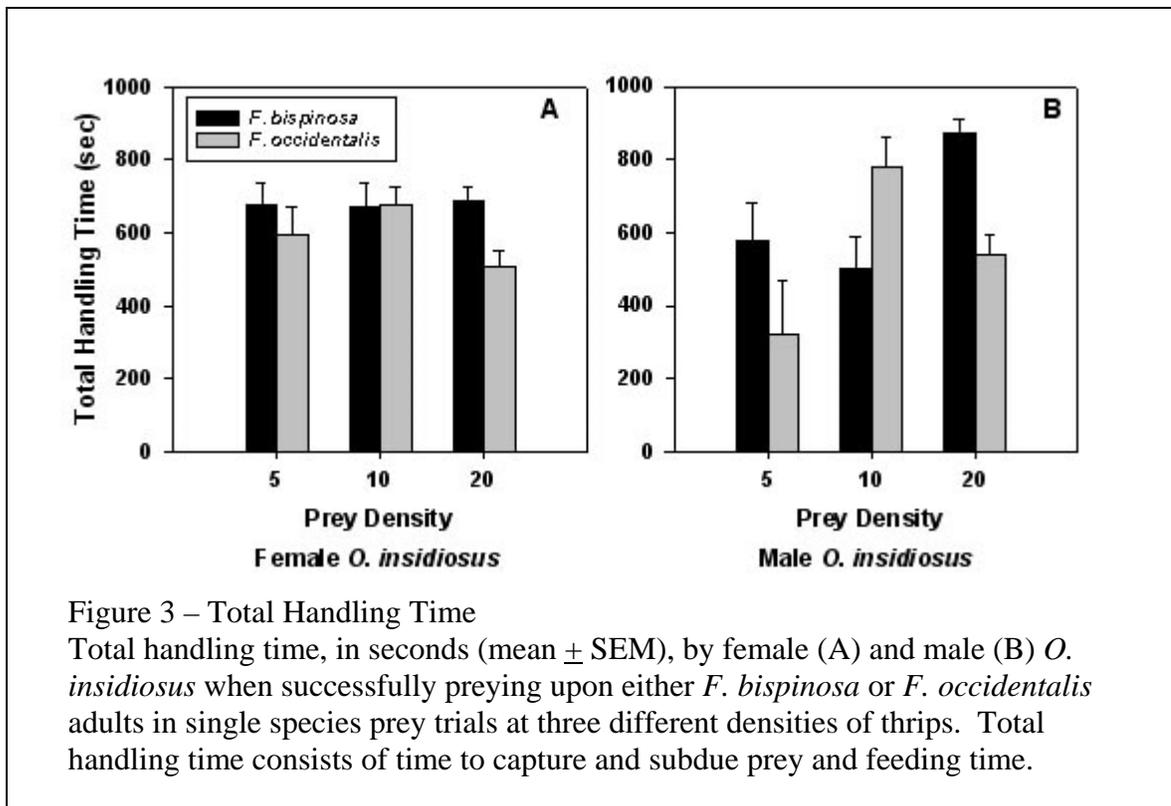


The level of encounters as related to density was not significant for female *O. insidiosus* ( $P > 0.05$ , least squares means *t*-tests; Fig. 1A); however, males had significantly more encounters at the highest density (20 thrips per arena) than at the lower densities ( $P < 0.05$ , least squares means *t*-tests; Fig. 1B).

While *O. insidiosus* had more encounters with *F. bispinosa* than with *F. occidentalis*, there was no difference in the numbers of the two prey species captured ( $F = 0.03$ ,  $df = 1, 168$ ,  $P = 0.86$ , Fig. 2). The capture rate was significantly higher with 20 thrips per arena than at the two lower densities ( $F = 5.32$ ,  $df = 2, 168$ ,  $P = 0.0057$ ). There was a significant difference in the number of captures and encounters between the predator sexes. Females caught significantly more thrips than males did ( $F = 35.07$ ,  $df = 1, 168$ ,  $P < 0.0001$ ).



The mean time for a capture to occur was  $1.5 \pm 0.07$  sec. Although *F. occidentalis* are larger than *F. bispinosa*, *O. insidiosus* spent significantly more time subduing and feeding on *F. bispinosa* ( $722 \pm 29.7$  sec) than on *F. occidentalis* ( $618 \pm 35.5$  sec;  $F = 6.24$ ,  $df = 1, 78$ ,  $P = 0.0146$ : for trials in which feeding was completed before the end of the observation session; Fig. 3).



### Objective 1.2: Mixed Species Arenas

Both male and female predators encountered significantly more *F. occidentalis* than *F. bispinosa* in mixed arenas (test for intercept:  $F = 103.19$ ,  $df = 1, 38$ ,  $P < 0.0001$ ; Fig. 4A). *O. insidiosus* attacked both species of thrips when encountered, but individuals of *F. bispinosa* exhibited behavior of deliberately evading predators as well as more consistent movement. In contrast, *F. occidentalis* appeared more inactive, which left

them more prone to attack from *O. insidiosus*. My conclusion is that the prey of *O. insidiosus* (in regards to flower thrips) is based on the vulnerability of the prey.

Female *O. insidiosus* are better hunters than males with a higher number of captures ( $F = 5.02$ ,  $df = 1, 38$ ,  $P = 0.031$ ). Overall, both male and female *O. insidiosus*

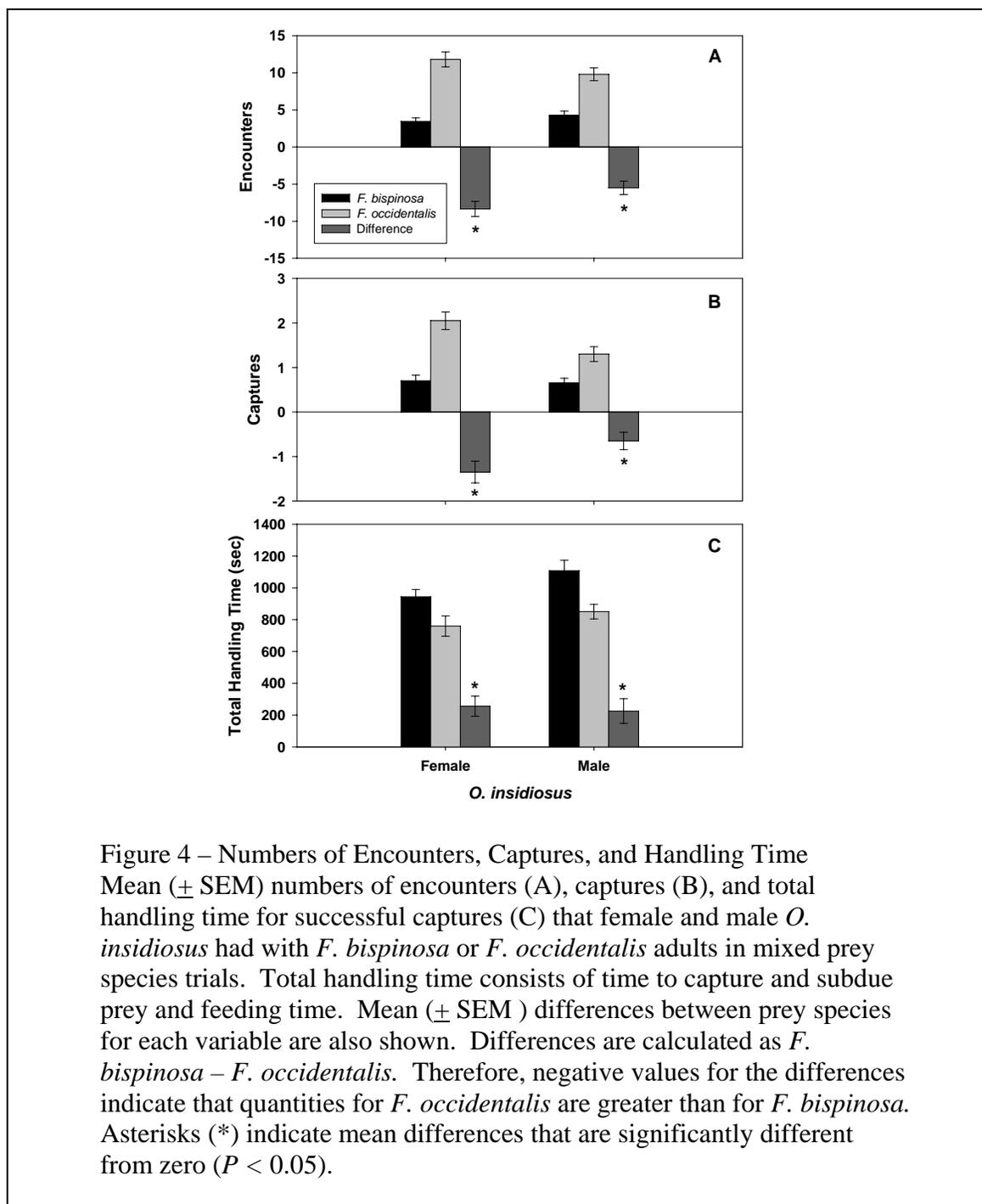


Figure 4 – Numbers of Encounters, Captures, and Handling Time Mean ( $\pm$  SEM) numbers of encounters (A), captures (B), and total handling time for successful captures (C) that female and male *O. insidiosus* had with *F. bispinosa* or *F. occidentalis* adults in mixed prey species trials. Total handling time consists of time to capture and subdue prey and feeding time. Mean ( $\pm$  SEM) differences between prey species for each variable are also shown. Differences are calculated as  $F. bispinosa - F. occidentalis$ . Therefore, negative values for the differences indicate that quantities for *F. occidentalis* are greater than for *F. bispinosa*. Asterisks (\*) indicate mean differences that are significantly different from zero ( $P < 0.05$ ).

captured significantly more *F. occidentalis* than *F. bispinosa* (test for intercept:  $F = 40.97$ ,  $df = 1, 38$ ,  $P < 0.0001$ ; Fig. 4B). Both female and male *O. insidiosus* spent significantly more time feeding on the smaller *F. bispinosa* than on the larger *F. occidentalis* ( $F = 23.63$ ,  $df = 1, 23$ ,  $P < 0.0001$ ). This difference in feeding times between the two prey species was similar for both male and female *O. insidiosus* (predator sex by prey species interaction:  $F = 0.10$ ,  $df = 1, 23$ ,  $P = 0.758$ ; Fig 4C).

### **Objective 1.3: Whole Plant Arenas**

The effect of predation in the whole plant assays was determined by comparing the number of thrips surviving in the experimental arenas (with predator) with the number surviving in the corresponding control arenas (without predator). There was a significant difference in the number of thrips surviving between the experimental and control arenas. Although the impact was dependent on prey density, significantly more *F. bispinosa* survived than *F. occidentalis* in the predator treatments ( $F = 4.28$ ,  $df = 3, 96$ ,  $P = 0.0070$ ; Fig. 5). Due to the significant interaction between predation and prey density, I analyzed prey species separately for each density x predator treatment.

In treatments without *O. insidiosus*, there were no significant differences in survival of *F. bispinosa* and *F. occidentalis* at the two lowest densities of 10 and 20 total thrips per arena ( $P > 0.05$  for least squares means  $t$ -tests that mean differences between species = 0); yet, at the higher densities of 40 and 80 thrips per arena, significantly more *F. occidentalis* survived than *F. bispinosa* ( $P < 0.05$ ). However, at every density when *O. insidiosus* was present, significantly more *F. bispinosa* than *F. occidentalis* survived ( $P < 0.05$  for least squares means  $t$ -tests that mean differences between species = 0; Fig. 5).

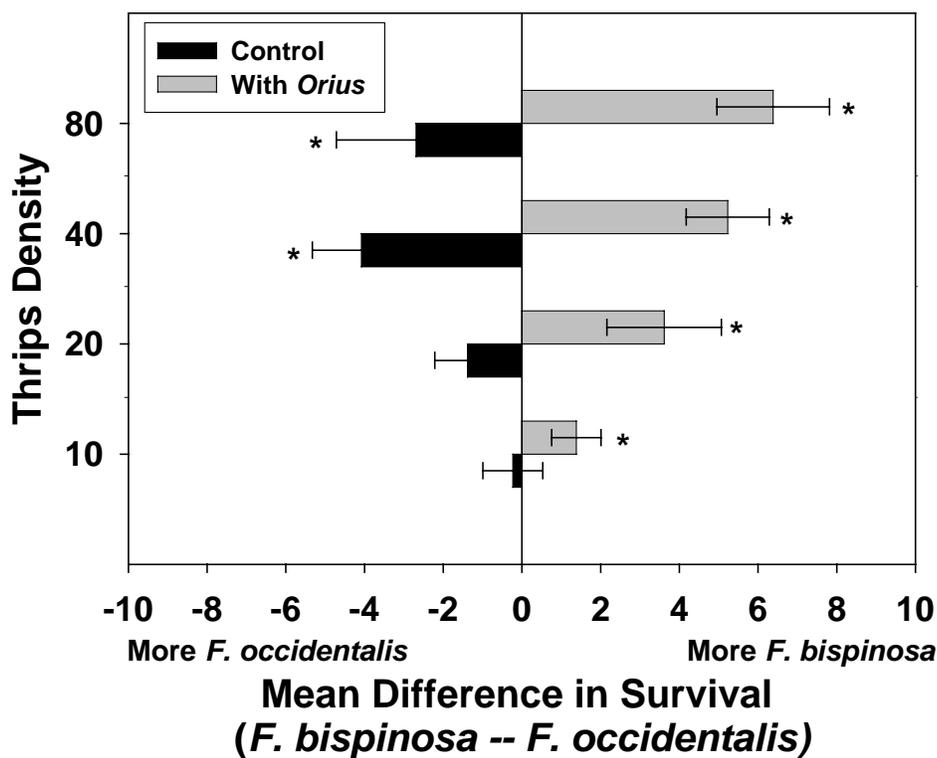
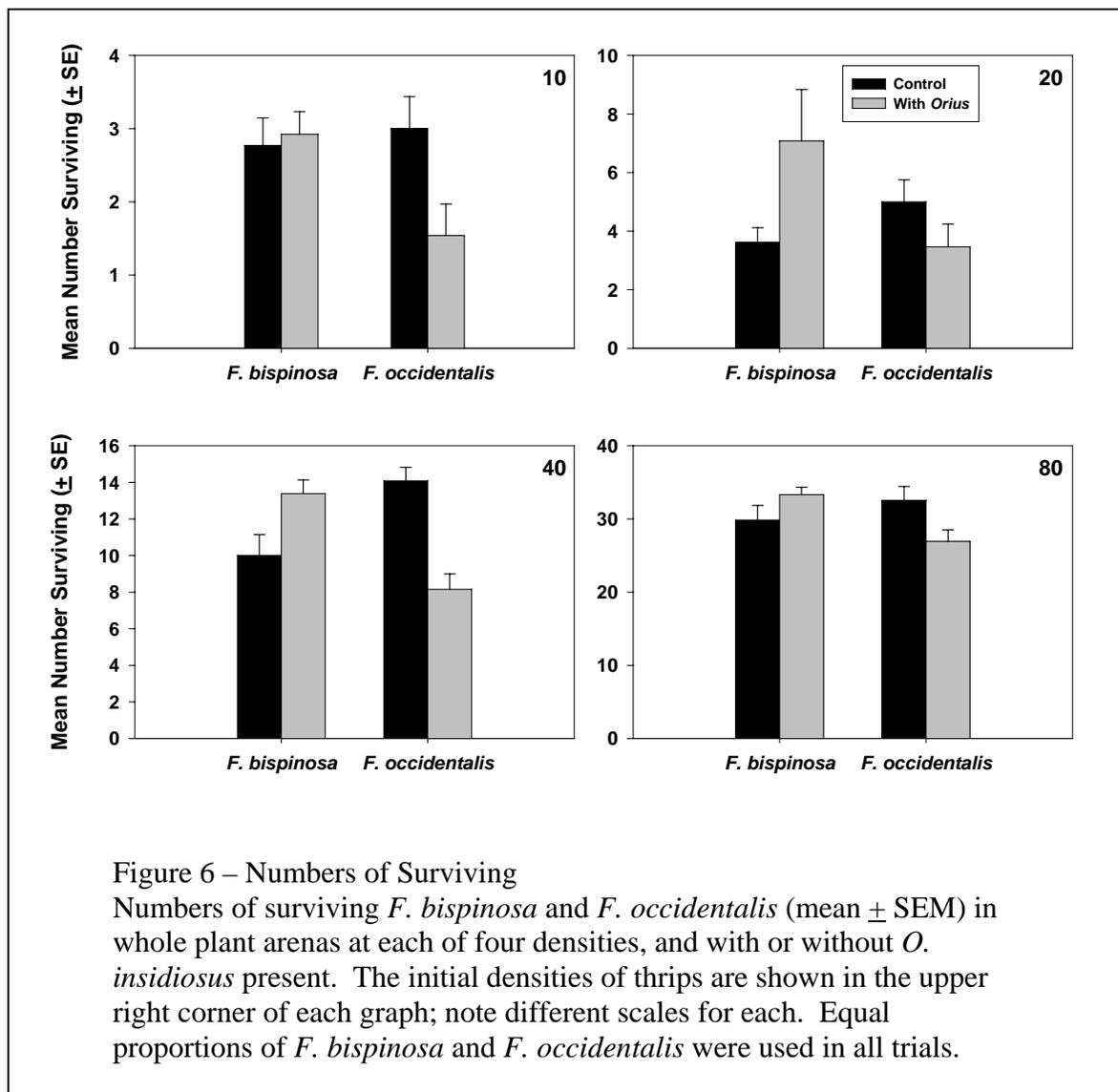


Figure 5 – Mean Differences in Number Surviving  
 Mean differences ( $\pm$  SEM) in numbers of surviving *F. bispinosa* and *F. occidentalis* in whole plant arenas at each of four densities, with or without *O. insidiosus* present. Differences are calculated as *F. bispinosa* – *F. occidentalis*. Therefore, negative values for the differences indicate that quantities for *F. occidentalis* are greater than for *F. bispinosa*. Asterisks (\*) indicate mean differences that are significantly different from zero ( $P < 0.05$ ).

To determine if predation was a significant factor for either prey species, we compared numbers of survivors between the control and experimental treatments. At each density, there were significantly fewer *F. occidentalis* that survived with *O. insidiosus* present than without ( $P < 0.05$  for least squares means *t*-tests that mean differences between treatments for each prey species = 0; Fig. 6). In contrast, it was determined that there was no significant difference in the numbers of *F. bispinosa* that

survived with predators present and without ( $P > 0.05$ ; Fig. 6). These results suggest that *F. bispinosa* are able to survive better in mixed species environments than *F. occidentalis*.



## DISCUSSION

Previous research indicated that *O. insidiosus* is a significant predator of flower thrips. This study supports those assertions on a small arena and single-plant basis, but also reveals that the species and numbers of prey available can influence short-term results of predation. Specifically, my research indicates that there is a difference in the level of predation by *O. insidiosus* of *F. occidentalis* over *F. bispinosa* when these two species are presented together. A reason for this preference may be accounted for through visual observations and previous movement/dispersal studies of the two prey species (Ramachandran et al. 2001). Prior work with Heteroptera have shown that species demonstrate preferential predation in mixed-species environments (Foglar et al. 1990, Hazzard and Ferro 1991, Cloutier and Johnson 1993, Cisneros and Rosenheim 1997, Eubanks and Denno 2000). Tests of Heteropteran predators have also shown that there may often be a marked preference for one species out of a group of confamilial prey (Fritsche and Tamo 2000, Meyling et al. 2003). The slightly different behaviors of even the most closely related prey species can have far reaching consequences for the ecological interactions and population dynamics in any given system.

*Orius insidiosus* is known to prey on both *F. bispinosa* and *F. occidentalis* in field and laboratory conditions (Funderburk et al. 2000). Flower thrips are known to be

suitable for providing nutrient to active and gravid *Orius* spp. (Chyzik et al. 1995, Wearing and Colhoun 1999, Fritsche and Tamo 2000, Venzon et al. 2002; Paik et al. 2003). While conducting my research, I did not observe *O. insidiosus* rejecting either species of thrips once it had been captured and subdued and failing to indicate any non-preference for prey of a substandard quality (Meyling et al. 2003). Therefore, I concluded that the lower levels of predation that I observed on *F. bispinosa* are likely a result of some other difference than being a nutritionally less desirable food source.

Since *F. bispinosa* are significantly smaller than *F. occidentalis*, *O. insidiosus* needed to capture and consume more than one *F. bispinosa* to receive the same nutritional gain as from one *F. occidentalis*. However when the different species of prey were presented individually in the single species arenas, there was no significant difference in the capture rate between *F. bispinosa* and *F. occidentalis*. Furthermore the overall success rate (captures per encounter) was approximately 50% less for *F. bispinosa* than it was for *F. occidentalis* in the single species trials.

While the smaller *F. bispinosa* took longer to subdue and consume than the larger *F. occidentalis*, there were no observable interactions between *F. bispinosa* and *O. insidiosus* that would indicate that the predator was avoiding *F. bispinosa* during the mixed-species trials. The behavior of *O. insidiosus* was to attack any thrips that it was aware of and that was nearby. The visual observations and data combined render a scenario in which *F. bispinosa* were able to better avoid and escape predation by *O. insidiosus*. As a result, the predator was able to capture more *F. occidentalis* than *F. bispinosa* when they were presented together. It is important to note that in the mixed-species arenas that, *O. insidiosus* encountered both prey throughout the trials. This

indicated that predator satiation had no influence on its prey choice. This being said, selection for *F. occidentalis* by *O. insidiosus* was consistent during the entire series of experiments. From this we can conclude that selective predation on *F. occidentalis* appears to be a result of the behavioral characteristics of the prey as opposed to a nutritional preference on the part of the predator (Lang and Gsödl 2001, Sukhanov and Omelko 2002).

In related research, Fritsche and Tamo (2000) found that the thrips predator *Orius albidipennis* (Reuter) captured and consumed fewer *Megalurothrips sjostedti* (Trybom) than *Ceratothripoides cameroni* (Priesner) and *Frankliniella schultzei* (Trybom). The difference was attributed to the behavior of *M. sjostedti* (Trybom) in that it was more active and vigorous in its movement while avoiding predators. Meyling et al. (2003) hypothesize that *Anthocoris nemorum* (L.) and *A. nemoralis* (F.) forage more heavily on *Myzus persicae* Sulzer than *Macrosiphon euphorbiae* (Thomas) because *M. euphorbiae* is more prone to movement after an initial contact with a predator.

In the whole-plant arenas, where there was a greater expanse of space for the thrips to occupy and utilize, the differences in predation were even more apparent. The more vagile *F. bispinosa* incurred less mortality as a result of predation than did *F. occidentalis*. Ramachandran et al. (2001) support these results in that they found that *F. bispinosa* and *F. tritici* are more actively moving from plant to plant and colonize plant resources faster than *F. occidentalis*. Baez et al. (2004) showed that *F. tritici* disperses at greater levels than does *F. occidentalis*, and that the level of dispersal increases in the presence of *O. insidiosus*. However, they also showed that *O. insidiosus* moves as readily, enabling it to prey upon both species.

*Orius insidiosus* prefer to prey on *Frankliniella* larvae in field and lab conditions, but as larvae become less abundant, predation on adult thrips increases (Baez et al. 2004). My data and corresponding field observations suggest that *O. insidiosus* would have a similar impact on single-species populations of *F. occidentalis* and *F. bispinosa*, but suppression of *F. bispinosa* populations would take longer than that of a *F. occidentalis* population (Sabelis and Van Rijn 1997, Nomikou et al. 2002). As seen in field observations in Florida, *O. insidiosus* would first suppresses *F. occidentalis* populations and then eventually those of *F. bispinosa* (Funderburk 2002, Reitz et al. 2002).

Populations *F. bispinosa* and *F. occidentalis* increase during spring then decline rapidly by early summer and remain at low levels until the following year (Chellemi et al. 1994, Funderburk et al. 2000, Ramachandran et al. 2001, Funderburk 2002, Reitz 2002). Contrary to hypotheses by Parrella and Lewis (1997) that natural enemies are not a significant factor in the regulation of thrips populations, Funderburk et al. (2000) determined that there was a strong negative correlation between the level of thrips in the field and the number of *O. insidiosus* .

While *O. insidiosus* are able to sustain populations on secondary sources of nutrient (i.e. pollen and other species of prey) (Kiman and Yeargan 1985), female *O. insidiosus* are unable to obtain sufficient protein for reproduction in the winter and until prey once again becomes available in spring (Ruberson et al. 1998, 2000). Because of this break in the reproduction cycle of *O. insidiosus*, thrips populations are able to build up in the temporary absence of recruitment by the predator (Sabelis and Van Rijn 1997; Funderburk et al. 2000; Funderburk 2002).

The research I present here is a proposal that differential predation in this plant-prey-predator trophic system is an important factor contributing to the fluctuating population dynamics of *F. occidentalis* and *F. bispinosa*, as well as other *Frankliniella* species observed in Florida. These findings provide evidence that prey preference of a generalist predator does not depend solely on the behavior and characteristics of the predator, but can be affected by slight – yet not insignificant – differences in the behavior and characteristics of closely related prey. In this case, these two closely related thrips differ in the use of their environment and their response to the presence of a predator enough to allow one species (*F. bispinosa*) to persist longer in the field than the other (*F. occidentalis*).

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## BIOGRAPHICAL SKETCH

I was born in Rochester, New York, in the Fall of 1972. Two weeks after my birth my parents and I moved to Bradenton, Florida where I attended Palma Sola Elementary School for kindergarten through fifth grade. I then rode my bike a little further down 5<sup>th</sup> Avenue NW to King Middle School, where I attended sixth through eighth grades. I started senior high at Manatee High School. It was in the middle of the tenth grade that my family moved to Palatka, Florida, where I entered Palatka High School.

Upon graduating from Palatka High in 1990, I attended one year of classes at Santa Fe Community College before returning to Palatka to attend St. Johns River Community College, where I received my Associate of Arts Degree in 1993. I immediately moved to Asheville, North Carolina, and took a couple of years off school before entering The University of North Carolina at Asheville (UNCA). Shortly after entering UNCA I got married and started a family and began to attend classes part time. Eventually I earned my Bachelor of Science degree in biology in 2000.

I immediately moved to Gainesville, Florida, and began work in the lab of Marjorie Hoy as a research assistant. After three months I started as a grad student under Joe Funderburk. Just after finishing my classes I moved back to Asheville, North Carolina, to deal with a family situation. In the time between finishing my classes and defending my thesis I have taught as an adjunct professor at UNCA, functioned as Staff

Ecologist of the Southern Appalachian Biodiversity Project and currently am a Research Technician and Lab Manager in the Biology Department of the University of North Carolina at Chapel Hill.