CRAPEMYRTLE BARK SCALE *ACANTHOCOCCUS LAGERSTROEMIAE* KUWANA (HEMIPTERA: ERIOCOCCIDAE): ANALYSIS OF FACTORS INFLUENCING INFESTATION AND CONTROL

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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December 2020

Major Subject: Entomology

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ABSTRACT

Crapemyrtle bark scale, *Acanthococcus lagerstroemiae* (Kuwana), a new non-native pest from Asia first discovered in the U.S. in 2004 has now been reported in 14 states. The scale jeopardizes the future of crapemyrtles use as a popular ornamental landscape tree in the U.S. Management of this pest will likely include biological strategies. Before such strategies can be implemented it is important to examine relative abundances and distributions of arthropod species associated with the scale in the geographic area targeted for biological control. In the first objective, surveys of crapemyrtle ecology from two varietal groups of crapemyrtle trees (*Lagerstroemia* spp.) were undertaken in Tarrant and Brazos counties across six consecutive seasons in 2018 – 2019. A rich arthropod community was discovered. The most common predators were spiders, coccinellids, and chrysopids. Insects in the families Eriococcidae, Aphididae, and Thripidae were common herbivores on *Lagerstroemia* spp. Numerous phytophagous and mycophagous mites were also collected. These herbivores constitute a reservoir of alternative prey for generalist predators that may also feed on *A. lagerstroemiae*. A food web was constructed to illustrate direct and indirect effects of the predator community on *A. lagerstroemiae* in Texas. This approach should identify available niches whereby the release of natural enemies not occurring in Texas could lead to effective and sustainable biological control. In the second objective habitat variables associated with crapemyrtles, *Lagerstroemia* spp. were characterized. Data were analyzed using principal component analysis to create a reduced set of independent variables. The principal components were then included in a least squares stepwise multiple progression procedure to test for the influence of landscape composition on scale and select associated arthropod populations. Though some variables were statistically significant ($p<0.05$), no models had an adjusted R^2 value greater than 0.10. In these minimal input landscapes where trees, turf, and hardscape represent the dominant habitat variables, landscape variables were not a strong predictor of *A. lagerstroemiae* populations or *A. lagerstroemiae* natural enemy populations, suggesting that manipulation of these parameters will have minimal effects on the abundances and distributions of these species.

DEDICATION

Dedicated to my parents and the friends I made in College Station, Texas.

ACKNOWLEDGEMENTS

I would like to thank College Station Parks and Recreation, The Texas Department of Transportation, Resource Connection of Tarrant County, Laura Miller of Texas A&M AgriLife Extension, the city of Saginaw, Texas, and Eagle Mountain-Saginaw ISD facilitated the sampling of crapemyrtles. Technical assistance was provided by John and Patricia Gilder, Janaina Siqueira Da Cunha, Jose G. Juarez, Silvana Caravantes, Patricia Ishii, Kenneth Masloski, Bala Sapkota, Dr. Steve Arthurs, and Pete Krauter. Dr. James B. Woolley, Department of Entomology at Texas A&M University, provided taxonomic expertise in the identification of specimens.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a thesis committee consisting of professor and major advisor Kevin M. Heinz of the Department of Entomology and Mengmeng Gu and Mike Merchant of theTexas A&M AgriLife Extension Eervice.

Funding Sources

Graduate study was supported by a research assistantship from Texas A&M University and teaching assistantships from Texas A&M University.

This work was also made possible in part by the USDA-NIFA-SCRI-006175 grant titled “Systematic Strategies to Manage Crapemyrtle Bark Scale, An Emerging Exotic Pest.” This work’s contents are solely the responsibility of the author and do not necessarily represent the official views of the USDA.

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1. INTRODUCTION

1.1. Introduction

Crapemyrtle bark scale, *Acanthococcus lagerstroemiae* (Kuwana) (Order: Hemiptera; Family: Eriococcidae), is a pest of crapemyrtles *Lagerstroemia* spp. from East Asia (Wang et al. 2016). It was first discovered in the United States in 2004, and has now been reported in 13 other states (EDDMaps 2020). It is a threat to crapemyrtles and the crapemyrtle industry in the United States. The wholesale value of *Lagerstroemia* spp in the U.S. is $66 million dollars (USDA 2014). As an ornamental tree the value of *Lagerstroemia* spp. is intrinsically tied to its appearance. Damage caused by the scale includes branch dieback, reduced growth and black sooty mold which grows on the honeydew secreted by the scale. Heavy infestations may blacken leaves and bark. These effects reduce the aesthetic value of the tree and may discourage consumers from purchasing *Lagerstroemia* spp. trees in the future (Wang et al. 2016).

Acanthococcus lagerstroemiae begin life as pink-colored eggs, 0.35 mm long. Eggs are laid inside the waxy felt-like covering, or test, of the adult female scale (Jiang1998, Wang 2016). After eclosion, the mobile first instar scales disperse and settle on woody parts of the plant. After each instar the female nymphs have a mobile stage until adulthood. Female scales undergo two nymphal instars and have a mobile stage after each molt (Stehr 1991). Female nymphs and female adults secrete honeydew as a result of feeding. Unlike females, after the first instar males undergo a pre-pupal then a pupal stage before emerging as winged non-feeding adults.

Research from comparable latitudes and climates in China indicates the scale has 3 generations per year in cooler climates (USDA plant hardiness zone 8) and three to four in warmer climates (USDA plant hardiness zones 9 and 10) (Gu et al. 2010). Current knowledge of *A. lagerstroemiae*'s dispersal methods are sparse. Insects in the superfamily Coccoidea such as *Icerya seychellarum* (Westwood), *Dactylopius austrinus* (De Lotto), and *Pseudococcus longispinus* (Targioni-Tozzetti) use aeolian, or wind dispersal, to colonize new sites (Barras et al. 1994, Hill 1980, Mow et al. 1982). However, species that use aeolian dispersal often have long filaments to better catch the wind, a feature *A. lagerstroemiae* crawlers lack.

Another potential dispersal method is phoretic dispersal. Laboratory experiments demonstrated the ability of armored scales, *Aspidiotus nerii* (Bouché) to cling to ants, flies and ladybeetles for extended periods of time (Magsig-Castillo et al., 2010). Larger animals, such as birds and mammals, are also possible means of transport for some scale insects (Greathead 1997). Over long distances human activities and transport likely play a role. The scales' presence in disparate urban and suburban areas, and across arid regions such as West Texas and New Mexico, supports this.

The research done in this thesis is intended to discover interactions between *A. lagerstroemiae,* the landscape surrounding *Lagerstroemia* spp., and arthropod natural enemies present in the environment. Ecological studies of a pest species and its natural enemies are used as first step in the development of integrated pest management strategies (Walter 2003). Natural enemies present in the environment may negatively impact *A. lagerstroemiae;* however, they cannot currently prevent the pest from causing aesthetic damage to *Lagerstroemia* spp. (Wang et al. 2016). As this pest was only recently discovered, little is known about the factors influencing its abundance and distribution.

Two studies are presented in this thesis: 1) factors affecting *A. lagerstroemiae* natural enemy populations located in Brazos County and Tarrant County were analyzed using principal component analysis followed by multiple regression similar to studies done in the past such as Brazzle, et al., 1997. Seasonal sampling and the use of two geographic locations permitted examination of these two sources of variation on the abundance and distribution of the populations. Landscape structure and its impact on A. lagerstroemiae numbers as well as natural enemy numbers were included in these analyses. 2) The *Lagerstroemia* spp. sampling from the first study generated a seasonal arthropod inventory associated with *Lagerstroemia* spp. Using this arthropod survey data and information gathered from existing literature a food web with special focus on *A. lagerstroemiae* was constructed. This research is intended to provide essential information prior to the implementation of large-scale control methods. It is hoped this research will provide a foundation for further experiments and studies, particularly the research and design of an importation biological control program, focusing on the control of *A. lagerstroemiae*.

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2. INVENTORY AND FOOD WEB OF ARTHROPOD FAUNA ASSOCIATED WITH *LAGERSTROEMIA* SPP. (MYRTALES: LYTHRACEAE) IN TEXAS

2.1. Introduction

Since 2004, the non-native crapemyrtle bark scale *Acanthococcus lagerstroemiae* (Kuwana) (Hemiptera: Eriococcidae) has become widely distributed in the Southern U.S. (EDDmaps 2020). While it is commonly found on crapemyrtles, *Lagerstroemia indica* (L.) (Myrtales: Lythraceae), *L. fauriei* (Koehne), and their hybrids *L. indica* x *fauriei, A. lagerstroemiae* can also infest native plants such as American beautyberry, *Callicarpa Americana* L. (Xie 2020). Control of *A*. *lagerstroemiae* is important to nurserymen, landscape professionals, garden centers and property owners. *Lagerstroemia* spp. have an annual wholesale value of $67 million dollars in the United States (USDA, 2014) and are widely used in southern U.S. landscapes for their attractive blooms and relative lack of diseases and pests (Chappell et al. 2012, Pooler 2007). Damage caused by the scale is largely aesthetic due to the accumulation sooty mold and presence of scales, but may include branch dieback, reduced flower size and number, and reduced growth (Chappell et al. 2012, Ma 2011, Wang, et al. 2016)

Wang et al. (2016) studied the phenology of the pest and noted five Coleoptera species associated with *A. lagerstroemiae* in Texas and Louisiana:

Chilocorus cacti (L.) (Coleoptera: Coccinellidae), *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae), *Hyperaspis bigeminata* (Randall) (Coleoptera: Coccinellidae), *Hyperaspis lateralis* Mulsant (Coleoptera: Coccinellidae), and *Cybocephalus nipponicus* Endrödy-Younga (Coleoptera: Cybocephalidae). Documentation of the abundance and distribution of this pest species and its natural enemies is an essential first step in the development of integrated pest management strategies (Walter 2003).

To fulfill this essential first step, this study has two objectives. Objective 1 is the characterization of arthropod communities associated with *Lagerstroemia* spp. in two Texas counties, Brazos and Tarrant. *Acanthococcus lagerstroemiae*, was first discovered in Richardson, Texas (75 km from the center of Tarrant county) in 2004. *A. lagerstroemiae's* geographic spread through Texas encompasses a variety of ecosystems that include woodlands, prairies, plateaus, and savannahs (EDDmaps 2020; Gould et al, 1960). This landscape diversity provides an excellent background to catalog the diversity of *A. lagerstroemiae's* natural enemies from geographically distinct locales. Sampling was conducted in multiple seasons to assess the occurrence and magnitude of season-specific variation in *A. lagerstroemiae* and natural enemy populations. Seasonal changes can be a major factor in the application of biological control programs (Georgis and Gaugler 1991, Murphy et al. 1998, Thorbek et al. 2004). Samples were divided by *Lagerstroemia* spp. cultivar to determine if cultivar affected arthropod numbers.

In objective 2, a food web was constructed as a means of formulating preliminary hypotheses for interspecific interactions within the arthropod community. Food webs function as maps describing interspecific relationships among organisms within a community (Pimm et al. 1991). This food web highlights interactions in the *Lagerstroemia* spp. ecosystem that could potentially be encouraged via future conservation or augmentation biological control programs. The food web also serves as a resource for future classical biological control programs. For example, arthropod predators such as coccinellids and chrysopids may be obstacles to any parasitoid species introduced as a control measure (Chacón et al. 2008). Furthermore, food webs can provide insight into indirect effects of species in an ecosystem. For example, herbivores are the most common constituents in an ecosystem and may trigger plant defenses by their presence (Ohgushi 2008.) The presence of one predator may cause behavioral changes in another predator that adversely affect their pest control effectiveness (Moran and Hurd 1994). Forecasting the effects of introduced biological control agents is integral to any classical biological control program.

2.2. Materials and Methods

2.2.1. Objective 1

Arthropod sampling was performed in the spring, summer and fall of 2018 and the winter, spring, and summer of 2019 in Tarrant and Brazos counties

Texas. Tarrant county (32°46'12.00" N -97°17'24.00" W) is 160 kilometers northwest of Brazos county (0°39'36.00" N -96°17'60.00" W). Sampling was conducted in multiple seasons to assess the occurrence and magnitude of season-specific variation in *A. lagerstroemiae* and natural enemy populations. Seasonal changes can be a major factor in the application of biological control programs (Georgis and Gaugler 1991, Murphy et al. 1998, Thorbek et al. 2004). Sites within counties were chosen based on *Lagerstroemia* spp. accessibility, but also where there is likely to be minimal cultural inputs such as chemical application, irrigation, fertilization, and pruning. Samples were taken across fourteen sites in Brazos County and across twelve sites in Tarrant County from *Lagerstroemia* spp. along roadways, parks, schools government buildings and around the landscaping of businesses such as hotels and hospitals. Sites are defined here as locations (ex., Wolf Pen Creek Park in Brazos County) where multiple *Lagerstroemia* spp. exist in close proximity to each other and share a common landscaping maintenance regime. All *Lagerstroemia* spp. within a site likely experience the same landscaping care (e.g., fertilizer application, watering, pesticide application, mowing, and pruning). Distance between sites within counties ranged from 1-14 km.

Trees used in this test were characterized as either ‘Natchez’ cultivar or ‘non-Natchez.’ Every season within each county samples were collected from 40 trees belonging to the ‘Natchez’ cultivar and 60 trees from a mix of non-‘Natchez’ cultivars. The cultivars in the non- ‘Natchez’ group were not identified to cultivar. A comparison of the samples collected from these two cultivar groups can provide a preliminary suggestion as to whether there exist cultivar-specific differences in *A. lagerstroemiae* infestations and their associated natural enemies. There is some evidence in the literature that crapemyrtle aphids, *Sarucallis kahawaluokalani* (Kirkaldy) (Hemiptera: Aphididae), may have cultivar preferences, but similar studies have not been published for *A. lagerstromia*e (Herbert 2009, Mizell and Knox 1993). Pettis et. al (2004) found that *L. indica x fauriei* hybrid cultivars had reduced damage from flea beetles and Japanese beetles. However, they found mixed results with the hybrids against crapemyrtle aphids, though the hybrid cultivars 'Miami', 'Natchez', 'Pecos', 'Sioux' and 'Tuskegee' performed relatively well. Past studies have revealed cultivar preferences in other hemipteran and ornamental plant interactions such as pseudococcids, aleyrodids, and tingids (Avery 2015, Kirker 2008, Vitullo 2009). In order to obtain reliable data about *A. lagerstroemiae* and its natural enemies, preliminary data were collected to determine appropriate sample sized based mean/variance relationships of *A. lagerstroemiae* numbers within and between trees. Ten 30 cm branches each were taken from 40 trees. At 40 trees, the change in standard error was less than .005 for each additional tree included in the sample. Similar results were seen when standard error was taken between branches within the same tree. In order to avoid excessive damage to trees that would affect their health and skew data, only ten branches were collected per tree. Trees were used as the sample unit with branches as the sub-sample.

Trees ranged in height from 3 m to 5 m. Trees were sampled between 06:00:00 and 12:00:00 Central Standard Time (CST). The 30 cm branches were collected using a telescoping 2.7-meter pruner. Upon clipping, samples were placed immediately into Sure Fresh® rectangular deep storage containers, 10 cm x 35 cm (Greenbrier International, Inc., 1509 Sam's Circle Store No 502 Chesapeake, VA 23320-4694 United States, www.dollartree.com, SKU: 236854). Each tree in the study was assigned a unique number and its GPS coordinates were collected using a cellphone application, (GPS Status & Toolbox Pro version 9.0.183 2019) for purposes of repeated sampling over the course of the study.

After all clippings were taken for the day, samples were returned to the lab where the contents were shaken and then opened. All free-living arthropods found were collected with an aspirator and placed in vials of 70% ethyl alcohol with collection labels. With the aid of a stereo microscope (Olympus SZ60, Tokyo, Japan) zoom range 10× – 63×, the organisms were counted and identified to the lowest taxon possible. Next, branches were examined with the same microscopes, and, with the exception of eggs, all living *A. lagerstroemiae* counted. In Tarrant County, where these microscopes were not available, illuminated 30× magnifying glasses were used (Ylanfer 30x Handheld Lighted Magnifier, Extra Large Double Glass Lens Magnifying Glass With 12 LED Lights, Shenzhen, China). Branches with scales were then placed in sealed white paper bags (Uline white grocery bags, uline.com model no. S-11541, 19.685 cm ×

12.065 cm × 40.64 cm) labeled by date and tree number to allow for parasitoid emergence. After three months, bags were opened and their contents shaken into petri dishes containing 70% ethyl alcohol. Contents of petri dishes were examined under a stereo microscope, (10× – 63×). All arthropods found were counted, identified to the lowest taxon possible, and placed in vials of 70% alcohol with a label indicating the date they were collected, when they were bagged, when they were un-bagged, and what tree they were collected from. Voucher specimens from all samples were placed in the TAMU insect collection.

For purposes of the survey and table, arthropods collected were classified to family level with some notable exceptions. Oribatids and psocids were left at the order level. Many specimens in these orders were collected in immature life stages and could not be reliably identified to family. Coccinellids were identified and reported to species to distinguish scale specialists and generalist predators.

Taxonomic diversity within arthropod collections for each location, season and cultivar was characterized using the Shannon Diversity Index defined as $H = -\sum P_i \ln(P_i)$ where P_i is the proportion of individuals found in species i (Shannon 1948). Shannon's index is a descriptive statistic used to characterize the diversity of species within a community while accounting for both the number of species present (or richness) and their relative abundance (or evenness). It has also been used in studies to effectively characterize higher taxonomic level diversity (Gao et a. 2013, Gesteira et al. 2003, Hoback et al. 1999). The

Shannon index increases as both the richness and the evenness of the community increase. Values range from 0 to 5, usually ranging from 1.5 to 3.5.

For the purposes of the Shannon index calculations all arthropods were grouped by family in an attempt to reach a common taxonomic level for the sake of comparison. The family level was chosen because that was considered the most specific common level possible due to the numbers of immature arthropods collected. Despite this, as noted previously, the insect order Psocodea and the mite order Oribatida were left at the order level. During a preliminary inspection of our analysis it was noted that Shannon index values across all locations, seasons, and cultivars exhibited a low coefficient of variation of 0.407; thereby, allowing the use of this statistic to compare the richness and evenness among communities. A very high coefficient of variation might indicate communities are not comparable. When considering statistical approaches to analyzing the data, a three-way ANOVA was dismissed because the data did not meet the necessary assumptions associated with parametric statistical approaches. The number of zeroes and outliers in the collection data also precluded many other non-parametric methods of analyses. Therefore, we used observational approaches when presenting data in an attempt to determine the effects of our class variables (locality, season, and cultivar) on our response variables (the occurrence and abundance of arthropod species). This approach is appropriate to this kind of foundational study where it was difficult to randomly assign the species groups to experimental groups (Pearl 2009). We overcame this possible shortfall by using large sample sizes (the number of trees) associated with each class variable. It is also recognized that this approach cannot ensure independence among all variables which may create a problem of unintentional correlations among variables (Pearl 2009). To address this issue, we are cautious in the conclusions we attempt to draw from our observational analyses.

2.2.2. Objective 2

Using data collected in objective one and from a literature review. a food web was constructed. Since there appeared to be no difference in the most common arthropods among seasons, locations, or cultivars; one food web was made. Linkages in food webs are often derived on gut content analysis with gene amplification methods (Etzinger et al. 2013, Staudacher et al. 2016). These methods rely on the availability of primers keyed to specific insect species which are currently not available for this system. As a result, we used the literature to identify arthropod interactions, especially records of predator/prey interactions among arthropods collected. The food web design follows a rough layout used by Hudson et al. (2013) in the Cheddar R package.

2.3. Results

2.3.1. Objective 1

2.3.1.1. General

Over the course of this study 10,605 living specimens of *A. lagerstroemiae* were collected (Tables 2.1 and 2.2). They were the most common herbivores found on *Lagerstroemia* spp. and were collected from both localities, in every season, and every cultivar group. They were recovered from 59.75% of trees sampled (n= 1,200 trees). Because we observed a high variance in species counts among samples, we chose not to present mean census values in Tables 1 and 2; rather we presented the actual census values as well as the number of trees a taxon was collected from (in parentheses). An analysis revealed that in seasons when *A. lagerstroemiae* was most plentiful (spring and summer) variance was high, and measures of central tendency were could be misleading. In Brazos County, spring 2018, the average number of *A. lagerstroemiae* per tree was 3.15 (n=100 trees) with a variance of 19.4, and a range of 28. However, in Brazos County in the summer. In summer 2018 in Brazos County, when *A. lagerstroemiae* was most common, the average number of *A. lagerstroemiae* per tree was 40.32 (n=100 trees) with a variance of 5,060, and a range of 433. Other taxa were less consistently present on *Lagerstroemia* spp. This inconsistency can be seen in insect families such as Mantidae: A single mantid egg sac on a single branch in Brazos County hatched into 69 immature mantids (Table 2.1). However only a single adult mantid was collected across all seasons in Brazos County.

The most commonly collected predators were Araneae, which, as a group were also collected from both localities, in every season, and every cultivar group. The most commonly collected coccinellid species regardless of location or season was *C. cacti*. This coccinellid is a scale specialist, and has been found in association with *A. lagerstroemiae* in Louisiana, and Texas (Hicks et al. 2019, Wang 2016). The most commonly collected insect predators included anthocorids, chrysopids, and coccinellids. Anthocorids and larval chrysopids are generally thought of as generalist predators (Barber 1956, Coll and Ridgway 1995, Funderberk et al. 2000, Harwood et al. 2007, McCaffery and Horsburgh 1986, Miller et al. 2004).

A number of non-native species were collected over the course of this study. The most common were the herbivores *A. lagerstroemiae* and *S. kahawaluokalani* (crapemyrtle aphid). Non-native predators included *H. axyridis* and *Coccinella septempunctata* (L.). Non-native ants included *Solenopsis invicta* Buren, *Paratrechina longicornis* (Latreile), and ants in the genus *Brachymyrmex.* Despite the presence of non-native predators, most arthropod predators in any particular family were native.

Other common herbivorous arthropods included thrips in the family Thripidae and bark lice, Psocomorpha. Five families of Psocomorpha were identified from adult specimens: Caeciliusidae, Ectopsocidae, Lachesillidae, Psocidae, and Stenpsocidae. It should be noted that Liposcelididae numbers were separated from other Psocodea because Liposcelididae were found to be colonizing and reproducing in the bags employed for parasitoid emergence in storage, and therefore Liposcelididae numbers do not reflect field samples. Herbivorous mites were also very common, especially beetle mites, Oribatida, and mycophagous mites in the family Tydeiidae. The mistletoe weevil, *Pandeletius lineurus* in the family Curculionidae, and mycophagous beetles in the family Latridiidae were the most common Coleoptera collected other than beetles in the family Coccinellidae.

The most common parasitoid wasps collected were in the egg parasitoid family Platygastridae. Specimens were traced back to eggs of Pentatomidae, Coreidae, and Reduviidae. Wasps in the family Mymaridae were traced back to Cicadellidae. Pteromalidae in the genus *Pachyneuron* were recovered from syrphid pupae. In Spring 2018, the parasitoid *Marlatiella prima* Howard (Hymenoptera: Aphelinidae) emerged from Japanese maple scale, *Lopholeucaspis japonica* Cockerell (Hemiptera: Diaspididae) occurring on *Lagerstroemia* spp. foliage samples taken from foliage in Brazos County, Texas. These occurrences represent new Texas state record for *Lopholeucaspis japonica* Cockerell and *Marlatiella prima* Howard (Gilder et al. 2020).

A number of other parasitoid wasp species in various families were collected in small numbers, but with the aid of Dr. Woolley were ruled out as *A.*

lagerstroemiae parasitoids. No *A. lagerstroemiae* parasitoids were discovered during this intensive survey.

2.3.1.2. Locality

In total, 6,916 living *A. lagerstroemiae* were collected from trees in Brazos County and 3,689 living *A. lagerstroemiae* were collected in Tarrant County. In Brazos County they were recovered from 73.5% (n=600) of samples. In Tarrant County, they were recovered from 46.0% (n=600) of samples. The scale specialist *C. cacti* was also collected year-round in both locations. Generalist coccinellid species such as *Harmonia axyridis*, *Olla v-nigrum, Coccinella septempunctata,* and various species in the genus *Scymnus* were more common in Tarrant County than in Brazos County. This was also true of anthocorids (196: Tarrant vs. 52: Brazos), and for chrysopids (112: Tarrant vs. 77: Brazos).

In terms of other herbivore families present, and by extension alternative prey for generalist predators, Tarrant County also had considerably greater numbers of thrips and aphids: 4,582 versus 474 aphids, and 1,860 versus 658 thrips. However, fewer non-predatory mites, oribatids and tydeiids, were collected in Tarrant County than in Brazos County. Conversely, more predatory mites were collected in Tarrant county including a family not present in Brazos at all. This family, Camerobiidae, are predators of small mites and insects all over the world (Bolland and Mehrnejad 2001).

2.3.1.3. Season

In this study, living *A. lagerstroemiae* were collected through all seasons (Tables 2.1, 2.2). As reported by Vafaie et al. 2020 and Wang et al. (2019), much higher numbers of *A. lagerstroemiae* were collected in spring and summer. Like *A. lagerstroemiae,* its predator *C. cacti* was also collected year-round with larvae most commonly collected in the spring and summer months. The numbers of *A. lagerstroemiae* were the highest in the spring, with the exception of Tarrant County in 2019 when CMBS numbers were the highest in the summer. In Spring 2018 *A. lagerstroemiae* was collected in 44.0% of samples (n=200), and in Summer 2018, 56.5% of samples (n=200).

Acanthococcus lagerstroemiae natural enemy numbers were also highest in the spring, but again, Tarrant County was an exception in 2019 when scale predator numbers were highest in the summer. Generalist predators in the family Anthocoridae were more common in the spring and summer months and were most common when thrips populations were highest. thrips and anthocorids were more abundant in the 2018 spring and summer than in the 2019 spring and summer. In Brazos County diversity, measured by H’, was highest in the spring and fall. In Tarrant County the same was true except in Spring 2019 when diversity was much lower than it had been in spring 2018.

2.3.1.4. Cultivar

Cultivar differences in the abundance of *A. lagerstroemiae* were location-dependent. In Tarrant County A. lagerstroemia was recovered from only 35.8% of ‘Natchez’ samples (n= 240). In Brazos it was recovered from 74.6% of ‘Natchez’ samples (n= 240). Scale population numbers on other cultivars appears less location dependent; *A. lagerstroemiae* was recovered from 72.8% of non- ‘Natchez’ samples in Brazos (n= 360), and 57.8% of non- ‘Natchez’ samples in Tarrant (n=360). As a reminder, in each season 40 ‘Natchez’ trees were sampled in each county and 60 trees from other *Lagerstroemia* spp. cultivars.

Table 2.1 Total numbers of arthropods collected per season on *Lagerstroemia* spp. in Brazos County, TX. 2018-2019. Seasonal collections are divided into a column for the 'Natchez' cultivar (n= 40 each season) and a column for all other cultivars (n= 60 each season). The number of trees that a taxon was collected from is in parentheses. Orders are in bold. Suborders are underlined in the case of the hemipterans. For the Shannon Diversity Index all coccinellids were lumped as Coccinellidae.

Brazos		**Insecta**	*Acanthococcus*		
Spring 2018	Natchez		146(31)		
	Other		167(47)		
Summer 2018	Natchez		1489(35)		
	Other		2597(60)		
Fall 2018	Natchez		424(24)		
	Other		159(36)		
Winter 2019	Natchez		332(28)		
	Other		267(47)		
Spring 2019	Natchez		201(33)		
	Other		134(34)		
Summer 2019	Natchez		646(28)		
	Other		354(38)		

Table 2.1 (continued).

Brazos		**Coleoptera**	Coccinellidae	*Axion plagiatum*	*Chilocorus cacti*	*Chilocorus stigma*
Spring 2018	Natchez			3(3)	5(3)	
	Other			4(4)	7(6)	2(2)
Summer 2018	Natchez				3(3)	
	Other			1(1)	26(17)	
Fall 2018	Natchez			2(2)	3(2)	
	Other				10(6)	
Winter 2019	Natchez					
	Other				1(1)	
Spring 2019	Natchez			1(1)	8(5)	
	Other				14(12)	
Summer 2019	Natchez				1(1)	
	Other				5(5)	

Table 2.1 (continued).

Brazos		*Coccinella septempunctat*	*Cycloneda munda*	*Exochomus marginipennis*	*Harmonia axyridis*	*Hippodamia convergens*
Spring 2018	Natchez					
	Other	5(5)	4(4)	2(2)	2(2)	1(1)
Summer 2018	Natchez	1(1)				
	Other			3(2)	3(2)	
Fall 2018	Natchez					
	Other				4(4)	
Winter 2019	Natchez					
	Other					
Spring 2019	Natchez	1(1)		2(2)	1(1)	
	Other				5(5)	
Summer 2019	Natchez					
	Other					

Table 2.1 (continued).

Brazos		*Hyperaspis bigeminata*	*Hyperaspis lateralis*	*Nephus flavifrons*	*Olla v-nigrum*	*Scymnus loewii*
Spring 2018	Natchez					
	Other	1(1)	1(1)		4(3)	1(1)
Summer 2018	Natchez		1(1)	3(2)		
	Other					1(1)
Fall 2018	Natchez					
	Other					
Winter 2019	Natchez					
	Other	1(1)				
Spring 2019	Natchez				2(2)	
	Other		1(1)			2(2)
Summer 2019	Natchez			1(1)		
	Other	2(2)		2(2)		

Table 2.1 (continued).

Brazos		*Scymnus* sp.		Bostrichidae	Buprestidae	Curculionidae
Spring 2018	Natchez					21(8)
	Other					
Summer 2018	Natchez	1(1)				16(6)
	Other					1(1)
Fall 2018	Natchez					15(10)
	Other					6(5)
Winter 2019	Natchez					1(1)
	Other					1(1)
Spring 2019	Natchez	1(1)				5(3)
	Other	2(2)				
Summer 2019	Natchez					3(2)
	Other			1(1)	1(1)	4(3)

Table 2.1 (continued).

Brazos	**Spring 2018**		**Summer 2018**		**Fall 2018**		**Winter 2019**		**Spring 2019**		**Summer 2019**	
	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other
Latridiidae	1(1)		6(5)	16(8)	1(1)	5(3)			2(2)	3(3)		
Chrysomelidae	4(4)	5(5)							2(2)	1(1)	1(1)	
Anthicidae												
Diptera												

Table 2.1 (continued).

Hemiptera		Syrphidae	Milichiidae	Chironomidae		**Brazos**
			1(1)		Natchez	**Spring 2018**
				3(3)	Other	
			1(1)	1(1)	Natchez	**Summer 2018**
			1(1)	1(1)	Other	
				2(2)	Natchez	**Fall 2018**
		1(1)	1(1)	1(1)	Other	
				1(1)	Natchez	**Winter 2019**
				2(2)	Other	
					Natchez	**Spring 2019**
				1(1)	Other	
				(1)	Natchez	**Summer 2019**
					Other	

Table 2.1 (continued).

Brazos		Auchenorrhyncha	Cicadellidae	Cixiidae	Heteroptera	Anthocoridae
Spring 2018	Natchez		5(4)			28(15)
	Other		4(3)			6(5)
Summer 2018	Natchez					
	Other			1(1)		
Fall 2018	Natchez		1(1)			
	Other					
Winter 2019	Natchez					
	Other					
Spring 2019	Natchez		14(7)			4(2)
	Other					14(6)
Summer 2019	Natchez					
	Other		2(2)			

Table 2.1 (continued).

Brazos		Lygaeidae	Miridae	Pentatomidae	Reduviidae	Sternorrhyncha
Spring 2018	Natchez		1(1)			
	Other	1(1)	1(1)			
Summer 2018	Natchez			4(3)	5(4)	
	Other			1(1)	24(11)	
Fall 2018	Natchez				1(1)	
	Other			1(1)	4(1)	
Winter 2019	Natchez					
	Other					
Spring 2019	Natchez		1(1)			
	Other					
Summer 2019	Natchez				1(1)	
	Other			13(4)	3(3)	

Table 2.1 (continued).

Brazos		Aphididae	Coccidae	Diaspididae*	Psyllidae	
Spring 2018	Natchez	6(5)			3(3)	
	Other	26(9)			1(1)	
Summer 2018	Natchez	52(16)	1(1)			
	Other	214(23)	2(2)			
Fall 2018	Natchez	21(10)	5(5)			
	Other	69(19)	14(8)			
Winter 2019	Natchez		26(14)		1(1)	
	Other	1(1)	23(19)		1(1)	
Spring 2019	Natchez	4(1)	2(2)			
	Other	27(16)				
Summer 2019	Natchez	48(4)				
	Other	6(6)	3(2)			

Table 2.1 (continued).

Brazos		**Hymenoptera**	Vespidae	Cynipidae	Figitidae	Chalcidoidea
Spring 2018	Natchez					
	Other					
Summer 2018	Natchez					
	Other					
Fall 2018	Natchez					
	Other					
Winter 2019	Natchez					
	Other			2(2)		
Spring 2019	Natchez				1(1)	
	Other					
Summer 2019	Natchez					
	Other					

Table 2.1 (continued).

Brazos		Aphelinidae	Chalcididae	Encyrtidae	Eulophidae	Eupelmidae
Spring 2018	Natchez	3(2)		1(1)		
	Other			7(1)	5(2)	
Summer 2018	Natchez	5(3)				
	Other					
Fall 2018	Natchez					5(2)
	Other				5(2)	1(1)
Winter 2019	Natchez					3(1)
	Other					
Spring 2019	Natchez	1(1)				1(1)
	Other			1(1)		
Summer 2019	Natchez	1(1)			3(2)	
	Other	1(1)			1(1)	

Table 2.1 (continued).

Brazos		Mymaridae	Pteromalidae	Ichneumonoidea	Braconidae	Ichneumonidae
Spring 2018	Natchez					
	Other	1(1)	1(1)			1(1)
Summer 2018	Natchez					
	Other					
Fall 2018	Natchez					
	Other		11(1)			
Winter 2019	Natchez					
	Other					
Spring 2019	Natchez	3(3)				
	Other					2(2)
Summer 2019	Natchez					
	Other	2(2)			1(1)	

Table 2.1 (continued).

Brazos		Platygastroidea	Platygastridae	Formicidae		**Lepidoptera**
Spring 2018	Natchez		2(2)	37(12)		
	Other		2(2)	52(14)		
Summer 2018	Natchez		2(2)	28(14)		
	Other		2(2)	109(26)		
Fall 2018	Natchez		2(2)			
	Other		14(1)	2(2)		
Winter 2019	Natchez					
	Other					
Spring 2019	Natchez		14(5)	127(16)		
	Other		1(1)	42		
Summer 2019	Natchez			144(26)		
	Other		4(4)	32		

Table 2.1 (continued).

Brazos		Geometridae	Psychidae	Lycaenidae		**Mantodea**
Spring 2018	Natchez					
	Other		8(7)			
Summer 2018	Natchez		2(2)			
	Other		1(1)			
Fall 2018	Natchez		4(4)			
	Other		4(3)			
Winter 2019	Natchez		6(6)			
	Other		9(9)			
Spring 2019	Natchez		5(5)			
	Other	1(1)	9(7)			
Summer 2019	Natchez		1(1)			
	Other		1(1)			

Table 2.1 (continued).

Brazos		Mantidae		**Neuroptera**	Chrysopidae	Hemerobiidae
Spring 2018	Natchez				10(8)	
	Other				15(12)	
Summer 2018	Natchez					
	Other	1(1)			2(2)	
Fall 2018	Natchez				12(10)	
	Other				3(3)	
Winter 2019	Natchez	69(1)				
	Other				1(1)	
Spring 2019	Natchez				9 (8)	
	Other				24(18)	
Summer 2019	Natchez					
	Other				1(1)	

Table 2.1 (continued).

Brazos		**Psocodea**	Liposcelididae **		**Thysanoptera**	Phlaeothripidae
Spring 2018	Natchez	24(18)				3(3)
	Other	232(30)	8(6)			3(3)
Summer 2018	Natchez	59(14)	1(1)			2(2)
	Other	66(20)	2(2)			6(4)
Fall 2018	Natchez	34(15)				22(7)
	Other	134(34)				21(16)
Winter 2019	Natchez	58(20)	1(1)			3(3)
	Other	141(26)	1(1)			3(3)
Spring 2019	Natchez	19(13)	124(30)			1(1)
	Other	53(23)	124(38)			4(4)
Summer 2019	Natchez	10(6)	1(1)			5(5)
	Other	2(2)				23(16)

Table 2.1 (continued).

Brazos		Thripidae	Aeolothripidae		**Arachnida**	
Spring 2018	Natchez	196(29)				
	Other	351(33)	1(1)			
Summer 2018	Natchez	4(4)				
	Other	7(3)				
Fall 2018	Natchez					
	Other	1(1)				
Winter 2019	Natchez					
	Other					
Spring 2019	Natchez	34(10)				
	Other	64(17)	1(1)			
Summer 2019	Natchez	1(1)				
	Other					

Table 2.1 (continued).

Brazos	**Spring 2018**		**Summer 2018**		**Fall 2018**		**Winter 2019**		**Spring 2019**		**Summer 2019**	
	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other
Oribatida												
Oribatida	15(7)	107(23)	8(5)	84(17)	61(17)	477(41)	48(12)	707(37)	27(13)	450(38)	45(3)	213(18)
Trombidiformes												
Bdellidae		4(2)		1(1)		1(1)				1(1)		
Camerobiidae												

Table 2.1 (continued).

Brazos		Tydeidae		**Araneae**	Araneidae (orb-weavers)	Clubionidae/Anyphaenidae/
Spring 2018	Natchez	47(24)			2(2)	2(2)
	Other	133(35)			1(1)	1(1)
Summer 2018	Natchez	7(5)				17(15)
	Other	19(8)				27(19)
Fall 2018	Natchez	302(23)			4(4)	46(12)
	Other	273(23)			3(3)	49(34)
Winter 2019	Natchez	47(12)				2(2)
	Other	74(13)			3(3)	
Spring 2019	Natchez	65(7)			1(1)	5(5)
	Other	11(4)				9(9)
Summer 2019	Natchez	10(2)			1(1)	19(14)
	Other	17(5)			2(2)	36(25)

Table 2.1 (continued).

Spider (assorted	Salticidae	Philodromidae (running crab	Oxyopidae	Gnaphosidae		**Brazos**
20(16)	13(13)	79(1)			Natchez	**Spring 2018**
33(21)	17(19)	5(4)			Other	
7(6)	24(20)				Natchez	**Summer 2018**
20(15)	48(30)				Other	
4(1)	11(8)	(1)	1(1)		Natchez	**Fall 2018**
12(8)	27(22)	4(4)	6(5)		Other	
5(2)	4(3)	3(3)			Natchez	**Winter 2019**
7(7)					Other	
5(4)	12(12)	4(3)			Natchez	**Spring 2019**
6(6)	29(17)	8(8)			Other	
	20(14)	5(4)			Natchez	**Summer 2019**
3(3)	41 (25)	9(8)		1(1)	Other	

Table 2.1 (continued).

Shannon Diversity		Thomisidae	Theridiidae	Tetragnathidae		**Brazos**
1.105		7(7)	3(2)		Natchez	**Spring 2018**
1.651		10(10)	16(10)	2(2)	Other	
0.869		15(9)	10(8)		Natchez	**Summer 2018**
0.968		9(8)	46(29)		Other	
1.205			44(23)	1(1)	Natchez	**Fall 2018**
1.674		1(1)	79(38)	2(2)	Other	
0.838			7(7)	2(2)	Natchez	**Winter 2019**
1.114			12(8)		Other	
0.955			4(4)		Natchez	**Spring 2019**
1.229		1(1)	26(18)		Other	
0.945			13(12)		Natchez	**Summer 2019**
1.057		4(4)	19(16)		Other	

Table 2.2 Total numbers of arthropods collected per season on *Lagerstroemia* spp. in Tarrant County, TX. 2018-2019. Seasonal collections are divided into a column for the 'Natchez' cultivar (n= 40 each season) and a column for all other cultivars (n= 60 each season). The number of trees that a taxon was collected from is in parentheses. Orders are in bold. Suborders are underlined in the case of the hemipterans. For the Shannon Diversity Index all coccinellids were lumped as Coccinellidae.

Tarrant		**Insecta**	*Acanthococcus*		
Spring 2018	Natchez		737(33)		
	Other		826(57)		
Summer 2018	Natchez		101(14)		
	Other		870(48)		
Fall 2018	Natchez		12(7)		
	Other		189(28)		
Winter 2019	Natchez		3(3)		
	Other		135(18)		
Spring 2019	Natchez		1(1)		
	Other		61(20)		
Summer 2019	Natchez		41(10)		
	Other		713(37)		

Table 2.2 (continued).

Chilocorus stigma	*Chilocorus cacti*	*Axion plagiatum*	Coccinellidae	**Coleoptera**		<u>**Tarrant**</u>
1(1)	8(5)				Natchez	**Spring 2018**
	18(13)	1(1)			Other	
					Natchez	**Summer 2018**
	7(5)				Other	
					Natchez	**Fall 2018**
	3(3)				Other	
					Natchez	**Winter 2019**
1(1)	2(2)				Other	
		1(1)			Natchez	**Spring 2019**
					Other	
	1(1)				Natchez	**Summer 2019**
	10(7)				Other	

Table 2.2 (continued).

Tarrant		*Coccinella septempunctat*	*Cycloneda munda*	*Exochomus marginipennis*	*Harmonia axyridis*	*Hippodamia convergens*
Spring 2018	Natchez					
	Other	3(2)		1(1)	6(4)	2(2)
Summer 2018	Natchez					
	Other	1(1)		1(1)	2(1)	
Fall 2018	Natchez					
	Other					
Winter 2019	Natchez					
	Other					
Spring 2019	Natchez				2(2)	
	Other	1(1)			3(3)	
Summer 2019	Natchez				7(2)	
	Other	1(1)			3(2)	

Table 2.2 (continued).

Tarrant		*Hyperaspis bigeminata*	*Hyperaspis lateralis*	*Nephus flavifrons*	*Olla v-nigrum*	*Psyllobora renifer*
Spring 2018	Natchez		3(2)		4(4)	
	Other	1(1)	7(7)		16(10)	
Summer 2018	Natchez					
	Other		1(1)		2(2)	
Fall 2018	Natchez					
	Other				7(5)	
Winter 2019	Natchez					
	Other		4(4)		1(1)	
Spring 2019	Natchez					
	Other					2(2)
Summer 2019	Natchez			1(1)		
	Other		2(2)			

Table 2.2 (continued).

Tarrant		*Psyllobora vigintimaculata*	*Scymnus loewii*	*Scymnus* sp.		Curculionidae (other)
Spring 2018	Natchez			3(3)		
	Other		6(6)	11(8)		6(3)
Summer 2018	Natchez		2(2)	5(1)		
	Other		1(1)	2(2)		4(4)
Fall 2018	Natchez					
	Other	1(1)				
Winter 2019	Natchez					
	Other					1(1)
Spring 2019	Natchez					
	Other			1(1)		
Summer 2019	Natchez		1(1)	2(2)		1(1)
	Other		1(1)	1(1)		2(2)

Table 2.2 (continued).

Tarrant	**Spring 2018**		**Summer 2018**		**Fall 2018**		**Winter 2019**		**Spring 2019**		**Summer 2019**	
	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other
Latridiidae	2(2)	7(6)	1(1)	5(5)	1(1)	5(3)		2(2)	1(1)	5(2)	1(1)	4(4)
Chrysomelidae								2(2)	1(1)	2(2)		1(1)
Anthicidae		1(1)		1(1)								
Diptera												

Table 2.2 (continued).

Tarrant		Chironomidae	Chloropidae	Dolichopodidae	Milichiidae	Sciaridae
Spring 2018	Natchez					
	Other	2(2)				
Summer 2018	Natchez	1(1)				
	Other					
Fall 2018	Natchez	1(1)				
	Other	1(1)				
Winter 2019	Natchez					
	Other					
Spring 2019	Natchez	2(1)	1(1)			
	Other			1(1)		1(1)
Summer 2019	Natchez					
	Other	1(1)			2(2)	

Table 2.2 (continued).

Tarrant		Syrphidae		**Hemiptera**	Auchenorrhyncha	Cicadellidae
Spring 2018	Natchez					2(2)
	Other	1(1)				12(5)
Summer 2018	Natchez	17(8)				5(3)
	Other	15(6)				5(5)
Fall 2018	Natchez	1(1)				
	Other	1(1)				1(1)
Winter 2019	Natchez					
	Other					
Spring 2019	Natchez					32(16)
	Other					7(6)
Summer 2019	Natchez	35(15)				3(3)
	Other	9(8)				6(6)

Table 2.2 (continued).

Tarrant		Cixiidae	Cydnidae	Heteroptera	Anthocoridae	Berytidae
Spring 2018	Natchez				109(25)	
	Other				23(13)	
Summer 2018	Natchez	1(1)				
	Other	4(4)			5(5)	
Fall 2018	Natchez					
	Other					
Winter 2019	Natchez					
	Other					
Spring 2019	Natchez				49(17)	
	Other		1(1)		7(7)	
Summer 2019	Natchez				1(1)	
	Other	1(1)			2(2)	1(1)

Table 2.2 (continued).

Tarrant		Coreidae	Lygaeidae	Miridae	Membracidae	Nabidae
Spring 2018	Natchez			3(3)		
	Other			11(10)		
Summer 2018	Natchez					
	Other			2(2)		
Fall 2018	Natchez					
	Other					
Winter 2019	Natchez					
	Other					
Spring 2019	Natchez					
	Other			6(5)	1(1)	
Summer 2019	Natchez	2(1)				
	Other	1(1)		1(1)		

Table 2.2 (continued).

Coccidae	Aphididae	Sternorrhyncha	Reduviidae	Pentatomidae		**Tarrant**
9(7)	14(8)		1(1)		Natchez	**Spring 2018**
18(10)	14(8)		3(3)	1(1)	Other	
	1178(38)			5(4)	Natchez	**Summer 2018**
	1933(55)		12(9)	3(3)	Other	
23(13)	2(2)				Natchez	**Fall 2018**
18(14)	10(9)				Other	
					Natchez	**Winter 2019**
1(1)	3(3)				Other	
	6(4)		1(1)		Natchez	**Spring 2019**
			4(4)		Other	
	791(27)		9 (6)	2(1)	Natchez	**Summer 2019**
	631(34)		22(13)	8(3)	Other	

Table 2.2 (continued).

Vespidae	**Hymenoptera**		Psyllidae	Diaspididae*		**Tarrant**
					Natchez	**Spring 2018**
					Other	
					Natchez	**Summer 2018**
					Other	
					Natchez	**Fall 2018**
3(1)			12(8)		Other	
					Natchez	**Winter 2019**
			6(5)		Other	
					Natchez	**Spring 2019**
					Other	
					Natchez	**Summer 2019**
1(1)					Other	

Table 2.2 (continued).

Tarrant		Cynipidae	Figitidae	Chalcidoidea	Aphelinidae	Chalcididae
Spring 2018	Natchez					
	Other					
Summer 2018	Natchez					
	Other					
Fall 2018	Natchez					1(1)
	Other					
Winter 2019	Natchez					
	Other					
Spring 2019	Natchez		1(1)			
	Other					
Summer 2019	Natchez					
	Other					

Table 2.2 (continued).

Tarrant		Encyrtidae	Eulophidae	Eupelmidae	Mymaridae	Pteromalidae
Spring 2018	Natchez		9(3)		1(1)	1(1)
	Other	1(1)	2(2)		3(1)	1(1)
Summer 2018	Natchez				1(1)	2(1)
	Other		2(1)		1(1)	
Fall 2018	Natchez					
	Other		10(2)			
Winter 2019	Natchez					
	Other		1(1)	2(1)		
Spring 2019	Natchez		1(1)			
	Other		2(1)		19(4)	
Summer 2019	Natchez					
	Other		1(1)		1(1)	

Table 2.2 (continued).

Tarrant		Ichneumonoidea	Braconidae	Ichneumonidae	Platygastroidea	Platygastridae
Spring 2018	Natchez		1(1)			3(3)
	Other					10(9)
Summer 2018	Natchez					
	Other					1(1)
Fall 2018	Natchez					
	Other					
Winter 2019	Natchez					
	Other					
Spring 2019	Natchez					2(2)
	Other					16(11)
Summer 2019	Natchez					
	Other					10(5)

Table 2.2 (continued).

Tarrant	**Spring 2018**		**Summer 2018**		**Fall 2018**		**Winter 2019**		**Spring 2019**		**Summer 2019**	
	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other
Formicidae	30(6)	128(28)	32(13)	48(19)					2(2)	23(12)	5(4)	28(14)
Lepidoptera												
Psychidae												
Lycaenidae									9 (6)	9(5)		

Table 2.2 (continued).

Tarrant	**Spring 2018**		**Summer 2018**		**Fall 2018**		**Winter 2019**		**Spring 2019**		**Summer 2019**	
	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other
Sphingidae										1(1)		
Mantodea												
Mantidae					41(1)		197(1)					

Table 2.2 (continued).

Tarrant		**Neuroptera**	Chrysopidae	Hemerobiidae		**Psocodea**
Spring 2018	Natchez		3(3)			17(14)
	Other		4(4)	1(1)		113(33)
Summer 2018	Natchez		14(11)			4(2)
	Other		47(6)	13(9)		11(9)
Fall 2018	Natchez		1(1)			3(3)
	Other		3(3)			28(1)
Winter 2019	Natchez					
	Other		1(1)			25(12)
Spring 2019	Natchez		5(5)			3(3)
	Other		8(8)			33(17)
Summer 2019	Natchez		4(4)			
	Other		22(17)	9(7)		3(3)

Table 2.2 (continued).

Tarrant		Liposcelididae		**Thysanoptera**	Phlaeothripidae	Thripidae
Spring 2018	Natchez	1(1)			14(11)	1261(39)
	Other	30(7)			9(9)	362(42)
Summer 2018	Natchez	2(2)				70(13)
	Other	3(3)			1(1)	64(15)
Fall 2018	Natchez	3(2)				
	Other					1(1)
Winter 2019	Natchez					
	Other	5(5)				
Spring 2019	Natchez	14(12)				81(20)
	Other	108(26)			1(1)	17(10)
Summer 2019	Natchez	58(19)				6(3)
	Other	79(33)				2(2)

Table 2.2 (continued).

Tarrant	**Spring 2018**		**Summer 2018**		**Fall 2018**		**Winter 2019**		**Spring 2019**		**Summer 2019**	
	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other	Natchez	Other
Aeolothripidae		4(4)							1(1)			
Arachnida												
Oribatida												

Table 2.2 (continued).

Tydeidae	Camerobiidae	Bdellidae	**Trombidiformes**	Oribatida		**Tarrant**
2(2)	1(1)			8(7)	Natchez	**Spring 2018**
21(7)	26(8)			147(31)	Other	
1(1)				1(1)	Natchez	**Summer 2018**
	7(1)	3(3)		61(20)	Other	
29(5)				8(4)	Natchez	**Fall 2018**
170(19)	5(4)			140(26)	Other	
2(2)				3(3)	Natchez	**Winter 2019**
	1(1)	1(1)		125(29)	Other	
1(1)		1(1)		5(1)	Natchez	**Spring 2019**
	2(2)			87(31)	Other	
10(1)	1(1)	1(1)		2(2)	Natchez	**Summer 2019**
	2(1)			50(18)	Other	

Table 2.2 (continued).

Tarrant		**Araneae**	Araneidae (orb-weavers)	Clubionidae/Anyphaenidae/	Oxyopidae	Philodromidae
Spring 2018	Natchez			5(5)	5(5)	5(5)
	Other		2(2)	27(16)	1(1)	9(7)
Summer 2018	Natchez			1(1)		1(1)
	Other		1(1)	3(3)	1(1)	2(2)
Fall 2018	Natchez					1(1)
	Other		5(4)			3(3)
Winter 2019	Natchez		1(1)			1(1)
	Other		9(7)			5(5)
Spring 2019	Natchez					3(1)
	Other		4(4)	6(5)		14(11)
Summer 2019	Natchez		1(1)	10(9)	1(1)	1(1)
	Other		2(2)	31(19)	1(1)	11(9)

Table 2.2 (continued).

Thomisidae	Theridiidae	Tetragnathidae	Spider (assorted	Salticidae		**Tarrant**
11(9)	1(1)		35(17)	67(26)	Natchez	**Spring 2018**
7(5)	7(5)		105(35)	81(46)	Other	
6(4)	16(9)		1(1)	11(9)	Natchez	**Summer 2018**
12(12)	73(35)		9(7)	28(18)	Other	
1(1)	13(7)	1(1)	1(1)	2(2)	Natchez	**Fall 2018**
	134(37)	4(4)	6(6)	5(3)	Other	
	1(1)		2(2)	2(2)	Natchez	**Winter 2019**
	22(18)	1(1)	8(8)	2(2)	Other	
	11(10)		1(1)	12(11)	Natchez	**Spring 2019**
4(4)	60(34)		5(4)	25(17)	Other	
2(2)	20(14)			52 (20)	Natchez	**Summer 2019**
2(2)	74(34)			57(37)	Other	

Table 2.2 (continued).

Tarrant		**Shannon Diversity**
Spring 2018	Natchez	1.411
	Other	2.103
Summer 2018	Natchez	0.892
	Other	1.374
Fall 2018	Natchez	0.313
	Other	1.082
Winter 2019	Natchez	0.267
	Other	0.600
Spring 2019	Natchez	0.476
	Other	0.867
Summer 2019	Natchez	0.846
	Other	1.506

2.3.2. Objective 2

2.3.2.1. Introduction

Taxa were separated into three groups to facilitate interpretation of the survey data: 1) herbivores composing at least 10% of their corresponding category in seasonal collections from *Lagerstroemia* spp.; and 2) scale predators where evidence from the literature supports their likely consumption of *A. lagerstroemiae*; and 3) miscellaneous intraguild predators or other potential scale predators. This final category also includes commonly collected ant species that may engage in mutualistic behaviors with the hemipterans present on *Lagerstroemia* spp. Using the information in these paragraphs a food web was constructed.

2.3.2.2. Herbivores

Acanthococcus lagerstroemiae is a scale insect native to Asia associated with *Lagerstroemia spp.* (Wang 2016). In 2004 it was discovered in Richardson, Texas (Wang 2016). Previously reported predators in the U.S. include *H. bigeminata, C. cacti, C. stigma* and *H. axyridis* (Wang 2016). Hicks et al (2019) confirmed predation by H. axyridis and *C. Cacti* in lab experiments. In their native habitat they are preyed upon by *Chilocorus kuwanae* (Silvestri) (Ma 2011).

Frankliniella spp. (Karny) (Hemiptera: Thripidae) are common pests of many plant species and serve as vectors of tospoviruses. *Frankliniella occidentalis* (Pergande) alone is known to feed on over 250 crop species (Reitz 2009). Other major pest species in the United States include *Frankliniella fusca* (Hinds) and *Frankliniella tritici* (Fitch). All three species are found in Texas (Gaines 1965). *F. tritici* has been reported feeding on the eggs of alfalfa weevils in greenhouse conditions (Barney et al. 1979). Predators of *Frankliniella* spp. include mites in the family Phytoseiidae, coccinellids, chrysopids and hemipterans in the family Anthocoridae (Riudavets 1995; Sabelis and Van Rijn 1997).

Cicadellidae is a diverse family of Hemiptera containing about 2500 species of phytophagous sap-feeding insects (Johnson and Triplehorn 2005). *Homalodisca vitripennis* (Germar) was collected on *Lagerstroemia* spp. in Brazos County and Tarrant County. These insects are consumed by a wide range of predators, including reduviids, anthocorids, chrysopids, anthocorids and spiders (Fournier et al. 2008).

Sarucallis kahawaluokalani (crapemyrtle aphid) is a pest of *Lagerstroemia* spp. found worldwide in association with *Lagerstroemia* spp. (Herbert et al. 2009). It has been reported as prey for coccinellids such as *Hippodamia* *convergens* (Guerin-Meneville) and *Olla v-nigrum* (Casey), the syrphid fly *Allograpta obliqua* (Say) and the chrysopid *Chrysoperla rufilabris* (Burmeister) (Mizell and Schiffhauer 1987).

The arboreal representatives of the suborder Psocomorpha in the order Psocodea are typically grazers of fungi, algae and lichen (Thornton 1985). Five families were collected over the course of this study: Psocidae, Lachesillidae, Ectopsocidae, Liposcelididae and Stenopsocidae. Psocidae is the largest family in the order (Baz 2008). Psocidae are moderate-to-large-sized Psocomorpha that inhabit the branches and trunks of trees (Johnson and Triplehorn 2005). Like most psocomorpha members of this family are detritivores (Johnson and Triplehorn 2005). Psocomorpha are prey for many arthropod predators including both arachnids and insects. They are also parasitized by Hymenoptera in the families Mymaridae and Braconidae (Baz 2008).

Oribatida is an order of Acari consisting of around 11,000 described species (Walter and Proctor 1999). Often associated with soil and litter they are also the most common mite group in forest canopies (Behan-Pelletier and Walter 2000). Mites dwelling in the tree canopies of temperate and tropical forests occur in such quantities that they have been likened to ‘arboreal plankton’ (Walter and Proctor 1999). Oribatida is a diverse order that consumes a wide range of food, including algae, fungi, and small dead invertebrates

(Heethoff et al. 2009). While some soil dwelling oribatids are predators of nematodes, most species in this group are detritivores (Rockett 2009). Referred to as “beetle mites,” oribatids are characterized by a thick cuticle and are well-protected from predators. They have, however, been reported as prey for other mites with particularly well-developed chelicerae such as those in the family Bdellidae (Alberti 1973).

Tydeidae are a cosmopolitan family of soft-bodied mites. They are commonly found on plants but occur in many other environments including soil, caves, lichens, mosses and stored products (Krantz and Walter 2009). Some species consume plants and pollen, and some are predators, but most are scavengers or fungivores (Da Silva 2016). Some species play a role in the suppression of powdery mildew colonies in vineyards (English-Loeb et al. 1999).

2.3.2.3. A. lagerstroemiae predators

Chilocorus Leach (Coleoptera: Coccinellidae*)* is a genus of coccinellids with 70 species worldwide (Gordon 1985). This genus belongs to the tribe Chilocorini, a tribe composed of scale predators (Giorgi 2009). Two species were recovered in this study: *Chilocorus stigma* (Say) and *Chilocorus cacti* (L.) *C. stigma* has been recorded in association with the scale *Cryptococccus fagisuga* (Lind.) (Mayer 1983) as well as the scales *Chrysomphalus aonidum* (L.)

and *Lephidosaphes beckii* (Glover) (Muma 1955). *C. cacti* has been found in association with *A. lagerstroemiae* in Louisiana, and in Texas lab experiments, adults of *C. cacti* consumed *A. lagerstroemiae* nymphs, adult females, and male pupae (Hicks et al. 2019, Wang 2016).

The multicolored asian lady beetle, *Harmonia axyridis* is present on four continents and consumes many other arthropods (Brown et al. 2011). Prey includes numerous aphid species (Hodek 1996), psyllids, (Michaud, 2001b), chrysomelid larvae (Yasumatsu and Watanabe 1964), Curculionidae (Kalaskar and Evans 2001), Lepidoptera (Koch et al. 2003) and Coccoidea (McClure 1986, Yasumatsu and Watanabe 1964). In lab experiments, adults and larvae of *H. axyridis* consumed *A. lagerstroemiae* nymphs, adult females, and male pupae (Hicks et al. 2019). *H. axyridis* has been blamed for declines in the populations of several indigenous coccinellid genera including *Chilocorus* (Colunga-Garcia and Gage 1998). Clercq et al. (2003) discussed intraguild predation between *H. axyridis* and *Podisus maculiventris* (Say)*.* These interactions favored *P. maculiventris* (Clercq et al. 2003).

Two species in the genus *Hyperaspis* Redtenbacher (Coleoptera: Coccinellidae) were collected in both Brazos and Tarrant County. *Hyperaspis bigeminata* (Randall) is widely distributed in North America (Gordon 1985), and was also collected on *A. lagerstroemiae* infested *Lagerstroemia* spp. in

Louisiana (Wang 2016). This species has also been recorded feeding on other eriococcids, specifically *Eriococcus quercus* (Lambdin 2007). *Hyperaspis lateralis* (Mulsant) is a widespread predator of scale insects and mealybugs in the United States (Grasswitz and Burts 1995). Its range stretches from Louisiana to California and a population is also present in Florida. Pupae found in Brazos County were found parasitized by wasps in the genus *Homalotylus*: family Encyrtidae.

Lacewings in the genus *Chrysoperla* Steinmann (Neuroptera: Chrysopidae) were collected on *Lagerstroemia* spp. in Texas. A predator of aphids, larvae of *Chrysoperla rufilabris* (Burmeister) have also been reported feeding on four different families in the superfamily Coccoidea (Miller et al. 2004). Other species in this genus are reported to consume thrips (Luna-Espino et al. 2020) *C. rufilabris* is susceptible to parasitoid wasps such as those in the family Eulophidae (Ruberson and Kring 1995). The eggs of *C. rufilabris* are also consumed by coccinellids such as *Coleomegilla maculata* (Degeer) (Lucas 1998).

Coccinellids in the genus *Axion* (Mulsant) (Coleoptera: Coccinellidae) are scale predators in the coccinellid tribe Chilocorini (Gordon 1985). One species, *Axion plagiatum* (Olivier), was collected in Texas samples. It is native to the

Southwestern U.S. (Leng 1908). This species was introduced into Hawaii to control avocado mealybugs (Leeper 2015).

Exochomus (Redtenbacher) (Coleoptera: Coccinellidae) is another genus in the coccinellid tribe Chilocorini. *Exochomus marginipennis* (LeConte) (Coleoptera: Coccinellidae) was collected on *Lagerstroemia* spp. infested with scales in both Tarrant and Brazos.

Scymnus spp. Kugelann (Coleoptera: Coccinellidae) are typically considered predators of aphids. Two Texas species in this genus are *Scymnus loewii* Mulsant and *Scymnus louisianae* J. Chapin (Gordon 1985). *S. loewii* was introduced to Easter Island to control aphids (Ripa et al. 1995). *S. Louisianae* is considered a potentially important predator of soybean aphids (Brown et al. 2003). Beetles in the genus *Scymnus* are also known as predators of hemipterans in the superfamily Coccoidea (Tranfaglia and Viggiani 1972).

Orius spp. Wolff (Hemiptera: Anthocoridae) are generalist predators of small arthropods. *Orius insidiosus* (Say) is found in the eastern and mid-western United States (Isenhour and Yeargan 1981). Its prey records include mites, aphids, whiteflies, leafhoppers, thrips, lacewings, lepidopteran eggs, and beetle larvae (Barber 1956, Coll and Ridgway 1995; Funderberk et al. 2000; Harwood et al. 2007; McCaffery and Horsburgh 1986). In turn it is preyed on by spiders, larval chrysopids, and other predatory hemipterans (McCaffery and Horsburgh 1986).

2.3.2.4. Others

Olla Casey (Coleoptera: Coccinellidae) is a New World coccinellid genus associated with aphids (Gordon 1985). The ashy-gray lady beetle *Olla v-nigrum* (Mulsant) has been found on *Lagerstroemia* spp. in Texas. Found throughout the new world (Gordon 1985), this beetle consumes psyllids and aphids (Michaud 2001a, Mizell and Schiffhauer 1990, Vandenberg 1992).

Coccinella septempunctata L. (Coleoptera: Coccinellidae) is native to Eurasia. Attempts to introduce the coccinellid into the United States as an aphidophagous biological control agent began in 1956 in California (Angalet et al. 1979). The species has since become widespread in the United States and Canada (Krafsur et al. 2005). The species is considered polyphagous, but less so than *Harmonia axyridis,* preying on fewer aphid species, but capable of supplementing its diet as an adult with nectar, pollen and fungal spores (Hodek and Michaud 2013). Eggs and larvae of *C. septempunctata* are consumed by *H. axyridis* (Hodek and Michaud 2013).

Crematogaster laeviuscula Mayr (Hymenoptera: Formicidae) are arboreal ants that dwell in hollow branches and dead tree trunks (Tynes and Hutchins 1964). They are known to raid paper wasp nests belonging to *Polistes exclamans* (Viereck) (Hymenoptera:Vespidae). In Texas, *C. laeviuscula* has been observed tending herbivorous hemipterans and attacking caterpillars on mistletoe (Whittaker 1984).

The genus *Brachymyrmex* Mayr (Hymenoptera: Formicidae) consists of 38 species of ants worldwide, most occurring in the neotropics (Bolton 1995). There are at least eight species in the United States. However, due to lost type specimens, similarity of species appearance, and the poor quality of identification keys, species names and identifications are suspect (Deyrup 2003, MacGown et al. 2007). *Brachymyrmex patagonicus* Mayr is a non-native species that has established along the gulf coast of the United States (MacGown et al. 2007). Nests of *B. patagonicus* often occur in landscaping mulch (MacGown et al. 2007). Their diet is thought to consist largely of honeydew from various insects (Dash et al. 2004).

Solenopsis invicta Buren, is a non-native ant that arrived in the southern United States roughly a hundred years ago (Ascunce et al. 2011). Recent studies of genetic markers indicate the populations in southern states likely originated from Argentina (Caldera 2008). *S. invicta* is an aggressive invader blamed for decreased local vertebrate and invertebrate biodiversity (Allen et al. 2001, Porter and Savignano 1990, Thawley and Langkilde 2016). *S. invicta* is a consumer of many invertebrates as well as plant seeds (Vogt et al. 2002). It has also been recorded forming mutualistic relationships with hemipteran insects including Coccoidea (Helms and Vinson 2008). *S. invicta* is parasitized by Diptera in the family Phoridae (Porter 1998). It is uncertain whether *S. invicta* is a predator or a protector of *A. lagerstroemiae*.

Camerobiidae is a mite family in the order Trombidiformes. They are predators of phytophagous mites such as tetranychids and eriophyids in soil and on plants (Bolland 1991; Khanjani and Ueckerman 2011). Some species are reported to consume scale insect crawlers in the family Diaspididae (Gerson 1973, Meyer 1962, Richards 1962). This mite family was only found in Tarrant county collections. It is included here because there is a possibility it may consume *A. lagerstroemiae* crawlers.

Salticidae, or "jumping spiders," is the largest family in the order Araneae (Foelix 2011). Observations of these spiders indicate that in addition to being active visual hunters of small arthropods they also consume nectar from flowers (Jackson et. al 2001). Salticids are particularly good at visually distinguishing between potential prey, threats, and conspecifics (Forster 1985). Interest in prey is size-limited, with spiders only rarely attacking prey larger than themselves, but they display an increasing willingness to attack larger prey as they become hungrier (Drees 1952, Forster 1979).

Theridiidae, also known as comb-footed spiders and cobweb-weavers, is a family of web building spiders in the family Araneae. Spiders in the genus *Anelosimus* were collected on *Lagerstroemiae* spp. in this study. One common species, *Anelosimus studiosus* (Hentz), is known to form colonies of multiple individuals (Jackman 1997, Pruitt et al. 2008). These spiders spin a platform sheet of webbing with irregular capture threads (Jackman 1999). Large quantities of midges were found captured in one study (Muma 1975).

Anyphaenidae, Clubionidae, and Cheiracanthiidae were all once in the same family: Clubionidae (Brescovitt 2012). The genus Cheiracanthium was moved from Clubionidae to Miturgidae in 1997 by Ramirez et al., and then moved from Miturgidae to Eutichuridae by Ramirez in 2014. Eutichuridae was synonymized with Cheiracanthiidae by Ono and Ogata in 2018. Anyphaenidae or ghost spiders are hunting spiders with a wide range of prey and are preyed upon by wasps in the family Sphecidae (Platnick 1974). *Cheiracanthium inclusum* (Hentz) is a predator of many cotton pests in Texas (Durham et. al 2009).

2.3.2.5. Food Web

The food web presented in Figure 2.1 is organized vertically by trophic level. The bottom level represents the producer; *Lagerstroemia* spp. The middle level represents the herbivorous arthropods found and the top level represent the arthropod predators collected in the survey. For the purposes of space and clarity, arthropods were arbitrarily assigned a number for the node they occupy. A key is provided listing arthropod groups and their corresponding node. Arrows point towards the resource consumed by the herbivores and predators. Lines without arrows indicate potential mutualisms (e.g., between formicids numbers 19, 20 and 21 and Sternorrhyncha, 3 and 4). Intraguild predation and competition is likely a factor present in the system as well, given the number of generalists collected. Predators may consume one another, but the threat of predation may also alter predator behavior and effectiveness (Moran and Hurd 1994). Intraguild predation is indicated by the elbowed lines and arrows. As an egg predator, *Orius* spp. (16) will consume the eggs of many predatory arthropods. As seen in the figure, the generalist predators likely have multiple food sources in the *Lagerstroemia* spp. ecosystem. Node 27 represents Camerobiidae. This predatory mite was found only in Tarrant County.

2.4. Discussion

Ecological studies of a pest species and its natural enemies are a foundational step in the development of integrated pest management strategies (Walter 2003). Before introducing biological control agents, it is important to know the control agents already present in the environment. Previous studies have included observations of predators present in the environment, but before now an attempt has not been made to comprehensively quantify the *Lagerstroemia* spp. ecosystem over the course of multiple seasons, in multiple localities, by cultivar, and sampling hundreds of trees in the United States. Previous work has consisted of field observations and non-systematic collections of potential *A. lagerstroemiae* predators (Vafaie et al. 2020, Wang et al. 2016). Matos et al. (2019) sampled a total of 36 trees in three Louisiana cities across three seasons, but they also sought predators and scale counts only and did not include a parasitoid capture component. This study was designed to comprehensively survey the *Lagerstroemia* spp. ecosystem in a search for ecosystem interactions that might influence or aid future biological control strategies. Sample sizes were large and multiple seasons were sampled across two years.

A number of coleopteran predators found in conjunction with *A. lagerstroemiae* by earlier researchers such as *C. cacti, H. axyridis, H. bigeminata,* and *H. lateralis* were also found in this study (Vafaie et al. 2020;

Wang et al. 2016). Unlike earlier work in Louisiana by Wang in 2016 no specimens of the non-native *Cybocephalus nipponicus* (Endrödy-Younga) (Coleoptera: Cybocephalidae) beetles were found in the Brazos County and Tarrant County collections. However, previously unmentioned coleopteran scale predators were collected: *A. plagiatum* and *E. marginipennis*. Researchers in China report that the most effective natural enemy of *A. lagerstroemiae* in Guiyang, Guizhou province is *Chilocorus kuwanae* (Leach) a close relative of the most common coccinellid collected in this study, *C. cacti* (Luo et al. 2000). Being in the same genus the two *Chilocorus* species are likely behaviorally and ecologically similar. Given the relative number of *C. cacti* collected it is likely that *C. cacti* is the most effective coccinellid predator of *A. lagerstroemiae* in Texas. By extension, *Chilocorus* species are likely important coccinellid predators in other states as well.

While numerous arthropods that consume scale insects were recovered, no parasitoid wasps of *A. lagerstroemiae* were collected over the course of the study despite the collection of numerous parasitoid wasps of other arthropods. New records in Texas of the scale insect *Lopholeucaspis japonicus* (Cockerell) (Hemiptera: Diaspididae), the Japanese maple scale, and a parasitoid that uses *L. japonicus* as a host were also recorded over the course of the study. The sampling methods used are capable of collecting scale insect parasitoids. Worldwide, *A. lagerstroemiae* has been reported as a host for eleven parasitoid wasps (Suh 2020). Due to the lack of *A. lagerstroemiae* parasitoids present, the importation of parasitoid wasps as a biological control method may be a worthwhile avenue to investigate in the future.

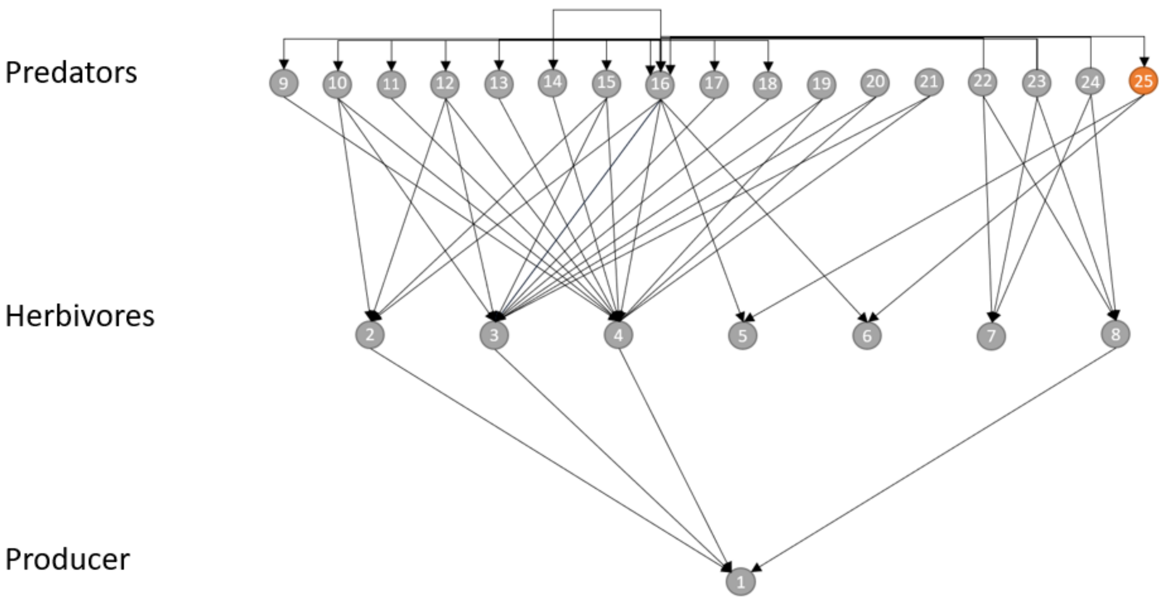
Overall, more *A. lagerstroemia* collected in Brazos county than Tarrant county. However, there were more herbivores of other families including Thripidae and Aphididae collected in Tarrant county. This may indicate that there is some competition between these herbivores. Insects such as aphids are known to attract large numbers of generalist predators such as chrysopids and coccinellids. The presence of *S. khawaluokalani* on crapemyrtles can cause declines in the populations of nearby pecan aphids *Monellia caryella* (Fitch) and *Monelliopsis pecanis* (Bissell) (Mizell 1987).

The arthropod community on crapemyrtles, *Lagerstroemia* spp. is extensive. In addition to supporting a wide range of native arthropod predators and herbivores, these introduced old world ornamental trees have brought with them plentiful prey resources unique to them, such as *A. lagerstroemia* and *S. kahawaluokalani*. The scientific literature about predators collected in this study indicates that many of them are generalists of small arthropods. The prey resources available to them on *Lagerstroemia* spp. likely bolsters arthropod predator populations in the urban and suburban landscape. Many generalist predators, including lacewings in the families Chrysopidae and Hemerobiidae as well as generalist coccinellids will consume the most common herbivore insect families present on *Lagerstroemia* spp.: Aphididae, Eriococcidae, and Thripidae.

The food web constructed in objective 2 is intended to provide preliminary hypotheses for interspecific interactions within the arthropod community. Food webs describe interspecific relationships among organisms within a community (Pimm et al. 1991). This particular food web, the first of its find for the *A. lagerstroemiae* ecosystem, highlights interactions of predator and prey that could potentially be encouraged via future conservation or augmentation biological control programs. The food web also serves as a resource for future classical biological control programs. The presence of one predator may cause behavioral changes in another predator that adversely affects their pest control effectiveness (Moran and Hurd 1994). Arthropod predators such as coccinellids and chrysopids, which were relatively common predators in in this study, may be obstacles to any parasitoid species introduced as a control measure (Chacón et al. 2008.) Forecasting the effects of introduced biological control agents is integral to any classical biological control program. The food web in figure 1 indicates that the ecosystem of *Lagerstroemia* spp. is competitive with a diverse array of predators and many commonly occurring herbivores other than *A. lagerstroemiae.*

The most common predators sampled were native species. Some research indicates that niche saturation makes food webs resistant to invasion by non-native species (David et al. 2017). The non-native scale predator *C. nipponicus* was found in Louisiana, but not in this study (Wang 2016). Food webs are also being used to predict indirect effects on an ecosystem from a conservation perspective (Memmott 2007). The presence of specialist scale-consuming coccinellids such as *A. plagiatum C. cacti, E. marginipennis, H. bigeminata,* and *H. lateralis*, makes introducing a non-native coccinellid such as the previously mentioned *C. kuwanae.* inadvisable even if an environmentally suitable candidate were found. Information like this is why ecological studies are so important. The *Lagerstroemia* spp. ecosystem is complex and attempts to alter it should be done with caution only after analysis of the possible impacts on the species present.

Before this study the *Lagerstroemia* spp. ecosystem in Texas was not well understood. The diversity present in the *Lagerstreomia* spp. ecosystem is remarkable, even more so because of the urban and suburban environments these plants are planted in. We now know far more about the scale predators present. There are native scale consuming specialist predators present, but they are not providing satisfactory control of *A. lagerstroemiae* by stakeholder standards. After two years of study it can be stated that if there are native parasitoid wasp species present in Texas that utilize *A. lagerstroemiae* as a host, then they are not common; no *A. lagerstroemiae* parasitoids were found in this study. Classical biological control via the introduction of non-native parasitoid wasp species would be a logical next research step.



1. *Lagerstroemia* spp.
2. Thripidae
3. Aphididae
4. *A. lagerstroemiae*
5. Oribatida
6. Tydeidae
7. Psocoptera
8. Cicadellidae
9. *Chilocorus* spp.
10. *H. axyridis*
11. *Hyperaspis* spp.
12. Chrysopidae
13. *Axion* spp.
14. *Exochomus* spp.
15. *Scymnus* spp.
16. *Orius* spp.
17. *Olla* spp.
18. *C. septempunctata*
19. *C. laeviuscula*
20. *Brachymyrmex* spp.
21. *S. invicta*
22. Salticidae
23. Theridiidae
24. Anyphaenidae, Clubionidae and Cheiracanthiidae
25. Camerobiidae

Figure 2.1 Food web of the *A. lagerstroemiae* and *Lagerstroemia* spp. ecosystem based on observations from Brazos and Tarrant County 2018-2019. Bottom level is producer (*Lagerstroemia* spp.) Mid-level is herbivores, and top level is predators. Arrows indicate an organism consumes the organism pointed to.

2.5. References

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3. LANDSCAPE STRUCTURE AND ITS EFFECT ON CRAPEMYRTLE BARK SCALE *ACANTHOCOCCUS LAGERSTREOEMIAE* (HEMIPTERA: ERIOCOCCIDAE) AND ITS NATURAL ENEMIES

3.1. Introduction

Acanthococcus lagerstroemiae (Kuwana) (Hemiptera: Eriococcidae), the crapemyrtle bark scale, is a non-native pest from Asia that was first discovered in 2004 in Richardson, Texas (Wang et al. 2016). The scale has now spread to 14 southern and southwestern U.S. states, where it affects the value and health of crapemyrtles, specifically *Lagerstroemia indica (L.)* (Myrtales: Lythraceae), *Lagerstroemia fauriei (Koehne),* and their hybrids *Lagerstroemia indica x fauriei* (EDDMaps 2020). These ornamental trees are ubiquitous features of the southern U.S. landscape due to their aesthetic appeal and relative lack of diseases and pests (Pooler 2007, Chappell et al. 2012). There are dozens of cultivars encompassing a wide range of flower colors, and ornate bark types. Infestation by the scale causes branch dieback, and heavy coverage by black sooty mold that grows on the honeydew excreted by *A. lagerstreomiae* (Jiang and Xu 1998, Luo et al. 2000, Ma 2011, Chappell et al. 2012).

Intensive surveys of *A. lagerstroemiae* infesting *Lagerstroemia* spp. in Texas documented a large number of scale insect predators and competitors, as well as a number of non-*A. lagerstroemiae* parasitoids. Hence, there is a keen interest in the biological control exerted by these indigenous and other exotic natural enemies. Among the different biological control agents, insects such as coccinellids and chrysopids commonly eat scale insects. Their augmentation might be worth investigating for *A. lagerstroemiae* control (Pappas et al. 2011, Wang 2016). Classical biological control efforts might focus on *A. lagerstroemiae* parasitoids such as those found in China (Wang 2016). Conservation biological seeks to maximize the effect of natural enemies by manipulating their environment (Barbosa, 1998). Known *A. lagerstroemiae* predators in the United States include *Hyperaspis bigeminata* (Randall), *Chilocorus cacti* (L.), *Chilocorus stigma (Say)*, and the introduced *Harmonia axyridis* (Pallas) (Wang 2016). All four of these coccinellids are also found in Texas. It is known that predators of *A. lagerstroemiae* are present in the southern U.S. landscape, but what influences their presence on *Lagerstroemia* spp. has yet to be examined

Lagerstroemia spp. are present in diverse urban, suburban and rural habitats. The occurrence of *Lagerstroemia* spp. results from direct planting of nursery grown stock or growth from winged seeds adapted for aeolian dispersal. These seeds can be blown considerable distances from the parent tree (Graham and Graham 2014), and growth from seed may best explain the occurrence of *Lagerstroemia* spp.

There is research that indicates insects with sucking mouthparts and limited mobility such as scale insects increase along an urbanization gradient (Raupp et al. 2012). As habitat fragmentation, human disturbance, and habitat modification increase there is a higher likelihood of sucking insects reaching outbreak population levels in urban areas than chewing insects such as Lepidoptera (Martinson and Raupp 2013). The diversity of the urban landscape plays a role as well. Research has found that increased landscape diversity may reduce the presence of scales on trees, possibly due to other landscape characteristics such as edge effects, patch sizes, and habitat fragmentation (Bāders 2018).

Since this pest was only recently discovered in the U.S., little is known about the faunistic and habitat factors influencing its abundance and distribution. The objective of this research is to determine factors influencing *A. lagerstroemiae* and its natural enemy populations in two Texas counties 160 Kilometers apart: Brazos (30°39'36.00" N -96°17'60.00" W) and Tarrant (32°46'12.00" N -97°17'24.00" W). Information will be collected about the landscape surrounding *Lagerstroemia* spp. as well as the arthropod fauna on *Lagerstroemia* spp. This data will then be analyzed using principal component analysis followed by stepwise multiple regression. The results of this analysis should identify landscape factors that influence the population of *A.lagerstroemiae* and its natural enemies.

3.2. Materials and Methods

Sampling was conducted within two Texas counties, Brazos and Tarrant. These counties are over 190 Kilometers apart, and represent different plant hardiness zones: Brazos is in plant hardiness zone 8b and Tarrant is in 8a (USDA 2012). Hardiness zones are defined by the average annual extreme minimum temperature in a zone. Zone 8b is -9.4 to -6.7 °C and zone 8a is -12.2 to -9.4 °C. Infestations in Tarrant County have existed longer than in Brazos County, as they are closer to the initial introduction of *A. lagerstroemiae* in adjacent Dallas County in 2004. Because quantification of the geographical, cultivar, and habitat structure on arthropod abundance and composition within *Lagerstroemia* spp. was the central focus of this study, the sampling protocol was based on a statistical evaluation of the appropriate number of trees to sample per county and the appropriate number of foliage samples to take per tree. Considerable variance was observed between populations on branches within the same tree and between different trees. In order to obtain reliable data about *A. lagerstroemiae* and its natural enemies, preliminary data were collected on mean/variance relationships and scale populations. Ten 30 cm branches each were taken from 40 trees. At 40 trees, the change in standard error was less than .005 for each additional tree included in the sample. Similar results were seen when standard error was taken between branches within the same tree. In order to avoid excessive damage to trees that would affect their health and skew data, only ten branches were collected per tree.

Arthropod sampling and habitat assessments were performed in spring 2018 (May 8-June 9), summer 2018 (August 9 - September 9), fall 2018 (November 10 – December 11), winter 2019 (February 9 – March 12), spring 2019 (May 8 – June 9), and summer 2019 (August 9 – June 9). Multiple seasons were sampled to determine if seasonality had any effect on the landscape factors influencing scale and natural enemy populations. Six total seasons were sampled to determine if any difference between successive years could be detected. Trees were sampled from a variety of landscapes. These included landscaping near roadsides, parks, schools, government buildings, hotels, apartment complexes, and medical facilities. On sample dates, foliage samples were collected from 40 trees belonging to the Natchez cultivar and 60 trees from a mix of other, non-Natchez cultivars. By comparing a known cultivar with a mix of unknown cultivars it is hoped that any differences in *A. lagerstroemiae* infestation between *Lagerstroemia* spp. cultivars will be detected. The crowns of sample trees were ideally separated from the crowns of neighboring *Lagerstroemia* spp. However, if the number of *Lagerstroemia* spp. in contact with one another was three trees or less, then they were sampled as one tree. Ten 30 cm branch tips serving as sub-samples were collected from each tree using a telescoping long-handled 2.7-meter pruner. An assistant caught the branches in containers, Sure Fresh® rectangular deep storage containers, 10 cm x 35 cm (Greenbrier International, Inc., 1509 Sams Circle Store No 502 Chesapeake, VA 23320-4694 United States, www.dollartree.com, SKU: 236854). Samples were labelled by tree, each tree was given a unique number and GPS data was collected using a cellphone application, (GPS Status & Toolbox Pro version 9.0.183 2019). The GPS coordinates were recorded for the purposes of using the same trees every season.

Non-migratory dispersal distances for natural enemies were obtained from a review of the literature. The review focused on 24 h dispersal distances as it reflects dispersal between short landscape distances and excludes seasonal migrations and long-distance dispersal. The twenty-four-hour dispersal distances for ten arthropod morphotypes, *Hippodamia convergens* (Guérin-Méneville)*, Orius* spp. (Wolff), Araneae, *Scymnus* spp. (Kugelann), *Aphis gossypii (Glover)*, *Myzus persicae* (Sulzer), *Phytoseiulus persimilis* (Athias-Henriot), *Neoseiulus fallacis* (Garman), *Neoseilus californicus* (Chant), *Kampimodromus aberrans* (Oudemans), and *Euseius finlandicus* (Oudemans), were examined (Heinz 1998, Prasifka et al. 1999, Jung and Croft 2001). The average dispersal distance of the ten species was 11.057 meters with a standard error of 4.363. The maximum distance for dispersal in applicable field studies with applicable insect species was 32.4 meters. The insect that had the greatest twenty-four-hour dispersal distance was *Orius* spp. Since natural enemies such as *Orius* spp. were of special interest to this study, landscape composition within a 32.4 -meter radius of each tree was measured during each arthropod sampling date.

Landscape cover measurements were estimated using GPS imagery checked by ground observations every season. If more than one plant type covered a space, the cover was subdivided equally among the overlapping plant types. For example, the area of tree cover over turf grass was divided equally between the categories of tree cover and turf grass.

In the laboratory, the plastic containers containing branch samples were placed in a cold room for at least twenty-four hours at 6°C in order to slow down arthropods and also for preservation during the sample processing period. After twenty-four hours elapsed the containers were removed, shaken vigorously by hand for ten seconds, and then opened. Branches were examined carefully and transferred from the capture container to a clean container of the same kind, and then back again. The branches were shaken individually into the containers during transfer. The purpose of this process was to dislodge any arthropods clinging to *Lagerstroemia* spp. branches while also preventing as few as possible from escaping. The displaced arthropods were aspirated into 12-dram vials. The vials were then filled with 70% ethyl alcohol to preserve the specimens. With the aid of a stereo microscope (Olympus SZ60, Tokyo, Japan) zoom range 10× – 63×, the organisms captured in the alcohol were counted and then identified to the lowest taxon possible. Adult scales and nymphs attached firmly to the branches were also counted in the lab using these microscopes. In

Tarrant County, where these microscopes were not available, illuminated 30× magnifying glasses were used (Ylanfer 30x Handheld Lighted Magnifier, Extra Large Double Glass Lens Magnifying Glass With 12 LED Lights, Shenzhen, China). Eggs hidden beneath the waxy covering of atrophied adult females and were not counted. The branches were then placed in sealed, white paper bags to allow for parasitoid emergence. After three months, the bags were opened and the contents were shaken into a petri dish containing 70% ethanol both to kill any living arthropods and to aid in the examination of the detritus from the bottom of the bag. Using a stereo microscope (Olympus SZ60, Tokyo, Japan) zoom range 10× – 63×, parasitoids were then counted and identified to the lowest taxonomic level possible before being placed in labelled vials with 70% ethanol for preservation. Dr. Jim Woolley at Texas A&M University at College Station provided taxonomic assistance, and voucher specimens were placed in the TAMU insect collection.

Factors influencing the abundance and distribution of select insect taxa were determined using a principal components analysis and stepwise multiple regression. This is a proven method that has been applied in entomology, horticulture and ecology in general (Brazzle, et al., 1997, Iezzoni and Pritts, 1991, Janžekovič and Novak, T., 2012). Principal components analysis creates a reduced number of orthogonal variables or factors, described by factor loading values, by mathematically maximizing spatial separation of the original variables (Brazzle, et al., 1997). Using this method creates a reduced set of variables that are more conducive to interpretation. Brazzle and colleagues (1997) used this approach in their study of *Bemisia argentifolli* Bellows & Perring (Hemiptera: Aleyrodidae) infesting cotton grown in the Imperial Valley of California in 1993 and 1994. Values from the statistically independent variables were then included in a least-squares multiple regression procedure to test for the influence of agronomic factors on immature *B. argentifolii* population densities*.*

When analyzing the *Lagerstroemia* spp landscape, variables used in the principal component analysis represented greater than 1% of landscape area sampled. Area of turf grass, *Lagerstroemia* spp cover, other tree cover and hardscape were included in the analysis. Flowerbeds containing annuals, small streams, and native brush were rarely found at sampling locations, and these measurements were not included. Out of 200 trees only two trees were near a body of water, and only four trees coexisted with flowering annuals. The analysis was limited to three principal components derived from the landscape measurements. The principal components were then saved and used as independent variables in a series of stepwise multiple regression analyses. The target pest, *A. lagerstromiae*, and, separately, its natural enemies were used as response variables for the stepwise multiple regression. Natural enemies were taken from the ecosystem survey. This category includes hemipterans in the family Anthocorridae (order Hemiptera), *Axion plagiatum* (Olivier) (Coleoptera: Coccinellidae), *Chilocorus* spp. (Coleoptera: Coccinellidae), *Exochomus* spp. (Coleoptera: Coccinellidae), lacewings in the families Chrysopidae and

Hemerobiidae (order Neuroptera), *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae), Hyperaspis spp. (Coleoptera: Coccinellidae), and *Scymnus* spp. (Coleoptera: Coccinellidae). The software used for statistical analysis was JMP®, Version 14.3. SAS Institute Inc., Cary, NC, 1989-2019.

3.3. Results

Three principal components cumulatively described at least 90% of the variance among four variables. The composition of the new independent variables generated by the analysis was affected by geographic location and cultivar (Tables 3.1-3.3). Organizationally, we will discuss the results by location (Brazos versus Tarrant County), cultivar (Natchez versus non-Natchez), and season (collections made in spring 2018, summer 2018, fall 2018, winter 2019, spring 2019, and summer 2019) in an effort to determine which class variables contributed most to variation in the principal components and subsequent regression analyses. The stepwise multiple regression models used did not produce high adjusted R^2 values when abundance of *A. lagerstroemiae* was the response variable or when abundance of *A. lagerstroemiae*'s natural enemies were the response variable.

3.3.1. Location

Principal component one represents the negative correlation between turf and hardscape in the landscape area measured. Principal component two represents the amount of area occupied by other *Lagerstroemia* spp. trees in the landscape. In principal component 3 the most prominent factor is non-*Lagerstroemia* spp. tree cover.

In the stepwise multiple regression analysis the adjusted R^2 was less than .01 for both Brazos County and Tarrant County (Table 3.4). In Brazos County the area of *Lagerstroemia* spp*.* measured in the landscape was positively correlated with *A. lagerstroemiae* collected with greater than 95% confidence. In Tarrant County the area of Lagerstroemia spp. is negatively correlated with *A. lagerstroemiae* with greater than 85% confidence. Natural enemy analysis using stepwise multiple regression was inconsistent between the two counties. In Brazos County PC3 was the most significant with a p-value of 0.19855, but an adjusted R^2 of 0.0011. In Tarrant County PC2 was the most significant with a p-value of 0.02073, and an R^2 of 0.0073.

3.3.2. Cultivar

As in the county comparison, principal component one represents the negative correlation between turf and hardscape in the landscape area measured. Principal component two represents a positive correlation between area occupied by other *Lagerstroemia* spp. trees in the landscape as well as other trees in the landscape. Principal component three is composed varying interactions depending on the cultivar, but in both cases explains less than 20% of the data.

The multiple regression analysis produced R^2 values less than .05 for both cultivars. Taking p-values into consideration, PC2 was significant with a p-value less than 0.05 for both cultivars (Table 3.5). It was positively correlated with the number of *A. lagerstroemiae* present. In the cultivar analysis of *A. lagerstroemiae'*s natural enemies' results were relatively consistent between cultivars. The p-values of PC2 were less than .05 and the p-values for PC3 were less than 0.09. Natural enemies were negatively correlated with PC2 and PC3 on the 'Natchez' cultivar. However, on the non- 'Natchez' cultivar they were negatively correlated with PC2, but positively correlated with PC3. Adjusted R2 values for 'Natchez' and non- 'Natchez' were 0.0150 and 0.0080 respectively.

3.3.3. Season

In the seasonal principal component analysis, principal components remained relatively steady across seasons due to the fact that the landscape area values in this study did not change unless they were altered due to human modification (Table 3.6). Principal component one represents the negative correlation between turf and hardscape in the landscape area measured. Principal component two represents a positive correlation between area occupied by other *Lagerstroemia* spp. trees in the landscape as well as other trees in the landscape, but with somewhat more emphasis placed on *Lagerstroemia* spp. Principal component three is composed of negative interactions between the area composed of *Lagerstroemia* spp., and other tree species. However, principal component three consistently describes less than 20% of the data.

In spring and summer, when *A. lagerstroemiae* numbers were highest, the stepwise multiple regression results were similar to the results for location and cultivar analyses: principal component two was the only component with a p-value less than 0.1. In the fall and winter, the regression analysis differed. In fall 2018 the analysis found no components with p-values less than 0.25. In winter 2019 principal component one was the most significant predictor of *A. lagerstroemiae* numbers. As in the analyses for county and cultivar R^2 values were low: none exceeded 0.0996. Regression analyses for *A. lagerstroemiae*'s natural enemies across seasons were even more inconsistent. However, PC1 was more consistently significant in the stepwise multiple regression results than in any other regression analyses performed in this study. R^2 values did not exceed 0.0832 in any season.

Table 3.1 Principal component analysis of landscape values surrounding sampled *Lagerstroemia* spp. in Brazos County and Tarrant County Texas 2018-2019. Numbers represent factor loadings of the principal components. Numbers in the final column represent the percentage of the variance explained by the principal component.

Brazos County PCA					
	Lagerstroemia spp. Cover	Other Tree Cover	Turf	Hardscape	Percent Explained
PC1	-0.26344	0.71304	0.92118	-0.96324	58.856
PC2	0.95879	0.18353	-0.00018	-0.12654	24.224
PC3	-0.10556	0.67578	-0.36421	0.18080	15.829
Total					98.909
Tarrant County PCA					
	Lagerstroemia spp. Cover	Other Tree Cover	Turf	Hardscape	Percent Explained
PC1	0.25610	0.48459	0.94407	-0.95373	52.532
PC2	0.84592	-0.58043	0.03878	-0.02938	26.437
PC3	0.46778	0.65436	-0.25122	0.20941	18.806
Total					97.740

Table 3.2 Principal component analysis of landscape values surrounding sampled 'Natchez' and non- 'Natchez' cultivar *Lagerstroemia* spp. in Texas in 2018-2019. Numbers represent factor loadings of the principal components. Numbers in the final column represent the percentage of the variance explained by the principal component.

'Natchez' Cultivar PCA					
	Lagerstroemia spp. Cover	Other Tree Cover	Turf	Hardscape	Percent Explained
PC1	-0.04940	0.58140	0.91276	-0.95022	51.913
PC2	0.89546	0.56729	-0.23355	-0.07620	29.601
PC3	-0.44207	0.58191	-0.22987	0.15822	15.298
Total					96.811
Non- 'Natchez' Cultivars PCA					
	Lagerstroemia spp. Cover	Other Tree Cover	Turf	Hardscape	Percent Explained
PC1	-0.30436	0.36805	0.94459	-0.97091	51.575
PC2	0.74772	0.72619	-0.12976	-0.08536	27.764
PC3	0.59006	-0.57953	0.25798	-0.15367	19.355
Total					98.694

Table 3.3 Principal component analysis of landscape values surrounding sampled *Lagerstroemia* spp. in Texas, spring 2018. Numbers represent factor loadings of the principal components. Numbers in the final column represent the percentage of the variance explained by the principal component.

Spring 2018 PCA					
	Lagerstroemia spp. Cover	Other Tree Cover	Turf	Hardscape	Percent Explained
PC1	-0.17939	0.46314	0.935293	-0.96953	51.543
PC2	0.83808	0.62705	-0.16460	-0.01507	28.072
PC3	-0.51508	0.62599	-0.25165	0.15077	18.581
Total					98.195
Summer 2018 PCA					
	Lagerstroemia spp. Cover	Other Tree Cover	Turf	Hardscape	Percent Explained
PC1	-0.17939	0.46314	0.935293	-0.96953	51.543
PC2	0.83808	0.62705	-0.16460	-0.01507	28.072
PC3	-0.51508	0.62599	-0.25165	0.15077	18.581
Total					98.195

Table 3.3 (Continued)

Fall 2018 PCA					
	Lagerstroemia spp. Cover	Other Tree Cover	Turf	Hardscape	Percent Explained
PC1	-0.18156	0.46352	0.93610	-0.97015	51.632
PC2	0.83810	0.62546	-0.25398	-0.15055	28.014
PC3	-0.51508	0.62599	-0.25165	0.15077	18.607
Total					98.252
Winter 2019 PCA					
	Lagerstroemia spp. Cover	Other Tree Cover	Turf	Hardscape	Percent Explained
PC1	-0.18156	0.46352	0.93610	-0.97015	51.632
PC2	0.83810	0.62546	-0.16336	-0.01564	28.014
PC3	-0.51430	0.62657	-0.25398	0.15055	18.607
Total					98.252
Spring 2019 PCA					
	Lagerstroemia spp. Cover	Other Tree Cover	Turf	Hardscape	Percent Explained
PC1	-0.16060	0.46476	0.93454	-0.97050	51.426
PC2	0.84223	0.61861	-0.17298	-0.00970	28.051
PC3	-0.51450	0.63236	-0.25183	0.14547	18.729
Total					98.206

Table 3.3 (Continued)

Summer 2019 PCA					
	Lagerstroemia spp. Cover	Other Tree Cover	Turf	Hardscape	Percent Explained
PC1	-0.20102	0.48179	0.93278	-0.97008	52.092
PC2	0.83972	0.62361	-0.16126	-0.01935	28.010
PC3	0.50436	-0.61437	0.26861	-0.15135	18.172
Total					98.274

Table 3.4 Stepwise multiple regression analysis of principal components derived from landscape measurements surrounding sampled *Lagerstroemia* spp. using population counts of *A. lagerstroemiae* from those sampled trees as a dependent variable 2018-2019, Brazos County and Tarrant County.

Brazos County Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=598)	P	R^2 Adjusted
PC2	3.2110687	4.068	0.04415	0.0051
Tarrant County Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=598)	P	R^2 Adjusted
PC2	-1.2481216	2.255	0.13371	0.0021

Table 3.5 Stepwise multiple regression analysis of principal components derived from landscape measurements surrounding sampled 'Natchez' and Non- 'Natchez' cultivar *Lagerstroemia* spp. using population counts of *A. lagerstroemiae* from those sampled trees as a dependent variable 2018-2019, Texas.

'Natchez' Cultivar Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df= 476)	P	R^2 Adjusted
PC1	2.1375641	3.578	0.0592	
PC2	6.1537886	16.908	<0.001	
PC3	3.9444391	3.590	0.0587	
				0.0481
Non- 'Natchez' Cultivars Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=717)	P	R^2 Adjusted
PC2	1.9172471	4.077	0.04385	
PC3	-1.3945836	1.504	0.22052	
				0.0050

Table 3.6 Stepwise multiple regression analysis of principal components derived from landscape measurements surrounding sampled *Lagerstroemia* spp. using population counts of *A. lagerstroemiae* from those sampled trees as a dependent variable across seasons in Texas.

Spring 2018 Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=196)	P	R^2 Adjusted
PC1	1.3855466	1.519	0.21929	
PC2	-3.4949266	5.263	0.02284	
PC3	-2.8769606	2.360	0.12606	
				0.0299
Summer 2018 Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=197)	P	R^2 Adjusted
PC2	16.8319101	21.501	< 0.000001	
PC3	7.807940824	2.518	0.11419	
				0.0996

Table 3.6 (Continued).

Fall 2018 Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=196)	P	R^2 Adjusted
N/A	N/A	N/A	N/A	N/A
Winter 2019 Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=198)	P	R^2 Adjusted
PC1	-1.1613293	7.893	0.00546	
				0.0335
Spring 2019 Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=198)	P	R^2 Adjusted
PC2	-0.55382264	3.433	0.06538	
				0.0121
Summer 2019 Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=198)	P	R^2 Adjusted
PC2	5.15414386	5.748	0.01743	
				0.0233

Table 3.7 Stepwise multiple regression analysis of principal components derived from landscape measurements surrounding sampled *Lagerstroemia* spp. using population counts of *A. lagerstroemiae* natural enemies from those sampled trees as a dependent variable 2018-2019, Brazos County and Tarrant County.

Brazos County Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=598)	P	R^2 Adjusted
PC3	-0.0619465	1.657	0.19855	
				0.0011
Tarrant County Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=598)	P	R^2 Adjusted
PC2	0.15670772	5.378	0.02073	
				0.0073

Table 3.8 Stepwise multiple regression analysis of principal components derived from landscape measurements surrounding sampled 'Natchez' and Non-'Natchez' cultivar *Lagerstroemia* spp. using population counts of *A. lagerstroemiae* natural enemies from those sampled trees as a dependent variable 2018-2019, Texas.

'Natchez' Cultivar Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df= 477)	P	R^2 Adjusted
PC2	-0.177487	6.029	0.01443	
PC3	-0.1821285	3.281	0.07072	
				0.0150

Table 3.8 (Continued).

Non- 'Natchez' Cultivars Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=717)	P	R^2 Adjusted
PC2	-0.0841436	4.764	0.02938	
PC3	0.08090885	3.071	0.08014	
				0.0080

Table 3.9 Stepwise multiple regression analysis of principal components derived from landscape measurements surrounding sampled *Lagerstroemia* spp. using population counts of *A. lagerstroemiae* natural enemies from those sampled trees as a dependent variable across seasons in Texas.

Spring 2018 Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=198)	P	R^2 Adjusted
PC2	-0.405411	7.024	0.00869	
				0.0294
Summer 2018 Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=196)	P	R^2 Adjusted
PC1	0.10058732	3.107	0.0795	
PC2	-0.1561718	4.080	0.04476	
PC3	-0.2781173	8.564	0.00383	
				0.0602

Table 3.9 (Continued)

Fall 2018 Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=197)	P	R^2 Adjusted
PC1	0.03899781	2.651	0.1051	
PC2	0.13564622	17.400	<0.000001	
				0.0832
Winter 2019 Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=196)	P	R^2 Adjusted
N/A	N/A	N/A	N/A	N/A
Spring 2019 Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=198)	P	R^2 Adjusted
PC1	-0.2365337	10.108	0.00171	
				0.0438
Summer 2019 Multiple Regression				
	Partial Correlation Coefficient	F Ratio (df=197)	P	R^2 Adjusted
PC1	0.06426231	2.712	0.10116	
PC2	-0.1713291	10.367	0.0015	
				0.0527

3.4. Discussion

The multivariate analysis methods used in this paper could not adequately explain why *A. lagerstroemiae* was more common on some trees than others. Principal component analysis paired with stepwise multiple regression analysis produced models with low adjusted R^2 values. Though some variables returned p-values less than .05, no models had an adjusted R^2 value greater than or equal to 0.10. This was true for analyses by season, cultivar, and location.

All *Lagerstroemia* spp. trees sampled in this study were in non-residential urban and suburban environments. In North America, *Lagerstroemia* spp. are non-native ornamentals that most often occur in these environments. Past research indicates that populations of scale insects belonging to other species may increase along an urbanization gradient (Raupp et al. 2012). However, not all *Lagerstroemia* spp. trees in this study had high numbers of *A. lagerstroemiae* colonizing them regardless of their surroundings. It was common to find heavily colonized trees only a few meters from trees with only a handful of individuals. Even within trees, some branches might be covered in scales, and other branches ignored.

Measurements of the landscape were taken within a 32.4-meter circle surrounding the tree. Measurements of landscape variables within this area could vary considerably, but the landscape typically consisted of concrete, turf grass, *Lagerstroemia* spp. trees, other trees, and buildings. Other variables were rare and were not included in the analysis. Notably, two sample trees were near a wide creek, and water composed a significant portion of their landscape area. Flowering annuals were found planted in a 32.4-meter radius of four trees. Given the limited occurrence of these factors, it is not possible to judge how water features and flowering annuals would have affected the analysis in this study if they had been common enough to analyze. A manipulative experiment of these factors was not carried out due to the dramatic landscape and landscape infrastructure modifications a manipulative experiment would entail, e.g. irrigation systems for flowering annuals and large water features. Properties were not under the management of the researchers, but entities such as state and city governments, or private businesses.

Multivariate analysis of *A. lagerstroemiae* natural enemy population numbers in this study did not produce adequate or consistent results (Tables 3.7-3.9). Though some variables returned p-values less than .05, no models had an adjusted R^2 value greater than or equal to .10. This may be a result of A. *lagerstroemiae*'s sporadic population numbers. Prey populations influence predator populations, and *A. lagerstroemiae* was the most common scale insect and the most common herbivore collected in samples (Lotka 1925). Many *A.*

lagerstroemiae predators were present in the environment. However, there were no parasitoids of *A. lagerstroemiae* recovered in this study despite efforts to do so which resulted in the collection of parasitic Hymenoptera from ten different families.

One biological control strategy for augmenting natural enemy numbers is planting flowering plants near plants of interest (Buchanan 2018). The flowering plants attract and support natural enemy species such as coccinellids, chrysopids, and parasitic Hymenoptera by providing resources such as pollen and nectar (Johanowicz and Mitchell 2000, Patt 1997). In this study, flowering annuals were found within a 32.4-meter radius of only four trees. However, If the planting of annuals is to be widely implemented, then many sites in this study, and by extension elsewhere in Texas, would need a higher degree of management as well as the installment of irrigation systems. Furthermore, while there are plenty of natural enemies in the environment already, they are not providing adequate control of *A. lagerstroemiae* population numbers.

This study highlights the sporadic and clumped colonization habits of *A. lagerstroemiae*. Infestations and outbreaks of this pest are difficult to predict. Initial colonization of new trees by *A. lagerstroemiae* is not well understood: adult males can fly, but females cannot. In some Coccoidea species female dispersal is phoretic, they cling to other animals, while in others their dispersal is aeolian, they are blown by the wind (Barras et al. 1994, Hill 1980, Magsig-Castillo et al., 2010, Mow et al. 1982). Understanding the means of female dispersal may provide some insight into the population distribution of *A. lagerstroemiae*.

This study analyzed the landscape factors influencing A. *lagerstroemiae* populations and *A. lagerstroemiae* natural enemy populations on *Lagerstroemia* spp. in non-residential urban and suburban environments in Texas, and it also characterized these environments. *Lagerstroemia* spp. trees are typically found near other trees of the same species, in locations dominated by turf grass and concrete, often with other tree genera nearby. It is lacking in plant species diversity and water sources. This is a harsh artificial habitat where management practices consist of mowing the grass and little else. Despite this, its arthropod community is diverse and complex.

3.5. References

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4. CONCLUSIONS

4.1. Conclusions

Studies of a pest species' habitat, its natural enemies and its ecology are a necessary first step before control methods can be implemented (Walter 2003). Intensive seasonal sampling, the most comprehensive to date, of the *Lagerstroemia* spp. ecosystem in Texas was undertaken in this research (Wang 20a6, Matos 2020). One hundred trees were sampled in two Texas counties: Brazos County and Tarrant County. Sampling was carried out across six consecutive seasons and separated by cultivar groups; 'Natchez' and non-'Natchez.' The information in the studies presented here has progressed the knowledge of *A. lagerstroemiae* in Texas ecosystems, and the information presented can be used to inform future *A. lagerstroem*iae control programs in other states.

In the first study, a diverse and complex array of natural enemies was discovered. More than 150 morphospecies were collected in over seventy families. This inventory was combined with information from scientific literature about the arthropods collected, and a food web was constructed to illustrate key links between *A. lagerstroemiae*, its arthropod natural enemies, and other potentially important arthropod players in the *Lagerstroemia* spp. ecosystem. A number of predatory arthropods collected are likely to consume *A.*

lagerstroemiae. These include arthropods in the family Anthocorridae (order Hemiptera), *Axion plagiatum* (Olivier) (Coleoptera: Coccinellidae), *Chilocorus* spp. (Coleoptera: Coccinellidae), *Exochomus* spp. (Coleoptera: Coccinellidae), lacewings in the families Chrysopidae and Hemerobiidae (order Neuroptera), *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae), Hyperaspis spp. (Coleoptera: Coccinellidae), and *Scymnus* spp. (Coleoptera: Coccinellidae). Arthropod sampling also contributed to knowledge about possible herbivore competitors such as aphids, specifically *Sarucallis kahawaluokalani*, as well as potential mutualistic interactions with ants that *A. lagerstroemiae* may benefit from. No parasitic Hymenoptera were reared from *A. lagerstroemiae* in this study. This is important because parasitic Hymenoptera are often used to effectively control pests in the order Hemiptera (Greathead 1986).

In the second study, landscape measurements were taken in a 32.4-meter radius of the trees sampled in the first study. Principal component analysis was used to create a reduced number of orthogonal variables more conducive to interpretation. The new independent variables generated by the PCA were then used in a stepwise multiple regression analysis. The dependent variables used were the seasonal *A. lagerstroemiae* counts from the arthropod survey and merged counts of select predators from the survey likely to consume *A. lagerstroemiae* based on scientific literature. The statistical analysis of landscape factors and their influence on *A. lagerstroemiae* numbers and A. lagerstroemiae natural enemy numbers did not produce multiple regression models with significant power. Principal component two consistently returned p-values less than .05 when *A. lagerstroemiae* numbers were analyzed. This component was predominantly composed of the amount of other *Lagerstoemia* spp. trees in the landscape. However, across both locations, all seasons and both cultivar groups the adjusted R^2 values for all multiple regression models was less than .10 for both *A. lagerstroemiae* counts and *A.lagerstroemiae* natural enemy counts. This is likely caused by the sporadic and haphazard distribution of *A. lagerstroemiae* populations in the urban and suburban environments *Lagerstroemia* spp. are planted in. In some cases, hundreds of individual *A. lagerstroemiae* were collected on a single tree. In contrast, samples from a neighboring tree only a few meters distant might produce only a few individuals, or none at all.

Data collection was limited by sampling methods. Branches collected per tree were limited to ten which, while higher than a similar study that was carried out in Louisiana, is not perfect when dealing with a pest species whose populations are as sporadically distributed within a tree as *A. lagerstroemia*e's are (Matos Franco 2020). In preliminary sampling of 40 trees to determine sample size, the change between standard error was less than .005. Similar results were seen when standard error was taken between branches within the same tree. However, in order to avoid excessive damage to the sample trees that would permanently affect the health of the plant and skew data, only ten branches were collected per tree. Excessive damage was also avoided because all trees sampled were on public or private property, and permission was acquired to sample them. Assurances were made that the trees would not be permanently damaged and any aesthetic damage from sampling would not be noticeable.

There were other limitations to the research in this thesis. The food web was constructed using published literature about arthropod diets. Many modern food webs are constructed with gut content analysis using polymerase chain reaction data (Juen and Traugott 2005, Lundgren et al. 2009, Zöllner et al. 2003). However, this method requires the use of species-specific genetic primers to match predator and prey (Hougendoorn and Heimpel 2001). Given the large and diverse number of arthropods sampled in this study, and limited time and resources for this project this method of food web construction was deemed unfeasible.

Despite the presence of diverse predators of *A. lagerstroemiae,* adequate scale control is inconsistent. Scale infestations still cause damage that affects the value of Lagerstroemia spp. in the ecosystem. Applications of systemic neonicotinoid insecticides and mechanical control using soap and water are the most commonly used methods of dealing with this pest (Cranshaw 1996, Wang et al. 2016). Chemical control via neonicotinoids can be expensive and may adversely affect pollinators and other beneficial insects (Matos Franco 2020, Cloyd and Bethke 2011, Yang et al. 2008). Biopesticides have been investigated, producing mixed results and adverse effects on natural enemies

(Matos Franco 2020). More insecticide research is ongoing to develop novel chemical control strategies (Vafaie and Knight 2017).

In the future classical biological control may prove useful for control of *A. lagerstroemiae.* This scale is native to East Asia and natural enemies from its native range, in particular parasitic Hymenoptera, are being examined as control agents. Parasitoid wasps are ideal for importation biological control because they are often specific to a small number of related species which limits their impact on native species (Conti et al. 2004, Greathead 1986). They are also efficient. Unlike insect predators such as coccinellids and chrysopids they do not require a large supply of prey to complete their life cycles: adult wasps typically consume nectar and similar sugary substances, while immatures require only a single host organism (Benelli 2017, Greathead 1986). No native parasitic Hymenoptera were reared from *A. lagerstroemiae* in this study despite the collection of numerous parasitic Hymenoptera reared from other arthropods in the samples. Competition for *A. lagerstroemiae* hosts would be non-existent in Texas.

Ant mutualism with scale insects is well documented and, as illustrated in the food web, several ant species are common in the environment, these include *Solenopsis invicta, Crematogaster laeviuscula* and *Brachymyrmex* spp. Ants tend hemipterans in many families for honeydew, and may attack or deter predators and parasitoids (Mgocheki and Addison, 2009). However, some ant species also consume scale insects and suppress their populations (Ozaki

2000). The exact relationship between ants and *A. lagerstroemiae* has not been researched, but should be examined if biological control measures using arthropod natural enemies are pursued.

Future *A. lagerstroemiae* research should be carried out to determine the methods the scale uses to colonize trees in new locations. Current knowledge of *A. lagerstroemiae*'s dispersal methods are sparse. Insects in the superfamily Coccoidea such as *Icerya seychellarum* (Westwood), *Dactylopius austrinus* (De Lotto), and *Pseudococcus longispinus* (Targioni-Tozzetti) use aeolian, or wind dispersal, to colonize new sites (Barras et al. 1994, Hill 1980, Mow et al. 1982). However, species that utilize aeolian dispersal often have long filaments to better catch the wind which *A. lagerstroemiae* crawlers lack. Laboratory experiments demonstrated the ability of armored scales, *Aspidiotus nerii* (Bouché) to cling to ants, flies and ladybeetles for extended periods of time (Magsig-Castillo et al., 2010). Larger animals, such as birds and mammals, are also possible means of transport for some scale insects (Greathead 1997). Over long distances human activities and transport likely play a role. The scale's presence in disparate urban and suburban areas across arid regions such as West Texas and New Mexico supports this. Educating horticulture industry suppliers about *A. lagerstroemiae* as well as monitoring and screening could reduce the transport of scale by the nursery trade and other human means of transport.

The studies performed in this research progressed our knowledge of *A. lagerstroemiae,* a pest of *Lagerstroemia* spp. a common tree in the Texas landscape widely utilized for its beauty and hardiness. Not all results were expected and the diversity of insects sampled from *Lagerstroemia* spp trees in the urban and suburban landscapes of this study was incredible. Based on landscape data collected the urban and suburban landscape is not particularly diverse in terms of plant species which makes the arthropod diversity all the more remarkable. The distribution of *A. lagerstroemiae* colonies was difficult to predict with the statistical analyses used. Based on observations this is not a condemnation of the analyses used, but a characteristic of *A. lagerstroemia*e's colonization patterns. The studies in this thesis are meant to serve as a foundation for future studies. There is a lot of research to be carried out, but researchers are learning more about this pest every day, and in light of studies in this thesis, future biological control methods such as importation biological control hold promise.

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