THE EFFECTS OF CULTIVAR DIVERSITY ON TURFGRASS VISUAL QUALITY, ARTHROPOD DIVERSITY, AND SOUTHERN CHINCH BUG (*BLISSUS INSULARIS*) ABUNDANCE IN ST. AUGUSTINEGRASS

By

BRIANNA MARIE WHITMAN

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To Colleen
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Abstract of Thesis Presented to the Graduate School
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THE EFFECTS OF CULTIVAR DIVERSITY ON TURFGRASS VISUAL QUALITY,
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By

Brianna Marie Whitman

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In the United States, turfgrass covers over 40 million acres and is the largest
irrigated crop. St. Augustinegrass, *Stenotaphrum secundatum* (Walt.) Kuntz, is the most
common turfgrass used in lawns in the southern U.S. and accounts for over 50% of the
sod produced in Florida. Warm-season turf is produced, planted, and maintained as
genotypic monocultures of different cultivated varieties. Over 80 percent of St.
Augustinegrass in Florida is a single cultivar “Floratam”. The practice of planting
monoculture lawns and the general lack to plant diversity in a lawn may predispose
lawns to insect pest attack. Controlling pests is important for maintaining healthy turf
and its beneficial ecosystem services to people and the environment. The southern
chinch bug, *Blissus insularis* Barber, is the most damaging insect pest of *St.
Augustinegrass*, reducing turf health and requiring insecticide applications to prevent
lawn death. One approach to managing pests with reduced inputs is increasing plant
diversity. Increasing genotypic diversity by mixing cultivars of St. Augustinegrass may
reduce pests by increasing natural enemies and reducing herbivore fitness, while also
conserving desirable lawn traits. Monocultures and two, and four cultivar mixtures were planted in a common garden experiment and surveyed for plant characteristics and arthropods. Insects were collected to measure community-level diversity and southern chinch bug abundance. Turfgrass quality was measured by digital image analysis and industry stakeholder surveys.

Total insect community richness was greatest in the four-cultivar mixture plots. Differences were not detected in southern chinch bug abundance between the treatments over the survey period. Visual analyses found that the four-cultivar mixture plots had significantly higher percent green cover and dark green color index (DGCI). Similarly, industry surveys showed that greater cultivar diversity was rated better than monoculture turfgrass plots. Our results suggest that mixing cultivars may increase overall insect richness, which may support greater ecosystem stability and reduce the need for supplemental turfgrass maintenance inputs. In addition, visual quality of mixed stands showed improvement over monoculture stands. Genotypically diverse lawns could provide a plausible integrated pest management strategy for urban landscapes.
Turfgrasses are grown on over 20 million hectares and are the largest irrigated crop in the United States. The U.S. turfgrass industry generates over $60 billion in annual revenue yields (Morris 2006). Florida, USA, has the largest turfgrass industry in the country, generating over $1 billion dollars annually (2014). Turfgrasses are arguably the most ubiquitous plant type in urban and residential landscapes (Wheeler et al. 2017), which are home to over 80% of people in the U.S. (2014). Importantly, healthy turfgrass provides many ecosystem services to people and the environment such as air filtration, carbon sequestration (Stier 2013), temperature reduction (Parker 1983), and soil stabilization (Beard 1994), which benefit human physical and mental health (Stier 2013). Therefore, protecting these ecosystem services through effective plant and pest management is critical for protecting human and environmental health in urban ecosystems.

Warm-season turfgrasses (C4 photosynthesis) are the predominant urban and residential lawn plant throughout the southern United States south of North Carolina and west to California (Christians 2011). Warm-season turfgrasses include bermudagrass (*Cynodon* spp. Rich), bahiagrass (*Paspalum notatum* Flugge), seashore paspalam (*Paspalum vaginatum* O. Swartz.), zoysiagrass (*Zoysia* spp. Willd.), carpetgrass (*Axonopus* spp.), centepedegrass (*Eremochloa orphiuroides* [Munro] Hack.), and St. Augustinegrass (*Stenotaphum secundatum* [Walt.] Kuntze) (McCarty 2004, Christians 2011). Each warm-season turfgrass species is used based on site-specific cultural requirements like salinity tolerance, maintenance intensity, or aesthetic quality. For example, bermudagrass and zoysiagrass are most frequently used in high
maintenance sites (i.e. athletic fields and golf courses), whereas bahiagrass and centipedegrass are more frequently used in low maintenance areas like roadsides or low-maintenance lawns (Christians 2011). In Florida, the most prevalent residential turfgrass species is St. Augustinegrass, which makes up over 50% of Florida sod production and 70% of residential lawns (Satterthwaite et al. 2009).

Although there is often miscommunication or debate about the provenance of St. Augustinegrass, it is presumed that most genotypes originated in Central America and the Mediterranean (Casler and Duncan 2003). St. Augustinegrass is reported to have been planted as a lawn in Florida as early as 1880 (Casler and Duncan 2003) and has since become the most dominant lawn species in the state (Hodges and Stevens 2010, Satterthwaite et al. 2010). This grass species is often preferred over others due to its relatively high shade tolerance and tolerance to a variety of soil conditions (Busey and Davis 1991). St. Augustinegrass has a stoloniferous growth habit, wide leaves with a blunt leaf tip, and a constricted collar. Unlike some other warm-season grasses, St. Augustinegrass produces few or no seeds and is therefore almost entirely vegetatively propagated (Christians 2011). This is done either by sodding, plugging, or sprigging (Trenholm 2017). The following are commercially available cultivars of St. Augustinegrass used in Florida:

**Bitterblue.** A common cultivar used throughout Florida that was originally selected in the 1930s. It has a dark, blue-green color and good shade and cold tolerance (White and Busey 1987, Trenholm 2017).
**Captiva.** Released by the Florida Agricultural Experiment Station in 2007. It is a dwarf cultivar with short, narrow, leaf blades with reduced vertical leaf extension. It is slow growing with a dark green color. It was originally released for its resistance to southern chinch bug (Nagata et al.) but is susceptible to diseases such as large patch (*Rhizoctonia solani*) (Flor 2009).

**Classic.** This is a proprietary cultivar released by Woerner Turf in the early 2000s. It has good cold tolerance and dark green color (Ferrell et al. 2009).

**Floratam.** This St. Augustinegrass cultivar was released by UF and Texas A&M in 1973 (Busey 1979). It is currently the most widely produced and planted St. Augustinegrass cultivar in Florida due to its resistance to southern chinch bug at the time of release (Busey 1979, Christians 2011). It is coarse textured with poor cold and shade tolerance compared to other cultivars with vigorous growth in the spring and summer. It is susceptible to gray leaf spot (*Pyricularia grisea*) and other diseases (Cherry et al. 2012).

**Palmetto.** This cultivar was found by a Florida sod grower in 1988 and later released in the mid-1990s. It is a semi-dwarf cultivar with shorter growth habit and internodes compared to other cultivars. It is neither disease nor pest resistant and does not do well in denser shade (Kirkland and Wagner 1995).

**Raleigh.** This cultivar, released by North Carolina State University in 1980, has a medium green color and coarse texture (Ferrell et al. 2009, Trenholm 2017). It is resistant to the virus St. Augustine Decline (SAD) (*Panicum mosaic virus*) (Christians 2011). It is susceptible to both southern chinch bug and large patch disease (*Rhizoctonia solani*) (Ferrell et al. 2009, Cherry et al. 2012). Highly susceptible to gray
leaf spot, it is more commonly used in northern Florida due to its cold tolerance (Cherry et al. 2012). However, it can yellow and grow less aggressively in high heat (Trenholm 2017).

**Seville.** This cultivar was released in 1980 by O.M. Scott and Sons Company. It is a dwarf cultivar with a low growth habit and wide leaf blade with a short leaf length. It is considered to have one of the darker green colors and retains color even at low fertility (Riordan et al. 1980). It is susceptible to southern chinch bug and sod webworm (*Toumeyella liriodendri* Gmelin) damage and is prone to thatch buildup. It is also more susceptible to cold damage than other cultivars (Busey 1995).

**Residential Lawns as Arthropod Habitat**

In addition to providing benefits for people and the environment, lawns also provide habitat for several important arthropods (Held and Potter 2012). For example, Carabid beetles, which include many predatory and omnivorous species, rely on grass habitats to support their populations in urban areas (Delgado de la Flor et al. 2017). Several other predatory arthropods like ants, spiders, and rove beetles are among the most abundant turfgrass-dwelling arthropods that occur in urban and residential lawns (Cherry 2006). Presence of these insects provides important ecosystem services like biological control of insect herbivore populations (Price 2011).

Although lawns harbor a diversity of beneficial arthropods, there are many pests that repeatedly outbreak and negatively affect St. Augustinegrass lawns (Held and Potter 2012). In fact, it is well established that several arthropod herbivores are frequently more abundant and damaging in urban than natural or rural landscapes (Raupp et al. 2010). Urban areas often contain high concentrations of preferred food sources with less competition from other herbivores (Barbosa et al. 2009).
systems, these herbivore pests most commonly include white grubs (*Cyclocephala* spp.), mole crickets (*Scapteriscus* spp.), southern chinch bugs, sod webworms, armyworms (*Spodoptera* spp.), and cutworms (*Agrotis ipsilon* Hufnagel, *Nephelodes minians* Guenée, and *Feltia subteranea* Fabricius) (Christians 2011).

Of all turfgrass arthropod pests that affect warm-season species, the most economically important is the southern chinch bug (*Blissus insularis* Barber). Insecticide applications targeting southern chinch bug and plant replacement due to damage, is estimated to cost homeowners and landscape industry professionals about five million dollars annually in Florida (Kaur 2013). Currently, many pest control operators make calendar-based, cover-spray application of insecticides up to six times per year in attempts to control southern chinch bug. As a result, management costs are high, but so is the risk for non-target effects on southern chinch bug, other organisms, and the environment (Cherry and Nagata 2005, Cherry and Nagata 2007, Vazquez et al. 2011). For example, despite multiple cultural and chemical pest control efforts, this insect has developed resistance to several insecticide classes and overcome host-plant resistance (Cherry and Nagata 2005, Cherry and Nagata 2007, Vazquez et al. 2011). Indiscriminate use of insecticides in urban and residential landscapes also presents risks to applicators, people, and beneficial insects (Desneux et al. 2007, Damalas and Eleftherohorinos 2011).

**Southern Chinch Bug Biology**

Southern chinch bug undergoes incomplete metamorphosis and therefore, has three life stages: egg, nymph, and adult. A female will deposit up to 300 eggs in her lifetime and average about 4.5 per day. Eggs are small, oblong, about 1 mm long, and laid singly on the soil surface, thatch layer, and on the leaves (Kerr 1966, Reinert and
Kerr 1973, Kaur 2013). They are initially whitish in color and gradually turn orange as they develop. After 8 to 25 days, depending on temperature, a nymph will emerge from an egg. Nymphs resemble the adult, but are different in color, size, and do not have wings. Southern chinch bug nymphs are initially bright red with a white stripe on the abdomen. Dependent upon temperature, it takes approximately 34 to 94 days to develop from a nymph to an adult, and as a nymph develops, its body darkens, becoming orange brown and then finally dark brown. Adults reach about 4.7 mm in length (Kerr 1966, Kaur 2013, Williamson et al. 2013). Adult southern chinch bugs may mature into brachypterous (short-winged) or macropterous (long-winged) forms (Williamson et al. 2013). Southern chinch bug can be distinguished from other Blissus spp. by the silvery gray pubescence or hairs on the front of the thorax (Kaur 2013).

Southern chinch bug development rate can vary because it is dependent on temperature and other seasonal differences. For example, southern chinch bug reaches adulthood more rapidly when temperatures are warmer. In northern Florida, southern chinch bugs are active from about March to October and have 3 to 4 generations a year. In southern Florida, warmer temperatures result in about 7 to 10 generations a year (Kerr 1966, Reinert and Kerr 1973). Southern chinch bugs live in groups or aggregates, which results in rapid, concentrated plant damage to a heavily-infested lawn. Even though macropterous adults can fly, southern chinch bugs often walk from one lawn to another. These insects tend to reside in the thatch layer where they are protected. However, when population densities are high, the bugs can be seen resting on leaf blades in the upper parts of the turfgrass canopy (Kerr 1966, Kaur 2013, Williamson et al. 2013, Kaur et al. 2016).
Cultural Maintenance of St. Augustinegrass

To grow a healthy planting of turfgrass and maximize its natural resistance to herbivore pest invasive and damage, plant must be maintained in compliance with evidence-based cultural practices. Mowing is an important cultural practice for maintaining turfgrasses. With standard St. Augustinegrass cultivars, a mowing height of 3 to 4 inches is recommended (Trenholm et al. 2017). Frequent mowing, so that no more than 1/3 of the leaf blade is removed at one time, will prevent the turf from becoming stressed, which may reduce defense against pests or its ability to compensate for damage. Mower blades must be kept sharp, so that the blades cut cleanly and facilitate plant recovery (Beard 1973). Clippings from mowing should be left on the lawn, since they break down easily, returning nutrients to the soil and grass roots, and do not contribute to thatch buildup (Beard 1973). Correct and consistent mowing practices prevent the grass from becoming stressed and increase tolerance to southern chinch bug and other insect pests (Potter 1998).

Thatch is a collection of turfgrass stolons, roots, and crowns in the top layer of the soil. Thatch accumulates quickly in lawns that are over fertilized or overwatered because both increase growth rates and the associated accumulation of plant material. If the thatch layer becomes too thick, it can prevent water, fertilizer, and pesticide infiltration, reducing their ability to reach their intended target. Thatch can be reduced by verticutting, which is when a mower with vertically oriented blades is used to slice through the thatch and into top of the soil. The dead material is then collected from the top of the lawn canopy and removed from the site (Christians 2011). Topdressing a lawn by applying a sand or soil mixture similar to the soil the turfgrass is growing is
another method for reducing thatch and preventing over-accumulation (Trenholm et al. 2017).

Proper irrigation is also key for maintaining healthy St. Augustinegrass plantings. While increased moisture and reduced drought stress can suppress southern chinch bug numbers, increased watering can also cause rapid plant growth and thatch accumulation, which may predispose the turf to other pest problems like fungal diseases. Fertilization is often recommended to keep St. Augustinegrass healthy and prevent stress that can lead to injury from southern chinch bugs. However, fertilizers should be applied in moderation and in compliance with UF/IFAS fertilizer BMPs (2010). Over-fertilization also causes rapid plant growth and thatch accumulation, which can benefit southern chinch bugs by providing them with an ideal microhabitat where they can reproduce and seek refuge from predators, parasitoids, and pesticide applications. Research has shown that higher levels of nitrogen applied to St. Augustinegrass plantings increases southern chinch bug abundance in Florida, which is consistent with other studies that identify a connection between sap-feeding insects and plant nutrient content (Kerr 1966, White 1984, Kaur et al. 2016).

**Southern chinch bug Management**

Early damage symptoms of southern chinch bug begin as patchy areas that yellow and eventually die over a period of days to weeks (Williamson et al. 2013). The turfgrass will initially appear to be drought-stressed from the bug feeding. The plants will discolor, wilt, and have stunted growth. These patchy areas are generally circular in shape, and damage symptoms will spread outward over time as the bugs move from the dying grass into healthy grass. Usually bright sunny areas in open locations are the first to be attacked by southern chinch bug.
An excellent and often-sought after cultural control strategy is the use of pest-resistant or tolerant plants. Pest-resistant turfgrass cultivars can better withstand damage and are not as easy for insects to feed and develop on. This can be because of higher concentrations of oxidative enzymes in the plant after insect feeding which can reduce tissue damage (Rangasamy et al. 2009). ‘Captiva’ is currently the only commercially available cultivar of St. Augustinegrass that is resistant to southern chinch bug (Rangasamy et al. 2006). Although pest-resistant cultivars can provide an excellent integrated pest management (IPM) tool, they cannot succeed as the only approach. For example, ‘Floratam’ St. Augustinegrass was resistant to southern chinch bug when released in Florida in 1973. However, after widespread planting throughout Florida, populations of southern chinch bug overcame host plant resistance within 15 years (Busey and Center 1987).

Fortunately, several predatory and parasitic insects naturally attack and control southern chinch bug in turfgrass systems (Reinert 1978). One of the most common are big-eyed bugs, *Geocoris* spp., predators that resemble southern chinch bug, but actively feed on them (Kerr 1966, Reinert 1978, Williamson et al. 2013). Two species of minute pirate bug, *Xylocoris vicarious* and *Lasiochilus pallidulus*, have been found to reduce *Southern chinch bug* populations (Kaur 2013). Other generalist predators such as the striped earwig *Libiura riparia* (Pallas), and *Sinea* spp. assassin bugs have been observed attacking southern chinch bugs in Florida (Reinert 1978). Sometimes populations of the red imported fire ant, *Solenopsis invicta*, can control southern chinch bug. However, fire ants must be highly abundant, which is typically not acceptable or safe in lawns (Kerr 1966, Reinert 1978, Kaur 2013). There is only one known parasite of
southern chinch bug, a wasp, *Eumicrosoma benefica* Gahan, which parasitizes chinch bug eggs. The wasp is present in Florida and can be found associated with southern chinch bug populations in lawns (Reinert 1972, Cherry 2011).

Despite the prevalence of natural enemies, the turfgrass industry predominantly relies on insecticides for managing southern chinch bugs in Florida lawns. This is primarily due to a lack of effective and easily-implemented alternatives and the frequency of southern chinch bug outbreaks. Many pest management professionals rely on preventive, calendar-based, cover-spray applications of insecticide to ensure pest management success. Previous research has determined that such calendar-based, broad-spectrum applications are not environmentally or economically sustainable, and often contribute to more severe or recurring pest problems (Raupp et al. 2001). Over time *Southern chinch bug* populations have developed resistance to insecticides from repeated exposure, including pyrethroids, neonicitinoids, organochlorines, and organophosphates (Cherry and Nagata 2005, Cherry and Nagata 2007, Vazquez et al. 2011). Therefore, it is highly recommended that insecticides with different modes of action, or insecticide resistance action committee (IRAC) classification numbers, be rotated in a management program. That way, chinch bugs are less able to develop resistance to the insecticides professionals depend on (Kaur 2013, Williamson et al. 2013).

To reduce risks of non-target effects of insecticide applications on beneficial arthropods, natural resources, and people and increase the longevity of healthy plants, an IPM approach is necessary (Raupp et al. 2001, Desneux et al. 2007, Christians 2011, Damalas and Eleftherohorinos 2011). For example, making spot treatments of
insecticides in locations where southern chinch bug are abundant concentrates insecticides on the pests, reduces exposure to non-target organisms, and conserves product and money (Kerr 1966). The most effective pest control tactics that reduce chemical inputs and promote plant health and defense against insect pests and other stress factors are preventive cultural practice. In urban landscapes, one of the most important cultural practices is proper plant selection (Raupp et al. 1992, Dale et al. 2016), which can include manipulating plant diversity to increase the resilience of a plant community to biotic or abiotic stress factors (Andow 1991, Barbosa et al. 2009, Tooker and Frank 2012).

**Effects of Plant Diversity on Insect Ecology in Residential Landscapes**

In general, arthropod diversity declines with urbanization due to a combination of reduced plant diversity, maintenance inputs, and habitat fragmentation (McIntyre et al. 2001, Avolio et al. 2018). One factor attributed to this decline in arthropod diversity is a loss of plant diversity and structural complexity associated with urban development. Greater plant diversity can support greater arthropod abundance and diversity by providing habitat refuges and supplemental resources (Sattler et al. 2010a., Smith 2014, Williams et al. 2014). Declines in plant diversity can select for individual species which utilize the remaining plant species. This process simplifies arthropod richness and biodiversity (Sadler et al. 2006, Haddad et al. 2009, Knop 2016). A loss of biodiversity can reduce the ecosystem services those organisms provide, such as decomposition, pollination, and pest control (Sattler et al. 2010b., Martinson and Raupp 2013, Harrison et al. 2014). Therefore, creating landscapes with more diverse plant communities may conserve arthropods and contribute to more stable ecosystems within highly disturbed

Unfortunately, urban and residential landscapes are frequently dominated by one or few plant species (Raupp et al. 2006), which may predispose those landscapes to colonization and attack from plant pests. For example, widespread plantings of American elm (Ulmus americana Chapm) were decimated by the introduction of Dutch Elm Disease (Ophiostoma ulmi [Buisman] Nannfeldt) vectored by the elm bark beetle (Scolytus multistriatus Marsham) causing over 80 percent urban forest tree loss in some areas (Strobel and Lanier 1981, Hubbes 1999). Similarly, the overuse of single or few turfgrass species and cultivars in lawns may predispose these landscapes to large scale impacts under the right pest threat. However, this risk may be masked by our ability to rapidly produce and replant turfgrasses and the small physical size of the plants compared to trees.

Turfgrass monocultures dominate residential lawns throughout the country, although species identity varies by geographic region. Despite this geographic variability, it was recently documented that residential lawn plant communities are highly similar across the entire U.S. (Wheeler et al. 2017). In warm-season turfgrass systems, plants are produced by vegetative propagation, so they have limited diversity since they are genetic replicates of the parent plant (Christians 2011, Hartmann et al. 2011). Although there are multiple benefits associated with producing and planting turfgrasses in monoculture (e.g., conserving favorable traits), there are also documented benefits associated with mixing cool season turfgrass species or varieties. For example, Kentucky bluegrass (Poa pratensis L.) and fine fescue (Festuca spp.) are often seeded
together as the Kentucky bluegrass cultivars do better in sunny areas while fine fescue cultivars are better adapted to shade (Hunt and Dunn 1993, Christians 2011). These mixtures are possible because cool-season grasses are phenotypically similar, therefore aesthetic quality is not lost (Christians 2011). Furthermore, Thompson and Kao-Kniffin (2016) found that increasing diversity in cool season turfgrasses by mixing fescues, bluegrasses, and perennial rye grass (Lolium perenne L.), reduced nitrate leaching and increased biomass.

Effects of Plant Diversity on Aesthetics/Importance of Aesthetics

Increasing turfgrass diversity may be an effective strategy for reducing impacts of biotic and abiotic stressors and the need for supplemental maintenance inputs (Baker 1991, Peacock and Herrick 2000, Tooker and Frank 2012). However, aesthetic quality is a primary driver of turfgrass marketability and consumer demand. Visual uniformity is an important factor in aesthetic quality and preference (Kader 2002, Bauerly and Liu 2008, Creusen et al. 2010). Florida has the highest number of homeowner associations (HOAs) in the U.S., with about 46 percent of people living within some type of association (2014, 2016). Many HOAs have landscaping aesthetic requirements, which presents a challenge for using lawns with interspecific turfgrass mixtures. Therefore, mixing different warm season turfgrass species may not meet consumer and association demands, thereby reducing implementation.

One must consider the morphological characteristics, like texture, color, and growth, but also the species-specific maintenance requirements like mowing height, fertilization, or irrigation. For example, variation in texture, color, and growth habit makes matching aesthetic qualities of Zoysia spp., Cynodon spp., Paspalum spp., or St. Augustinegrass very difficult (Christians 2011). Mowing a grass too low can result in
stress and increase biotic or abiotic pressure, while mowing too high can reduce aesthetic quality and increase thatch accumulation (Salaiz et al. 1995, Liu and Huang 2002). Pesticide use in warm-season turfgrass interspecific mixtures may also present challenges because some herbicides such as flazasulfuron, sulfentrazone quinclorac, and carfentrazone quinclorac can be applied to *Cynodon* spp. and *Zoysia* spp., but not *St. Augustinegrass* (Katana Turf Herbicide: Use Label, Solitare Herbicide: Use Label, SquareOne Hebicide: Use Label). The herbicide ethofumesate and the fungicide tebuconazole can be applied to *St. Augustinegrass* but will cause damage to *Cynodon* spp. (Prograss: Use Label, Torque Fungicide: Use Label).

**Research Objectives**

Despite evidence of benefits in other horticultural and agricultural systems, little research has investigated mixing warm-season grasses as a cultural management tactic (Andow 1991, Baker 1991, Peacock and Herrick 2000, Zhu et al. 2000, Randlkofe et al. 2010). The limited research on warm-season turfgrasses has found that planting multiple warm-season species together can translate to greater foliage density and reduced weed invasion (Stott et al. 2010, Simmons et al. 2011). However, the turfgrass industry is primarily driven by aesthetic quality and maintenance uniformity, which is unlikely to be met with interspecific plantings. Therefore, it can be argued that increasing intraspecific diversity in warm-season lawns may provide ecological and pest management benefits while meeting industry demands (Tooker and Frank 2012). Our first objective was to determine if increased genetic diversity would increase arthropod abundance, richness, and diversity, as well as to determine effects on *Southern chinch bug* abundance. To test this, we set up a common garden field
experiment to determine the effects of St. Augustinegrass cultivar diversity on southern chinch bug abundance, arthropod communities, and turfgrass quality. We hypothesized that southern chinch bug abundance would decrease as St. Augustinegrass diversity increased and that the abundance and diversity of other beneficial arthropods would increase. The second objective was to determine if cultivar mixtures would impact aesthetic quality. It was hypothesized that turfgrass visual quality would be maintained in cultivar mixtures compared to monocultures.
CHAPTER 2
EFFECTS OF TURFGRASS CULTIVAR DIVERSITY ON INSECT PEST ABUNDANCE AND ARTHROPOD DIVERSITY

As the most ubiquitous residential landscape plant, turfgrasses provide many benefits to people and the environment, such as filtering the air, sequestering carbon (Stier et al. 2013), reducing temperatures (Parker 1983), and mitigating soil erosion (Beard and Green 1994). These services are particularly important in urban landscapes where roads, buildings, and other impervious surfaces are rapidly replacing vegetation (Nowak and Greenfield 2012). For example, Parker (1983) found that turfgrasses adjacent to residential homes reduced the amount of energy needed for air conditioning by 50 percent. Urban green spaces also benefit human physical and mental health by encouraging physical activity and reducing stress (Stier et al. 2013). These spaces also support important wildlife like carabid beetles, who rely on grass habitats for refuge in urban areas (Delgado de la Flor et al. 2017). However, dead or dying plants, a frequent occurrence under stressful biotic and abiotic conditions, do not provide these benefits (Grimm et al. 2008, Dale and Frank 2014). Since urban and residential landscapes are the most rapidly expanding land use type in the U.S. and turfgrasses are arguably the most abundant plant type in these spaces, it is important to identify strategies to manage them more sustainably (Brown et al. 2005).

Warm-season turfgrasses (C4 photosynthesis) are the predominant urban and residential lawn plant throughout the southern United States south of North Carolina and west to California (Christians 2011). Most warm-season turfgrasses are generally grown from vegetative cuttings, which results in genetically identical stands of plant material (Castler and Duncan 2003, Christians 2011). Among these, the most common species is St. Augustinegrass (Stenotaphrum secundatum [Walt] Kuntze) (McCarty et
al. 2004). In Florida St. Augustinegrass comprises 50 percent of all sod production and 70 percent of residential lawns, of which, 81 percent is the single cultivar, ‘Floratam’ (Satterwaite et al. 2009). Thus, plant diversity is relatively low in urban and residential lawns throughout Florida and the southern United States. This widespread homogenous planting provides herbivorous insects that specialize on St. Augustinegrass with an abundant food source and few feeding deterrents to overcome (Root 1973). These plant pests may easily move from plant to plant and overcome resistance of a single cultivar planted en masse (Andow 1991, Tooker and Frank 2012). Therefore, monoculture lawns may result in chronic pest pressure that requires frequent and recurring pesticide applications.

In general, arthropod diversity declines with increasing urbanization (McKinney 2008, Martinson and Raupp 2013). One factor often attributed to this decline is a reduction in plant diversity (McIntyre et al. 2001). More diverse plant communities support more abundant and diverse arthropod communities by providing habitat refuges and food resources (Sattler et al. 2010a, Smith et al. 2014, Williams et al. 2014). As plant diversity declines, it selects for insect species who can utilize the remaining plant species, often simplifying arthropod richness and diversity (Sadler et al. 2006, Haddad et al. 2009, Knop 2016). Biodiversity is important because diverse and abundant organisms provide multiple valuable ecosystem services in the form of decomposition, pollination, and pest control (Sattler et al. 2010b, Martinson and Raupp 2013, Harrison et al. 2014). Therefore, creating landscapes with more diverse plant communities may provide arthropod conservation benefits and more stable ecosystems within highly
Due to the elevated pest pressure and the high risk associated insect pest outbreaks in lawns, maintenance professionals often rely on preventive, cover-spray chemical applications to control herbivorous pests and maintain high aesthetic standards (Reynolds et al. 2015). Evidence indicates that repeat cover-spray insecticide applications cause pesticide resistance in key pest populations (e.g., southern chinch bug, *Tetranychus urticae*, and others), making those pesticides ineffective (Desneux et al. 2007, Damalas and Eleftherohorinos 2011). Moreover, cover-spray applications can kill natural enemies, resulting in secondary pest outbreaks, which further reduce plant health and require additional pesticide use (Raupp et al. 2001, Desneux et al. 2007, Damalas and Eleftherohorinos 2011). The most effective pest control tactics that reduce chemical inputs are preventive cultural practices that promote plant and ecosystem health and resilience to biotic and abiotic stress. As described above, increasing plant diversity may reduce herbivore pest pressure and promote more diverse and functional arthropod communities that provide valuable services and reduce the need for supplemental management (Tahvanainen and Root 1972, Root 1973).

*Blissus insularis* Barber (Hemiptera: Blissidae) is the most economically important insect pest of lawns in the southeastern United States, largely due to the prevalence of its primary host plant St. Augustinegrass (Cherry and Nagata 2005). Southern chinch bugs feed on plant phloem, causing drought stress-like symptoms and resulting in rapid chlorosis, wilting, and death (Kerr 1966, Rangasamy et al. 2009, Kaur 2013, Williamson et al. 2013). Due to the high risk associated with rapid damage, over
five million dollars is spent annually in southern chinch bug control in Florida alone (Kaur 2013). Reliance on preventive insecticide applications has led to multiple populations of southern chinch bug resistant to the most effective tools for controlling this pest (Cherry and Nagata 2005, Cherry and Nagata 2007, and Vazquez et al. 2011). Although cultural management practices such as proper plant maintenance can reduce southern chinch bug pressure, effective integrated pest management (IPM) practices are limited and rarely practical.

Florida sod growers currently produce six genera of warm-season turfgrasses, which are heavily biased towards one species, St. Augustinegrass (Satterthwaite et al. 2009). St. Augustinegrass is the most common residential, business, and urban lawn species, which are the most rapidly expanding land use types in Florida. Within St. Augustinegrass, there are trait variations associated with genetic differences that lead to cultivar differences in shade tolerance (Busey and Davis 1991), drought resistance and survival (Atkins et al. 1991, Miller and McCarty 2001), and salinity tolerance (Dudeck et al. 1993). Moreover, cultivars vary in tolerance to biotic pests like southern chinch bug (Reinert and Dudeck 1974), sting nematode (Belonolaimus longicaudatus Rau) (Busey et al. 1993), and pathogens (Atilano and Busey 1983).

The most economically important insect pest of turfgrasses in the southern U.S. is a sap-feeding pest, the southern chinch bug (Kerr and Robinson 1958, Reinert 1982, Reinert and Dudeck 1974, Crocker 1993). These insects primarily feed on St. Augustinegrass and have developed resistance to cultural and chemical control tactics, which makes them particularly challenging to manage (Busey 1990, Nagata and Cherry 1999). This is largely due to their rapid development, relative sedentary behavior, and
the widespread abundance of their host plant in urban and residential lawns (Kerr 1966, Busey 1990).

Several arthropod groups rely on grasses for their primary habitat, particularly in urban landscapes. Among the most prevalent arthropods are predators like carabid beetles, staphylinid beetles, spiders, ants, and earwigs (Cherry 2006). Important detritivores like collembola and oribatid mites also utilized grass habitat and break down organic material, which helps preserve lawn quality and promote plant health (Stork and Eggleton 1992). In addition, several herbivores that do not cause economic damage utilize these spaces as habitat refuges and food resources, which provides food for other predators and serves an important ecological function in the broader urban ecosystem (Andow 1991, Crutsinger et al. 2006, Barbosa et al. 2009).

New IPM approaches like increasing lawn diversity may mitigate the negative effects of southern chinch bug and protect the valuable ecosystem services that lawns provide. Here, the objective was to determine if mixing St. Augustinegrass cultivars affected lawn insect communities, particularly pest and beneficial species. To test this, a common garden field experiment was set up and data was collected on southern chinch bug abundance and arthropod diversity over one year. It was hypothesized that southern chinch bug abundance would decrease as St. Augustinegrass diversity increased and that the abundance and diversity of other beneficial arthropods would increase.

**Materials and Methods**

**Study Design**

To determine the effects of St. Augustinegrass cultivar diversity on arthropod communities and southern chinch bug abundance, a common garden field experiment
was conducted at the University of Florida Plant Science Research and Education Unit in Citra, Florida. In November 2016, St. Augustinegrass cultivars were planted in 3m x 3m plots (Figure 1) at three different levels of cultivar diversity using six of the most common commercially produced St. Augustinegrass cultivars: ‘Floratam’, ‘Bitterblue’, ‘Palmetto’, ‘Classic’, ‘Captiva’, and ‘Seville’. The monoculture (M1) treatment consisted of two or three replicates of each cultivar planted as monocultures (n=15). The mixture of two cultivars (M2) treatment consisted of all combinations of two cultivars from the pool of six, resulting in 15 unique combinations (n=15). The mixture of four cultivars (M4) treatment consisted of all combinations of four cultivars from the pool of six, also resulting in 15 unique combinations (n=15). Therefore, plots assigned to the same level of diversity varied in their cultivar composition, although only the effect of diversity was measured.

The experiment was a complete randomized block design with 15 blocks and 3 treatments, each replicated 15 times, for a total of 45 plots (Figure 2-1). Cultivars within a plot were planted as 15 cm plugs, 30 cm apart and randomly assigned a location at 0.3 m spacings, per 0.4 m² to ensure equal and unbiased distribution within a plot (100 plugs per 3m x 3m plot). Each plot was separated by a 1 m alleyway of bare soil maintained with glyphosate and manual edging. Plots were watered as needed. Hand weeding was done from November 2016 to June 2017. Herbicide (Ronstar-G) was used throughout to control weeds as needed. Grasses were maintained at a 7.6 to 10 cm mowing height weekly with a zero-turn mower.

**Arthropod Surveys**

Field plots were surveyed for arthropods monthly from April 2017 to August 2017 using pitfall traps made of a 50 ml plastic centrifuge tube filled with 20 ml propylene glycol.
Pitfall traps were placed in the center of each plot, level with the soil surface for one week, once per month. Collected specimens were sorted, identified to family, and counted in the lab under a stereo microscope.

Field plots were also surveyed for arthropods monthly from July through September 2017 using a vacuum sampling technique by converting a leaf blower to a landscape vacuum (STIHL, Virginia Beach, VA). Collected specimens were captured in a mesh bag, which was kept in a cooler in the field. In the laboratory, contents were transferred to 50 ml centrifuge tubes and preserved in 70% ethanol. All collected specimens were sorted, identified to family, and counted in the lab, along with southern chinch bug collected in vacuum samples per plot on each date.

**Statistical Analysis**

To determine the effects of St. Augustinegrass diversity on arthropod communities inhabiting these plantings, all collected arthropods were categorized into functional groups (community, herbivores, predators) and quantified abundance, family-level richness, and Shannon’s H diversity index for each plot. To determine the effect of cultivar diversity on each of these measures, an analysis of variance (ANOVA) was conducted with *St. Augustinegrass* cultivar diversity level as a main effect and block as a random effect. If ANOVA detected a significant main effect, Tukey’s HSD was used for post-hoc means comparisons to determine if there were differences between cultivar diversity levels. Repeated measures ANOVA was used to determine if there was an effect of time on arthropod communities and if any effects of cultivar diversity level were dependent on time. Alpha was 0.05 for all analyses.
**Results**

**Arthropod Community**

A total of 10,831 individuals were collected from the pitfall traps across all sampling dates. Fifty-two different arthropod families were identified, representing natural enemies, herbivores, and detritivores. Detritivores were the most abundant functional group collected, primarily composed of springtails (Collembola: Isotomidae) and oribatid mites (Acari: Oribatidae). Isotomidae comprised 69 percent of the total arthropods surveyed, while Oribatidae and Labiduridae were second most abundant, each representing 5 percent of the total arthropods collected in pitfall traps.

In pitfall survey data, arthropod abundance, richness, and diversity increased over time in all St. Augustinegrass cultivar diversity treatments (abundance: $F_{4,198.9}=5.76$, $P=0.0002$; richness: $F_{4,198.8}=16.22$, $P<0.0001$; diversity: $F_{4,198.3}=11.96$, $P<0.0001$) (Table 2-1). Arthropod abundance was greatest during June and July, and richness and diversity were greatest in August (Table 2-1). Differences in total arthropod abundance and diversity between St. Augustinegrass diversity treatments were detected. However, there was an effect of St. Augustinegrass diversity on arthropod community richness ($F_{2,200.5}=4.27$, $P=0.0125$) (Figure 2-2), such that plots composed of a mixture of four cultivars (M4) supported significantly more arthropod families than the plots composed of two cultivars (M2). Monoculture (M1) plots did not differ from either M2 or M4 treatment plots in arthropod community richness (Table 2-2).

In total, 92,691 individuals were collected using the vacuum surveys across all sampling dates, July through September 2017. A total of 92 different arthropod families were identified, composed of individuals representing natural enemies, herbivores, and detritivores. The most numerous families were Oribatidae (decomposer), Formicidae
(predator), and Cicadellidae (herbivore), representing 30, 13, and 11 percent, respectively. Collembola were not counted in the vacuum survey samples since they were well-represented in the pitfall trap data and vacuuming is not as effective of a survey method for Collembola. Vacuum sample arthropod community abundance and richness increased significantly over time (abundance: $F_{2,114.2}=53.88$, $P<0.0001$; richness: $F_{2,114.1}=53.79$, $P<0.0001$) while the diversity of arthropods decreased ($F_{2,113.9}=4.91$, $P=0.0090$) (Table 2-3). Significant differences between St. Augustinegrass diversity treatments were not detected (Table 2-4).

**Predators**

Arthropod natural enemies collected in pitfall traps contained 2,010 total individuals representing 18 families. Labiduridae, or striped earwigs, were the most abundant family, making up 26 percent of all natural enemies. Labiduridae is an introduced family of generalist predators (Shepard et al. 1973, Tripplethorn and Johnson 2005). The second most abundant family were predatory mites in the family, Phytoseiidae, representing 20 percent of the total, followed by predatory beetles in the family Staphylinidae, which comprised 15 percent. Finally, ants (Formicidae) represented 13 percent of all predators collected in pitfall traps. In general, predator abundance, richness, and diversity increased over time (abundance: $F_{4,198}=9.33$, $P<0.0001$; richness: $F_{4,196.6}=9.79$, $P<0.0001$; diversity: $F_{4,196.4}=5.61$, $P=0.0003$). Peak abundance occurred in June and July, while richness and diversity were highest in August (Table 2-1). Differences in pitfall-collected predator communities between St. Augustinegrass cultivar diversity treatments were not found (Table 2-2).

Predators collected using vacuum plot surveys numbered 25,107 individuals among 40 families. The most abundant family was Formicidae, representing 48 percent
of the total. Spiders in the families, Agelenidae and Lycosidae, represented 18 and 10 percent of the total, respectively. Again, predator abundance and richness significantly increased over time (abundance: $F_{2,114.2}=135.72$, $P<0.0001$; richness: $F_{2,114.2}=58.16$, $P<0.0001$) while diversity decreased over time ($F_{2,114}=3.56$, $P=0.0315$), such that September samples were least diverse while July represented the most diverse predator community (Table 2-3). Differences between St. Augustinegrass cultivar diversity treatments in natural enemy abundance, richness, or diversity collected with insect vacuum sampling were not found (Table 2-4).

**Herbivores**

In total, 375 individual insect herbivores from 17 families were collected in our pitfall traps across all sampling dates. The most abundant families were Gryllidae (27%), Miridae (16%), Cicadellidae (13%), and Pseudococcidae (11%). Herbivore abundance decreased over time ($F_{4,197.7}=15.50$, $P<0.0001$), with the greatest abundance occurring in April (Table 2-1). Herbivore abundance did not differ between sampling dates from May to August. Herbivore richness and diversity also decreased over time (richness: $F_{4,198.1}=10.45$, $P<0.0001$; diversity: $F_{4,198.1}=9.75$, $P<0.0001$) (Table 2-1) with the April sampling date being significantly different from the August sampling date. However, richness and diversity began to increase again late in the season. On average over the sampling period, St. Augustinegrass cultivar diversity treatments significantly differed in herbivore richness ($F_{2,197.4}=3.32$, $P=0.0380$) (Table 2-2). The monoculture (M1) treatment supported the greatest number of herbivore families, while the two cultivar (M2) treatment supported the least. There was no difference between the four cultivar (M4) treatment and either the M1 or M2 treatments. In contrast, no
differences were found between St. Augustinegrass diversity treatments in herbivore abundance or diversity (Table 2-2).

Insect herbivores collected using insect vacuum sampling numbered 24,246 individuals among 28 families. Cicadellidae was the most abundant at 57 percent followed by Cecidomyiidae which represented 29 percent of herbivores collected. Over time, abundance and richness increased (abundance: $F_{2,114.1}=25.97, P<0.0001$; richness: $F_{2,113.9}=5.69, P=0.0044$) (Table 2-3) with July representing the lowest herbivore abundance and richness and August and September having the greatest. Diversity decreased ($F_{2,113.9}=10.32, P<0.0001$) (Table 2-3) over time with July representing the most diverse herbivore community. No difference were found in vacuum samples between St. Augustinegrass diversity treatments in abundance, richness, or diversity (Table 2-4).

Southern chinch bug

Although not highly abundant, we collected 281 individual southern chinch bugs using the insect vacuum surveys and did not capture any southern chinch bugs in our pitfall traps. Average southern chinch bug abundance per plot ranged from 0 to 59 with a mean 10.35 ($\pm 0.93$). Importantly, southern chinch bug abundance increased significantly over time ($F_{2,1004}=4.58, P=0.0120$) (Figure 2-3). Interestingly, southern chinch bug abundance quantitatively increased with St. Augustinegrass cultivar diversity on all dates (Figure 2-3), although we did not detect a statistical difference between treatments on any date.
Discussion

Reduced arthropod diversity in urban ecosystems has been attributed to reduced plant diversity or a lack of native plant species (McIntyre et al. 2001, McKinney 2008, Martinson and Raupp 2013). This study tested the hypothesis that increasing the genotypic diversity of a cosmopolitan turfgrass species would increase arthropod diversity. The results suggest that time was the most important factor associated with increasing overall arthropod abundance and richness, indicating successful colonization and establishment by arthropods across all diversity levels. Arthropod diversity also increased over time in the pitfall samples, although the opposite trend in the insect vacuum samples was observed. Study results found that increasing cultivar diversity does not have a negative impact on biodiversity in lawns. Plots with the highest cultivar diversity (M4) resulted in community richness and diversity that was similar to monoculture plots. Arthropod community abundance was highest in the monoculture treatment, but diversity and richness were not, suggesting that monocultures may be likely to be dominated by one or few arthropod groups. These results are in line with the results found in Bennett and Gratton (2013), who surveyed beneficial arthropods in one, two, and seven species mixtures of upper-Midwest prairie native flowers and found that the greatest plant diversity supported the greatest beneficial arthropod richness. While there were few differences between the monoculture and polyculture plots with respect to arthropod diversity and richness, results indicate that increasing the cultivar diversity of warm-season lawns may have an effect on arthropod communities in urban landscapes.
Predatory arthropods are an important component of any arthropod community and are highly desirable to reduce plant pests (Martinson and Raupp 2013). Previous studies have found that Formicidae, Linyphidae, Lycosidae, Carabidae, Staphylinidae, Histeridae, Cicindelidae and Dermaptera are the most common and active predatory arthropods in turfgrass systems (Reinert 1978, Terry et al. 1993, Cherry 2006). The pitfall and vacuum survey results support previous findings and indicate that the same primary natural enemies inhabited our plots. Predator abundance, richness, and diversity increased over time across all cultivar diversity treatments. Although differences in St. Augustinegrass cultivar diversity treatments were not detected, pitfall samples indicate that mixtures of four St. Augustinegrass cultivars (M4) had the greatest predator abundance, richness, diversity. Interestingly, predator abundance, richness, and diversity in the pitfall traps was lowest in the second highest diversity treatment (M2). This reduction in predator abundance, richness, and diversity within the M2 treatment was unexpected since previous studies have shown that predator abundance and richness increases with increasing plant community diversity (Haddad et al. 2009). Future studies should expand the investigation of the relationship between cultivar diversity and resulting predator abundance, richness, and diversity to determine stand maturity and/or plot size may better explain this relationship.

While herbivore pests are not desirable in the landscape because they can cause plant damage, greater herbivore richness and diversity can also indicate a more stable ecosystem that is less prone to pest outbreaks (Raupp et al. 2010). Effects of cultivar diversity on herbivores were highly variable, preventing the detection of many effects. In contrast to the arthropod community and natural enemies, the pitfall surveys suggest
that herbivore abundance, richness, and diversity decreased initially over time and then was maintained. Though not statistically significant, the vacuum surveys indicated that St. Augustinegrass monocultures tended toward having the least rich and least diverse herbivore communities and the mix of four cultivars (M4) tended toward supporting the most rich herbivore communities. This is similar to other studies that showed that richness and diversity increases with greater plant diversity (Haddad et al. 2009). Declining herbivore richness and diversity over time suggests that one or few herbivores were becoming more abundant and dominating the community. This is supported by the fact that the families Ciccadellidae and Cecidomyiidae account for over 85 percent of total herbivores. In fact, this is a frequent occurrence in St. Augustinegrass lawns where southern chinch bug outbreak and cause significant economic damage (Busey and Center 1987, Cherry and Nagata 2007).

Southern chinch bug frequently infest lawns and rapidly cause plant death if not controlled with insecticides. Although none of the plots were attacked and damaged by this pest, southern chinch bugs became more abundant over time across all St. Augustinegrass diversity levels. This reflects plot colonization since plots were planted relatively free of southern chinch bug. No effects of St. Augustinegrass cultivar diversity treatments were detected, although southern chinch bugs were numerically increasing as cultivar diversity increased on all sampling dates (Figure 2-3). Although increased plant diversity can reduce herbivore pest abundance, this effect on herbivores may be species or cultivar specific (Peacock and Herrick 2000, Grettenberger and Tooker 2016). It was predicted that southern chinch bug would become less abundant with increasing St. Augustinegrass cultivar diversity. Although we did not detect an effect,
the trends suggest that southern chinch bug abundance may become different between treatments over time, where the most diverse planting supports the highest southern chinch bug abundance, in contrast to prediction.

Contrary to the hypothesis, southern chinch bug was not affected by increasing cultivar diversity. In fact, they became slightly more abundant with increasing diversity. These results may be explained by the relatively low number of cultivars used in the diversity mixtures. In other studies, the most diverse treatments had between 5 and 16 species or genotypes (Peacock and Herrick 2000, Haddad et al. 2009, Bennet and Gratton 2013, Smith et al. 2014). Effects on arthropod diversity could be more obvious with greater plant diversity and also over more extended time periods. However, the ability to increase St. Augustinegrass cultivar diversity is limited given the number of commercially available cultivars. Future studies should investigate more diverse stands of St. Augustinegrass over longer time scales. Additionally, since the turfgrass industry is largely driven by aesthetic quality and maintenance uniformity, further research must investigate how manipulating St. Augustinegrass cultivar diversity affects lawn quality.
Table 2-1. Pitfall sample arthropod community, herbivore, and predator abundance, richness, and diversity for each sampling date. Letters indicate significant differences (P<0.05).

<table>
<thead>
<tr>
<th>Date</th>
<th>Community Abundance (±SD)</th>
<th>Community Richness (±SD)</th>
<th>Community Diversity (±SD)</th>
<th>Herbivore Abundance</th>
<th>Herbivore Richness (±SD)</th>
<th>Herbivore Diversity (±SD)</th>
<th>Predator Abundance</th>
<th>Predator Richness (±SD)</th>
<th>Predator Diversity (±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>50.72 (±8.86)abc</td>
<td>6.10 (±0.30)ab</td>
<td>0.99 (±0.06)a</td>
<td>4.49</td>
<td>0.40 (±0.16)a</td>
<td>0.99 (±0.06)a</td>
<td>4.95</td>
<td>2.56 (±0.20)ab</td>
<td>0.82 (±0.07)ab</td>
</tr>
<tr>
<td>May</td>
<td>31.02 (±4.47)c</td>
<td>4.86 (±0.27)b</td>
<td>0.98 (±0.05)a</td>
<td>0.81</td>
<td>0.51 (±0.09)b</td>
<td>0.03 (±0.02)b</td>
<td>6.66</td>
<td>2.47 (±0.18)b</td>
<td>0.62 (±0.07)a</td>
</tr>
<tr>
<td>June</td>
<td>70.29 (±8.78)a</td>
<td>7.47 (±0.31)cd</td>
<td>1.11 (±0.05)a</td>
<td>1.18</td>
<td>0.76 (±0.11)bc</td>
<td>0.11 (±0.04)bc</td>
<td>14.02</td>
<td>3.87 (±0.20)c</td>
<td>0.80 (±0.05)ab</td>
</tr>
<tr>
<td>July</td>
<td>60.64 (±6.63)ab</td>
<td>6.71 (±0.41)ad</td>
<td>1.06 (±0.05)a</td>
<td>0.80</td>
<td>0.67 (±0.12)bc</td>
<td>0.11 (±0.04)bc</td>
<td>11.11</td>
<td>3.36 (±0.29)ac</td>
<td>0.70 (±0.07)a</td>
</tr>
<tr>
<td>August</td>
<td>36.16 (±2.85)bc</td>
<td>8.36 (±0.38)c</td>
<td>1.43 (±0.06)b</td>
<td>1.68</td>
<td>1.13 (±0.16)c</td>
<td>0.22 (±0.05)c</td>
<td>8.98</td>
<td>3.89 (±0.25)c</td>
<td>0.99 (±0.06)b</td>
</tr>
</tbody>
</table>

Table 2-2. Pitfall sample arthropod abundance, richness, and diversity for the overall community, herbivores, and predators within each St. Augustinegrass cultivar diversity treatment. Letters indicate significant differences (P<0.05).

<table>
<thead>
<tr>
<th>Diversity Treatment</th>
<th>Community Abundance (±SD)</th>
<th>Community Richness (±SD)</th>
<th>Community Diversity (±SD)</th>
<th>Herbivore Abundance</th>
<th>Herbivore Richness (±SD)</th>
<th>Herbivore Diversity (±SD)</th>
<th>Predator Abundance</th>
<th>Predator Richness (±SD)</th>
<th>Predator Diversity (±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>54.78 (±5.91)</td>
<td>6.86 (±0.29)ab</td>
<td>1.10 (±0.05)</td>
<td>1.90 (±0.32)</td>
<td>1.04 (±0.12)a</td>
<td>0.19 (±0.04)</td>
<td>9.53</td>
<td>3.30 (±0.20)</td>
<td>0.81 (±0.05)</td>
</tr>
<tr>
<td>M2</td>
<td>41.76 (±6.03)</td>
<td>5.97 (±0.29)b</td>
<td>1.08 (±0.05)</td>
<td>1.57 (±0.42)</td>
<td>0.70 (±0.10)b</td>
<td>0.12 (±0.03)</td>
<td>7.76</td>
<td>3.00 (±0.20)</td>
<td>0.72 (±0.05)</td>
</tr>
<tr>
<td>M4</td>
<td>52.95 (±5.87)</td>
<td>7.23 (±0.28)a</td>
<td>1.17 (±0.05)</td>
<td>1.70 (±0.23)</td>
<td>1.00 (±0.12)ab</td>
<td>0.20 (±0.04)</td>
<td>10.42</td>
<td>3.45 (±0.18)</td>
<td>0.83 (±0.05)</td>
</tr>
</tbody>
</table>
Table 2-3. Insect vacuum surveys of total community, herbivore, and predator abundance, richness, and diversity for each sampling date. Letters indicate significant differences (P<0.05).

<table>
<thead>
<tr>
<th>Diversity Treatment</th>
<th>Community</th>
<th>Herbivore</th>
<th>Predator</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Abundance</td>
<td>Richness</td>
<td>Diversity</td>
</tr>
<tr>
<td>July</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>182.86</td>
<td>(±17.16)a</td>
<td>2.37</td>
</tr>
<tr>
<td>August</td>
<td>630.13</td>
<td>(±75.78)b</td>
<td>2.24</td>
</tr>
<tr>
<td>Sept</td>
<td>1279.30</td>
<td>(±123.59)c</td>
<td>2.16</td>
</tr>
</tbody>
</table>

Table 2-4. Insect vacuum survey data comparing St. Augustinegrass cultivar diversity treatments to abundance, richness, and diversity in total sampled families, herbivore families, and predator families.

<table>
<thead>
<tr>
<th>Diversity Treatment</th>
<th>Community</th>
<th>Herbivore</th>
<th>Predator</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Abundance</td>
<td>Richness</td>
<td>Diversity</td>
</tr>
<tr>
<td>M1</td>
<td>736.16</td>
<td>(±138.41)</td>
<td>2.23</td>
</tr>
<tr>
<td>M2</td>
<td>677.81</td>
<td>(±91.48)</td>
<td>2.25</td>
</tr>
<tr>
<td>M4</td>
<td>675.96</td>
<td>(±85.37)</td>
<td>2.30</td>
</tr>
</tbody>
</table>
Figure 2-1. Aerial image of the plots. The orange box indicates a single block. Each block contained all three treatments (M1, M2, M4) randomly assigned a location within the block. Photo taken on 3/31/18, 508 days after initial planting. Photo credit: Joseph G.
Figure 2-2. Arthropod community richness over time for each St. Augustinegrass cultivar diversity treatment collected in pitfall traps.
Figure 2-3. Southern chinch bug abundance over time for each St. Augustinegrass cultivar diversity treatment. Insects were collected with vacuum surveys.
CHAPTER 3
CULTIVAR MIXTURES: A POTENTIAL NEW APPROACH TO BETTER WARM-SEASON LAWNS

Turfgrasses are the fourth largest crop area and the largest irrigated crop in the United States (Morris 2006). Healthy turfgrasses actively sequester carbon (Stier et al. 2013), filter nutrients (Shaddox et al. 2016), and reduce temperatures (Parker 1983). Moreover, well-maintained turfgrasses enhance real estate aesthetic and economic value as well as human mental and physical health (Stier 2013). Aesthetic value is also a primary driver of the turfgrass industry and consumer practices. Correct cultural management practices (e.g. mowing, irrigation, fertilization) are essential to promote and maintain aesthetic value by increasing tolerance to weeds, diseases, insect pests, and foot traffic (Tegg and Lane 2004, Jiang and Carrow 2005, Reynolds et al. 2015). Despite the known cultural requirements for most residential lawn species, there is a heavy reliance on non-renewable inputs like irrigation, fertilization, and pesticides. This reliance is often driven by heightened pest pressure in the form of insects, disease or weeds, or the desire for high quality, dense, green lawns (Byrne 2005, Ghimire et al. 2016).

The most effective pest control tactics that reduce chemical inputs are preventive cultural practices that promote plant health and resilience to biotic and abiotic stress. One approach to this in urban landscapes is proper plant selection (Raupp et al. 1992, Dale et al. 2016), which should consider local and regional site characteristics like climate, precipitation, soil type, shade/sun, and other abiotic factors that affect plant performance. Another approach to cultural management is habitat manipulation, which includes manipulating inter- or intraspecific plant diversity (Andow 1991, Barbosa et al. 2009, Tooker and Frank 2012). More diverse plant communities generally support more
abundant and diverse natural enemies, which promote ecological stability and theoretically reduce management needs (Tahvanainen and Root 1972). Therefore, incorporating such preventive cultural control practices during turfgrass production or planting may enhance lawn quality and resilience to stress over time.

Many cool season turfgrass species (C3 photosynthesis) are produced and/or planted as mixtures of cultivars or species (Christians 2011). These mixed plantings are a strategy for increasing site adaptability and resilience to foot traffic and diseases (Hunt and Dunn 1993, Thompson and Kao-Kniffin 2016). Thompson and Kao-Kniffin (2016) found that mixing 8 species and 7 genotypes in groups of 1, 3, 6, and 12, reduced nitrate leaching and increased above and below ground biomass as the diversity of the groups increased. Moreover, mixing cool season species, tall fescue (*Festuca arundinacea* Schreb) and Kentucky bluegrass (*Poa pratensis* L.), reduces weed density and disease severity, and increases turfgrass density compared to either species planted in monoculture (Cutulle et al. 2013). Therefore, manipulating turfgrass diversity can address a variety of industry challenges and demands. Unfortunately, little research has investigated mixing cultivars or species of warm-season turfgrasses (C4 photosynthesis), the predominant urban and residential lawn plant throughout the southern United States (Christians 2011). Limited evidence suggests there may be benefits for warm-season species as well. For example, Simmons et al. (2011) and Stott et al. (2010) found greater foliage density and reduced weed invasion in warm-season grass species mixtures compared to monocultures (Stott et al. 2010, Simmons et al. 2011).
One hurdle to mixing warm-season turfgrasses is that most warm-season species are grown from vegetative propagules rather than seed (Casler and Duncan 2003, Christians 2011). The most common warm-season lawn species is St. Augustinegrass (*Stenotaphrum secundatum* [Walt] Kuntze) (McCarty et al. 2004), which, in Florida, comprises 50 percent of all sod production (Satterthwaite et al. 2009). This widespread planting of monocultures may predispose warm-season turfgrass lawns associated with pests like insects, mites, pathogens, or abiotic stress factors. However, another hurdle to mixing warm-season turfgrasses is that species often differ drastically in their phenotypes and cultural management requirements, which may prevent industry implementation or consumer buy-in.

Turfgrass morphological characteristics like texture, color, and growth, and maintenance requirements like mowing height or irrigation are important to consider because they are what most strongly regulate industry practices and consumer demand (Byrne 2005). Moreover, various cultural management practices affect warm-season turfgrass species differently and may lead to unintentional plant damage or death (Shearman et al. 1980, Salaiz et al. 1995, Liu and Huang 2002). However, cultivars within a species are often similar in their appearance and maintenance requirements. Therefore, increasing warm-season turfgrass diversity by mixing cultivars may provide a tractable approach to meeting industry demands and maintenance requirements, while increasing lawn resilience (Tooker and Frank 2012).

St. Augustinegrass a warm-season turfgrass that is globally distributed in subtropical and tropical regions of the world, with most commercially available genotypes originating from breeding programs (Sauer 1972, Casler and Duncan 2003).
Initially planted as a lawn turfgrass in Florida in the 1880s (Casler and Duncan 2003), St. Augustinegrass has since become the most dominant lawn species in the state, making up over 70% of residential lawns (Hodges and Stevens 2010, Satterthwaite et al. 2010). Since St. Augustinegrass produces few or no viable seeds, it is vegetatively propagated and planted in genotypic monocultures (Christians 2011). Different cultivars vary in terms of shade tolerance (Busey and Davis 1991), drought resistance, survival (Atkins et al. 1991, Miller and McCarty 2001), salinity tolerance (Dudeck et al. 1993), stig nematode tolerance (Busey et al. 1993), and pathogens (Atilano and Busey 1983).

To determine the effects of increasing warm-season turfgrass cultivar diversity on lawn quality and industry marketability, a field experiment was conducted to qualitatively and quantitatively evaluate turf quality, by testing the hypothesis that increasing St. Augustinegrass diversity would not reduce turfgrass visual quality and that plantings of cultivar mixtures would meet turfgrass industry standards.

**Materials and Methods**

**Study Design**

To determine the effects of increasing St. Augustinegrass cultivar diversity on lawn quality, a field experiment was conducted at the University of Florida Plant Science Research and Education Center in Citra, Florida. In November 2016, St. Augustinegrass cultivars were planted in 3m x 3m plots (Figure 1) at three different levels of cultivar diversity using six of the most common commercially produced St. Augustinegrass cultivars: Floratam, Bitterblue, Palmetto, Classic, Captiva, and Seville. The monoculture (M1) treatment consisted of two or three replicates of each cultivar planted as monocultures (n=15). The mixture of two cultivars (M2) treatment consisted of all combinations of two cultivars from the pool of six, resulting in 15 unique
combinations (n=15). The mixture of four cultivars (M4) treatment consisted of all combinations of four cultivars from the pool of six, also resulting in 15 unique combinations (n=15). Although plots assigned to the same level of diversity varied in their cultivar composition, only the effect of diversity was measured. Each cultivar diversity level was randomly assigned to individual plots within blocks of three plots, one per treatment.

The experiment was a complete randomized block design with 15 blocks, each containing 3 treatments (M1, M2, M4) for a total of 45 plots (Figure 1). Each cultivar within a plot was planted as 15 cm diameter plugs, 30 cm apart and randomly assigned a location at 0.3 m spacing, per 0.4 m² to ensure equal and unbiased distribution within a plot (100 plugs total). Plots were irrigated 3-5 days per week, depending on local weather conditions, usually at a 6.35 mm per application. Herbicides were applied to all plots to control weeds as needed and any weeds that emerged were hand-pulled before setting seed. Grasses were maintained at a 7.6 to 10 cm cutting height with a zero-turn mower weekly. Plots were separated by a 1 m alleyway of bare soil maintained with glyphosate and manual edging.

**Turfgrass Quality Evaluations**

To quantitatively evaluate turfgrass planting quality, digital images were taken of each plot using a portable light box (Figure 3-2) and DSLR Cannon ProShot S110 monthly from May to November 2017 (Richardson et al. 2001). Every plot had three images taken in three different locations. The three photos were taken consecutively in a row down the center of each plot. Each photo location was marked with a green indicator so that the image locations were consistent across all sampling dates. Photos were not taken in September 2017 due to Hurricane Irma. Images were uploaded into
SigmaScan (Systat Software, Inc., San Jose, California USA) and assessed for percent green cover (lawn density) and dark green color index (DGCI). DGCI is an index from 0 to 1 based on Munsell color chips for turfgrass colors and is used as a standardized visual quality indicator (Karcher and Richardson 2003).

In addition to quantitative measures of lawn quality, it is important to evaluate industry stakeholder and consumer perceptions of increasing St. Augustinegrass cultivar diversity since they are who ultimately affect industry implementation. To obtain an industry stakeholder evaluation, a survey of 100 industry professionals was conducted on October 11, 2017 within the field plots at the University of Florida, Plant Science Research and Education Center in Citra, Florida. Plots were labeled A-I with field stakes and represented three replicates of each diversity level (M1, M2, and M4). Participants were unaware of the experimental design, treatments, or objectives prior to receiving and participating in the survey. Each participant was given a paper spreadsheet with one row for each plot and asked to rate the quality of each plot using the National Turfgrass Evaluation Standard (NTEP) rating scale from 1 to 9, where 9 is the highest quality turfgrass planting. All incorrect (plots rated 1 through 9 instead of individually) or incomplete surveys were discarded, resulting in 82 industry surveys used for analysis.

Statistical Analyses

To determine if there was an effect of St. Augustinegrass cultivar diversity treatment and time on percent green cover and DGCI, a repeated measures analysis of variance (ANOVA) was used. St. Augustinegrass diversity level and date were treated as main effects and block was treated as a random effect. If ANOVA detected a significant main effect, pairwise means comparisons between dates and cultivar
diversity levels were conducted using Tukey’s HSD test. To determine if St. Augustinegrass cultivar diversity affected industry perception of lawn quality as measured in the field survey, a Chi Squared test was used. Chi square was appropriate since reported quality ratings were discrete ordinal values (scale of 1-9) rather than continuous variables. For all tests, values were considered significant with alpha <0.05.

Results

Quantifying Turfgrass Density and Color

The main effects of cultivar diversity treatment ($F_{2,5} = 12.91$, $P<0.0001$) and sample date ($F_{2,5} = 259.49$, $P<0.0001$) on percent green cover were both significant. Turfgrass green cover increased over time from May to November, at which point all plots were on average 87% filled in and significantly different from the planting date (Figure 3-3). When comparing St. Augustinegrass cultivar diversity treatments across all assessment dates, percent green cover increased with cultivar diversity such that the plots containing mixtures of four cultivars had 2 to 6 greater percent cover than the cultivar monoculture plots over time (Figure 3-3). The mixtures of two cultivar plots were not different from the monoculture or mixture of four cultivar plots (Table 3-1).

Through the duration of the study, DGCI color indices for all field plots ranged from 0.34 to 0.84 with a mean of 0.46 (+/-0.06). DGCI increased over time ($F_{5,5} = 98.55$, $P<0.0001$) from May to November 2017 (Figure 3-4). At the final sampling date, treatments averaged 0.51 DGCI, which is 0.05 above the initial sampling date. In July 2017, the mixture of four St. Augustinegrass cultivar plots had higher DGCI values than the mixture of two cultivar plots (Table 3-3). In August and November 2017, the mixtures of four St. Augustinegrass cultivar plots had greater DGCI values than the
monoculture plots (Table 3-2). The monoculture and two-cultivar mixture plots were not different from each other on any date (Table 3-2).

**Qualitative Industry Evaluation**

Eighty-two survey participants completed the survey in compliance with the instructions. Turfgrass industry professional visual quality ratings ranged from 3 to 9 with a mean of 6.73 (±1.38). Average quality rating increased with St. Augustinegrass diversity level such that the mixtures of two cultivars (M2=6.95 ±1.38) and four cultivars (M4=6.74±1.28) were rated higher than the cultivar monoculture (M1=6.51±1.45) plantings (ChiSq =11.92, P = 0.0026) (Figure 3-5). All treatments resulted in acceptable quality.

**Discussion**

Increasing plant diversity can increase biodiversity, resilience to stress, and the ecosystem services provided by plants, wildlife, and soils (Stork and Eggleton 1992, Smith 2014). Since different plant species frequently require different maintenance inputs or have morphological differences, agronomic and horticultural crop producers can often mix cultivars of the same crop species to achieve benefits associated with plant diversity (Tooker and Frank 2012). Although widely produced and planted around the world, little is known about the effects of mixing warm-season turfgrass cultivars in lawns and if it may be a tractable approach to achieving the benefits associated with plant diversity. Interestingly, quantitative and qualitative measures of aesthetic and agronomic turfgrass stand quality indicate benefits associated with mixing commercially available cultivars of St. Augustinegrass. Therefore, cultivar mixtures may present a
viable approach to improving warm-season lawns without additional management inputs or time associated with new cultivar development.

The diversity of plant communities affects the soil properties of the areas they inhabit (Wardle 2002). Research has shown that cultivar diversity can interact with soils to affect overall plant quality and resilience through its effect on belowground processes like nutrient cycling and availability (Stork and Eggleton 1992). Turfgrass cultivars, including those of St. Augustinegrass, vary in chemical content (McCrimmon 2000, McCrimmon 2007), which suggests that tissue chemistry that is returned to the soil may influence a wide range of soil characteristics that affect St. Augustinegrass growth (Wardle 2002). Although direct measurements of any plant or soil nutrient content were not taken, turfgrass quality survey results indicate that St. Augustinegrass quality increases slightly when multiple cultivars are planted together.

Cultivars of various crops differ in their ability to uptake and utilize important soil nutrients (Borrell et al. 1998, Le Gouis et al. 2000), which may improve plant growth and productivity and translate to aesthetic value. For example, Kentucky bluegrass cultivars vary in their uptake of phosphorus and potassium (Mehall et al. 1983). This variation in soil nutrient uptake can facilitate more efficient use of nutrients and reduce competition between individual plants for water and other resources (Crutsinger et al. 2006). For example, plant diversity in cool season turfgrass species had greater site adaptability and improved foot traffic resilience (Hunt and Dunn 1993, Thompson and Kao-Kniffin 2016). Increased vigor from genetic mixtures could account for improved visual quality seen in the St. Augustinegrass diversity treatments over the monocultures. Therefore,
planting a variety of turfgrass cultivars in a location may help ensure the overall quality and resilience of a lawn in that area.

Turfgrass species and cultivars vary in density, texture, uniformity, and growth habit (Morris 2006). These differences between cultivars in physical characteristics such as internode length and leaf texture might allow them to utilize all available space when grown in combination, forming a denser stand of grass. This could account for the greater percent cover measured in the highest diversity (M4) St. Augustinegrass plantings. Not only may this increased density benefit aesthetic qualities of a lawn, but it can also reduce competition with other unwanted plant species and the invasion of weeds by increasing shade and reducing available soil space. In fact, Cutulle et al. (2013) found that increasing cool-season turfgrass species diversity reduced weed prevalence through increasing establishment speed and wear tolerance. Such an effect may increase the longevity of a high quality lawn and reduce herbicide use.

Using existing cultivars as a method to improve lawn quality may provide a readily available cultural management practice that can be incorporated into the production, planting, and maintenance of warm-season turfgrass lawns. Although new turfgrass cultivars are developed to maximize quality and minimize maintenance requirements, this takes several years to identify, register, and incorporate into commercial production (Philley and Krans 2010). Current cultivars are already relatively well understood by the industry and provide the best-known phenotypes and morphological traits of their respective species. Therefore, mixtures of currently available cultivars could be relatively quickly adopted, using plugs or sprigging either at the consumer site or at a sod farm (Christians 2011). As new, superior cultivars are
developed, they could be incorporated into mixtures and sold as part of an established process. Therefore, selecting new cultivars that exhibit superior traits and mixing them in plantings may provide an improved turfgrass lawn compared to the monoculture standard.

Current warm season turfgrass production and maintenance practices create cultivar monoculture lawns to preserve desirable cultivar traits. However, this practice may predispose lawns to pest damage and increased pesticide (insecticide, herbicide, or fungicide) or natural resource (water) inputs. Moreover, recent evidence suggests that lawn plant communities throughout Florida and the United States are becoming homogenized and composed of the same plant species and groups (Wheeler et al. 2017). Therefore, achieving ecosystem benefits associated with plant diversity while increasing aesthetic value may be a tractable and impactful approach to lawn integrated pest management. Future research is needed to evaluate cultivar mixtures as a long-term strategy since biotic and abiotic factors (e.g. diseases, weather, soil, ect.) or competition between cultivars may alter the composition and relative abundance of cultivars over time. Although this study only captured one year of field observations, it provides encouraging results that suggest cultivar homogenization may not be necessary to meet consumer and industry demands. If these traits are conserved over time, planting cultivar mixtures may provide an immediate strategy to improve the aesthetic quality of residential lawns while reducing non-renewable inputs.
Table 3-1. Mean percent cover and standard deviation for each treatment at each sampling date. Letters indicate significant differences (P<0.05).

<table>
<thead>
<tr>
<th>TRT</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>October</th>
<th>November</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>53.2(±3.07)</td>
<td>70(±1.53)</td>
<td>73.3(±1.79)a</td>
<td>79.82(±1.82)a</td>
<td>78.23(±2.03)a</td>
<td>85.43(±1.36)a</td>
</tr>
<tr>
<td>M2</td>
<td>49.49(±2.68)</td>
<td>70.43(±1.44)</td>
<td>73.92(±1.96)ab</td>
<td>82.75(±1.57)ab</td>
<td>80.78(±1.57)ab</td>
<td>87.05(±1.15)ab</td>
</tr>
<tr>
<td>M4</td>
<td>50.47(±2.46)</td>
<td>72.06(±1.35)</td>
<td>77.22(±1.68)b</td>
<td>84.54(±1.41)b</td>
<td>84.04(±1.41)b</td>
<td>88.58(±1.13)b</td>
</tr>
<tr>
<td>F ratio</td>
<td>1.26</td>
<td>1.59</td>
<td>3.34</td>
<td>5.14</td>
<td>6.69</td>
<td>3.33</td>
</tr>
<tr>
<td>P-value</td>
<td>0.2862</td>
<td>0.2051</td>
<td>0.0371</td>
<td>0.0065</td>
<td>0.0015</td>
<td>0.0374</td>
</tr>
</tbody>
</table>

Table 3-2. Mean dark green color index (DGCI) and standard deviation for each treatment at each sampling date. Letters indicate significant differences (P<0.05).

<table>
<thead>
<tr>
<th>TRT</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>October</th>
<th>November</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>0.45(±0.00)</td>
<td>0.46(±0.01)</td>
<td>0.42(±0.00)ab</td>
<td>0.44(±0.00)a</td>
<td>0.45(±0.01)</td>
<td>0.50(±0.00)a</td>
</tr>
<tr>
<td>M2</td>
<td>0.45(±0.00)</td>
<td>0.46(±0.00)</td>
<td>0.42(±0.00)a</td>
<td>0.45(±0.00)ab</td>
<td>0.46(±0.01)</td>
<td>0.51(±0.00)ab</td>
</tr>
<tr>
<td>M4</td>
<td>0.45(±0.00)</td>
<td>0.46(±0.00)</td>
<td>0.43(±0.00)b</td>
<td>0.46(±0.00)b</td>
<td>0.46(±0.01)</td>
<td>0.52(±0.00)b</td>
</tr>
<tr>
<td>F</td>
<td>0.6</td>
<td>0.13</td>
<td>4.14</td>
<td>3.31</td>
<td>0.54</td>
<td>4.7</td>
</tr>
<tr>
<td>P-value</td>
<td>0.5494</td>
<td>0.8753</td>
<td>0.017</td>
<td>0.038</td>
<td>0.5834</td>
<td>0.01</td>
</tr>
</tbody>
</table>
Figure 3-1. Aerial image of the plots. The orange box indicates a single block. Each block contained all three treatments (M1, M2, M4) randomly assigned a location within the block. Photo taken on 3/31/18, 508 days after initial planting. Photo credit: Joseph G.
Figure 3-2. Light box used to take digital images. Photo courtesy of author.
Figure 3-3. Percent green cover over time for each diversity treatment. Error bars represent standard error of the mean. Asterisk indicates statistical significance (P<0.05).
Figure 3-4. Dark green color index (DGCI) over time for each diversity treatment. Error bars represent standard error of the mean. Asterisk indicates statistical significance (P<0.05).
Figure 3-5. Average ratings (0-9 scale) from industry stakeholder surveys for each St. Augustinegrass cultivar diversity treatment.
CHAPTER 4
CONCLUSION

Urban areas are frequently characterized by low plant diversity, particularly in lawns, but little research has investigated its effects on insects. This is important because it is generally well-supported that insect diversity declines with increasing urban development. Therefore, developing strategies for urban and residential lawns to increase insect diversity could have far-reaching benefits within urban ecosystems. In addition to ecological benefits, turfgrass lawns enhance the aesthetic value of residential landscapes, which have benefits for human mental health. Therefore, visual quality is a key factor to consider when evaluating new turfgrass cultural or production practices.

Field experiments found that arthropod abundance, richness and diversity increased over time for all sampling methods. Pitfall sampling methods found that community richness and herbivore richness were greater in the high diversity plots towards the end of our sampling period. Southern chinch bug, the most important insect pest of St. Augustinegrass, abundance increased over time in all turfgrass plots, but there was no difference between the treatments. In terms of turfgrass aesthetic value, visual quality improved over time and was slightly better in the high diversity plots, both with percent green cover and DGCI. Industry surveys also found that high diversity plots were rated slightly better than monoculture plots. Therefore, this research suggests that there may be industry and ecological benefits associated with mixing St. Augustinegrass cultivars in lawns that warrant additional research.

Although the results suggest potential benefits, they remain somewhat preliminary since they are only based upon one season of data from one location.
Longer-term studies are needed to determine the longevity of cultivar mixtures for urban application. Insect communities should continue to be measured because they are likely to change significantly over time. Similarly, the primary pest, southern chinch bug, should be monitored in the field as well as in isolated studies to determine if there are any physiological effects on the insects. St. Augustinegrass should also be monitored in the field to determine if improved visual quality remains over time and to determine how the cultivars will compete with each other. It is possible that depending on the environment, a single cultivar will become dominant in a mixed cultivar planting. Therefore, cultivar composition may change over time, affecting aesthetic quality, density, color, and insect communities. Once these experiments are conducted and long-term viability is established, cultivar combinations could be a viable way to increase diversity in urban systems, as well in visual quality without increasing pest pressures.
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BIOGRAPHICAL SKETCH

Brianna Marie Whitman was born in Greenock, Scotland, to a US military family, and primarily raised in Post Falls, Idaho. In 2015, she graduated from the University of Idaho with a double B.S. in Sustainable Crop and Landscape: Insect and Society Emphasis, and Sustainable Crop and Landscape: Environmental Horticulture Emphasis, and a minor in crop science. In 2016, she began her master's in environmental horticulture at the University of Florida, with a minor in entomology and nematology. Brianna is currently pursuing a Doctor of Plant Medicine degree at the University of Florida.