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MANAGING *LINEPITHEMA HUMILE* (MAYR), THE ARGENTINE ANT, IN SOUTH CAROLINA STATE PARK CAMPGROUNDS

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ABSTRACT

*Linepithema humile* (Mayr), the Argentine ant, is known as a pest in many urban areas of the southeastern United States. In the Piedmont region of South Carolina, there is a documented problem with *L. humile* invading the campsites of state park campgrounds. While some parks have tried to implement proactive control programs, the most widely used tactic is spraying insecticides when *L. humile* populations become intolerable to visitors. Although park personnel are treating problem areas with liquid insecticide, park visitors also treat their campsites with insecticidal products, as well as products not labeled for ant control.

Surveys in 2008 showed that over 65% of campers, at three selected state parks, were planning to return despite *L. humile* infestations. However, between 19 and 33%, depending on the park, stated they were hesitant to use the campgrounds again. Through complaint logs maintained by park personnel, as well as surveys conducted in the field, it was found that over 50% of all campers were personally treating their campsites for *L. humile*. These findings and personal observations indicated a need to develop educational materials to inform park visitors about techniques for reducing *L. humile* infestations around their campsites. An educational brochure providing answers to the most common camper questions and tips for controlling *L. humile* was produced for distribution in campgrounds where *L. humile* infestations were known.

Through monitoring *L. humile* between July and October of 2007, it was found that *L. humile* activity remained relatively constant until a decline in October. It was also found that *L. humile* populations stay in the same general area, and typically maintained
foraging trails on the same trees throughout the camping season. Because *L. humile* populations remaining in the same areas allowed for targeted insecticidal treatments.

A series of four trials were conducted evaluating insecticidal spray treatments versus a combination of insecticidal spray and granular baits. Control areas were set up to evaluate the change in ants over the progression of a season without chemical interference. A bait (Niban® Granular Bait; orthoboric acid) and three insecticide sprays (Premise® 2; imidacloprid, Temprid™ SC; β – cyfluthrin and imidacloprid, and Tempo® Ultra SC; β – cyfluthrin) were evaluated to determine the best option in a park setting. Overall, granular bait did not perform as well as the spray insecticides for *L. humile* control. In general, treatment with Tempo® Ultra SC provided the best and most cost effective control. Future research is needed to assess different methods and timing for control of *L. humile* in campground environments.
ACKNOWLEDGMENTS

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Overview:

*Linepithema humile* (Mayr) was probably introduced to the United States by ships carrying coffee from Brazil in 1891 (Newell and Barber 1913). In 1908, in the United States, the common name of the Argentine ant was ascribed to *Linepithema humile* based on the location of the first specimens used to describe the species (Newell and Barber 1913). Since introduction, the species has become a pest throughout the United States in mainly southeastern states and California, but also in Arizona, Missouri, Illinois, Maryland, Oregon and Washington (Mallis 1942). Worldwide *L. humile* has been known as a pest in countries including Australia, France, Portugal and South Africa (Mallis 1942).

*Linepithema humile* is what Holldobler and Wilson (1990) termed a “tramp” species. Tramp ants are typically distributed by trade and are found living in close proximity to humans. The main route of dispersal for *L. humile* has been by ships and railways or by floating debris and driftwood (Barber 1916). Known also as a “fugitive” species, Argentine ants choose temporary nesting areas that can be abandoned quickly with little loss of resources and energy (Holldobler and Wilson 1990). When conditions worsen in the nest area, from factors such as extreme temperatures or flooding, *L. humile* is capable of relocating the entire nest by riding debris to a drier more acceptable environment (Barber 1916). Typical nesting sites are shallow and can range from cracks
and crevices on walkways, under stone piles and wood, or at the base of a tree (Mallis 1942).

*Linepithema humile* are effective scavengers because of their use of mass recruitment and trail pheromones when finding a resource, which allows them to respond and exploit a food source at a greater rate than other ant species (Aron et al. 1990). Another factor for the success of *L. humile* includes the behavior of constructing nests in close proximity to a large food resource (Newell and Barber 1913).

**Taxonomy:**

As of 1990, there were 11 subfamilies and 297 genera of Formicidae recognized (Holldobler and Wilson 1990). By 2009 there were 12,513 species identified (Agosti and Johnson), but estimates suggest there could be up to 20,000 species and 350 genera (Holldobler and Wilson 1990). When classifying Formicid species, a pentanomial system was used for naming the subgenus, species, subspecies, and variety (Creighton 1938). The first person to describe the Argentine ant and name them *Hypoclinea humilis* was Gustav Mayr in 1868 (Newell 1908). In 1888, Emery changed the genus name to *Iridomyrmex* (Bolton 1995). The genera *Iridomyrmex* was said to be poorly defined with unrelated species being placed into the genus (Shattuck 1992). As a result, in 1992 Shattuck changed the genus and species to the present name of *Linepithema humile* (Bolton 1995).

In 1878, Forel established the subfamily Dolichoderinae to separate previously identified genera incorrectly grouped within the subfamily Formicinae (Shattuck 1992). This separated the subfamily into two groups, one which had the characteristic of the
gaster terminating in a slit-like opening (Dolichoderinae) and the other with the gaster terminating in a circular orifice (Formicinae). The queens and workers in the subfamily Dolichoderinae are identified by the characteristics of a single-segmented petiole, a gaster lacking constriction between the first and second segments, and a slit like opening at the posterior tip of the gaster. Males can be distinguished from other subfamilies, excluding Formicinae, with the characteristics of a single segmented petiole with a short anterior peduncle, a gaster lacking a constriction between the first and second segments, and a subgenital plate without teeth (Shattuck 1992).

*Linepithema humile* workers are monomorphc, typically 2.2-2.9 mm, and have body coloration consistently brown to light brown. The antennae are 12 segmented and not clubbed, with the apex of the scape distinctly surpassing the heads posterior edge. The antennal fossa touches the posterior edge of the clypeus. Two large apical teeth are present on each mandible with irregular teeth or denticulae following. Neither maxillary palps nor third segment is long. The promesonotal suture is distinct with the mesoepinotal region containing a constriction or impression. Hairs are typically absent on the thorax. The abdominal pedicel is composed of the petiole, a single segment. In profile, the petiolar scale is suberect or inclined and can be easily viewed. The cloacal orifice is like that of other Dolichoderinae in that it is ventral, slit-shaped, transverse, and a fringe of hairs is absent (Smith 1965).

**Life Cycle:**

As with other holometabolous insects, there are three immature forms found in *L. humile* colonies: the egg, larva and pupa.
**Egg:** In appearance, the egg is typically elliptical, pearly white and lacks any type of markings. Size is typically 0.3 mm long and 0.2 mm wide. Depending on temperature and humidity, the incubation period during the summer averages 15 days (Barber 1916). Incubation has lasted up to 45 days in a laboratory setting (Newell and Barber 1913). In laboratory studies 3 to 30 eggs a day were found to be laid (Barber 1916), but it is thought that a queen can lay up to 60 eggs a day if conditions are optimal (Thompson 1990).

**Larva:** At the time of hatching, larvae are creamy white in appearance and curved (Barber 1916) with the anterior and posterior ends together making it difficult to distinguish from the original egg (Newell 1908). As growth continues, the larvae straighten. During this period the larvae are entirely dependent on workers in the colony for grooming and feeding, as well as being moved for optimal placement in changing weather conditions (Barber 1916). Last larval instars typically have a width of 0.66 mm and a length of 1.7 mm (Newell 1908). Larval development averages 13 days during optimal conditions (Barber 1916).

**Pupa:** In the pupa stage, the appearance is completely white, excluding two black compound eyes on each side of the head. As the pupa matures, coloration changes from light brown to medium brown through molting (Newell 1908). Once in the pupa stage, the sex of the immature can be determined (Barber 1916) as well as their mature form. Worker pupae are typically 2 mm long with their head and thorax making up the larger portion (Barber 1916). A male pupa can be distinguished from the worker by their abdomen being smaller than their thorax. The male’s body size is also 50% larger in
comparison to a worker pupa. Queen pupae are distinguished by their pedicel being more constricted than those found in male pupa (Barber 1916). Queens can also be distinguished from male pupae by their larger size (Barber 1916) and noticeable wing pads (Newell and Barber 1913). It is thought that queens develop from the over-wintering larvae or those that have hatched over the winter (Markin 1967).

**Adult:** Colony workers that are 2.2-2.9 mm in size comprise the majority of individuals within the colony. Life span ranges from 10 to 12 months for the average worker (Thompson 1990). Adult males are approximately 3 mm (Barber 1916) and are thought to comprise up to 15% of the nest (Markin 1967). The only function known for an adult male is for fertilization of a virgin queen (Barber 1916). They can be found up to a month after the last queen has departed (Markin 1967). May and June tend to be the most active months for males, and may be observed flying towards lights in the evening (Markin 1967). Adult queens emerge from the nest starting in April and continue until June. These individuals are identified by their wings, which remain with them until after copulation (Markin 1967). It is thought that mating occurs within the confines of the nest, as nuptial flights have never been documented (Smith 1965). Once queens are mated, they are no longer considered virgin queens, but rather dealated queens. Dealation is characterized by the shedding of the wings, which triggers the production and laying of eggs (Passera and Aron 1993). Queens are 4.5 mm to 5 mm in length and have the same coloration as other colony members (Newell and Barber 1913).
**Habitat:**

*Linepithema humile* can tolerate a variety of habitats, and can be found in nests ranging from 0 to around 1220 m above sea level (Mallis 1942). Nests are usually well hidden and virtually unseen unless a line of ants are prominent entering and exiting the nest (Vega and Rust 2001). Locations of nests depend on the time and season, but no matter the season, *L. humile* prefer to nest in areas with an adequate amount of moisture and in close proximity to a large amount of food (Mallis 1942).

In the spring, the large colonies previously formed during the winter are divided into smaller nests, typically in disturbed soil in open areas (Mallis 1942). During the autumn colonies search for warmer, more enclosed environments. Nests may be found in a variety of locations ranging from underneath loose boards, below building foundations, and in dead and decaying plant materials (Mallis 1942). During the winter months, nests have been found to combine and form larger colonies to maintain warmth more efficiently (Barber 1916). These types of nests are typically found in warm areas such as decomposing debris, and manure piles (Barber 1916). Tree bases are also ideal winter nesting areas, and nest tunnels can be as deep as 0.31 to 0.36 m (Newell and Barber 1913).

**Food Preference:**

In North America, *L. humile* is known as the Argentine ant, but in South America it is known as the sugar ant based on its preferred food source (Vega and Rust 2001). Whether named the Argentine or sugar ant, *L. humile* is one of the most significant pests in urban and agriculture settings due to their destructive nature when searching for food.
One reason *L. humile* is so successful is their ability to mass recruit cohorts. This allows the colony workers to divide labor when in search of food. Workers are either the foraging scouts, actively searching for a new food, or recruits that wait in the nest for the scouts to return with resources (Roulston and Silverman 2002). *Linepithema humile* will feed on a variety of foods, from carbohydrates to protein to lipids (Smith 1965). It has been shown that *L. humile* does have a preference towards certain food choices depending on the time of year. During the warm seasons, workers usually forage for sugars (Mallis 1942). These can be obtained from honey-dew secreted by mealy bugs and aphids, as well as from the floral secretions of plants (Smith 1965). During the winter season when temperatures fall, carbohydrate foraging declines and new forms of nutrition are sought (Mallis 2004).

**Economic Impact:**

According to Aron et al. (1990), *L. humile* is ecologically successful based on its ability to tolerate a variety of habitats, their polydomic and polygynic colonies, and their ability to use odor trails to perform mass recruitment. For individual homeowners, *L. humile* is a nuisance that may cause economic loss. Once food has been encountered by *L. humile*, products are often discarded due to possible contamination by bacteria carried on the foragers. As *L. humile* populations grow in residential environments, they can become almost unmanageable and have even been noted to cause property values to decrease (Barber 1916). In urban or agriculture settings, *L. humile* can be a pest in a variety of different forms. In agricultural areas, *L. humile* will steal planted seeds (Smith 1965) or even cause damage to irrigation drip tubes in fields by chewing large holes in
the tubing walls allowing excess water to leak into the fields (Vega and Rust 2001).

*Linepithema humile* also has been known to cause damage in chicken houses and honey bee colonies. When foragers invade a chicken house, hens are disturbed, which may lead to cracked eggs, which can encourage more foragers to infest the area. The distress to chickens may cause loss in profits due to poor animal health and the destruction of viable eggs (Smith 1965). In honey bee colonies, *L. humile* can be destructive in several ways. *Linepithema humile* can enter beehives for honey causing some colonies to abandon their nests. This can impact agricultural crops due to the loss of pollination (Vega and Rust 2001). In crop production, such as cotton, corn, and sugarcane, *L. humile* is a pest due to their mutualism with plant aphids. By tending aphids and other related plant pests, *L. humile* allows the progressive damage of crops leading to a decrease in profitable products (Barber 1916). The amount of economic damage caused by *L. humile* is hard to quantify monetarily due to the broad range of industries that it may impact.

**Control:**

After the banning of some organochlorine insecticidal sprays in the U.S., such as DDT, chlordane and lindane, long-term pest control has been harder to maintain. In the past 30 years there has been extensive research to find suitable control measures, both natural and chemical. In agriculture settings, control measures can range from barriers to baits to sprays. Costa and Rust (1999) found that when potted plants were treated with fipronil, *L. humile* vanished from the plants within 24 hours and remained absent for up to four months. Baiting is also a viable option for controlling *L. humile*, but it is challenging to find a bait preferred by *L. humile* that can also be mixed with slow acting
insecticides (Rust et al. 2003). Klotz (1998) found that when low concentrations of liquid boric acid is offered to trailing *L. humile*, there is a reduction in the ants entering surrounding buildings where they previously retrieved their food sources. However, one problem with liquid boric acid bait is that large volumes are needed to be available to the ant population to continue being effective (Klotz 1998). Unless bait is being replenished on a regular basis, the amount of insecticide needed to eliminate pest populations might never be reached. In addition, liquid baits can lose moisture over time concentrating the incorporated insecticide and rendering the bait repellent (Silverman and Brightwell 2008). Klotz (1998) did find that if bait stations were placed near foraging *L. humile* colonies in early spring, ant populations were reduced later in the season. In agricultural settings, control measures can consist of repellent barriers.

Some natural methods of *L. humile* management also have been attempted. Orr and Seike (1998) found that the presence of the parasitoid wasp, *Pseudacteon pusillum*, caused *L. humile* to abandon their foraging trails. Another natural method of control was demonstrated with the use of aromatic cedar chips. Meissner and Silverman (2003) reported mulch beds of aromatic cedar contained fewer ant nests (3) when compared with pine and cypress mulch nests (26).

Over the decades, a variety of control measures have been implemented to manage the impact *L. humile*. Early attempts in residential settings were made trying to deter *L. humile* by banding furniture legs with tape soaked in a corrosive sublimate or by placing panes of glass coated in petroleum jelly. In addition to baits and sprays, many
other chemical methods have been used including fumigation and insecticidal dusts (Mallis 1942).

In the Piedmont region of South Carolina, there is a documented problem with *L. humile* invading campsites in state park campgrounds. *Linepithema humile* has been reported to infest personal recreational vehicles, tents, public facilities and a variety of locations accessed by campers (Stan Hutto, personal communication, Appendix A, p. 69). While some state parks have attempted control, the most widely used “program” is applying liquid insecticides when *L. humile* populations become intolerable to visitors in certain campsites. Seasoned campers often come prepared with their own “control” products, which include a variety of powders and sprays that they place around the vehicles, tents, eating areas. When visiting campsites, it is not uncommon to see rings of powder in multiple sites around the campgrounds. According to Rust et al. (2003), spraying and dust applications have been used in campgrounds for years, where the powder is placed around the tires of a recreational vehicle (RV) to deter the invading pest. While this does seem to repel *L. humile* from entering vehicles, the powders do not appear to be toxic (Rust et al. 2003).

This research was conducted to better understand *L. humile* distribution and impact in campgrounds, educate campers about *L. humile* infestations and to develop a more effective management program to control *L. humile* in state park campgrounds in the Piedmont region of South Carolina. The major objectives were to: 1) determine *L. humile* locations in park areas, 2) survey campers and develop an educational brochure and 3) evaluate chemical control strategies.
CHAPTER TWO

ACTIVITY OF *LINEPITHEMA HUMILE* (MAYR) IN SOUTH CAROLINA
STATE PARK CAMPGROUNDS AND CORRESPONDING CAMPER
ATTITUDES

Introduction

*Linepithema humile* (Mayr), the Argentine ant, was probably introduced to the United States in 1891 (Newell and Barber 1913) and was documented in California in the early 1900’s. In 2000 the results of a survey of pest management professionals in the United States reported that *L. humile* ranked among the top five pest ant species nationwide (Hedges 2000). The northwestern and southwestern US populations are thought to be a *L. humile* “supercolony,” due to a low number of introductions of this pest ant (Suarez et al. 2001; Tsutsui and Case 2001). Supercolonies are constituted by neighboring, seemingly related, ant colonies with no intraspecific aggression, due to a loss in genetic diversity (Holway et al. 2002; Tsutsui et al. 2000). In the southeastern US there are areas of unicoloniality, but aggression between nests is higher than those of the west. The higher level of aggression is thought to be due to the multiple introductions that have occurred over the past 100 years (Buczkowski et al. 2003).

The way in which *L. humile* expands geographic distribution is through budding. Budding is when one or more queens and a number of workers leave their home nest found satellite nests (Newell and Barber 1913). This allows up to 50% of workers to move between all related nests, functioning in a unicolonial fashion (Markin 1968; Holway et al. 2002). This allows *L. humile* to have a wider foraging range without
aggression from competing ant species. Suarez et al. (2001) noted that *L. humile* can spread in territory between 5 to 270 m per year in Northern California, depending on the environmental conditions present. Foraging is typically suspended once temperatures fall below 5°C (Markin 1970). This is why foraging territories increase between the months of May to September, and decrease from September to May in temperate areas (Sanders et al. 2001). However, in North Carolina it was observed that sun exposed bark of loblolly pine trees allows for continual foraging through colder months due to heating of the foraging surface (Brightwell 2008). Adult queens start emerging from nests in April and continue until June. During proper environmental conditions, a queen can potentially lay up to 60 eggs a day (Thompson 1990), and approximately 20,000 eggs during her lifetime. Even if queens are killed the colony can continue. In the absence of queens, workers can rear eggs and larvae into reproductives (Passera et al. 1988). This makes elimination of an entire colony with insecticides difficult.

*Linepithema humile* will feed on a variety of foods, from carbohydrates to protein to lipids (Smith 1965). However, Markin (1970) noted that > 99% of the food being brought back into the nest from fruit orchards was comprised of nectar or honeydew. *Linepithema humile* does have a preference towards certain food choices depending on the time of year. During the warm seasons, workers usually forage for sugars (Mallis 1942). During the colder seasons, carbohydrate foraging declines and *L. humile* focus on foraging for proteins (Mallis 2004). It is believed that food preference corresponds to the life cycle of *L. humile* (Reierson et al. 1998). As egg production and larval growth occur in the spring, large amounts of protein are needed.
It can be difficult to discover *L. humile* nests. They are usually well hidden, unless a trailing line can be found entering or exiting the nest (Vega and Rust 2001). Depending on the time of year, the location of a nest can vary. During the autumn, colonies search for warmer, more enclosed environments. Nests may be found in a variety of locations ranging from underneath loose boards, below building foundations, and in dead and decaying plant materials (Mallis 1942). During the winter months, nests have been found to combine and form larger colonies to maintain warmth more efficiently (Barber 1916). Tree bases are also ideal winter nesting areas, and nest tunnels can be as deep as 0.31 to 0.36 m (Newell and Barber 1913). In the spring, large colonies formed during the winter are divided into smaller nests, typically in disturbed soil in open areas (Mallis 1942). Nests are usually shallow and can be located in cracks or crevices on walkways, under stone piles or wood, or often at the base of a tree (Mallis 1942). However, no matter the time of year, *L. humile* prefer a nest that has an adequate amount of moisture and in close proximity to a large amount of food (Mallis 1942). Construction of nests in close proximity to large food resources (Newell and Barber 1913) makes campgrounds a prime location for an abundance of *L. humile*.

In the Piedmont region of South Carolina, there is a documented problem with *L. humile* invading campsites of recreational campers in state park campgrounds (Stan Hutto, personal communication, Appendix A, p. 69), often in close proximity to lakes and streams (Ellis personal observation). *Linepithema humile* have been reported to infest personal recreational vehicles, tents, public facilities, and a variety of locations accessed by campers (S. Hutto, personal communication, Appendix A, p. 69). While staff at some
state parks implement control measures, the most common strategy is spraying broad-
spectrum insecticides when *L. humile* populations become intolerable and campers
complain. Seasoned campers often come prepared with their own “control” products,
powders and sprays that are placed around sleeping and eating areas. Some of the
methods used include insecticidal dusts and sprays, cleaning powders, bleach, oil and
other home remedies passed from camper to camper. In the campgrounds, it is not
uncommon to see rings of powder in multiple sites. While placing powder around RV’s
seems to temporarily deter *L. humile* from entering vehicles, the powders often do not kill
the ants due to their avoidance of the treated area (Rust et al. 2003).

This study had two main objectives: 1) survey camper attitudes and knowledge
about *L. humile* to develop educational materials and 2) determine *L. humile* locations in
campground areas. Although park personnel treat problem areas with liquid insecticide,
park visitors also apply insecticidal products, as well as products not labeled for ant
control. The hypothesis for this survey was that *L. humile* activity, noted by the number
of ant trails on trees, would remain constant from July to October at state parks. I also
hypothesized that a majority of campers personally treat their camping areas for *L. humile*
and need better education on proper control steps.

**Materials and Methods**

In the summer of 2006, a preliminary survey of ten South Carolina state park
campgrounds was conducted to determine the presence of *L. humile*. A park was selected
if it had recreational vehicle (RV) campsites and was located in the Piedmont region of
South Carolina (Figure A-1). Complaints were documented by interviewing park
personnel to determine if campers reported problems with ants in their campsites. Visual inspections of campsites were performed for presence of *L. humile*. Ant specimens were collected and identified to confirm presence of *L. humile* at campsites. Voucher specimens were placed in the Clemson University Arthropod collection. Using data on *L. humile* presence from the preliminary survey, study sites were chosen in 2007 at Baker Creek State Park (McCormick, SC; 33° 53’ 36.996” N, 82° 21’ 19.008” W), Calhoun Falls State Park (Calhoun Falls, SC; 34° 1’ 23.016” N, 82° 35’ 29.004” W), and Lake Greenwood State Park (Ninety Six, SC; 34° 11’ 58.7904” N, 81° 58’ 0.8868” W).

A written camper complaint log and personal survey was developed (Appendix A). Surveys were administered to campers by both a camper complaint log maintained by park personnel (Figure A-2) and by personal questioning (Figure A-3), during the 2007 and 2008 camping season. Initially campers were verbally asked all questions contained on the survey, but it became apparent that most campers could not knowledgeably answer all questions, such as: 1) what were the ants foraging for, 2) where did the ants seem to invade from and 3) do you know of any non-chemical ways to get rid of ants. Questions relating to knowledge of the ants in the campgrounds, problems involving ants in campsites, product usage to control ants and probability of return to the park were focused on. Based on survey results and personal observations of inappropriate treatment methods, an educational brochure (Figure A-4) recommending techniques for reducing *L. humile* infestations around their campsite was produced for distribution to campground visitors.
To determine the most appropriate time spans for observation of ant trails, preliminary field tests were run. These tests involved sampling active ant trails on the Clemson University campus (Clemson, SC; 34° 40’ 42” N, 82° 50’ 21” W) every fifteen minutes between 0800 h – 0930 h, 1200 h – 1300 h, and 1630 h – 1800 h to determine when ant trails contained the highest number of workers. It was found that ants are trailing most heavily between the hours of 0800 h – 0930 h and 1630 h – 1800 h.

Based on the preliminary survey, Baker Creek, Calhoun Falls and Lake Greenwood were selected for detailed sampling to determine the distribution and abundance of *L. humile* in the campgrounds and surrounding areas. Aerial maps of Baker Creek (Figure A-5), Calhoun Falls (Figure A-6), and Lake Greenwood (Figure A-7) were obtained using Google Earth™ (http://earth.google.com). Grids depicting 90 m² plots were overlaid on each map. Ten plots were randomly selected throughout each park for observation. By comparing the selected sites with a detailed, schematic map of the campgrounds obtained from the SC Department of Parks, Recreation and Tourism (http://www.southcarolinaparks.com) (Figure A-5, A-6 and A-7), sites were located for monitoring. At each park, eight sections were designated campsite areas and two sections were designated natural areas. Natural areas were considered sites at least 4.5 m away from active campsites. Once a month, each plot was surveyed in the morning (0800 h) and again in the afternoon (1630 h). Morning and evening counts were averaged within each park. All trees within each plot were observed to confirm *L. humile* trail presence or absence. Trees were designated as any free standing, living plant that is at least 0.08 m wide and 1.83 m in height. By determining the number of trees on which ants were
trailing and the total number of trees in each site, the overall percentage of trees with *L. humile* was calculated. Trees within each area were counted during the most active camping months of July, August, September and October 2007. All observations were made on days of similar weather patterns to reduce variability.

Total number of *L. humile* trails present and absent were tallied for all plots in each park. Month to month comparisons within and among parks were made to evaluate any change in ant presence from July-October. The mean number of trails present within and among parks was analyzed by ANOVA (SAS 2003) followed by LSD test.

**Results**

During the 2006 survey, seven of the 10 parks had logs of campers complaining of ants invading campsites (Table 2.1). Only five of the parks were confirmed to have *Linepithema humile* by site visits. Three parks had no previous camper complaints of *L. humile* invading campsites. Although there had been no reported complaints, Table Rock had *L. humile* foraging in multiple locations of the campground.
Table 2.1. South Carolina State Parks selected for preliminary survey of *Linepithema humile* (Mayr) presence during Summer 2006. Complaints were based on ranger records and site inspections were performed to confirm infestation.

<table>
<thead>
<tr>
<th>Park</th>
<th>Complaints</th>
<th>Ant Presence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baker Creek (3)</td>
<td>Yes</td>
<td>Confirmed</td>
</tr>
<tr>
<td>Calhoun Falls (6)</td>
<td>Yes</td>
<td>Confirmed</td>
</tr>
<tr>
<td>Devil’s Fork (13)</td>
<td>Yes</td>
<td>Not confirmed</td>
</tr>
<tr>
<td>Lake Greenwood (26)</td>
<td>Yes</td>
<td>Confirmed</td>
</tr>
<tr>
<td>Hickory Knob (20)</td>
<td>Yes</td>
<td>Confirmed</td>
</tr>
<tr>
<td>Keowee-Toxaway (24)</td>
<td>Yes</td>
<td>Not confirmed</td>
</tr>
<tr>
<td>Lake Hartwell (27)</td>
<td>Yes</td>
<td>Confirmed</td>
</tr>
<tr>
<td>Oconee State (35)</td>
<td>No</td>
<td>Not confirmed</td>
</tr>
<tr>
<td>Sadler’s Creek (42)</td>
<td>No</td>
<td>Not confirmed</td>
</tr>
<tr>
<td>Table Rock (45)</td>
<td>No</td>
<td>Confirmed</td>
</tr>
</tbody>
</table>

*Numbers correspond to location on South Carolina Department of Parks, Tourism and Recreation map (Figure A-1)*

Surveys of campers at Baker Creek, Calhoun Falls and Lake Greenwood State Parks in 2007 and 2008 recorded that 147 individuals (N = 157) had been camping prior to the time of survey. When asked if the camper had heard of the problem of *Linepithema humile* in the campground, 131 individuals reported previously knowing about the issue before visiting the park. When asked if there had been a problem involving *L. humile* in their individual campsite, only 37 campers reported no, while 120 stated they were currently or had previously had a problem with *L. humile*.

Table 2.2. Results of the personal camper survey at Baker Creek, Calhoun Falls, and Lake Greenwood State Parks in 2007 and 2008.

<table>
<thead>
<tr>
<th>Survey question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you previously been camping?</td>
<td>147</td>
<td>10</td>
</tr>
<tr>
<td>Have heard of <em>L. humile</em> problem in the campground?</td>
<td>131</td>
<td>26</td>
</tr>
<tr>
<td>Have had a problem with <em>L. humile</em> in your campsite?</td>
<td>120</td>
<td>37</td>
</tr>
</tbody>
</table>
Park complaint logs recorded that 63% (n = 43) of campers in 2007 and 58% (n = 24) of campers in 2008 at Calhoun Falls (Figure 2.1, Table A-1) used some form of product to combat against *L. humile* in their camping areas. These included products labeled for ant control, as well as products not labeled for ant control. At Lake Greenwood, 100% (n = 2) of campers in 2007 and 80% (n = 10) in 2008 reported using product(s) in their campsites to deter or eliminate their problem ants. No results from Baker Creek were obtained.

![Figure 2.1](image-url)

**Figure 2.1.** Percentage of campers surveyed ± standard error reporting use of a product against *Linepithema humile* (Mayr) at Calhoun Falls and Lake Greenwood State Parks, as recorded by park personnel in 2007 and 2008.
Surveys of Baker Creek campers (Figure 2.2, Table A-2) indicated that 79% (n = 14) of park visitors in 2007 and 67% (n = 6) in 2008 claimed using products to combat against *L. humile* in their camping areas. At Calhoun Falls, 83% (n = 12) of campers in 2007 and 96% (n = 45) in 2008 reported using products in their campsites. Camper use of product(s) against *L. humile* at Lake Greenwood was 89% (n = 53) in 2007 and 89% (n = 27) in 2008.

Figure 2.2. Percentage of campers surveyed ± standard error reporting use of a product against *Linepithema humile* (Mayr) at Baker Creek, Calhoun Falls, and Lake Greenwood State Parks in 2007 and 2008.
Surveys of Baker Creek campers (Figure 2.3, Table A-3) indicated that 93% (n = 14) of park visitors were willing to return to the campground despite the *L. humile* problems, while 7% stated their return depended on improved control of ants in their campsites. At Calhoun Falls, 58% (n = 12) of campers said they planned to return to the park and 33% were unsure. At Lake Greenwood 34% (n = 53) of campers stated they planned to return to the campground in the future, while 32% remained unsure.

![Bar chart showing percentage of campers who will return, will not return, and have a questionable decision across three state parks: Baker Creek, Calhoun Falls, and Lake Greenwood.](image)

**Figure 2.3.** Percentage of campers surveyed ± standard error reporting their probability of return to Baker Creek, Calhoun Falls, or Lake Greenwood State Park, as recorded from July through October 2007.
Surveys of Baker Creek campers (Figure 2.4, Table A-4) indicated that 67% (n = 6) of park visitors were willing to return to the campground despite the *L. humile* problems, while 33% stated their return depended on improved control of ants in their campsites. At Calhoun Falls, 87% (n = 45) of campers said they planned to return to the park and 11% were unsure. At Lake Greenwood 81% (n = 27) of campers reported they planned to return to the campground in the future, while 11% remained unsure.

**Figure 2.4.** Percentage of campers surveyed ± standard error reporting their probability of return to Baker Creek, Calhoun Falls, or Lake Greenwood State Park, as recorded from June through September 2008.
Through monitoring trees for presence of *L. humile* foraging trails (Table 2.3), the months of August and September had the highest percentage of foraging trails in Baker Creek, Calhoun Falls and Lake Greenwood. August had the highest percentage of trees with active foraging trails at Lake Greenwood ($t = 3.87$, df = 19, $P = 0.0010$) and Calhoun Falls ($t = 2.42$, df = 25, $P = 0.0231$); however, Baker Creek had its highest percentage of trees with foraging trails in September ($t = 4.04$, df = 25, $P = 0.0005$). Foraging trail activity decreased from September to October in Baker Creek ($t = -2.94$, df = 25, $P = 0.007$) and Lake Greenwood ($t = -0.23$, df = 19, $P = 0.8223$). Foraging trail activity at Calhoun Falls had a slight increase in foraging trail activity from September to October ($t = 0.59$, df = 25, $P = 0.5637$).

Table 2.3. Percentage of trees in Baker Creek, Calhoun Falls, and Lake Greenwood State Park sampling areas with *Linepithema humile* (Mayr) foraging trails present from July through October 2007. Different letters within an individual park (across rows) represent a significant difference at $\alpha = 0.05$ (least squares means test).

<table>
<thead>
<tr>
<th>Park</th>
<th>July</th>
<th>Month of Observation</th>
<th>August</th>
<th>September</th>
<th>October</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baker Creek</strong></td>
<td>0.2709</td>
<td>b</td>
<td>0.3852</td>
<td>a</td>
<td>0.411</td>
</tr>
<tr>
<td><strong>Calhoun Falls</strong></td>
<td>0.1269</td>
<td>ab</td>
<td>0.1728</td>
<td>ab</td>
<td>0.1065</td>
</tr>
<tr>
<td><strong>Lake Greenwood</strong></td>
<td>0.4373</td>
<td>ab</td>
<td>0.4463</td>
<td>a</td>
<td>0.3513</td>
</tr>
</tbody>
</table>
Discussion

*Linepithema humile* is ecologically successful due to its ability to tolerate a variety of habitats (Aron et al. 1990). State parks in the Piedmont of South Carolina are ideal habitats for *L. humile*, due to their location near water sources (lakes) and continual food sources supplied by campground visitors. As visitors continue to frequent *L. humile* infested campsites, inappropriate products to control pest ants will persist. Through surveying campers, it was reported that many different products (Table A-5), not all labeled for insect control, were being placed out in campsites in an attempt to eliminate ants present or deter ants from entering the area.

Both park complaint logs and personal surveys indicated over 50% of campers were inappropriately treating camping areas, in both 2007 and 2008 with products not labeled for insect control. These numbers suggest that better education of campers on non-chemical techniques for ant control is needed. Also, campers need to be educated not to use non-labeled products for ant control and not to overuse labeled products for *L. humile* infestations. An educational brochure was produced for distribution in the parks for the 2008 camping season (Figure A-4). Brochures were intended to be distributed to campers or posted in areas frequented by visitors, but the decision of how to use the brochure was left up to individual park personnel in this study. However, if educational materials are not made easily accessible in campgrounds, changing camper actions towards *L. humile* will take longer than necessary.

Through the survey of campers from three state parks I found that to the question “Will you return to the park after having an issue with Argentine ants?” rates of return
were over 65% at all parks, 2008. While this percentage does not seem unreasonable, at the parks monitored in this study, between 19% and 33% of campers who had come into contact with *L. humile* were unsure of their return to the campground. To put this in perspective, South Carolina parks make their revenue on day trip visitors and campsite renters. In two parks used in this research, yearly revenue ranges from $330,000 (Lake Greenwood) to $418,000 (Calhoun Falls) (D. Drake and F. Yenny, personal communication, Appendix A, p. 68). If campers decide to decline on a return stay in the campground, it is a loss of $15 to $21 per night for each campsite not being rented. Losses in camper rates due to *L. humile* infestations, revenue could potentially decrease revenue from $42,900 to $137,900 annually.

In 2007, after the first month of monitoring *L. humile* foraging trails on individual trees, I noted that areas not associated with campsites (“natural areas”) were less likely to have dispersed ant trail populations. After counting the presence and absence of *L. humile* in July, no ants were in the two “natural area” locations selected. To get the most effective information on ant presence for a camping season, the two plots were replaced with plots where *L. humile* was known to occur. The significant difference indicated between the months of July and August for percentage of trees with *L. humile* foraging trails at Baker Creek could be accounted for by the shift of two observation plots where no ants were found, and no campers were located. At Calhoun Falls, two plots located in “natural areas” were initially chosen at random for monitoring. Again, after determining no ants were present, these plots were exchanged in July for areas where *L. humile* was known to be active. The increase in the amount of observed trees with ant trails seen at
Calhoun Falls also was likely due to the change in plots, even though from July to August no significant difference was observed. At Lake Greenwood, the two “natural spots” abutted infested campground areas and remained in the set of 10 plots monitored. All three parks had the highest percentage of trees with foraging trails in either August or September. While a decrease in percentage of trees with foraging trails was expected in October, and seen at Baker Creek and Lake Greenwood, there was a slight increase in the percentage of trees with foraging ants at Calhoun Falls. This is an indication that ant infestations will either stay constant or decrease later in a camping season.

In conclusion, surveys and personal observations indicated that state park campers needed to be better informed about *L. humile* and provided techniques for reducing *L. humile* infestations around their campsites in ways other than applying product(s). Although educational materials were produced, it was not evident that campers were receiving the brochures and learning from the tips provided. By having park personnel post brochures in bath houses, check-in desks, and other common areas, campers are more likely to have opportunities to increase their knowledge about *L. humile*. It was also found that *L. humile* populations not only stay in the same general area, but also tended to maintain foraging trails on the same trees throughout the camping season. This indicates that if started at the right time of year, a targeted control program could be implemented earlier with greater success during the months leading up to July.
CHAPTER THREE

EVALUATION OF CHEMICAL CONTROL STRATEGIES AGAINST LINEPITHEMA HUMILE (MAYR) IN SOUTH CAROLINA STATE PARK CAMPGROUNDS

Introduction

Linepithema humile (Mayr), the Argentine ant, was probably introduced to the United States in 1891 (Newell and Barber 1913). It can be found in states ranging from Washington, Arizona, Indiana, and Maryland, but has become an established pest in Hawaii, California and throughout the South (Mallis 2004). Linepithema humile has been reported to inhabit all continents, except Antarctica, as well as many oceanic islands (Suarez et al. 2001). In 2000 the results of a survey of pest management professionals in the United States reported that L. humile ranked among the top five pest ant species nationwide (Hedges 2000). According to Aron et al. (1990), L. humile is ecologically successful for three reasons: 1) their ability to tolerate a variety of habitats 2) polydomic and polygynic colonies, and 3) their ability to lay down pheromone trails.

Nesting sites are usually shallow and can range from cracks and crevices on walkways, under stones and wood, at the base of a tree (Mallis 1942) or even inside appliances and cars (Smith 1965). Linepithema humile is a unicolonial ant, meaning that each new nest that is formed remains associated with the original nest (Passera 1994), thus permitting L. humile to have a wider foraging range without aggression from competing ant species.

Linepithema humile is an effective scavenger due to its use of mass recruitment and trail pheromones when finding a resource (Aron et al. 1990). They can recruit cohorts
up to 6 mm away from an active trail (Van Vorhis Key et al. 1981). By laying down a pheromone trail on the way to a food source and returning to its nest, *L. humile* has an advantage over other ant species in their ability to exploit food sources at a greater rate (Deneubourg et al. 1990; Aron et al. 1990). Human and Gordon (1996) attribute the high number of *L. humile* concentrated in an area to a reduction in ant species richness (Human and Gordon 1996), leaving *L. humile* able to dominate entire habitats (Holldobler and Wilson 1977).

Due to the recruitment behavior of *L. humile*, baiting is one viable option for control. Baits are an attractive option in treating pest ants because their use usually results in applications of smaller, concentrated amounts of insecticide (Taniguchi et al. 2005), rather than spraying a broad area with liquid toxicant. Klotz (1998) found when low concentrations of liquid boric acid (≤ 1.0 %) were offered to trailing *L. humile*, there was a reduction in ants entering surrounding buildings where they previously retrieved food. However, in Hawaii it was reported that when offered either liquid sucrose baits or granular baits, *L. humile* readily accepted either formulation (Krushelnycy and Reimer 1998).

In general, when using baiting for ant treatment, there are two application choices: scattering or clumping. If small granular objects for retrieval are scattered, those objects will be recovered more quickly than if placed only in one pile. Conversely, it is thought that when social insects use recruitment techniques for finding objects, the trailing behavior allows for a more efficient manner of returning food to nests from clumped sources (Roulston and Silverman 2002). However, Silverman and Roulston (2003)
reported that whether scattered or clumped, there is no difference in the total amount of granular bait gathered.

Another strategy which takes advantage of *L. humile*’s foraging behavior is the application of non-repellent chemical barriers. Rust et al. (1996) reported that barrier sprays were effective, but only within the first 30 days, due to uncontrollable environmental factors. Horizontal transfer of insecticide from barrier treatments was effective in killing worker ants, by both live ants and dead ants which had come into contact with insecticide (Soeprono and Rust 2004). Vail and Bailey (2002) tested whether perimeter baits, sprays or a combination were most efficient in treating the odorous house ant, *Tapinoma sessile* (Say), in residential areas. They reported that bait-only treatments did not perform as well as perimeter spray applications. Although perimeter spray-only sites were not statistically different from combination treatment areas, a combination of both treatments was reported to be more effective for eliminating >94% of the population for up to four months.

In any treatment targeting pest ants (spray, bait or a combination), the factor of delayed toxicity must be considered. Stringer et al. (1964) defined an effective insecticide as one that must exhibit delayed toxicity over a wide range of dosages, be readily transferred from one ant to another lethally, and be non-repellent when used in bait form. Markin (1968) discovered that after taking up a labeled sucrose solution, within four hours, 53% of the colony had been exposed to the same solution. However, at 96 hours only 32.8% of the colony still showed exposure to the solution. Due to trophallaxis or sharing of food sources with nest mates, solutions are diluted over time. This requires that
the toxicants of choice delayed in action, so workers are able to survive long enough to return to the colony and distribute the active ingredient.

In a preliminary 2007 survey of three South Carolina state park campgrounds, I determined *L. humile* resides in specified locations throughout prime camping season. Based on this information, I determined that a targeted treatment program was possible. The objective of this study was to evaluate an effective treatment strategy for state park campgrounds in South Carolina. I hypothesized that by revealing the most effective chemicals and application methods to implement in an IPM program, better control of *L. humile* would be achieved.

**Materials and Methods**

This study was conducted in Baker Creek State Park (McCormick, SC; 33° 53’ 36.996” N, 82° 21’ 19.008” W), Calhoun Falls State Park (Calhoun Falls, SC; 34° 1’ 23.016” N, 82° 35’ 29.004” W), and Lake Greenwood State Park (Ninety Six, SC; 34° 11’ 58.7904” N, 81° 58’ 0.8868” W) from June to September 2008. Between three and five campsites with known ant infestations in each park were selected to evaluate different chemical treatments. Each campsite had the capability for RV parking, water and electrical hook-up access, trees around the perimeter, and had a high occupancy rate.

Three treatment areas (one control and two treatments) were assigned to each park, at least 60 m (Vega and Rust 2003) apart to prevent the interaction of foraging ants from one area to another. Control areas were locations untreated by park personnel, but still frequented by campers. Due to the actions of park visitors, each research area had the potential for other chemical treatments.
Prior to insecticide application, landmarks were chosen to observe the ant numbers throughout the duration of each insecticide trial. Ants were collected, identified as *L. humile* and voucher specimens were stored at the Clemson University Arthropod Collection. Landmarks consisted of trees and cross-ties where heavy foraging trails were present. Once each landmark was chosen, the ant trail with the greatest number of individuals was counted for 30 seconds and recorded. Counts were achieved by recording the number of ants that crossed an arbitrary line, in both up and down directions (Moreno et al. 1987). All counts within a given treatment area were summed weekly, and then averaged to provide a mean number of ants per landmark (Rust et al. 2000). Ant trails were counted at weeks 0, 1, 2, 3 and 4.

In Trial 1, both Treatment 1 and Treatment 2 hard-scape areas were sprayed with a 0.1% formulation of Premise® 2 (21.4%; imidacloprid; Bayer Environmental Science 2 T.W. Alexander Drive Research Triangle PK, NC 27709). Hard-scape was defined as all pavement edges surrounding parking areas, stairs and cross-tie bases encompassing each campsite. In addition to hard-scape applications, Treatment 1 sites had Premise® 2 applied to all trees within 3 m of each campsite, according to label specification. An attempt was made to use minimal amounts of spray, yet enough to achieve control. In addition to hard-scape spraying, Treatment 2 sites also had Niban® Granular Bait (5.0% orthoboric acid; Nisus Corporation, 100 Nisus Drive Rockford, TN 37853) placed around trees within 3 m of each campsite. To determine the best bait granule for use in the campground, a preliminary survey was performed in early Summer 2008. The bait
recruited to most by *L. humile*, Niban® Granular Bait, was chosen for use in further trial treatments.

In Trial 2, the same procedure was performed as in Trial 1; however, more spray was applied to ant trails and visible nests (Table 3.2). Crosstie bases were treated as before, but Trial 2 consisted of additional spraying to each crosstie in a wall stack and in grooves where ants could potentially trail. All ants trailing on the ground and nests were sprayed as encountered.

In Trial 3, the same methods performed in Trial 2 were applied, but an experimental insecticide Temprid™ SC (21.4% imidacloprid; 11.8% β-cyfluthrin; Bayer Environmental Science) was exchanged for Premise® 2 for treatment of hard-scapes. Trees within 3 m of Treatment 1 sites were sprayed with Temprid™ SC as in previous trials, and Niban® Granular Bait was once again used around trees in Treatment 2 areas.

In Trial 4, Treatment 1 was applied in the same manner as Trial 3 using Temprid™ SC again. In Treatment 2, hard-scapes and trees within 3 m of each campsite were sprayed with a 0.025% formulation of Tempo® Ultra SC (11.8%; β-cyfluthrin; Bayer Environmental Science) in the same manner as in Treatment 1.

At week 0 of each trial (time before application), the mean number of ants in a foraging trail for each treatment area was recorded. Means among treatments within a park were compared by Analysis of Variance (ANOVA) followed by a t-test based on least square means. If significant differences were found, mean numbers were re-expressed as a mean change from the original number to adjust for differences among ants in the parks.
For each trial, all ants counted in foraging trails within a treatment area were then averaged for remaining three weeks. The objectives were to determine if there were differences among the treatments and if any of the treatments resulted in a decline in *L. humile*. Ant numbers were averaged across parks to produce treatment means for each trial. The mean change in ant numbers was compared by Analysis of Variance (ANOVA) followed by a t-test based on least square means. The ant changes were also compared to 0 to determine if a significant drop had occurred using Fisher’s LSD test. All calculations were performed using the statistical analysis system (SAS 2003).

**Results**

The mean number of *L. humile* at Baker Creek (F=9.17, df=2, 31, P = 0.0007), Calhoun Falls (F = 5.74, df = 2, 51, P = 0.0056), and Lake Greenwood State Parks (F = 7.61, df = 2, 47, P = 0.0014) were significantly different in at least one treatment area, when all three areas were compared for Trial 1 (Table 3.1). To better compare treatments within and among parks, the overall change in the mean number of *L. humile* was then calculated instead of the actual mean number.

**Table 3.1.** Mean number ± standard error of *Linepithema humile* (Mayr) present in foraging trails at Baker Creek, Calhoun Falls, and Lake Greenwood State Parks during Week 1 counts for Trial 1. Different letters within an individual park represent a significant difference at α = 0.05 (t-test based on least square means).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>State Park</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baker Creek</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>62.43 ± 6.99</td>
</tr>
<tr>
<td><strong>Treatment 1</strong></td>
<td>28.44 ± 8.72</td>
</tr>
<tr>
<td><strong>Treatment 2</strong></td>
<td>20.18 ± 7.89</td>
</tr>
</tbody>
</table>

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The combined mean change of _L. humile_ in foraging trails observed over the four week period of Trial 1 (Figure 3.1, Table B-2) indicated there was a significant difference between the control area and Premise® 2-only treated areas (Treatment 1)\(t = -2.86, \text{ df} = 4, P = 0.0461\). However, no significant difference was found between the control and Premise® 2 + Niban® Granular Bait treated areas (Treatment 2) \(t = -1.61, \text{ df} = 4, P = 0.1825\) or Premise® 2 only and Premise® 2 + Niban® Granular Bait treated areas \(t = -1.36, \text{ df} = 4, P = 0.2447\). Although there was no significant difference between Premise® 2-only treated areas and Premise® 2 + Niban treated areas, there was a larger decrease in the average number of ants trailing over the four week period in Premise® 2-only treated areas that was less than 0 \(t = -2.13, \text{ df} = 4, P = 0.04995\).
Figure 3.1. Combined mean change in number of *Linepithema humile* (Mayr) present in foraging trails ± standard error at Baker Creek, Calhoun Falls and Lake Greenwood State Parks over the course of Trial 1. Different letters represent a significant difference at $\alpha = 0.05$ and * indicates significance less than 0 (means were compared using ANOVA followed by Fisher’s LSD).

The mean change of *L. humile* in foraging trails observed over the four week period of Trial 1 at Baker Creek State park (Figure 3.2, Table B-3) indicated there was a significant difference between the control area and Treatment 1 (Premise® 2) ($t = -3.04$, $df = 31$, $P = 0.0048$). However, no significant difference was found between the control and Treatment 2 (Premise® 2 + Niban® Granular Bait) ($t = -1.34$, $df = 31$, $P = 0.1895$) or Treatment 1 and Treatment 2 ($t = -1.69$, $df = 31$, $P = 0.1012$). Treatment 1 was the only area to have a decrease in *L. humile*. 
Figure 3.2. Mean change in number of *Linepithema humile* (Mayr) present in foraging trails ± standard error at Baker Creek State Park over the course of Trial 1. Different letters represent a significant difference at $\alpha = 0.05$ (t-test based on least square means).

The mean change of *L. humile* in foraging trails observed over the four week period of Trial 1 at Calhoun Falls State Park (Figure 3.3, Table B-4) indicated there was a significant difference between the control area and Treatment 1 (Premise® 2) ($t = -2.79$, df = 51, $P = 0.0074$). However, no significant difference was found between the control and Treatment 2 (Premise® 2 + Niban® Granular Bait) ($t = -1.23$, df = 51, $P = 0.2233$) or Treatment 1 and Treatment 2 ($t = -1.69$, df = 51, $P = 0.0970$). While there was no significant difference, there was a larger decrease in *L. humile* in Premise® 2 only treated areas than in Premise® 2 + Niban® Granular Bait treated areas ($t = -3.76$, df = 51, $P = 0.0396$).
Figure 3.3. Mean change in number of Linepithema humile (Mayr) present in foraging trails ± standard error at Calhoun Falls State Park over the course of Trial 1. Different letters represent a significant difference at $\alpha = 0.05$ and * indicates significance less than 0 (means were compared using ANOVA followed by Fisher’s LSD).

The mean change of L. humile in foraging trails observed over the four week period of Trial 1 at Lake Greenwood State Park (Figure 3.4, Table B-5) indicated that there no significant difference among the control, Treatment 1 (Premise® 2) or Treatment 2 (Premise® 2 + Niban® Granular Bait).
The mean amount of product used in Treatment 1 areas for Trial 1 (Table 3.2) was 2.84 L/campsite, while 1.82 more L/campsite was placed in the same area during Trial 2. In Treatment 2 areas during Trial 1 product was used at a rate of 2.15 L/campsite, however during Trial 2, the rate of product used was increased only increased by 0.28 L/campsite. Overall, during Trial 2 more product was applied in each treatment area than was in Trial 1.

Figure 3.4. Mean change in number of Linepithema humile (Mayr) present in foraging trails ± standard error at Lake Greenwood State Park over the course of Trial 1. Different letters represent a significant difference at $\alpha = 0.05$ (t-test based on least square means).
Table 3.2. Mean amount of spray insecticide (L/campsite) ± standard error used in Treatment 1 and Treatment 2 areas ± standard error in Trial 1 and Trial 2.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Treatment 1 (L/campsite)</th>
<th>Treatment 2 (L/campsite)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>2.84 ± 0.29</td>
<td>2.15 ± 0.30</td>
</tr>
<tr>
<td>Trial 2</td>
<td>4.66 ± 0.54</td>
<td>2.43 ± 0.42</td>
</tr>
</tbody>
</table>

The mean number of \textit{L. humile} at Baker Creek (F = 18.01, df = 2, 31, P = 0.0001), Calhoun Falls (F = 2.71, df = 2, 51, P = 0.0764), and Lake Greenwood State Park (F = 5.70, df = 2, 47, P = 0.0061) were significantly different in at least one treatment area, when all three areas were compared for Trial 2 (Table 3.3). To better compare treatments within and among parks, the overall change in the mean number of \textit{L. humile} was then calculated instead of the actual mean number.

Table 3.3. Mean number ± standard error of \textit{Linepithema humile} (Mayr) present in foraging trails at Baker Creek, Calhoun Falls, and Lake Greenwood State Parks during pre-treatment counts for Trial 2. Different letters within an individual park represent a significant difference at $\alpha = 0.05$ (t-test based on least square means).

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<thead>
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<th>Treatment</th>
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</tr>
</thead>
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<td></td>
<td>Baker Creek</td>
</tr>
<tr>
<td>Control</td>
<td>77.57 ± 10.60</td>
</tr>
<tr>
<td>Treatment 1</td>
<td>22.56 ± 2.47</td>
</tr>
<tr>
<td>Treatment 2</td>
<td>18.63 ± 2.26</td>
</tr>
</tbody>
</table>
The combined mean change of *L. humile* in foraging trails observed over the four
week period of Trial 2 (Figure 3.5, Table B-2) indicated there were no significant
difference among the control, Treatment 1 (Premise® 2) or Treatment 2 (Premise® 2 +
Niban® Granular Bait) areas. Although there was no difference, all treatment areas had
an increase in *L. humile* in foraging trails, instead of the expected decrease due to
treatment.

**Figure 3.5.** Combined mean change in number of *Linepithema humile* (Mayr) present in
foraging trails ± standard error at Baker Creek, Calhoun Falls and Lake Greenwood State
Parks over the course of Trial 2. Different letters represent a significant difference at \( \alpha = 0.05 \) (t-test based on least square means).
The mean change of *L. humile* in foraging trails observed over the four week period of Trial 2 at Baker Creek State Park (Figure 3.6, Table B-3) indicated there was no significant difference among the control, Treatment 1 (Premise® 2) or Treatment 2 (Premise® 2 + Niban® Granular Bait) areas. While there was no statistical difference, the only treatment area decrease in *L. humile* was Treatment 1 (Premise® 2-only).

![Figure 3.6](image)

**Figure 3.6.** Mean change in number of *Linepithema humile* (Mayr) present in foraging trails ± standard error at Baker Creek State Park over the course of Trial 2. Different letters represent a significant difference at $\alpha = 0.05$ (t-test based on least square means).
The mean change of \textit{L. humile} in foraging trails observed over the four week period of Trial 2 at Calhoun Falls State Park (Figure 3.7, Table B-4) indicated there was a significant difference between the control area and Treatment 1 (Premise® 2) ($t = -2.83$, $df = 51$, $P = 0.0389$). However, no significant difference was found between the control and Treatment 2 (Premise® 2 + Niban® Granular Bait) ($t = -1.90$, $df = 51$, $P = 0.0626$) or Treatment 1 and Treatment 2 ($t = -1.02$, $df = 51$, $P = 0.3121$). Although no difference was seen, the only area to decrease in \textit{L. humile} was Treatment 1 (Premise® 2-only).

![Mean change in number of \textit{Linepithema humile} (Mayr) present in foraging trails ± standard error at Calhoun Falls State Park over the course of Trial 2. Different letters a significant difference at $\alpha = 0.05$ (t-test based on least square means).](image)

\textbf{Figure 3.7.} Mean change in number of \textit{Linepithema humile} (Mayr) present in foraging trails ± standard error at Calhoun Falls State Park over the course of Trial 2. Different letters a significant difference at $\alpha = 0.05$ (t-test based on least square means).
The mean change of *L. humile* in foraging trails observed over the four week period of Trial 2 at Lake Greenwood State park (Figure 3.8, Table B-5) indicated there was a significant difference between the control area and Treatment 1 (Premise® 2) \((t=2.12, df = 47, P = 0.0389)\). However, no significant difference was found between the control and Treatment 2 (Premise® 2 + Niban® Granular Bait) \((t = 1.46, df = 47, P = 0.1506)\) or Treatment 1 and Treatment 2 \((t = 0.81, df = 47, P = 0.4223)\). While there was no significant difference between the control and Treatment 2 areas, there was a larger decrease in *L. humile* in control areas than in either treated areas \((t = -1.84, df = 47, P = 0.03575)\).

**Figure 3.8.** Mean change in number of *Linepithema humile* (Mayr) present in foraging trails ± standard error at Lake Greenwood State Park over the course of Trial 2. Different letters represent a significant difference at \(\alpha = 0.05\) and * indicates significance less than 0 (means were compared using ANOVA followed by Fisher’s LSD).
The mean number of *L. humile* at Baker Creek ($F = 7.59, df = 2, 31, P = 0.0021$), Calhoun Falls ($F = 1.19, df = 2, 51, P = 0.3125$), and Lake Greenwood State Parks ($F = 3.73, df = 2, 47, P = 0.0314$) was significantly different in at least one treatment area, when all three areas were compared for Trial 3 (Table 3.4). To better compare treatments within and among parks, the overall change in the mean number of *L. humile* was then calculated instead the actual mean number.

**Table 3.4.** Mean number ± standard error of *Linepithema humile* (Mayr) present in trail counts for Trial 3. Different letters within an individual park represent a significant difference at $\alpha = 0.05$ (t-test based on least square means).

<table>
<thead>
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</thead>
<tbody>
<tr>
<td></td>
<td>Baker Creek</td>
<td>Calhoun Falls</td>
<td>Lake Greenwood</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>59.21 ± 6.38 a</td>
<td>64.13 ± 7.95 a</td>
<td>49.93 ± 11.13 Ab</td>
<td></td>
</tr>
<tr>
<td>Treatment 1</td>
<td>27.44 ± 7.96 b</td>
<td>53.95 ± 7.06 a</td>
<td>30.60 ± 11.13 B</td>
<td></td>
</tr>
<tr>
<td>Treatment 2</td>
<td>26.27 ± 7.20 b</td>
<td>47.95 ± 6.88 a</td>
<td>70.20 ± 9.64 A</td>
<td></td>
</tr>
</tbody>
</table>

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The combined mean change of *L. humile* in foraging trails observed over the four week period of Trial 3 (Figure 3.9, Table B-2) indicated there was no significant difference observed between the control and Temprid™ SC + Niban® Granular Bait treated areas (Treatment 2) \((t = -1.17, \text{df} = 4, \text{P} = 0.3060)\). However, a significant difference existed between the control and Temprid™ SC-only treated areas (Treatment 1) \((t = -3.95, \text{df} = 4, \text{P} = 0.0168)\), as well as between Temprid™ SC-only and Temprid™ SC + Niban treated areas (Treatment 2) \((t = -2.86, \text{df} = 4, \text{P} = 0.0457)\). The control and Temprid™ SC + Niban® Granular Bait treated areas increased in *L. humile*, while Temprid™ SC-only areas indicated a decrease in the average number of trailing *L. humile* over the four week period \((t = -2.81, \text{df} = 4, \text{P} = 0.02425)\).
The mean change of *L. humile* in foraging trails observed over the four week period of Trial 3 at Baker Creek State Park (Figure 3.10, Table B-3) indicated there was a significant difference between the control and Treatment 1 (Temprid™ SC) ($t = -6.25$, df = 31, $P = <0.0001$), as well as between Treatment 1 and Treatment 2 (Temprid™ SC + Niban® Granular Bait) ($t = -4.51$, df = 31, $P = <0.0001$). However, no significant difference was observed between the control and Treatment 2 (Temprid™ SC + Niban® Granular Bait) ($t = -1.60$, df = 31, $P = 0.1202$). The only area to decrease in the average number of ants trailing over the four week period was the Temprid™ SC-only treated area, which was less than 0 ($t = -3.76$, df = 31, $P = 0.0035$).
The mean change of *L. humile* in foraging trails observed over the four week period of Trial 3 at Calhoun Falls State Park (Figure 3.11, Table B-4) indicated there was a significant difference between the control and Treatment 1 (Temprid™ SC) \( (t = -2.02, df = 51, P = 0.0487) \), as well as between Treatment 1 and Treatment 2 (Temprid™ SC + Niban® Granular Bait) \( (t = -69, df = 51, P = 0.0095) \). However, no significant difference was observed between the control and Treatment 2 (Temprid™ SC + Niban® Granular Bait) \( (t = 0.48, df = 51, P = 0.6304) \). All areas showed a decrease in *L. humile* over the trial period, but Treatment 1 gave the greatest decrease below 0 \( (t = -2.69, df = 51, P = 0.00475) \).
Figure 3.11. Mean change in number of *Linepithema humile* (Mayr) present in foraging trails ± standard error at Calhoun Falls State Park over the course of Trial 3. Different letters represent a significant difference at $\alpha = 0.05$ and * indicates significance less than 0 (means were compared using ANOVA followed by Fisher’s LSD).
The mean change of *L. humile* in foraging trails observed over the four week period of Trial 3 at Lake Greenwood State Park (Figure 3.12, Table B-5) indicated there was a significant difference between the control area and Treatment 1 (Temprid™ SC) \( (t = -2.30, df = 47, P = 0.0258) \). However, no significant difference was found between the control and Treatment 2 (Temprid™ SC + Niban® Granular Bait) \( (t = -1.78, df = 47, P = 0.0818) \). Although there was no significant difference between Treatment 1 and Treatment 2 \( (t = -0.68, df = 47, P = 0.4958) \), Treatment 1 had larger decrease in the average number of ants trailing over the four week period that was less than 0, but not significant \( (t = -1.37, df = 47, P = 0.08925) \).

**Figure 3.12.** Mean change in number of *Linepithema humile* (Mayr) present in foraging trails ± standard error at Lake Greenwood State Park over the course of Trial 3. Different letters represent a significant difference at \( \alpha = 0.05 \) (least squares means test).
The mean number of *L. humile* at Baker Creek ($F = 16.34, \text{df} = 2, 31, P = <0.0001$), Calhoun Falls ($F = 3.51, \text{df} = 2, 51, P = 0.0373$), and Lake Greenwood State Parks ($F = 5.37, \text{df} = 2, 47, P = 0.0080$) were significantly different in at least one treatment area, when all three areas were compared for Trial 4 (Table 3.5). To better compare treatments within and among parks, the overall change in the mean number of *L. humile* was then calculated instead the actual mean number.

**Table 3.5.** Mean number ± standard error of *Linepithema humile* (Mayr) present in trails at Baker Creek, Calhoun Falls, and Lake Greenwood State Parks during pre-treatment counts for Trial 4. Different letters within an individual park represent a significant difference at $\alpha = 0.05$ (t-test based on least square means).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>State Park</th>
<th>Baker Creek</th>
<th>Calhoun Falls</th>
<th>Lake Greenwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td>66.36 ± 7.10 a</td>
<td>30.13 ± 6.53 ab</td>
<td>71.00 ± 10.09 A</td>
</tr>
<tr>
<td>Treatment 1</td>
<td></td>
<td>2.44 ± 8.59 c</td>
<td>20.05 ± 5.80 b</td>
<td>35.07 ± 10.09 B</td>
</tr>
<tr>
<td>Treatment 2</td>
<td></td>
<td>31.64 ± 8.01 b</td>
<td>41.50 ± 5.65 a</td>
<td>76.65 ± 8.74 A</td>
</tr>
</tbody>
</table>
The combined mean change of *L. humile* in foraging trails observed over the four week period of Trial 4 (Figure 3.13, Table B-2) indicated there was a significant difference between the control area and Tempo® Ultra SC treated areas (Treatment 2) *(t = -3.49, df = 4, P = 0.0252)*. However, no significant difference was between the control and Temprid™ SC-only treated areas (Treatment 1) *(t = -0.95, df = 4, P = 0.3943)*. Overall, both Temprid™ SC-only and Tempo® Ultra SC-only were statistically not different from each other *(t = 2.50, df = 4, P = 0.0667)*. While there was no significant difference, there was a larger decrease below 0 in *L. humile* in Tempo® Ultra SC-only treated areas than in Temprid™ SC treated areas *(t = -3.19, df = 4, P = 0.0288)*.
The mean change of *L. humile* in foraging trails observed over the four week period of Trial 4 at Baker Creek State Park (Figure 3.14, Table B-3) indicated there was a significant difference between the control area and Treatment 2 (*Tempo® Ultra SC*) \( t = -2.41, \text{df} = 31, P = 0.0220 \). However, no significant difference was found between the control and Treatment 1 (*Temprid™ SC*) \( t = -1.17, \text{df} = 31, P = 0.2516 \) or Treatment 1 (*Temprid™ SC*) and Treatment 2 (*Tempo® Ultra SC*) \( t = 1.05, \text{df} = 31, P = 0.3010 \).

While there was no significant difference, there was a larger decrease below 0 in *L. humile* in Treatment 2 \( t = -1.65, \text{df} = 31, P = 0.0544 \).
The mean change of *L. humile* in foraging trails observed over the four week period of Trial 4 at Calhoun Falls State Park (Figure 3.15, Table B-4) indicated there was a significant difference between the control area and Treatment 2 (Tempo® Ultra SC) ($t = -3.17$, $df = 51$, $P = 0.0026$). However, no significant difference was found between the control and Treatment 1 (Temprid™ SC) ($t = -1.73$, $df = 51$, $P = 0.0890$) or Treatment 1 (Temprid™ SC) and Treatment 2 (Tempo® Ultra SC) ($t = -1.51$, $df = 51$, $P = 0.1381$). While there was no significant difference, Treatment 2 had the largest decrease below 0 in *L. humile* over the trial period ($t = -2.29$, $df = 51$, $P = 0.01295$).
Figure 3.15. Mean change in number of *Linepithema humile* (Mayr) present in foraging trails ± standard error at Calhoun Falls State Park over the course of Trial 4. Different letters represent a significant difference at $\alpha = 0.05$ and * indicates significance less than 0 (means were compared using ANOVA followed by Fisher’s LSD).

The mean change of *L. humile* in foraging trails observed over the four week period of Trial 4 at Lake Greenwood State Park (Figure 3.16, Table B-5) indicated there was a significant difference between the control area and Treatment 2 (Tempo® Ultra SC) ($t = -4.55$, df = 47, $P = <0.0001$), as well as between Treatment 1 (Temprid™ SC) and Treatment 2 (Tempo® Ultra SC) ($t = 4.34$, df = 47, $P = <0.0001$). However, no significant difference was found between the control and Treatment 1 (Temprid™ SC) ($t = -0.20$, df = 47, $P = 0.8441$). Treatment 2 showed the largest decrease in *L. humile* below 0 over the trial period ($t = -6.75$, df = 47, $P = 0.00005$).
Figure 3.16. Mean change in number of *Linepithema humile* (Mayr) present in foraging trails ± standard error at Lake Greenwood State Park over the course of Trial 4. Different letters represent a significant difference at $\alpha = 0.05$ and * indicates significance less than 0 (means were compared using ANOVA followed by Fisher’s LSD).
Discussion

Although Klotz (1998) found liquid boric acid baits to be attractive and effective at decreasing *L. humile* around structures, the campground setting is more complex. Due to the curiosity of wildlife and park visitors, it is necessary to use a container that discourages tampering or consumption of product. The container must provide an adequate amount of bait to sate the high populations of *L. humile* recruited to the food source. Also, containers would need to inhibit microbial growth and reduce evaporation, as well as protect the bait from an influx of water (precipitation or irrigation), to keep it from becoming unpalatable, and thus ineffective (Silverman and Brightwell 2008).

Finding one station that meets these requirements, yet allows *L. humile* to actively forage on the enclosed bait is a problem. Previous attempts in campgrounds with makeshift stations containing Terro® Liquid Ant Bait, resulted in depleted containers which were rarely refilled, and thus remained empty and ineffective (S. Hutto, personal communication, Appendix A, p. 69). However, when offered either liquid sucrose baits or granular baits, *L. humile* readily accepted either formulation (Krushelnycky and Reimer 1998). During a preliminary survey of several granular baits, in May 2008, we determined that *L. humile* recruited most to a boric-acid based granular formulation. For this reason Niban® Granular Bait was selected for our trials.

I found that during Trial 1, although there was no significant difference between Premise® 2 and Premise® 2 + Niban® Granular Bait treatments, there was a larger decrease in the number of *L. humile* trailing in Premise® 2-only treated areas. In Trial 2, even though targeted treatments were made and more thorough sprayings were applied to
both treatment areas than were made in Trial 1 (Table B-1), both treatment and control areas were not statistically different, and *L. humile* increased over the four week period in all areas. In Trial 3, the insecticide was changed to Temprid™ SC, which is formulated with both active ingredients from Premise® 2 (imidacloprid) and Tempo® Ultra SC (β-cyfluthrin). During Trial 3, I found that Temprid™ SC-only was more effective than Temprid™ SC + Niban® Granular Bait. Because granular bait was not as effective as liquid insecticide in reducing ant numbers during the first three trials, during Trial 4 liquid insecticide only was chosen for treatment in both areas. Again, Temprid™ SC (imidacloprid and β-cyfluthrin) was used as Treatment 1, but Tempo® Ultra SC (β-cyfluthrin) was used as Treatment 2. Tempo® Ultra SC was selected because Premise® 2 (imidacloprid) had already been tested alone, and I questioned if it was a particular component of the Temprid™ SC causing the effectiveness or the combination of the two active ingredients. I found that Tempo® Ultra SC-only was the most effective at Lake Greenwood, but overall both Temprid™ SC-only and Tempo® Ultra SC-only were statistically the same.

If selecting a treatment for *L. humile* in park campgrounds is based on efficacy, Temprid™ SC-only or Tempo® Ultra SC-only treatments would be chosen. However, in a campground setting product cost to control a pest is important. In our trials, the treatment cost using Tempo® Ultra SC was $0.37/L, and $0.86/L when treating with Temprid™ SC, thus Tempo® Ultra SC was the more cost effective choice. When treating a sensitive environment where water, wildlife and humans can be affected, many considerations are necessary. If choosing a chemical for the least amount of active
ingredient placed in the campground, Tempo® Ultra SC also would be preferred. Temprid™ SC was applied at 0.249 ml/L and 0.452 ml/L A.I., β-cyfluthrin and imidacloprid, respectively, but Tempo® Ultra SC was applied at a rate of only 0.249 ml/L (imidacloprid). Not only did Tempo® Ultra SC treatments result in less active ingredient being applied than in Temprid™ SC treatments, but the active ingredient was lower in toxicity. While Tempo® Ultra SC’s active ingredient has an oral LD₅₀ of 960mg/kg, Temprid™ SC has two active ingredients with oral LD₅₀’s of 960mg/kg and 4143 mg/kg.

When deciding on the best option for treating an area, two strategies can be used: 1) one to three larger volume insecticide applications or 2) many smaller volume applications. Many smaller volume applications may cost more due to product usage and cost of applicator time, potentially place more insecticide into the environment, and possibly magnify the current pest problem (Silverman and Brightwell 2008). Although an alternate to liquid insecticide applications for *L. humile* management at SC state parks is desirable, the use of targeted Tempo® Ultra SC treatments would result in less insecticide being applied compared to the current park program. The current practice is to spray an area if campers complain, even if this means spraying sites more than once a week. The one larger volume spray per trial in this research was chosen in an attempt to reduce the amount of insecticide applied in the campgrounds over the season.

Although the use of boric acid granular bait was discontinued after Trial 3, further research to test bait efficacy against *L. humile* in the campgrounds earlier in the year may be useful. Because our trials did not begin until June, there may be several reasons why
targeted baiting performed poorly. In June, *L. humile* populations were peaking and the high number of foraging ants may have overwhelmed the available bait. Brood production may also be declining and workers may not have been foraging for the nutritional components offered in the bait selected. Finally, food sources from campers and honeydew secreting insects in the area may have competed with the bait.

In conclusion, it was found that the best choice for treatment against *L. humile* in this study was Tempo® Ultra SC from June-August by spraying insecticide on hardscapes, visible trails and nests, and the base of trees within 3 m of each campsite. However, there may be application strategies and a combination of products used at different times of the year that could be more effective, such as targeted treatments with scatter baits applied earlier in the season.
SUMMARY AND RECOMMENDATIONS

*Linepithema humile* (Mayr) is known as a pest in many urban areas in the southeastern United States (Mallis 2004). In the Piedmont region of South Carolina, there is a documented problem with *L. humile* invading the campsites of state park campgrounds. While some parks implemented proactive control programs, the most widely used tactic is spraying insecticides when *L. humile* populations become intolerable and visitors complain.

The first study in this research had two main objectives: 1) survey campers to understand their level of knowledge and attitudes about *L. humile* for use in designing educational materials and 2) determine *L. humile* locations in campground areas. Although park personnel treat problem areas with liquid insecticide, park visitors also apply insecticidal products, as well as products not labeled for ant control. Through complaint logs maintained by park personnel, as well as surveys conducted in the field, it was found that over 50% of all campers were personally treating their campsites for *L. humile*. These findings and personal observations indicated a need to develop educational materials to inform park visitors about safe and legal techniques for reducing *L. humile* infestations around their campsites. However, if educational materials are not made easily accessible in campgrounds, changing camper actions towards *L. humile* will take longer than necessary. By posting brochures in bath houses, check-in desks, and other common areas, campers are more likely to have opportunities to increase their knowledge about *L. humile*. 
Through monitoring selected South Carolina parks between July and October of 2007, I found that *L. humile* activity remained relatively constant until a decline around October. I also found that *L. humile* populations not only stay in the same general area, but also tended to maintain foraging trails on the same trees throughout the camping season. The determination of *L. humile* populations to remain in the same areas allowed for targeted insecticidal treatments.

The second study was a series of four trials evaluating insecticidal spray treatments versus a combination of insecticidal spray and granular baits. Control areas were set up to evaluate the change in ants over the progression of a season without chemical interference. A bait (Niban® Granular Bait) and three insecticide sprays (Premise® 2, Temprid™ SC, and Tempo® Ultra SC) were evaluated to determine the best option in a park setting. In our study, granular bait did not perform as well as liquid insecticide. However, it was found that both Temprid™ SC and Tempo® Ultra SC resulted in a decrease in *L. humile* over a four week period. Although both insecticides were comparable, I found the best choice for treatment in this study was Tempo® Ultra SC from June-August by spraying insecticide on hard-scapes, visible trails and nests, and the base of trees within 3 m of each campsite. It also was relatively inexpensive ($0.37/L vs. $0.86/L) and had lower toxicity. However, there may be application strategies and a combination of products used at different times of the year that could be more effective, such as targeted treatments with scatter baits applied earlier in the season.

Although an alternate to liquid insecticide applications for *L. humile* management at South Carolina state parks is desirable, the use of targeted treatments would result in
less insecticide being applied compared to the current park program. The current practice is to spray an area if campers complain, even if this means spraying sites more than once a week.

An additional short study also was conducted to inspect park campgrounds in February 2008 (Appendix C). I observed that *L. humile* did not forage on trees as heavily as in the warmer months, though they did trail on 53% of the trees monitored and on the ground near the base of trees, particularly pine trees (*Pinus spp.*). I also found that *L. humile* will nest in fallen trees and limbs that have started to rot. With this knowledge, targeted baiting could be an option for early season treating. Knowing that *L. humile* is nesting mainly at the base of *Pinus spp.*, targeted granular baits or station baits earlier in the year might be more effective than the granular bait applications in 2008 trials, as food preference changes seasonally.

Barrier sprays and baits can be effective in treating *L. humile* around building structures and agricultural areas, but treatment of natural settings, such as state parks, can be more difficult. However, effective control of *L. humile* in state park campgrounds is essential. In two of the parks with heavy *L. humile* infestations, yearly revenue from visitors ranges from $418,000 to $600,000. Although 65% of campers surveyed in 2008 stated they would return even after having a problem with *L. humile*, 30% are undecided about visiting the campground again. To put this in perspective, South Carolina parks make their revenue on day trip visitors and campsite renters. In two parks from this research, yearly revenue ranges from $330,000 (Lake Greenwood) to $418,000 (Calhoun Falls). If campers decide to decline on a return stay in the campground, it is a loss of $15
to $21 per night for each campsite not being rented. With losses in camper rates due to *L. humile* infestations, revenue at two of the parks included in this research could potentially decrease from $42,900 to $137,900 per year.

The research presented here provides information on camper attitudes and habits, concerning *L. humile* infestations in South Carolina State Park campgrounds. This work also identified seasonal activity and foraging patterns of *L. humile* around selected campsites. The evaluation of bait and spray treatments identified the best insecticide (*Tempo® Ultra SC*) and application method of the products tested. However, future research is needed to find more effective and environmentally sustainable methods to control *L. humile* infestations in South Carolina State Park campgrounds.
Appendix A

SUPPORTING DATA FOR CHAPTER TWO

Email requesting confirmation of topics discussed with Stan Hutto

Subject: RE: Argentine ant update
From: Stan Hutto <shutto@scprrt.com>
Date: Wed, September 3, 2008 11:42 am

Hope this helps,
Stan Hutto
Resource Management Biologist
SC Department of Parks, Recreation & Tourism
1205 Pendleton St.
Columbia, SC 29201
Phone: (803) 734-0532
Fax: (803) 734-1017

-----Original Message-----
From: brittar@CLEMSON.EDU [mailto:brittar@CLEMSON.EDU]
Sent: Sunday, August 31, 2008 7:30 PM
To: Stan Hutto
Subject: Argentine ant update

Stan:

I just wanted to send a quick update on where I am in my research. After September 7th I will be done with the actual surveying of ants from treatments at each park. I also had a few questions that I hoped you could fill in the blanks for. I think the answers to these will help put the project into perspective for people and add a bit more depth to my presentations and thesis. If after reading these questions you think of other points I may have left out, I would appreciate anything you have to add that you feel is important information (financially important or just other facts). Thank you again for all of the help you have provided over the past couple of summers. Once all of the data is put together I will get back in touch with you and let you know how it turned out.

1) Is there a set amount of money allocated (for the state, for each park, any way you can answer) for pesticide treatment in the parks?

There is not a set amount of money allocated for pesticide control in State Parks. Although we have established a Budget category for the parks to request funding for any pesticide/herbicide related project. This includes, termite & pest control contracts on park...
structures as included in this budget. As far as funding for Argentine ants or any pest goes, if a pest causes a significant or potentially significant impact to revenue generation we have been able to fund as needed to protect the visitor experience and revenue generation.

Email cont.

2) How long has the parks system been putting out Tempo or other chemicals to combat the ants? (I guess an estimate of how long the ant problem has been going on).

We have been working on Argentine ants for the last 3 years. We tried several baits including several granular type baits and the liquid bait Terro-PCO with little relief. The first chemical that gave any relief was Tempo. It was used as a barrier. After working with the Clemson Entomology department we began investigating additional chemicals and are currently using Premise, Phantom, Termidor and Tempo depending on the location and conditions of the site.

3) How many parks in the state would you say are having problems with Argentine ants?

Seven parks including Hamilton Branch, Hickory Knob, Baker Creek, Calhoun Falls, Lake Hartwell, Lake Greenwood and Dreher Island State Parks.

4) Is it possible to say how much Tempo and Phantom and any other pest chemical each park receives and how much they actually use in a year?

Tempo is chemical we have used at all sites on an as needed basis to spray around camping pads. I would estimate we have used the following amounts of concentrate over the past 3 year period:
Tempo 8.64 liters
Termidor 624 ounces
Premise 22.5 ounces of the 75 WP
Phantom 108 ounces.
It is hard to put a yearly total on use as the initial treatment with termidor on nests is the largest application. Then each spring just as the ants are becoming active we spot treat any new nests found during the survey. We also treat any new nests throughout the season. All treatments are mapped to insure no more that 2 treatments with Termidor in the same area per year. These follow up treatments are greatly reduced to probably no more that 8 gallons of mix a year. We have used the Premise as an initial treatment along hard surfaces like walks and roads. We have not used this product to date as a retreatment. We have used the Phantom as needed to spray the interior and exterior bases of comfort stations, cabins and loge rooms. Tempos has always been used on an as needed basis especially on sites where we have not used large scale spraying with the other chemicals. To date we have treated campgrounds at Dreher Island, Lake Hartwell
and the lodge and cabin areas as well as portions of the campground at Hickory Knob
with Termidor & Premise

Email cont.

5) How much money was spent at Dreher during the "eradication" attempt? What all was
used chemical wise and how/where? Have there been complaints or even small problems
with the Argentine ants since the big treatment there?

Approximately $2000 was used in chemicals at Dreher Island during the eradication
phase this was for Termidor, Premise and Phantom. Both Campgrounds were completely
treated and required only minimal follow-up that same year. Termidor was applied
throughout the entire area to all ant nests, Premise was used along the edges of all hard
surface roads and walkways and also to spray in cracks within the hard surfaces. Phantom
was used on the bases of interior and exterior comfort station walls. Prior to the treatment
we had received in excess of 150 complaints and issued refunds in excess of $1500. Since
the initial phase complaints we have received a total of 3 complaints, 2 of which were
immediately after the initial treatment where some nests had been missed. Follow-up
treatment in 2007 cost $200. Of note is the fact that there was a change in park managers
from 2007 to 2008. In the early summer of 2008 it has been noted complaints were rising.
An investigation into the situation revealed that with park management turnover,
treatment for ants complaints had revert to using tempo rather than locating nests and
treating with Termidor due to the immediate action of Tempo. Park staff has since been
reeducated and ant populations are again under control with minimal treatment.

6) Approximately, how much revenue do campers and day trippers supply to the park
budget?
That's a hard one. I don't have access to figures per user group. Gross revenue for Dreher
island is probably in excess of $600,000 per year. But that would include all sales
including gas and boat ramp fees, marine fees, villa & camping users, park entrance fees
etc. There are in excess of 125 campsites at Dreher island that rent from $15-$21 per
night depending on site and season.

Thanks again,

Brittany (Russ) Ellis
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Revenue Data from Lake Greenwood State Park

1) How much revenue do campers/day trippers/etc. bring into the park each year? If you could find the numbers for the past couple of years that would be great too, but if not that's fine.

Our Fiscal years run from July 1 - June 30th. This past FY (fiscal year 08) we brought in $270,318.00 in camping and $59,711 in admissions. The year before (FY 07) we brought in $233,342.00 in camping and $55,941 in admissions. The year before that (FY 06) we brought in $213,834.00 in camping and $54,890.00 in admissions.

2) Is it possible to find the number of refunds given in the past year(s) and their total(s)?

I do not have refund totals for any year other then last year. The estimated refund amount for FY 08 is $565.54

Fayette R. Yenny
Manager, Lake Greenwood State Recreation Area
SC Department of Parks, Recreation & Tourism
302 State Park Road
Ninety Six, SC 29666
Phone: (864) 543-3535
www.southcarolinaparks.com

Revenue Data from Calhoun Falls State Park

1) How much revenue do campers/day trippers/etc. bring into the park each year? If you could find the numbers for the past couple of years that would be great too, but if not that's fine.

04-05--269,000.00
05-06--332,000.00
06-07--371,000.00
07-08--418,000.00

David Drake
Park Manager, Calhoun Falls State Recreation Area
SC Department of Parks, Recreation & Tourism
46 Maintenance Shop Rd.
Calhoun Falls, SC 29628
Phone: (864)-447-8267
Figure A-1. South Carolina Department of Parks, Recreation, and Tourism map of state parks.
Figure A-2. Camper complaint log distributed to state park personnel to record camper complaints about *Linepithema humile*.

**Camper Complaint Log - Argentine ants**

This complaint log is designed to collect important data to help SC Park staff develop information sheets and better control strategies for Argentine ants. It was created to take as little time as possible to complete. For each complaint received from campers concerning Argentine ants, please record and ask for as much of the following information as possible. Thank you!

Date: ________________
Park Name: ________________________________
Your Name: ________________________________
Campsite (#): __________

1. Check the time of day the camper claims the ants were first a problem:
   Morning: ____
   Afternoon: ____
   Evening: ____

2. When making the complain, did the camper:
   Stop a ranger while in the campgrounds: ____________
   Call the office: ______________
   Come to the office: ______________
   Other: ______ if other, explain: ________________________________________

3. Check the area(s) reported to be infested:
   R.V.: ____
   Tent: ______
   Picnic Table: ______
   Other: _____; if other, explain: ________________________________________

4. Estimate how many ants did the camper report:
   ________________________________________

5. Besides making a complaint, what did the camper claim to do for the ants:
   Nothing other than make a complaint: ______
   Wash the ants away: ______
   Use an insecticide spray: ______
   Use an insecticide dust: ______
   Removed trash: ______
   Removed food: ______
   Sealed food: ______
   Removed drinks: ______
   Sealed drink containers: ______
   Other: _____; if other explain: ________________________________________
Figure A-2 (cont.)

6. What did the camper ask you to do for the ants:
Treat with insecticides: __________
Remove trash: __________
Ask for refund: __________
Other: ___; if other explain: ________________________________

7. Does the camper intend to return to this park if these problems persist? ___ Y ___ N

Staff, One Day Follow Up

8. When you arrived at the problem campsite, how many did you estimate:
0 to 1,000: ______
1,001 to 10,000: ______
More than 10,000: ______

9. What did you do to control the ants:
Treated with insecticides: ___; if so, what did you use: ________________________________
Removed trash: __________
Gave refund: ______
Advised campers to remove food: ___ and/or drinks: ______
Advised campers to seal food: ___ and/or drinks: ______
Other: ___; if other explain: ________________________________

10. One day after control measures were applied:
You were satisfied with the ant control, Yes ___ No ___; if no explain: ______

(When possible)
11. The camper was satisfied with the ant control, Yes ___ No ___; if no explain:

12. Other comments or notes:
__________________________________________________________________________

Contact information:
Brittany Ellis
Clemson University
Phone: 864-656-3111
Email: brettar@clemson.edu
Figure A-3. Survey administered to campers in 2007 and 2008.

Camper Survey

Date: ____________________________
Park: _____________________________
Campsite (#): ______________________

1. Have you ever camped before this? _____ Y _____ N
   If so how many times? ______ Total ______ This year

2. How long have you been here? __________________________

3. Have you seen any ants during your stay? ____ Y ____ N
   Where? _______________________________________

4. Have you had a problem with ants in your campground during your stay? ____ Y ____ N

5. Have you done anything to eliminate/alleviate them? ____ Y ____ N
   If you have attempted control, what did you do?

6. What items were the ants foraging for:
   Food: _______
   Water: _______
   Nothing: _______
   Other: _____ if other, explain: _______________________________________

7. From what area(s) did the ants seem to invade from:
   From the ground: _______
   From a tree: _______
   Other: _____ if other, explain: _______________________________________

8. Have you heard of any homemade remedies for getting rid of them? _____ Y _____ N
   Have you ever tried any? _____ Y _____ N
   If so, what are they?

9. Do you know of any non-chemical ways to get rid of them?
   If so, what?
   Have you ever tried any? _____ Y _____ N
   If yes, explain:

10. Does this problem make you hesitant to return to this park if the ant problem persists?
    _____ Y _____ N _____ M
What should I do if the ants are already in my campsite?
Several steps can be taken to counter their invasion. When ant trails are observed, follow
the trail to the source. Make sure to clean the area thoroughly with a spray of the hose or a
swipe of a wet, soapy cloth to remove the trail the ants were following. This is not the most
high-tech method, but will slow the ants down and hopefully cause them to search elsewhere
for food.

What should I do if cleaning and sealing entry points does not work?
If ants continue to invade after taking preventative measures, an insecticide product
may be necessary to spray on or in your R.V. or tent. **DO NOT SPRAY OR DUST THE
CAMP_SITE.** If populations are still unmanageable after cleaning and spraying R.V.,
contact park staff and report your problem.

This information is supplied with the understanding that no discrimination is
intended and no endorsement by the Clemson University Cooperative Extension Service is
implied. Brand names of pesticides are given as a convenience and are neither an endorsement
nor guarantee of the product nor a suggestion that similar products are not effective. Use
pesticides only according to the directions on the label. Follow all directions, precautions and
restrictions that are listed.

Providing Leadership in Environmental Entomology
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Benson, undergraduate Department of Parks,

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Do you have an un-invited
guest in your campsite?

---

Argentine ant/Sugar ant
Have you had problems with ants invading your campsite? If so, this brochure will answer frequently asked camper questions and provide helpful tips on how to reduce the number of ants in your campsite.

**Q & A's:**

**What are all of these ants invading my campsite?**

There are several ants that are routinely found in campgrounds: fire ants, Acrobat ants, carpenter ants and Argentine ants. Research reported from Clemson University stated that the Argentine ant is the #1 ant invading campites. Argentine ants are a trailing ant. They will travel 200 ft or more in search of food.

![Argentine Ant](www.bugguide.net)

**Are these ants dangerous?**

While some ants sting, Argentine ants do not. However, they can bite when provoked, which can feel like a small pinch on the skin. Argentine ants can carry germs from dirty surfaces to food. Thoroughly clean surfaces to eliminate germs. Contaminated food should be thrown away.

I have heard that if you sprinkle powder around your RV/tent that the ants will not come into my campsite. Is this true? This is FALSE. If every camper put insecticide dust or cleaning powder around their campsite, that site and other areas, including the lake, could become contaminated. Another problem with the using powders is the potential for Argentine ant nests to split from one into many nests making the problem worse.

![Ants in Basket](www.bugguide.net)

**How can I keep the ants out of my campsite?**

- Clean up after each meal, making sure not to leave plates or open drinks for too long. Take time to wipe up spills and crumbs no matter how small the mess.
- Store food, drinks, candy and anything edible in an airtight container. Ants are resourceful and can squeeze into the smallest spaces, so get clever with your storage.
- Remove bags daily to designated trash bins. Do not let your trash pile up. A bag of trash is just a big "Welcome" mat for insects.
- Give your pet the food they will eat at one sitting. Even though your pet may prefer to snack all day, so do ants. A big bowl of food gives them prime opportunity.

I am very careful when it comes to food/drink/trash clean-up. Is there any other way I can decrease the chance of having ants in my campsite?

- Avoid contact with low hanging tree branches when setting up your site. If not possible to avoid, contact a ranger and have the limb trimmed back.
- Avoid tying direct lines from surrounding trees to tents and RVs. While these are easy made clothes lines and tent supports, ants use them as bridges to invade with greater ease.
- Eliminate excess leaks at the nozzle. Ants are always in search of water. They often use this hose line as a bridge as well.
- Secure seals on all windows, hatches, and doors. Check screens of tent and RV windows for holes. Ants are small and will use any opening they come across.
Figure A-5. Google Earth™ images (A and C) (http://earth.google.com) and South Carolina Parks Department map (B and D) (http://www.southcarolinaparks.com) of Baker Creek State Park.
Figure A-6. Google Earth™ images (A) (http://earth.google.com) and South Carolina Parks Department map (B) (http://www.southcarolinaparks.com) of Calhoun Falls State Park.
Figure A-7. Google Earth™ images (A and C) (http://earth.google.com) and SC Parks Department map (B and D) (http://www.southcarolinaparks.com) of Lake Greenwood State Park.
Table A-1. Percentage of campers surveyed ± standard error stating usage of chemical against *Linepithema humile* at Calhoun Falls and Lake Greenwood State Parks, as recorded by park personnel in 2007 and 2008.

<table>
<thead>
<tr>
<th>Year</th>
<th>Calhoun Falls</th>
<th>Lake Greenwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>0.63 ± 0.07</td>
<td>1.0 ± 0</td>
</tr>
<tr>
<td>2008</td>
<td>0.58 ± 0.10</td>
<td>0.8 ± 0.13</td>
</tr>
</tbody>
</table>

Table A-2. Percentage of campers surveyed ± standard error stating usage of chemical against *Linepithema humile* at Baker Creek, Calhoun Falls and Lake Greenwood State Parks in 2007 and 2008.

<table>
<thead>
<tr>
<th>Year</th>
<th>Baker Creek</th>
<th>Calhoun Falls</th>
<th>Lake Greenwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>0.79 ± 0.10</td>
<td>0.83 ± 0.10</td>
<td>0.89 ± 0.04</td>
</tr>
<tr>
<td>2008</td>
<td>0.67 ± 0.19</td>
<td>0.96 ± 0.03</td>
<td>0.89 ± 0.06</td>
</tr>
</tbody>
</table>

Table A-3. Percentage of campers surveyed ± standard error stating probability of return to Baker Creek, Calhoun Falls and Lake Greenwood State Parks, as recorded from Jul-Oct 2007.

<table>
<thead>
<tr>
<th>Survey Answer</th>
<th>Baker Creek</th>
<th>Calhoun Falls</th>
<th>Lake Greenwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Will return</td>
<td>0.93 ± 0.07</td>
<td>0.58 ± 0.14</td>
<td>0.34 ± 0.07</td>
</tr>
<tr>
<td>Will not return</td>
<td>0</td>
<td>0.06 ± 0.07</td>
<td>0.34 ± 0.07</td>
</tr>
<tr>
<td>Questionable</td>
<td>0.07 ± 0.07</td>
<td>0.33 ± 0.14</td>
<td>0.32 ± 0.06</td>
</tr>
</tbody>
</table>
Table A-4. Percentage of campers surveyed ± standard error stating probability of return to Baker Creek, Calhoun Falls and Lake Greenwood State Parks, as recorded from Jun-Sept 2008.

<table>
<thead>
<tr>
<th>Survey Answer</th>
<th>Baker Creek</th>
<th>Calhoun Falls</th>
<th>Lake Greenwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Will return</td>
<td>0.67 ± 0.19</td>
<td>0.87 ± 0.05</td>
<td>0.81 ± 0.08</td>
</tr>
<tr>
<td>Will not return</td>
<td>0</td>
<td>0.02 ± 0.02</td>
<td>0.08 ± 0.05</td>
</tr>
<tr>
<td>Questionable</td>
<td>0.33 ± 0.19</td>
<td>0.11 ± 0.05</td>
<td>0.11 ± 0.06</td>
</tr>
</tbody>
</table>
Table A-5. Products reported for use by campers against *Linepithema humile* in campsites and the number of individuals reporting usage (N = 137).

<table>
<thead>
<tr>
<th>Product</th>
<th>Number of individuals reporting use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerosol Fogger</td>
<td>2</td>
</tr>
<tr>
<td>Ant bait traps</td>
<td>2</td>
</tr>
<tr>
<td>Baby powder</td>
<td>1</td>
</tr>
<tr>
<td>Bayer Home Pest spray</td>
<td>1</td>
</tr>
<tr>
<td>Bengal Fire Ant dust</td>
<td>1</td>
</tr>
<tr>
<td>Bengal Ultra Dust</td>
<td>1</td>
</tr>
<tr>
<td>Black Flag spray</td>
<td>1</td>
</tr>
<tr>
<td>Bleach</td>
<td>3</td>
</tr>
<tr>
<td>Borax</td>
<td>2</td>
</tr>
<tr>
<td>Boric acid granules</td>
<td>1</td>
</tr>
<tr>
<td>Bug Bomb</td>
<td>1</td>
</tr>
<tr>
<td>Bug Out</td>
<td>1</td>
</tr>
<tr>
<td>Bug Stop</td>
<td>3</td>
</tr>
<tr>
<td>Citronella tiki torches</td>
<td>1</td>
</tr>
<tr>
<td>Comet</td>
<td>12</td>
</tr>
<tr>
<td>Diazinon granules</td>
<td>1</td>
</tr>
<tr>
<td>Diazinon spray</td>
<td>2</td>
</tr>
<tr>
<td>Gasoline</td>
<td>1</td>
</tr>
<tr>
<td>Hot Shot spray</td>
<td>7</td>
</tr>
<tr>
<td>Hot Shot flea killer</td>
<td>1</td>
</tr>
<tr>
<td>Maximum SP 785</td>
<td>1</td>
</tr>
<tr>
<td>OFF</td>
<td>2</td>
</tr>
<tr>
<td>Ortho Garden and Landscape Insect Killer</td>
<td>1</td>
</tr>
<tr>
<td>Ortho Home Defense</td>
<td>8</td>
</tr>
<tr>
<td>Ortho Termite and Ant</td>
<td>1</td>
</tr>
<tr>
<td>Raid spray</td>
<td>24</td>
</tr>
<tr>
<td>Rid A Bug</td>
<td>3</td>
</tr>
<tr>
<td>Sevin</td>
<td>17</td>
</tr>
<tr>
<td>Spectracide</td>
<td>7</td>
</tr>
<tr>
<td>Talstar</td>
<td>1</td>
</tr>
<tr>
<td>Various Sprays</td>
<td>28</td>
</tr>
<tr>
<td>WD-40</td>
<td>1</td>
</tr>
</tbody>
</table>

*Numbers add up to more than actual individuals surveyed due to multiple product usage. Twenty campers surveyed reported use of no product(s) for *Linepithema humile* control.*
Appendix B

SUPPORTING DATA FOR CHAPTER THREE

Table B-1. Combined mean change in number of *L. humile* ± standard error present in foraging trails over the course of Trials 1-4. Different letters within a row represent a significant difference at $\alpha = 0.05$.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Treatment 1</th>
<th>Treatment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>6.50 ± 6.93</td>
<td>a</td>
<td>-14.97 ± 7.02</td>
</tr>
<tr>
<td>Trial 2</td>
<td>4.59 ± 7.04</td>
<td>a</td>
<td>1.22 ± 7.13</td>
</tr>
<tr>
<td>Trial 3</td>
<td>9.42 ± 8.08</td>
<td>a</td>
<td>-17.22 ± 8.18</td>
</tr>
<tr>
<td>Trial 4</td>
<td>10.77 ± 9.84</td>
<td>a</td>
<td>-0.82 ± 9.96</td>
</tr>
</tbody>
</table>

Table B-2. Mean change in number of *L. humile* ± standard error present in foraging trails at Baker Creek State Park over the course of Trials 1-4. Different letters within a row represent a significant difference at $\alpha = 0.05$.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Treatment 1</th>
<th>Treatment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>21.83 ± 6.66</td>
<td>a</td>
<td>-10.56 ± 8.31</td>
</tr>
<tr>
<td>Trial 2</td>
<td>1.64 ± 5.76</td>
<td>a</td>
<td>-0.93 ± 7.19</td>
</tr>
<tr>
<td>Trial 3</td>
<td>21.71 ± 5.46</td>
<td>a</td>
<td>-19.22 ± 6.81</td>
</tr>
<tr>
<td>Trial 4</td>
<td>17.55 ± 9.89</td>
<td>a</td>
<td>-0.93 ± 12.33</td>
</tr>
</tbody>
</table>

Table B-3. Mean change in number of *L. humile* ± standard error present in foraging trails at Calhoun Falls State Park over the course of Trials 1-4. Different letters within a row represent a significant difference at $\alpha = 0.05$.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Treatment 1</th>
<th>Treatment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>2.87 ± 7.33</td>
<td>a</td>
<td>-24.46 ± 6.51</td>
</tr>
<tr>
<td>Trial 2</td>
<td>23.73 ± 7.00</td>
<td>a</td>
<td>2.77 ± 6.22</td>
</tr>
<tr>
<td>Trial 3</td>
<td>-6.18 ± 9.13</td>
<td>a</td>
<td>-21.67 ± 8.02</td>
</tr>
<tr>
<td>Trial 4</td>
<td>13.09 ± 5.95</td>
<td>a</td>
<td>-0.70 ± 5.28</td>
</tr>
</tbody>
</table>
Table B-4. Mean change in number of *L. humile* ± standard error present in foraging trails at Lake Greenwood State Park over the course of Trials 1-4. Different letters within a row represent a significant difference at $\alpha = 0.05$.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Treatment 1</th>
<th>Treatment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>-4.67 ± 11.82</td>
<td>-9.71 ± 11.82</td>
<td>-11.90 ± 10.23</td>
</tr>
<tr>
<td>Trial 2</td>
<td>-11.69 ± 6.34</td>
<td>7.36 ± 6.34</td>
<td>0.57 ± 5.49</td>
</tr>
<tr>
<td>Trial 3</td>
<td>13.05 ± 9.21</td>
<td>-9.43 ± 9.21</td>
<td>-3.20 ± 7.98</td>
</tr>
<tr>
<td>Trial 4</td>
<td>1.76 ± 10.41</td>
<td>-1.16 ± 10.41</td>
<td>-60.87 ± 9.01</td>
</tr>
</tbody>
</table>
Appendix C

INQUIRY INTO THE FORAGING ACTIVITY OF *LINEPITHEMA HUMILE* (MAYR) IN THE PIEDMONT REGION OF SOUTH CAROLINA IN FEBRUARY 2008

Introduction

*Linepithema humile* (Mayr), the Argentine ant, is ecologically successful due to its ability to tolerate a variety of habitats (Aron et al. 1990). As changes in season occur, *L. humile* is able to shift nesting areas to account for temperature changes. During the winter months, nests combine to form larger colonies to maintain warmth more efficiently (Barber 1916). Tree bases also are ideal winter nesting areas, and nest tunnels can be as deep as 0.31 m to 0.36 m inches (Newell and Barber 1913). Foraging is typically suspended once temperatures fall below 5°C (Markin 1970) or carbohydrate foraging declines and *L. humile* focus on foraging for proteins (Mallis 2004).

Although I found *L. humile* were remaining in the same area during warmer months, I did not know if or where ants continued foraging during cooler months within the campgrounds. While most ant control in the parks is taking place during warmer months, if it is known where and when *L. humile* start foraging and spreading through the campsites, better control may be possible.

The objectives of this preliminary research were to determine 1) if *L. humile* were actively foraging in February, 2) where *L. humile* were foraging in February and 3) if any environmental factors affected foraging trail activity. It was hypothesized that foraging activity would not be as heavy as during warmer months, and that nests would be located at the bases of trees with moist soil areas for nesting.
Materials and Methods

In 2008, Baker Creek, Calhoun Falls and Lake Greenwood State Park, previously monitored for *L. humile* populations in warmer months, were surveyed for presence/absence of foraging trail activity in February. Twelve trees of various species were selected at each park (N = 36). Areas within each park were chosen based on knowledge of previous infestations during warmer seasons. Measurements of tree diameter (cm), temperature of inner bark in the shade (°C), temperature of outer bark in the shade (°C), temperature of inner bark in the sun (°C), and temperature of outer bark in the sun (°C) were all obtained. Outer bark was defined as the layer on the outermost of the tree. Inner bark was defined as the deepest point on the bark in a crevice. Temperatures were recorded an Oakton InfraPro® infrared thermometer (OAKTON Instruments, P.O. Box 5136 Vernon Hills, IL 60061, USA). Tree species was also recorded. To determine if foraging trail presence/absence was affected, each measurement was analyzed by ANOVA (SAS 2003) followed by LSD test.

Results

Of the 36 trees surveyed in February 2008, 19 were found to have active *L. humile* foraging trails (Figure A-1). Active trails were only on trees of the *Pinus spp.* Eight other pine trees and nine other tree species (*Acer, Quercus, Juglans*, etc.) were surveyed and showed no trailing activity.
Foraging trail activity

<table>
<thead>
<tr>
<th>Present</th>
<th>Absent</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

Figure C-1. Total number of trees ± standard error with *Linepithema humile* foraging trails present or absent in February 2008
Measurements indicated that foraging trail activity was not statistically significant when the diameter of a tree (cm) \( t = -1.18, \text{df} = 34, P = 0.245 \) was evaluated (Table C-1). Temperature of the outer bark in the shade \( (^\circ \text{C}) \) \( t = -0.29, \text{df} = 34, P = 0.77 \), temperature of the inner bark in the shade \( (^\circ \text{C}) \) \( t = -0.47, \text{df} = 34, P = 0.643 \), temperature of the outer bark in the sun \( (^\circ \text{C}) \) \( t = 0.24, \text{df} = 34, P = 0.814 \), and temperature of the inner bark in the sun \( (^\circ \text{C}) \) \( t = -0.15, \text{df} = 34, P = 0.879 \) were not statistically significant in determining foraging trail presence or absence.
Table C-1. Mean diameter and temperatures ± standard error with P-value for a t-test of *Linepithema humile* foraging trail present and absent

<table>
<thead>
<tr>
<th></th>
<th>Foraging Trail Present</th>
<th>Foraging Trail Absent</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter of Tree (cm)</td>
<td>37.48 ± 2.61</td>
<td>32.71 ± 3.12</td>
<td>0.25</td>
</tr>
<tr>
<td>Temperature of Outer Bark in the Shade (°C)</td>
<td>12.17 ± 0.59</td>
<td>11.88 ± 0.85</td>
<td>0.77</td>
</tr>
<tr>
<td>Temperature of Inner Bark in the Shade (°C)</td>
<td>16.44 ± 0.51</td>
<td>15.92 ± 1.04</td>
<td>0.64</td>
</tr>
<tr>
<td>Temperature of Outer Bark in the Sun (°C)</td>
<td>15.29 ± 0.52</td>
<td>15.51 ± 0.80</td>
<td>0.81</td>
</tr>
<tr>
<td>Temperature of Inner Bark in the Sun (°C)</td>
<td>18.32 ± 0.68</td>
<td>18.13 ± 1.02</td>
<td>0.88</td>
</tr>
</tbody>
</table>
Discussion

Brightwell (2008) found that *L. humile* in North Carolina were able to actively forage during winter months, due to the heating of sun exposed bark on pine trees to a temperature above the outside ambient temperature. It was suspected that foraging was concentrated around these trees due to hemipterans which infested the trees and provided honeydew for the ant during a time when other food sources were sparse. I also found that *Pinus spp.* was the tree of choice for foraging activity within the South Carolina campgrounds. However, temperature of tree bark (shade or sun/inner or outer) was not found to affect foraging trail presence or absence.

These findings are important when determining when and where to begin targeted treatment of an area for *L. humile*. If it is known that *L. humile* only congregates around *Pinus spp.* during cooler months, treatments can be placed appropriately. During a brief survey in February 2009, it was observed that while *L. humile* does not forage on trees as heavily as in the warmer months, it does forage on the ground near its nest. It was also found that *L. humile* will also nest in fallen trees and limbs that have started to rot or have beetle or termite damage present.

By using this information, development of a treatment program to better targeted treatments of *L. humile* may be possible. If scatter baits or arena baits were tested once more, perhaps the results would differ from the bait tested in summer 2008.
REFERENCES


