S-1073 ANNUAL REPORT FOR 2019 AND PLANS FOR 2020

IMPACT STATEMENT:

The biological control challenges we address in this multistate project are broad reaching from natural systems and invasive plants to urban landscapes. To address these problems, we study compatibility of insecticides with biological control, plant diversity, and building efficiency in rearing and deployment of biological control agents. Our work benefits municipalities, landscape professionals, landscape designers, urban planners, and the millions of residents of the US who interact with ornamental landscapes each day. Furthermore, vegetables and ornamental plants grown in fields, greenhouses and nurseries, as well as ornamental plants and grasses maintained in urban landscapes, are highly valuable to the economy and wellbeing of our citizens. But, these valuable plants are often attacked by a myriad of insect and mite pests. These endemic and invasive pests have traditionally been managed through the frequent applications of insecticides, which resulted in reduced efficacy, pesticide resistance, and human and environmental risks. By researching and integrating biological control within the larger framework of vegetable and ornamental plant management, we will be able to reduce pesticide applications and the associated environmental, pest management and socioeconomic consequences. Research and extension activities conducted under this project result directly in achieving pest management goals while alleviating the associated problems. This is because preventing and reducing pest infestations reduces the economic costs associated with maintaining trees and other landscape plants and reduces the amount of insecticide applied to those plants. We conduct this work in collaboration with a diverse team of undergraduate and graduate students, post docs, technicians, and colleagues in the US and around the world. We also work with stakeholders and conduct extension activities to disseminate our findings to end users. Through better understanding of the ecological relationship between pests and their natural enemies, and better utility of compatible insecticides, we will be able to develop integrated pest management programs that reduce pest damage, improve economic returns, and alleviate negative consequences of pest management activities.

S-1073 ANNUAL REPORT FOR 2019 AND PLANS FOR 2020

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ACCOMPLISHMENTS

1. To discover, assess, and release new biological control agents

2. To characterize and evaluate the impact of native and introduced biocontrol agents

Based on lack of research on whitefly natural enemies in the landscape, we began a study in 2019 and continued in 2020 to document predators of whiteflies in cotton fields. In addition, we know little about the dynamics of predators and pests in peanut systems. During 2019-2020 seasons we partnered with the GA Peanut Commission to initially fund work to sample peanut fields across GA. Over the two seasons we sampled 60+ fields using a spatially balanced design for future statistical rigor. Samples are still being processed from both of these studies.

Work began in pecan systems too. We funded two projects to document pecan natural enemy communities, and later to study effects of current cultural practices on biocontrol efficacy.

3. To develop integrated pest management programs that have a biological control component

4. To develop augmentation and conservation biological control tactics, especially to improve the quality of agricultural habitats for pollinators

Building on our past work of pollinator plants, we partnered with NREL and Solar America companies to begin establishing wildflower habitat is solar arrays and helping the solar industry with this conservation practice. During this same period, we partnered similarly with the NRCS to begin building habitat enhancement demonstration areas for pollinators and natural enemies in blueberry landscapes.

UTILITY OF FINDINGS

To fully utilize biodiversity for the ecosystem services provided, we must document diversity patterns and also the interactions under natural conditions. Our work attempts to document diversity at large scales and also the frequency of interactions between biocontrol agents and pests in agricultural landscapes.

WORK PLANNED FOR NEXT YEAR (2020-2021)

We will publish work from the 2 year projects in cotton landscapes for whiteflies and peanut landscapes. These data will likely be used for multiple publications and we will work to also produce extension materials on biological control agents in these landscapes.

PUBLICATIONS (2019-2020)

Snyder, WE. 2019. Give predators a complement: conserving natural enemy biodiversity that improves biocontrol. Invited contribution to special feature “Next generation conservation biological control of arthropods.” *Biological Control* 135:73-82.

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S-1073 ANNUAL REPORT FOR 2019, 2020 AND PLANS FOR 2020, 2021

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ACCOMPLISHMENTS

5. To discover, assess, and release new biological control agents

Brazilian peppertree. The stem thrips *Pseudophilothrips ichini* (Thysanoptera: Phlaeothripidae); *Calophya latiforceps*, *Calophya terebinthifolii*, and *Calophya lutea* (Hemiptera: Calophyidae) are currently under study at the University of Florida Institute of Food and Agricultural Sciences (UF/IFAS) Biological Control Research and Containment Laboratory for use as biological control agents for the invasive Brazilian peppertree. Release permits for *C. latiforceps* and *P. ichini* were issued in June 2019. Host range testing of the other two other *Calophya* spp. is completed. Since release permits were issued for *P. ichini*, UF and federal collaborators (USDA-ARS) have released over 400,000 *P. ichini* at sites throughout Florida. Evaluation of impacts on this biological control agent is discussed under Objective 2.

Continued maintaining a colony of the stem-boring weevil *Apocnemidophorus pipitzi* in the EDCL. During this reporting period, a total of 646 adults were produced (319 males, 327 females). The sex ratio of 1.03 indicates normal colony reproduction. A manuscript describing the host range of the weevil *A. pipitzi* was submitted to Biocontrol Science and Technology.

Cogongrass. During this reporting period, traveled to Bogor Agricultural University (BAU), West Java, Indonesia between 22- 28 June 2019 to meet our project collaborator, collect the cogongrass gall midge *Orseolia javanica* (Diptera: Cecidomyiidae) and attempt to establish a colony in the laboratory at BAU. Viable populations of the gall midge (indicated by the presence of abundant stem galls) were located in Cianjur District, Indonesia and also the Cipaku Chinese cemetary near BAU. Galls, along with stem crowns, roots and pieces of rhizome removed from soil at Cianjur and Cipaku cemetary were transported to Bogor Agricultural University for processing. Galls averaged 8.9 cm in length. In total, 95 galls were collected from Cianjur site but only 6 adults (3 males and 3 females) emerged in screen cages (6.3% emergence success). Because adults are short-lived (only 24 hours) and emergence was asynchronous, mating did not occur. At Cipaku cemetary, 180 galls were

collected from 9 July – 26 September 2019. In total, 9 adults (6 males and 3 females) emerged (5.0%). One female apparently mated and deposited 240 eggs on 12 July 2019. Eggs were transferred to potted cogongrass plants but to date no galls have been observed.

The low emergence rate may have been due to parasitism (9.4%) by two parasitoids, *Aprostocetus* sp. and *Platygaster* sp. (probably the specialist *P. orseoliae*). In total, 3,820 adults of the parasitoid *P. orseoliae* emerged from only 91 galls in the laboratory. The enormous number of wasps that emerged from less than 100 galls indicates this pupal wasp exhibits a form of reproduction referred to as polyembrony, where multiple parasitoid larvae are produced from a single egg. The significance of the high incidence of parasitism (30-40%) by the platygasterid wasp *Platygaster orseoliae* cannot be overstated. The numerical response of the cogongrass gall *midge O. javanica* will be significantly enhanced if it can be released in the USA without this parasitoid.

A field experiment was conducted to determine the effect of mowing cogongrass on *Orseolia javanica* gall development. The study was done in Cianjur District, West Java. After preparation of field plots, daily observations were made on gall growth, and duration of gall midge emergence. The emergence time for *O. javanica* was shorter on the mowed versus the unmowed cogongrass. This may be due to changes in microclimate (more sunlight exposure and higher temperature in the mowed plots). The gall midge population in the Cianjur district also was positively correlated with rainfall. These preliminary results suggest that *O. javanica* is compatible with mowing cogongrass, which can shorten the life cycle of the gall midge and may increase its effectiveness as a biological control agent.

Earleaf acacia. *Acacia auriculuformis*, is a fast-growing, evergreen tree from Australia that was purposefully introduced into the United States as an ornamental plant at the turn of the 20th century. The first note of the potential weedy nature of this species was in 1976. Since that time, earleaf acacia has become more prevalent and more of an issue in Florida. It is now listed as a Category I plant on the Florida Exotic Pest Plant Council's 2017 List of Invasive Species. Multiple sources list this species as high risk for invasive potential, and there is a lack of long-term control options outside of chemical basal bark and "cut and spray" treatments. This makes earleaf acacia a good candidate for biological control. Currently, 89 arthropod species that feed on earleaf acacia in its native range have been found. Several of those arthropods have the potential to be host specific and damaging to the weed. One of those species, *Calomela intemerata* (Coleoptera: Chrysomelidae), has been introduced into containment labs in Florida for study. So far, *C. intemerata* has been tested on 21 species of native plants and remains host specific to *A. auriculiformis.*

6. To characterize and evaluate the impact of native and introduced biocontrol agents

Brazilian peppertree. In total, 13,000 Brazilian peppertree thrips (*P.ichini*) have been released at two field plots in southern Florida. Plant growth data were collected immediately post-release (July 2019) and again in November 2019, February 2020, and July 2020. No differences in growth between plants treated with thrips and plants protected by a systemic insecticide have been found as of yet, nor are they expected until thrips populations increase at each site and supply significant insect pressure on the plants.

Organic squash pests. A combination of tactics was used to suppress squash pests such as aphids, sweetpotato whiteflies, and thrips, as well as maintaining a healthy community of beneficial arthropods. Non-crop flowering plants such as sweet alyssum, African marigold, or cowpea were introduced as alternative food and shelter for pollinators, predators, and parasitoids. The predatory mite *Amblyseius swirskii* was released for suppression of whiteflies and thrips. The research showed that refugia increased pollinators and naturally occurring predators and parasitoids around organic squash. There was an inverse ecological relationship between *A. swirskii* and the sweetpotato whitefly when *A. swirskii* was released in the squash. Low numbers of the predatory mites were successfully established in organic field-grown squash, which suppressed whitefly populations; thus, reducing the need for frequent insecticide applications.

Predatory mites and thrips. (a) Libraries for 23 populations of predatory mites representing seven species: *Phytoseiulus persimilis* (5), *Neoseiulus californicus* (4), *N. cucumeris* (4), *N. fallacis* (2), *Amblyseius swirskii* (4), *A. andersoni* (3), *Amblydromalus limonicus* (1) have been constructed and Illumina sequencing is currently being finished and evaluated for this barcoding project. Benefits to stakeholders include new tools to identify/validate current and new predator populations and association of traceable genetic markers w/effective predator populations being used in commercial settings. (b) Completed studies comparing the potential of the predatory mite species *Amblyseius swirskii* and *Amblydromalus limonicus* to control chilli thrips. (c) Determined the efficacy of a pepper-based banker plant system utilizing *Amblyseius swirskii* and *Amblydromalus limonicus* for control of chilli thrips on rose. (d) Assessing the suitability of *Artemia* cysts for development and reproduction of *Franklinothrips vespiformis* and determined preference for cysts over the target prey *Echinothrips americanus*. (e) Conducted greenhouse studies to determine if the application of *Artemia* cysts as an alternative food source for *Franklinothrips vespiformis* enhanced biological control of *Echinothrips americanus*.

Invasive mole crickets. Invasive mole crickets are damaging pests of turfgrass and forage crops. With funding from USDA-NIFA, my lab partnered with Florida cattlemen and IFAS research stations to study the effects of an introduced parasitic nematode, *Steinernema scapterisci*, on two invasive mole cricket species over time. We found the parasite has established and dispersed throughout north-central Florida and that mole crickets remain abundant. We also found that invasive mole crickets are up to 10% larger now than they were prior to nematode introduction. We speculate that mole cricket-parasite interactions have selected for larger, more fit mole crickets, which has implications for future management and further dispersal into the U.S. This work was recently published in *Biological Invasions.*

Urban landscape pest management. Biodiversity loss and associated conservation efforts are widespread and becoming increasingly important. Among the most recognized insect species of conservation interest is the monarch butterfly. As such, efforts around the country have focused on creating milkweed habitats to support monarch migration, reproduction, and development. Little is known about how the design and composition of monarch conservation plantings affect the bottom-up and top-down regulation pressures on monarchs. For example, gardens composed of many wildflower species may be expected to attract

greater biological control of monarch caterpillars compared to gardens composed of only milkweed. We investigated this question and found that diverse wildflower gardens were in fact more valuable to monarchs than milkweed monocultures because they encouraged greater oviposition and did not increase predation or parasitism of monarch larvae. This work was recently published in *Insects*.

7. To develop integrated pest management programs that have a biological control component

   Sweet potato whitefly. Sweet potato whitefly, thrips and aphids are major insect pests in vegetable crops in north Florida. The use of "push-pull" technology is a cultural control method which may mitigate damage by insect pests. We evaluated the "push" component in the "push-pull" technology in controlling insect pests in organic vegetables in a screened structure. We used potted repellent plants of citronella, garlic society and lemon grass. Flowering plants such as marigold and basil were placed on the edge of the screenhouse. Commercial "preda-lure" volatiles were placed next to the basil plants. These flowering plants and lures were used to complement the "push-pull" strategy by enhancing the beneficial insects that may reduce the numbers of insect pests. Preliminary results indicate that sweet potato whiteflies, aphids and thrips were the common insect pests in the tomato crop. A caterpillar-like pest, the yellow striped armyworm, was observed to feed on the tomato fruit. The beneficial insects were mainly the minute pirate bug and whitefly parasites, *Encarsia* and *Eretmocerus* spp. The use of "push-pull" technology complemented with use of flowering plants and commercial attractants of beneficial insects, may be part of an integrated pest management program to control major insect pests in vegetables.

   Whitefly and thrips pests. (a) During the life of this NACA, 936 whitefly samples representing 14,112 individual whitefly have been molecularly biotyped for growers/researchers free of charge so that management programs could be tailored to an individual nursery or greenhouse grower's whitefly population (MEAM1 vs MED / B vs Q). (b) Management plans for thrips (https://edis.ifas.ufl.edu/pdffiles/IN/IN114500.pdf) and whiteflies http://edis.ifas.ufl.edu/pdffiles/IN/IN117100.pdf are continually updated/available online. (c) Non-neonicotinoid rotation greenhouse trials (2) with new chemistry insecticides that were previously determined to be compatible with *Amblyseius swirskii* are complete. Seven rotation regimes were evaluated and the trial was repeated. Third rotation trial with the top three insecticides were evaluated to determine if insecticide placement within the rotation regime affected MED whitefly control. Data is being analyzed and a manuscript is in preparation. (d) Investigating Chilli thrips true host range.

8. To develop augmentation and conservation biological control tactics, especially to improve the quality of agricultural habitats for pollinators

   Trichogramma mass production. *Ephestia kuehniella* is a post-harvest storage pest that attacks many cereal grains, nuts, fruits, and animal feed. This study determined that the standard and most expensive *E. kuehniella* larval diet resulted in production of large eggs that are the most acceptable to the egg parasitoid *Trichogramma brassicae* (Hymenoptera: Trichogrammatidae) for parasitism and produce the most high-quality progeny. Therefore,

the standard diet is the most cost-effective.

Chilli thrips. Assessed the potential of the generalist predatory mite, *Amblyseius swirskii* (Acari: Phytoseiidae) to control the invasive chilli thrips, *Scirtothrips dorsalis* (Thysanoptera: Thripidae) in greenhouse studies using potted strawberry plants. The *A. swirskii* treatment was compared with spinetoram and an OMRI certified capsicum oleoresin-based pesticide treatments. The control plants had ~2–4 times higher *S. dorsalis* nymph numbers compared to the plants treated with *A. swirskii* and spinetoram, respectively. Results indicate that *A. swirskii* is an effective candidate for augmentative biological control agent of *S. dorsalis*.

Urban landscape pest management. Urbanization is commonly associated with habitat loss and declining beneficial insects. With more golf courses than any U.S. state, Florida is well-positioned to strategically utilize them as ecologically functional green spaces. I have partnered with the golf industry to develop methods for increasing pollinating and predatory insects in golf course out-of-play areas. We have found that diverse wildflower habitats not only boost pollinator abundance and richness, but also translates to a 50% increase in biological control of golf course insect pests in nearby golf course fairways. This work was recently published in *Urban Ecosystems*.

UTILITY OF FINDINGS

Brazilian peppertree. The introduction of multiple *Calophya* spp. that can establish across the different climatic zones in Florida can increase chances for establishment and target plant suppression. For example, *C. terebinthifolii* should be introduced in areas with cold climate like North Florida, *C. lutea* should be introduced in areas with mild winter, and *C. latiforceps* should be introduced in areas with high humidity and summer temperatures.

Cogongrass. In 2009, the state of Alabama spent $6.3 million of federal stimulus funds exclusively for control with herbicides. A biocontrol agent could substantially reduce costs for cogongrass management. If we are successful in developing a laboratory rearing method for the gall midge *O. javanica*, we can import the insect into Florida for host range testing. If the gall midge is found to be host specific (which preliminary testing by Mangoendihardjo (1980) suggests it is), then its impact could be devastating to cogongrass. The insect would be released into Florida free of the deleterious effects of parasitism, which significantly impedes the population growth of *O. javanica* in its native range of Indonesia.

Sweet potato whitefly. These research areas will enhance cultural and conservation biocontrol methods such as “push-pull” strategies complemented with use of flowering beneficial plants to control insect pests in vegetables in an integrated pest management program.

Organic squash pests. Organic growers who have limited options to manage whiteflies can use *A. swirskii* as a management tactic. However, more research is needed to determine when releases should occur and the suitable conditions that are needed to allow *A. swirskii* to thrive.

Trichogramma mass production. Wasps called “Trichogramma” are mass produced by

biological control companies and sold throughout the world to control worms that destroy crops each year worth millions of dollars. Well known pests are armyworms, bollworms, and the gypsy moth. Our research objective was to reduce the cost of diet for rearing the insects that are used to produce the wasps. We determined that the standard and most expensive diet was cost-effective relative to cheaper diets because it resulted in the highest quality wasps. This research assures that growers will continue to purchase effective wasps to protect their crops.

Predatory mites and thrips. We have presented more than 25 talks to aid growers and the general public's knowledge of biological control and IPM. We have trained hundreds of growers on how to evaluate commercial biological control agents and how to use banker plant systems in their operations. We have colonized and distributed to select cooperators new predators and parasitoids for the management of key pests of plants grown in protected culture including industrial hemp.

Chilli thrips. Findings from these studies will provide information to support and improve the adoption of augmentation and conservation biological control agents for conventional and organic strawberry production.

Invasive mole crickets. Our work with invasive mole crickets and their introduced parasites has advanced our understanding of classical biological control and generated insights into host-parasite interactions over extended time and space. Our results have generated data for future grant proposals and research projects.

Urban landscape pest management. Our work creating golf course conservation habitats and urban conservation gardens has generated a significant amount of interest among the Florida golf industry and other urban green spaces. This work has also generated guidelines that should improve golf course IPM programs throughout Florida and the Southeast. This work has also generated data to fuel future grant proposals and publications.

WORK PLANNED FOR NEXT YEAR (2021)

Brazilian peppertree. Resubmit petition to USDA, APHIS, TAG requesting field release of the stem boring weevil *A. pipitzi*. Conduct initial field releases of the yellow Brazilian peppertree leaf galler *C. latiforceps*, monitor its establishment and continue impact studies with the thrips *P. ichini*. Determine the best methods to integrate the biological control agents for Brazilian peppertree with other commonly used methods for control.

Cogongrass. Continue developing a mass rearing procedure for the gall midge *O. javanica* in Indonesia.

Sweet potato whitefly. We will evaluate the effects of the "pull" component in a "push-pull" strategy complemented with beneficial flowering plants to control insect pests in vegetables in high tunnel and/or enclosed structures.

Organic squash pests. Studies for next year will involve biological control of key agricultural pests (whiteflies and thrips) that threaten vegetable production worldwide. We will survey

predators and parasitoids in organic vegetables to investigate the potential for natural predation of key pests. Depending on our findings, we will then examine the effects of an introduced predator such as the predatory mite (*Amblyseius swirskii* or *Amblyseius cucumeris*), and predatory mirids (*Dicyphus hesperus* or *Macrolophus pygmaeus*).

Predatory mites and thrips. We will continue to evaluate commercially available predatory mites (*Amblyseius swirskii*, *Amblyseius cucumeris* and *Amblyseius andersonii)* for development and integration into BMPs including their susceptibility to alternative insecticides and their utility in banker plant systems currently under development. We have developed BMPs for whitefly targeted at propagated ornamentals and plants for planting intended for export as well as BMPs for thrips targeted at plants for planting. We have initiated new projects aimed at enhancing biological control for citrus and madeira mealybugs and are developing a biological control program for poinsettia thrips using the predatory thrips *Franklinothrips vespiformis*. All management programs are evolving, and new data will be integrated into existing programs and programs yet to be developed for potential new invasive pests of ornamental and floriculture production.

Whitefly and thrips pests. The neonicotinoid class of insecticides is widely used for controlling whiteflies in many cropping systems including ornamental and floriculture crops and are in very grave danger of being removed from the marketplace in the United States due to concerns over toxicity to pollinators. This class of insecticides has already been banned from use in the European Union and the state of Oregon has recently taken measures to do the same. Environmental groups want the entire neonicotinoid class removed which would be catastrophic not only to the ornamental and floriculture industry but also to cotton, field, and vegetable production as they all rely heavily on this class to manage many economically important plant sucking pests. We will evaluate alternatives to this class of insecticides by working closely with the chemical industry to identify registered pesticides and those near registration that could fill the void created if the neonicotinoid class was banned. We will focus on whitefly control, since this is the primary pest affected and will cause the greatest amount of damage/cost to the ornamental and floriculture industry if neonicotinoids are lost.

Chilli thrips. Assess the potential of the generalist predatory mite, *A. swirskii* to control the invasive chilli thrips, *S. dorsalis* in greenhouse studies using potted strawberry plants. Repeat the abovementioned greenhouse study to collect data for a second trial and publish findings. The compatibility of ultraviolet radiation - C spectrum with three species of predatory mites for twospotted spider mite, *Tetranychus urticae* (Acari: Tetranichidae), control in strawberries will be tested in laboratory studies. Results will add to the information about the effect of the same doses of UVC on *T. urticae* and phytoseiid mites that can be used as augmentative biological control agents in open field strawberries. Efficacy trials in open field strawberry will be conducted by releasing predatory mites, *A. swirskii,* and *Neoseiulus cucumeris,* two strains of entomopathogenic nematodes, and two biorational pesticides to manage arthropod pests. Effect on natural enemies also will be assessed, especially focusing on *Orius* spp. and geocorid species.

Urban landscape pest management. Continue research and extension projects associated with creating conservation habitats on golf courses and other urban green spaces for IPM, conservation biological control, and pollinator conservation. We plan to continue building

partnerships with industry groups and stakeholders to expand our research and Extension reach. Plan to pursue additional funding for conservation biological control efforts in urban landscapes.

Citrus pests. Automated monitoring of invasive insects and their natural enemies using imagery and artificial intelligence in agricultural and natural landscapes. Study the effect of multiple citrus pest infestations on the host location behavior of two Asian citrus psyllid parasitoids, *Tamarixia radiata* (Waterston) (Hymenoptera: Eulophidae) and *Diaphorencyrtus aligarhensis* (Shafee, Alam and Agarwal) (Hymenoptera: Encyrtidae).

Yellowmargined leaf beetle. Assess the possibility of classical biological control for *Microtheca ochroloma* Stål (Coleoptera: Chrysomelidae), an invaisve cruciferous crop pest native to South America.

PUBLICATIONS (2019, 2020)

Refereed

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S-1073 ANNUAL REPORT FOR 2019 AND PLANS FOR 2020

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ACCOMPLISHMENTS

9. To discover, assess, and release new biological control agents

10. To characterize and evaluate the impact of native and introduced biocontrol agents

    We have studied the ecology of native biological control organisms including predators and parasitoids of gloomy scale, lecanium scale, crape myrtle aphids, brown scale, whiteflies, and others. We measured effects of nitrogen and drought on natural enemies and pests associated with maples. We measured predation of crape myrtle aphids and scales as related to landscape variables such as impervious surface cover and canopy cover and as related to local variables such as plant diversity within 10m of the tree. We also studied predators associated with oak lecanium scale and gloomy scale and their effects on scale populations and other pests. Again, we evaluated landscape and local variables including tree diversity and tree density that could affect scale and natural enemy abundance and fitness. We also have studied the differences between native and exotic trees in the natural enemy communities they support.

11. To develop integrated pest management programs that have a biological control component

    We are developing IPM programs including planting recommendations for urban trees that will maximize natural enemy abundance and efficacy by planting trees in the correct location for them to thrive and by increasing habitat complexity. Location characteristics include impertvious surface, tree diversity, and tree density. In addition, our work will help identify tree species that support the most natural enemies and fewest pests so these can be planted in locations that are especially pest prone or stressful.

12. To develop augmentation and conservation biological control tactics, especially to improve the quality of agricultural habitats for pollinators

Our conservation biological control program development focuses on natural enemies rather than pollinators this year. Our work focuses on urban landscapes and urban forest fragments.

UTILITY OF FINDINGS

Our research has shown that habitat complexity within 10m of trees like crape myrtles and red maples is a primary factor determining natural enemy abundance and efficacy. Landscape scale density of trees and tree species is also important. In addition, tree planting recommendations (locations and species) will help reduce pest pressure and increase natural enemies on those trees. This will improve IPM and reduce the need for insecticide applications.

WORK PLANNED FOR NEXT YEAR (2020)

We will continue studying how aspects of urbanization affect conservation biological control in urban landscapes. This will include more work on several scale insect species and possibly other pests like aphids.

PUBLICATIONS (2019)

Frank, S.D. (2019) A survey of key arthropod pests on common southeastern street trees. *Arboriculture & Urban Forestry*, 45(5): 155-166.

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IMPACT STATEMENT : https://www.enago.com/academy/writing-an-impact-statement-four-things-you-need-to-know/

The problem we address in our research program is that urban landscape plants often have more pests and require more insecticides than plants in rural or natural locations. To address this problem we study the effects of urban landscape factors such as impervious surface, tree cover, plant diversity, and temperature to determine how they affect pests and natural enemies and biological control. Our work benefits municipalities, landscape professionals, landscape designers, urban planners, and the millions of residents of the US who interact with ornamental landscapes each day. This is because preventing and reducing pest infestations reduces the economic costs associated with maintaining trees and other landscape plants and reduces the amount of insecticide applied to those plants. We conduct this work in collaboration with a diverse team of undergraduate and graduate students, post docs, technicians, and colleagues in the US and around the world. We also work with stakeholders and conduct extension activities to disseminate our findings to end users.

S-1073 ANNUAL REPORT FOR 2020 AND PLANS FOR 2021

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ACCOMPLISHMENTS

I am participating in objectives 2, 3 and 4 as outlined in the multistate research project. **Objective 2. To characterize and evaluate the impact of native and introduced agents.** Research continues to focus on native agents that attack insect pests, and describing aphid parasitism in agricultural landscapes. In 2020, submitted for publication results of a multi-year study to examine aphid parasitism in agricultural landscapes landscapes. Sentinel aphids were deployed and aphids and natural enemies were monitored in winter and summer crops. In addition, parasitoid exclusion cages were utilized to quantify parasitism rates. Results clearly indicated the re-emergence of a native parasitoid *Aphelinus nigritus*, primarily due to the presence of the invasive sugarcane aphid on sorghum. Completed and published studies related to the dynamics of sugarcane aphid on resistant plants provide the framework for future tri-trophic interaction studies. Studies were initiated to describe the latitudinal ecology of aphid parasitoids in the Southern Plains with an emphasis on describing competitive interactions, the role of symbionts, and how diapause may influence effective parasitism. **Key Outcomes:** Based on studies completed in Oklahoma, crop diversity that includes summer crops is more likely to support key parasitoid populations that prevent aphid outbreaks in winter crops. The native *Aphelinus nigritus* has re-emerged as an important aphid parasitoid in cereal crops, and there is no evidence that it enters diapause in the southern plains. **Objective 3: To develop augmentation and conservation biological control tactics, especially to improve the quality of agricultural habitats for pollinators.** Research is focusing primarily on conservation approaches. Studies describing pest suppression and conservation of natural enemies and pollinators in landscapes with winter canola were completed. **Key Outcome:** Crop diversity in time and space in agricultural landscapes has a positive effect on aphid suppression by parasitoids and diversity of pollinators. Management of pests in winter canola has short-term effects on honey bees and native pollinators. **Objective 4. To develop integrated pest management programs that have a biological control component.** Studies will evaluate interactions between wheat and sorghum germplasm that is resistant to aphids and effective parasitism in simple and diverse ecological settings. Recently, both aphid tolerant and resistant germplasm has been identified that will be moved into variety development pipelines and studies are planned to describe aphid / parasitoid dynamics on these germplasm sources. **Key Outcome.** Studies are just being initiated with the goal to incorporate expected aphid suppression by plant resistance and parasitism into pest management programs.

WORK PLANNED FOR NEXT YEAR (2021):

*Continued studies related to objectives 2, 3, and 4.

*Studies describing spatial and temporal patterns of aphid parasitism and pollinators in agriculture landscapes of the Southern Plains will continue. A new study will be initiated to document aphid parasitism in organic wheat systems with the specific goal to include parasitism level into management programs, similar to that utilized in conventional wheat systems.

*Studies investigating the interaction between host-plant resistance in winter wheat and aphid parasitism will be initiated.

PUBLICATIONS/PRESENTATIONS (2019/2020)

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Conference Papers & Presentations

Rudin, N. R., K. L. Giles, H. E. Butler and N. C. Elliott. The influence of temperature and photoperiod changes on the Nearctic cereal aphid parasitoid *Aphelinus nigritus* (Howard). Poster: Entomological Society of America. Online.

S-1073 ANNUAL REPORT FOR 2018 AND PLANS FOR 2019

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ACCOMPLISHMENTS

Objective 2. To characterize and evaluate the impact of native and introduced biocontrol agents

Juang Chong and Cory Tanner (PhD student) conducted an on-going study to document predator and parasitoid species of the muhly grass mealybug, *Stemmatomerinx acircula*, This is a new mealybug species (likely native to North America) on muhly grasses in South Carolina. To date, an egg predatory wasp have been collected but identification is on-going.

Objective 3. To develop integrated pest management programs that have a biological component

Juang Chong and Annie Borlik (MS student) have completed an evaluation of the compatibility of IRAC Group 9 insecticides (chordotonal organ TRPV channel modulators) with the minute pirate bug, *Orius insidiosus*, which is an important predators of thrips and other soft-bodied insects in the fields and greenhouses. Group 9 insecticides are being used by growers as replacements or alternatives to neonicotinoids. The insecticides tested include Endeavor (pymetrozine; IRAC Group 9A), Rycar (pyrifluquinazon; 9A) and Ventigra (afidopyropen; 9D). Safari (dinotefuran, a neonicotinoid; 4A) is the negative control and was extremely toxic to *Orius* in this study, causing 100% mortality within 3 hours of exposure in both direct contact and residual toxicity bioassays. Study results suggested that Group 9 insecticides are compatible with *Orius* (i.e. causing less than 25% mortality), except for Ventigra applied as immersion at high application rate. Group 9 insecticides also have minimal impacts on the fecundity and survival of *Orius*.

UTILITY OF FINDINGS

Muhly grass is prized as an ornamental plant, as well as of cultural and economic significance as the raw materials for sweetgrass baskets. Understanding the natural enemy complex of the muhly grass mealybug will allow researchers to develop integrated management plan for the invasive

mealybug species in order to protect the valuable muhly grass from this new pest. The study on the compatibility of Group 9 insecticides will allow growers to better develop an effective pest management plan that integrates chemical and biological control, making the use of Group 9 insecticides against sucking pests (such as whiteflies and aphids) and the biological control of thrips more effective.

WORK PLANNED FOR NEXT YEAR (2020)

Efforts will continue to collect and identify natural enemies of thrips, whiteflies and spider mites in the tomato and squash fields in South Carolina, North Carolina, Georgia and Florida (Objective 1). Project to document the diversity and impact of natural enemies of muhly grass mealybug will also continue (Objective 1). Manuscript reporting on the compatibility of Group 9 insecticides with minute pirate bugs (Objective 3) will be published. Additional studies will be conducted to determine the compatibility between pest-resistant tomato lines with pests and biological control agents, as well as compatibility of OMRI-listed insecticides with common biological control used in augmentation biological control programs in vegetable production (Objective 3 and 4).

PUBLICATIONS

Peer-reviewed article:
None.

Trade journal articles:
Chong, J. H. 2020. Soft scale crawlers, Bt and herbicide crop safety summaries. PestTalks 8 May 2020.

Chong, J. H. 2019. Nematodes vs flea beetles; Boxwod health workshop and hemp pesticides. 26 December 2019.

Chong, J. H. 2019. Sugarberry decline; Ventigra and downy mildew summaries; Mealybug management. 9 December 2019.

Chong, J. H. 2019. Tomato virus, hemp pesticides, biological control course and support FWMA. PestTalks 26 November 2019.

Chong, J. H. 2019. Crapemyrtle bark scale in SC; gloomy scale; drone for beneficials; wage and benefit surveys. PestTalks 23 September 2019.

IMPACT STATEMENT :

Vegetables and ornamental plants grown in fields, greenhouses and nurseries, as well as ornamental plants and grasses maintained in urban landscapes, are highly valuable to the economy and wellbeing of our citizens. But, these valuable plants are often attacked by a myriad

of insect and mite pests. These endemic and invasive pests have traditionally been managed through the frequent applications of insecticides, which resulted in reduced efficacy, pesticide resistance, and human and environmental risks. By integrating biological control within the larger framework of vegetable and ornamental plant management, we will be able to reduce pesticide application and the associated environmental, pest management and socioeconomic consequences. Research and extension activities conducted under this project result directly in achieving pest management goals while alleviating the associated problems. The multi-state survey of natural enemies of thrips, whiteflies and spider mites will inform organic vegetable growers in the southern US on the diversity of natural enemies occurring in their fields, as well as the impacts of these natural enemies. Muhly grass is prized as an ornamental plant, as well as of cultural and economic significance as the raw materials for sweetgrass baskets. Understanding the natural enemy complex of the muhly grass mealybug will allow researchers to develop integrated management plan for the invasive mealybug species in order to protect the valuable muhly grass from this new pest. The study on the compatibility of Group 9 insecticides will allow growers to better develop an effective pest management plan that integrates chemical and biological control. Through better understanding of the ecological relationship between pests and their natural enemies, and better utility of compatible insecticides, we will be able to develop integrated pest management programs that reduce pest damage, improve economic returns, and alleviate negative consequences of pest management activities.

S-1073 ANNUAL REPORT FOR 2019 AND PLANS FOR 2020

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ACCOMPLISHMENTS

1. To discover, assess, and release new biological control agents

2. To discover, assess, and release new biological control agents

Research continued to assess the natural enemy complex of crapemyrtle bark scale, a new invasive threat in Tennessee, to determine unoccupied niches as a target for biological control. Although collaboration has been established in a climate- matched area of China to search for natural enemies of crapemyrtle bark scale, this cooperative effort was suspended in 2020 due to Covid-19. Hopefully, this cooperative effort can be continued in the future.

The Lindsay Young Beneficial Insects Laboratory (LYBIL) at the University of Tennessee rears two predators of hemlock woolly adelgid (HWA): Laricobius nigrinus (introduced from the Pacific Northwest) and Laricobius osakensis (introduced from Japan). L. nigrinus has been reared here since 2005. L. osakensis was reared here in 2011, and from 2013 to present. A third predator, Sasajiscymnus tsugae, was reared here from 2003-2018; production ceased in 2019 to focus time and resources on rearing and releasing Laricobius. Substantial mortality of beetles in storage and oviposition jars earlier in 2019 affected ability to rear large numbers in 2019/2020. Beetles began emerging from soil boxes on August 12, 2019, with a total of 3,398 emerging by January 19, 2020. Releases, made from August 29, 2019 to December 18, 2020, are detailed below. As with L. nigrinus, the number of mature larvae produced earlier in 2019 was less than for previous years, due to substantial mortality in storage and oviposition jars. Resulting adults began emerging in the lab on August 27, 2019. A total of 3,337 had emerged by January 19, 2020. Beetle releases, made from September 26, 2019 to December 17, 2020, are detailed below.

Releases (location/numbers) of adult L. nigrinus in late 2019 and 2020 were: Great Smoky Mountains National Park, 535; Pickett State Forest, 53 (supplemental release); Hemlock Restoration Initiative lands (in NC), 883; Cumberland Gap National Historic Park, 587; and Catoosa Wildlife Management Area, 284 (supplemental releases). Releases (location/numbers) of adult L. osakensis were: Foothills Parkway, 128 (supplemental releases); Kentucky Division of Forestry lands, 948; Pickett State Forest, 363 (supplemental releases); and US Forest Service (NC), 831.

Purification of L. osakensis field-collected in Japan

In total, 143 L. osakensis were collected in northern Japan by Virginia Tech personnel and shipped to LYBIL on January 30, 2020 after held in quarantine in Blacksburg, VA for over 10 weeks. Beetles were separated into six lines and lines were reared separately to "purify" them of L. naganoensis, which is difficult to distinguish from L. osakensis morphologically.

Oviposition jars were established on January 30, 2020. The last jar was broken down on June 12, 2020. From February 24, 2020 to July 7, 2020, a total of 3,616 mature larvae were collected for all six lines. Adults began emerging on August 18, 2020. As of October 11,955 had emerged. All beetles dying during the oviposition period were stored separately in 95% ethanol for molecular analysis. The few surviving beetles at the end of the oviposition period were "euthanized" separately in 95% ethanol. Dead beetles were shipped to Virginia Tech where molecular analysis has, thus far,

not detected any L. naganoensis. Purified lines will be used for releases and rearing.

3. To characterize and evaluate the impact of native and introduced biocontrol agents

Hemlock Woolly Adelgid: A cooperative multi-state approach to assess establishment and impact of Laricobius nigrinus and Leucopis spp. on hemlock woolly adelgid in areas where they both have been released and recovered was initiated in late 2019. Initial populations of both predators were obtained from collections on hemlock in the northwestern U.S. and introduced to the eastern and southern U.S. States involved are MA, NC, TN and VA. One site (Cosby Site) in TN was used in the 2019- 2020 study. Data collected quantified predation of L. nigrinus and Leucopis spp. in a field setting across a wide geographical area. Data were shared with other cooperators. Results documented predation by L. nigrinus and provided additional support that this species can significantly impact HWA. Results also demonstrated that Leucopis spp. can survive, develop, and reproduce at least through one generation in this area. Leucopis spp. are compatible with Laricobius nigrinus in a biological control program against hemlock woolly adelgid in this region. Research continues to assess establishment of three parasitoids of emerald ash borer. Extremely low numbers of two parasitoids have been recovered in past years, suggesting that their establishment in the southern U.S. may be difficult due to asynchrony of adult parasitoids with larvae of emerald ash borer. Pan trap collections yielded potential recoveries of two of these introduced parasitoids in 2020. Species confirmation will be determined by expert taxonomists. The released egg parasitoid has not been recovered. Kudzu Bug (Megacopta cribraria): A two-year research project was initiated in late 2019 to determine temporal and seasonal presence of Beavueria bassiana in kudzu, in kudzu bug on kudzu, and in soil around kudzu. This fungal pathogen is an important mortality factor of kudzu bug, and little is known about ecological interactions among the host plant, the fungus, and the insect. This research has demonstrated that B. bassiana: 1) is present in kudzu bugs as early as June, 2) does not colonize kudzu until July, and 3)

4. To develop integrated pest management programs that have a biological control component

Impact of Dual-Use Cover Cropping on Beneficial Insects - A two-year study examined impact of a dual-use cropping system on pest and beneficial insects to enable growers to better manage pests in soybean. Cover crop species, such as crimson clover and woollypod vetch, with more biomass tended to have more arthropods (pest and beneficial). Cover crop species impacted arthropod community composition prior to soybean planting. However, no significant differences in pest or beneficial arthropod densities were observed among cover crop species after soybean planting. Results suggest that dual cropping did not serve as a reservoir for pests to move into soybean, but it did tend to preserve beneficial insects. No significant differences in average number of pest or beneficial arthropods were found between cover crop management practices. Results will enable soybean growers to make more informed decisions when choosing cover crops and planting methods.

What opportunities for training and professional development has the project provided?

(Opportunities were limited in 2020 due to Covid-19)

Provided opportunity to attend and participate in the 2019 Entomological Society of America National Meeting and become familiar with many new biological control activities taking place nationally, November 17-20, 2019, St. Louis, MO.

Provided opportunity to attend and participate in the USDA Interagency Forum on Invasive Species held 15-17 January 2020 in Annapolis, MD.

Provided opportunity to participate in the Virtual Annual Meeting of S1073 which was held 29 September 2020.

Provided opportunity to participate in the Tennessee Entomological Society Annual Meeting which was held virtually on 9 October 2020.

How have the results been disseminated to communities of interest?

Bechtel, D., J. Grant, G. Wiggins, B. Nichols, and J. Webster. 2020. Pollinators of rhododendron in hemlock-dominated forests. Southern Appalachian Forest Entomologists and Pathologists Seminar, March 5-6, 2020, Crossnore, NC. Cornish, A., J. Grant, F. Hale, D. Paulsen, and P. Lambdin. 2020. Crapemyrtle bark scale, Acanthococcus (= Eriococcus) lagerstroemiae (Kuwana), in Tennessee: distribution, life cycle, and natural enemies. Tennessee Entomological Society Annual Meeting (Virtual) (October 9, 2020).
Grant, J. F., and A. Michael. 2019. Natural Enemies: ENDGAME for kudzu bug, Megacopta cribraria. Entomological Society of America National Meeting, November 17-20, 2019, St. Louis, MO (poster)
Grant, J. F. 2019. Leaves of change: Invasive threats to Tennessee Forests. University of Tennessee Arboretum Society, Oak Ridge, TN, October 15, 2019, **INVITED PRESENTATION** (Keynote Speaker)
Hollabaugh, K., J. Grant, A. Michael, and W. Liang. 2020. Natural enemy targets invasive kudzu bug: where does the enemy originate? Tennessee Entomological Society Annual Meeting (Virtual), October 9, 2020).
Longmire, M., J. Grant, S. Stewart, and V. Sykes. 2020. The more crops the merrier: Impact of dual-use cover cropping on pest and beneficial arthropods in soybean in Tennessee. Tennessee Entomological Society Annual Meeting (Virtual), October 9, 2020).
Longmire, M., J. F. Grant, S. D. Stewart, and V. Sykes. 2019. Dual-cropping soybean systems: Impacts on pest and beneficial arthropods in Tennessee. Entomological Society of America National Meeting, November 17-20, 2019, St. Louis, MO (10- minute oral presentation)
Longmire, M., J. F. Grant, S. D. Stewart, and V. Sykes. 2019. Bugs and slugs: The thugs of soybean communities. Entomological Society of America National Meeting, November 17-20, 2019, St. Louis, MO (poster)

What do you plan to do during the next reporting period to accomplish the goals?

Hemlock woolly adelgid - continue to rear, release and evaluate biological control agents of hemlock woolly adelgid in forested systems; continue to assess establishment of introduced biological control agents; participate in multi-state project to assess impact of two introduced predators (Laricobius nigrinus and Leucopis sp.) on hemlock health as a result of reductions of hemlock woolly adelgid populations. Emerald ash borer - continue to assess establishment of introduced species of emerald ash borer using yellow pan trap sampling; an Emerald Ash Borer Aftermath Study has been established to determine if tree regrowth and reestablishment coincide with successful establishment of introduced parasitoids of emerald ash borer in the southern U.S. Kudzu bug - research will continue to evaluate the ecological interactions of kudzu, kudzu bug, soybean, and a fungal pathogen (Beauveria bassiana) to better understand disease epidemiology and to enhance management of kudzu bug. Crapemyrtle bark scale - Research continues to assess the distribution, seasonality, and lifecycle of crapemyrtle bark scale and assess the role of biological control agents in reducing its populations; efforts will be made to identify niches that provide potential for introduction of non-native biological control agents. Impact of Dual-Use Cover Cropping on Beneficial Insects - This research is completed; data will be thoroughly analyzed and research publications will be developed and submitted for publication.