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# Impact of Land Management on House Mice and Red Imported Fire Ants

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**IMPACT OF LAND MANAGEMENT ON HOUSE MICE AND RED IMPORTED FIRE ANTS**

by


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# ABSTRACT

Understanding of mechanisms that limit the abundance and distribution of species is central to ecology. The failure of mechanisms to regulate populations can result in population outbreaks. There have been two outbreaks of house mice in the past decade in central Florida. In my study, I examine the efficacy of landscape management in the form of mowing and plowed soil barriers to limit or prevent outbreaks of house mice in a former agricultural area. House mouse populations were highly variable, but were unaffected by mowing or plowed soil barriers. Red imported fire ants were ubiquitous in the study area regardless of land management treatments. Control of fire ants did not result in more house mice on treated plots.

**ACKNOWLEDGMENTS**

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**CHAPTER 1:  GENERAL INTRODUCTION**

Understanding the distribution and abundance of species is a central theme in ecology (Andrewartha and Birch 1954).  Mechanisms that affect reproduction, mortality, and migration patterns of populations have important ecological and economic consequences (Elton 1958, Pimental et al. 2005).  For example, agricultural crops on which human society depend are highly influenced by fluctuations in arthropod populations (Kaplan and Eubanks 2002, Lard et al. 2006).  However, the natural function of these mechanisms can be altered with human disturbance and the introduction of nonnative species (Elton 1958, Vitousek et al. 1997).

While many species that are introduced to novel environments do not become established or negatively impact the native ecosystems, a few of these colonizers are associated with large ecological and economic costs (Williamson and Fitter 1996, Pimental et al. 2001).  In the United States, damage (economic losses) attributed to invasive species is approximately $120 billion each year (Pimental et al. 2005).  Two species which cause large ecological and economic problems when introduced to new habitats are the house mouse, *Mus musculus*, and red imported fire ant, *Solenopsis invicta*.

Many species of invertebrates and small mammals exhibit explosive population growth in agricultural settings thereby reducing crop production and spreading diseases (Elton 1942, Singleton et al. 2007).  While population outbreaks are not exclusive to nonnative species, some invasive species under the right circumstances can demonstrate large changes in their population size in short periods of time (Elton 1942).  Population outbreaks of house mice are of particular importance in wheat growing reasons of Australia, where the density of house mice can increase

to >1000 mice per hectare (Bronson 1979). These instances can occur on a large scale encompassing thousands of hectares (Caughley et al. 1994, Singleton et al. 2005). House mouse outbreaks have also occurred in China and the United States; however, much less frequently and on a much smaller scale than in Australia (Elton 1942, Hall 1927, Pearson 1963 ). It is therefore important to understand the circumstances under which these population outbreaks can occur.

Nonnative arthropods also cause enormous damage to ecosystems and economic systems. Pimental et al. (2005) reported damages of red imported fire ants to economic activity in the United States as approximately $1 billion per year. Understanding the potential damages of the red imported fire ant (and other species) can help determine the strategies required to reduce ecological and economic impacts of these invaders.

My research addresses some of the factors that may influence the abundance and distribution of house mice and red imported fire ants. I also review and extrapolate some of the ecologic and economic consequences of these species. Chapter 2 focuses on the land management techniques (i.e. mowing and plowing) used by the St. Johns River Water Management District (SJRWD) to control populations of house mice within a former agricultural area. These strategies were developed to reduce the probability of population outbreaks of house mice within the vicinity of Lake Apopka, Florida. In addition, I examined the affect of the land management on the population of native cotton rat, *Sigmodon hispidus*. Chapter 3 examines the ecologic and economic impacts of the invasive red imported fire ant on the southeastern United States. The fourth chapter focuses on the impacts of the land management techniques and the

red imported fire ant on house mouse and cotton rat habitat usage. The final chapter summarizes

the findings of this thesis.

**CHAPTER 2:  THE EFFECTS OF LAND MANAGEMENT ON SMALL MAMMAL POPULATIONS WITHIN A FORMER AGRICULTURAL AREA**

**Introduction**

Understanding mechanisms that limit the abundance and distribution of species are central to ecology (Elton 1942).  The processes of reproduction, mortality, immigration, and emigration, which are influenced by abiotic and biotic factors, determine the abundance and distribution of species (Andrewartha and Birch 1954).  For example, the effects of weather, landscape, predation and competition on animal and plant populations are important to preserve endangered species and suppress non-native and nuisance species (Krebs 2001).

The failure of abiotic and biotic mechanisms to regulate populations can result in dramatic increases in population size which is sometimes undetected or ignored due to a lack of consistent ecological and economic impacts.  Many species of invertebrates and small mammals exhibit explosive population growth that can negatively impact agricultural and natural resource interests (Elton 1942).  For example, in southeastern Asia, rat 'floods' reportedly occur in response to the fruit production by bamboo forests.  These rats then feed upon the subsistence rice fields, causing massive famines (Normile 2010).  While outbreaks and plagues are not well defined by the number of individuals, they usually involve the explosive growth of a population and are considered plagues when these species become "conspicuous" and "troublesome" (Saunders and Giles 1977).  Many species of small mammal, including the house mouse, *Mus musculus*, have long histories of creating health and economic problems during outbreaks (Elton 1942, Singleton et al. 2007).  In Australia, the damage caused by house mice is normally

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insignificant when populations are at low densities (Redhead et al. 1985, Brown and Singleton 2002), but major economic losses amounting to tens of millions of dollars result when populations reach plague levels (Caughley et al. 1994, Singleton et al. 2005).

The house mouse was introduced to North America from Europe and exists as commensal (inhabiting manmade structures) and feral populations (Bronson 1979). These feral populations of house mice are often unstable, existing at low densities in a variety of habitats, including agricultural fields, grasslands and even in coal mines to depths to 550 meters (Bronson 1979). House mice are often the first colonizers into favorable habitats that have undergone a natural or human disturbance (Singleton et al. 2007). They are proficient tunnelers that can dig complex systems with multiple entry/exit points (Berry and Bronson 1992). House mouse populations are not often large, but occasionally populations can reach > 1,000 mice per hectare (Bronson 1979). In these cases, mice cause innumerable difficulties to rural and residential areas (Singleton et al. 2005). The house mouse is an agricultural and residential pest, in part because it has been widely distributed by human activity (Singleton et al. 2007). Though house mice are widespread in North America, outbreaks are both small in the amount of area affected and rare with only four documented cases (Hall 1927, Pearson 1963): the central valley of California in the 1920's (Hall 1927), near San Francisco during the early 1960's (Pearson 1963), and two near Lake Apopka in central Florida within the past decade (Stout et al. 2001, Stout 2007).

The first documented outbreak of house mice in the Eastern U.S. occurred in 1999 near Apopka, Florida and the North Shore Restoration Area (NSRA; Section 33, Township 20 South, Range 27 East). This outbreak caused complaints by nearby businesses and residents that the

NSRA, a property managed by the St. John's River Water Management District (SJRWMD), a state agency, was the source of the mouse infestations.  These complaints spurred the SJRWMD to investigate the population and movement dynamics of mice within the NSRA (Stout and Clerico 2000, Stout et al. 2001).  In addition, the Florida Fish and Wildlife Conservation Commission (FFWCC) conducted a 3 week experiment in the surrounding private lands that suggested mowing of pastures and fallow land drastically reduced the relative abundance of house mice (FFWCC 1999).  Recommendations from these studies resulted in the mowing of the former agricultural fields and plowing of a boundary approximately 4 meters wide around the NSRA to reduce house mouse abundance and create a dispersal barrier.  Both of these land management practices began in 2001 and continued into 2009.

The present research seeks to understand how alteration of habitat through the land management techniques (mowing and plowing) employed by the SJRWMD affect populations of house mice, *Mus musculus*, and cotton rats, *Sigmodon hispidus*, near Lake Apopka.  The management of the NSRA to mitigate house mouse plagues represents an opportunity to test concepts of population regulation and better understand the factors that may affect population growth.  Understanding how outbreaks begin and why population regulation breaks down are critical issues for population ecology.  In addition, the response of cotton rats to habitat alteration (mowing) was included due to the large number of captures of this native rodent.

Habitat structure is important to small mammal abundance (Seitman et al. 1994).  My first hypothesis is that mowing reduces the abundance of small mammals in the abandoned agricultural fields.  Habitats with different ground cover provide house mice and other small

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mammals with different levels of resource availability, refugia, and predation risk (Twigg and Kay 1994, Seitman et al. 1994, Fox et al. 2003, Jensen et al. 2003, Aurthur et al. 2004, Singleton et al. 2007). Mowing may reduce house mouse and cotton rat abundances for three reasons. First, mowed areas provide little vegetative cover, potentially increasing aerial predation or the perception of predation, thereby decreasing habitat suitability (Stickel 1979, Jensen et al. 2003). Second, mowing might alter important dietary requirements for house mice and cotton rats (DeLong 1967, Randolph et al. 1991). Third, the mowing itself may directly cause mortality of small mammal or induce emigration.

It is also important to understand the movement of house mice within and beyond the agricultural fields of the NSRA. Barriers can be an effective means of fragmenting habitats and thereby reducing small mammal populations (Andren 1994, McCoy and Mushinsky 1999). Small mammals exhibit wide variation in behavioral responses to barriers (Kozel and Fleharty 1979, Shepard et al. 2008, Oxley et al. 1974, Clark et al. 2001, Slade and Crane 2006). My second hypothesis is that the 4 meter plowed barrier inhibits the movements of house mice, regardless of the mowing treatment. I predict that there will be few captures on the trap line located within the plowed soil area. I also predict that few house mice will cross the barrier; therefore, the likelihood of recapture is greatest on the side of the barrier an individual was initially captured compared to recapture on the other side.

In addition, the structure of the habitat surrounding the barrier could be of interest. When the perception of predation risk is high, house mice will not use all available resources and will have a restricted use of space (Stickel 1979, Twigg and Kay 1994, Jensen et al. 2003). If the

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perception of predation risk is higher in mowed than unmowed areas, then both distance traveled by house mice and the frequency that house mice cross the plowed soil barrier should be reduced. My third prediction was that house mice will move less often across barriers in mowed than unmowed areas.

**Methods and Materials**

*Study Area*

The NSRA consists of almost 20,000 acres (8,000 hectares) of former agricultural land on the northern shore of Lake Apopka (Figure 1). The area was originally a shallow marsh, but the marsh was drained in 1941 for the production of corn and winter vegetables. This activity increased nutrient and pesticide influx into the lake, effectively eliminating recreational fishing and making Lake Apopka highly eutrophic. In 1996, the Lake Apopka Improvement and Management Act authorized the SJRWMD to acquire the farms located on the north shore of Lake Apopka for the purpose of restoring the hydrology and wetland marsh, thus reducing nutrient flow into the lake. When a portion of the NSRA was flooded in the fall of 1998, heavy bird mortality resulted from the consumption of prey contaminated by high levels of residual pesticides. Since this event, additional wildlife exposure to the pesticides has been avoided by maintaining the fields without flooding using the existing pumps, ditches, and levees. The result has been the persistence of old field habitats suitable for many small mammals, including the house mouse (Hoge et al. 2003). A majority of the NSRA was mowed and a 4 meter wide plowed boundary was maintained as a fire break as well as a potential barrier to house mouse dispersal to surrounding privately-owned property (Stout et al. 2001). These plow lines occur

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along the entire boundary of the NSRA with private lands and around the fields within the NSRA in an attempt to further fragment the area and reduce populations of house mice (pers. comm. SJRWMD staff).

*Experimental Design*

Two experimental areas with a randomized block experimental design (Figures 2 and 3) were used to determine if the abundance of mice and rats differed between mowed and unmowed fields. In addition, a barrier, similar in character to the plowed boundaries used by the SJRWMD around the NSRA, was established in one of the experimental area to determine if its presence influenced the movements of house mice. Blocks were oriented in the north, south direction following seasonally inundated ditches (remnants of agricultural production), which separated the blocks. A soil gradient occurred where well-drained sandy soils on the eastern edge (blocks 3) of both experimental areas transitioned to increasingly hydric soils on the western sections (blocks 1). Mowed and unmowed areas were randomly placed in each of the three blocks, while a 4 meter plow line was maintained through the middle of the three blocks (Figure 2). Mowing treatments were applied at 2-6 week intervals as determined by vegetation height, while plowing of the barrier maintained bare ground.

Within the first experimental area (Figure 2), a trapping grid was placed in each treatment to sample the small mammals. Grids were comprised of 25 trapping stations (each with 2 Sherman live-traps within 1 m of the station) and arranged in a 5 X 5 configuration with 10 m between stations. Trap stations were marked with 1 meter high white PVC pipe. Within the second experimental area (Figure 3) sampling grids were comprised of 20 trapping stations (each

with 2 Sherman live-traps within 1 m of the station) and each grid was arranged in a 4 X 5 configuration with 10 m between stations.

In both experimental areas, traps were baited with sunflower seeds, set in the afternoon, and checked the following morning. Weekly sampling for the first experimental area began on March 22$^{nd}$, 2008 and ended August 8$^{th}$, 2008, while the second experimental area began on June 7$^{th}$, 2008 and ended on August 9$^{th}$, 2008. Individual house mice were ear tagged, weighed with a Pesola spring scale to the nearest 0.5 grams, and classified by sex and reproductive condition. After the traps were checked and closed, they were placed upon the top of the PVC piping and the seeds used for bait were scattered onto the ground to reduce the attraction of ants to the traps.

Movement behavior of house mice in relation to the plowed soil barrier was inferred from recapture data. Finer-scale movements of mice and their willingness to cross the plow lines was also tested by dusting house mice (n = 8) with a florescent powder (Radiant$^{TM}$ fluorescent pigment). Mice were individually placed in a clear plastic bag with fluorescent powder, gently rolled in the dye for roughly 1 minute, and then released at the site of capture (Lemen and Freeman 1985). After waiting a period of at least 24 hours, mouse movements were observed using a black light at night (Lemen and Freeman 1985, Mikesic and Drickamer 1992). These movements were tracked by placing wire flags where there was fluorescent powder brushed off by vegetation. Direction and distance were later measured and recorded.

*Statistical Analyses*

A runs test was first used to understand if the fluctuations of the house mice and cotton rats were random. A zero-inflated negative binomial (ZINB) regression analysis was used to

examine the effects of mowing on count data derived from trapping house mice and cotton rats, due to the high frequency of zeroes (no captures) and overdispersion (i.e., standard deviation $\geq$ mean). A zero-inflated negative binomial regression uses a slightly altered negative binomial distribution which accounts for the high number or zeros within a data set. Using this type of analysis provides increased the precision of the coefficients and more robust standard errors (Lambert 1992, Hall 2000, Ogutu et al. 2010).

Two approaches using the ZINB were utilized to understand the effects of mowing on house mice and cotton rats. First, the count data was used with random effects due to the repeated measure of sites to examine the difference between mowed and unmowed areas. Second, the effect of the time since mowing was examined to understand if the mowing treatment created a cyclic effect in the count data for the mouse or rat populations. Experimental areas one and two were analyzed separately due to the different trapping efforts.

The binomial test was used to examine the willingness of house mice to cross the plowed soil barrier. Binomial tests are often used when there are small sample sizes (Zar 1984). The expected value of 50% was chosen to represent a null hypothesis that the plowed soil area is not different from the surrounding landscape. If movements were random, half the mice would cross the plowed soil area. Two methods were used to test the movement of house mice. First, the frequency of all movements was used, regardless of the frequency of capture of individual house mice. This assumes that each movement of an individual is independent of other movements. Therefore, whether an individual mouse crossed was also considered to account for territories (i.e. a single individual mouse's territory may or may not include the plowed barrier).

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The relationship between house mouse movements and grid characteristics was examined by contingency analysis using Fisher's exact test with small sample sizes (Zar 1984). Nominal variables used in this analysis were sex of the mice (Sex), whether a mouse crossed the constructed barrier (Cross), whether a mouse was captured within the mowed or unmowed treatment (Mowed), and whether a mouse traveled >10 m before it was recaptured (Distance). The Fisher's exact tests using the Sex variable were two sided because either sex could be a larger proportion in relation to crossing the barrier, the mowing treatment, or distances travelled. The mowing treatment analyses were examined as one-sided tests as there should be a significant bias against mowed. The Cross X Distance analysis was examined as a one-sided test because a higher proportion of individuals that crossed the barrier should also travel greater distances before recapture. All statistical analyses were preformed using STATA (Stata corp., version 11.0).

**Results**

*Overall Response of Small Mammals to Mowing*

House mouse capture rates in the mowing treatment followed a trend that differed from that of the control (Figure 4, a). Though, overall mean rates of capture were not significantly different (Figure 5). The rate of capture on the mowed areas peaked in June and July (Figure 4, a), whereas captures on the unmowed controls peaked in April (Figure 4, b). House mice were not captured on the mowed area during 8 of 21 weeks, in contrast to 3 of 21 weeks on the controls. Furthermore, house mice were not captured on the mowed grids until week 7, which

followed three mowing events. There was little apparent short-term response of house mouse capture rates to the mowing events (red linear blocks on Figure 4 a, b).

Cotton rats were captured more often then house mice and showed three distinct growth and decline phases in response to mowing (Figure 6, a). Cotton rats were not captured on the mowed areas during the first 5 weeks of the study and until 3 mowing events were completed. Rates of capture of cotton rats declined following 4 of 7 mowing treatments. The rate of capture of cotton rats on the control areas varied over the 21 weeks but did not oscillate like rates in the mowed areas (Figure 6, b), and there was no significant difference in the overall mean rates of capture for cotton rats. Cotton rats were captured at a greater mean rate on the unmowed areas relative to the mowed areas (Figure 7).

A runs test was used for house mice and cotton rats for both experimental areas to compare the increases and decreases in the weekly rates of capture to a random pattern (Figures 4 and 6). For each areas and each species, average rate of capture between mowed and unmowed did not significantly differ from random ($p > 0.10$).

Mowed areas did not significantly differ from unmowed areas in the number of house mice or cotton rats caught over time ($p > 0.10$; ZINB regression; Table 1). However, experimental area two did show a statistically significant block ($p < 0.05$) and mowed ($p < 0.01$) effect (Table 1). Mowed areas had relatively fewer cotton rats than unmowed areas as indicated by a negative coefficient for the "Mowed". The significant block effect for cotton rats in Area 2 indicates spatial patterns in cotton rat abundance.

There was no statistically significant effect of the variable time-since-mowed on house mice in Area 1 or 2 (Table 2). This demonstrates that mowing did not significantly affect house mouse abundance and there was no cyclic response of house mouse abundance through time. The time-since-mowed variable (Table 2) was marginally significant for cotton rats in experimental area one ($p < 0.10$), indicating that the mowing events contributed to cyclic increases and decreases in the population size of cotton rats (Figure 6). The coefficient for the time-since-mowed variable was positive, indicating that populations of cotton rats increased as time passed after a mowing event. The variables block ($p < 0.000$) and time-since-mowed ($p < 0.05$) were significant for cotton rats in Area 2 (Table 2). Positive coefficients on the blocks and time-since-mowed variables indicate that those blocks in well-drained soils had the greater relative abundance and that there was a cyclic effect of the mowing on cotton rat populations (Figure 3, Table 2).

### *Movement of House Mice*

In all, 10 individual house mice were recaptured a total of 25 times, with a few of the individuals recaptured multiple times. Of the 25 movements recorded, 8, or 32% of all movements, were recaptures that crossed the plowed soil area. The observed number of crossings was not significantly different ($p = 0.108$; binomial test) from random (12.5 crossings or 50%). Of the 10 individuals that were recaptured, 5 crossed the plowed soil area and this frequency was not statistically different from random ($p > 0.05$).

In general, most recaptures were at short distances with fewer longer distance recaptures (Figure 8). The average distance traveled by mice that crossed the barrier was 37.6 m, while the

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distance traveled by mice that stayed within a fragment was 15.2 m (Figure 9). The only statistically significant combination of nominal variables was whether a mouse crossed and the distance variable (Table 3). All other variables were statistically insignificant. None of the mice dyed with fluorescent pigment (Radiant[TM]) crossed the plowed barrier 24 hours after being released, making any test of crossing or not crossing irrelevant. Only one female was dyed with the pigment, therefore only the mowing and distance nominal variables were tested. The 1-sided Fisher's exact test between mowed and distance was not statistically significant ($p > 0.05$).

**Discussion**

My first hypothesis was that house mouse populations would decrease due to the mowing treatment; however, mowing did not significantly affect the relative abundance of house mouse populations. There are a number of reasons this could have occurred. First, even though the fields were mowed every 2 to 5 weeks, mowers left a small amount of vegetation on the ground. House mice prefer habitats with some vertical structure due to a perceived reduction of predation risk and therefore an increase in foraging opportunity (Stickel 1979, Arthur et al. 1994, Seitman et al. 1994). However, house mice are also opportunists and are usually first in the succession of small mammals to colonize a disturbed area (Fox et al. 2003). While not appearing substantial to the human eye, clipped vegetation left after mowing may have been sufficient for mice to remain sheltered and perceive little risk of predation. Therefore, mice were likely to be able to move freely within the area and gain access to all available resources.

Second, there is the possibility that the mowing treatment also exposed food resources (primarily insects) allowing increased feeding opportunities for house mice. This was often the

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case for cattle egrets, *Bubulcus ibis*, and other birds which followed the mowers and feed on exposed invertebrates and other small prey (personal observation). Third, house mice are proficient tunnellers and therefore could escape into burrows during mowing events. Anecdotally, house mice were never seen during mowing events, while cotton rats were observed running into surrounding areas.

The mowing treatment negatively affected cotton rat abundance (Table 2). Cotton rats showed aversion to mowers and mowed fields, with their numbers drastically reduced following most mowing events and then substantially increasing as vegetation regrew (Figure 6 a, b). Cotton rats prefer habitats with extensive ground cover and a mixture of monocots and dicots (Randolph et al. 1991, Browne et al. 1999), consistent with a diet that primarily consists of plants (Cameron and Spenser 1981). The mowed fields were dominated during the sampling by a number of graminoid species, while unmowed fields were dominated by elderberry, *Sambucus canadensis,* and other dicots as well as a mixture of monocots. Second, the cotton rat nests on the ground (Cameron and Spencer 1981) and therefore is more exposed to the mowers potentially leading to higher rates of mortality. Third, the reduction in vegetation would make the surface-dwelling cotton rat more vulnerable to diurnal and nocturnal aerial predators. Given that cotton rats were approximately five times the mass of house mice, an optimally-foraging aerial predator should prefer cotton rats over house mice. This is anecdotally supported by the contents of owl nest boxes within the area. Most of the small mammal remains within the owl pellets were cotton rats, with no house mouse specimens observed (unpublished data).

The significant block effect in the second experimental area for cotton rats may be related to the soils and water canals. Drier sandy soils which drained water quickly were found in the northeastern blocks and became more hydric when moving from north to south and east to west. The positive coefficient on the ZINB regression models suggest that the cotton rats preferred the drier habitat on the eastern edge of the NRSA property relative to those that did at times become partially inundated.

Most road and linear clearances inhibit small mammal crossings (Oxley et al. 1974, Merriam 1989, McGregor et al. 2008). House mice and cotton rats have even been found to avoid crossing dirt and field roads (Clark et al. 2001). My second hypothesis was that the plowed soil area would inhibit crossing by house mice. Three predictions followed from this hypothesis. First, there should be few captures in the middle trap line of each sampling grid, which was located in the plowed soil area. This turned out to be correct; no mice were caught in these traps. My second prediction was that few house mice will cross the barrier; therefore, the likelihood of recapture is greatest on the side of the barrier an individual was initially captured compared to recapture on the other side. While the half of the individual mice crossed the barrier, only 32% of all movements recorded were movements across the barrier. Therefore these data suggest the plowed soil area does not act as a complete barrier to house mouse movements but may inhibit some individuals. My third prediction was that the mowing treatment should alter movement behaviors in house mice, given a potentially greater predation risk in mowed areas. This was not supported as there was no significant difference between house mice movements inhabiting mowed and unmowed fields. In general, small mammals

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avoid linear barriers given a large barrier (e.g. $\geq$ 30 m; Oxley et al. 1974). The plowed barriers used by the SJRWMD were 4m wide, which may not be sufficiently wide to inhibit house mouse movement.

Low density house mouse populations such as those observed during this study, can be aggressive in defending their territory and rights to mates (Palanza et al. 2005). It is therefore not surprising that sex did not affect barrier crossing or movement distance. Also, it is not surprising that the non-significant mowing treatment did not significantly affect the number of house mice crossing the barrier or the distance they traveled. Mowing apparently left sufficient vegetation structure to allow house mice to persist in fields and move across the plowed barrier. Finally, the distance needed to be recaptured in a trap across the barrier was at least 20 meters, while the distance to the nearest trap on one side of the barrier was only 10 meters. Therefore those mice that crossed the barrier also traveled longer distances.

One of the difficulties in determining the effect of mowing and plowed barriers on house mice was the relatively low abundance of house mice as indicated by the low rate of capture (Figure 4 a, b). The average rate of capture of house mice was 1.1%, which was much lower than the 1999 outbreak event, which exceeded 24 to 30% capture rates of house mice (Stout et al. 2001, FFWCC 1999) or the outbreak events in Australia (Singleton 1989).

A second challenge was that house mice are trap shy (Krebs et al. 1994). Greater numbers of house mice caught in unmowed areas compared to mowed areas in the beginning of the experiment, may have been due to Sherman traps that were much more obvious in the mowed areas.

It is important to consider a species' spatial and temporal distribution to understand how land management techniques will affect the population in question. In particular, Fox et al. (2003) found that the relative abundance of house mice increased in response to a mowing regime in marginal wetland habitat. However, FFWCC (1999) found that relative abundance of house mice decreased in response to mowing in a former citrus grove habitat. Both land management techniques used by the SJRWMD within the former muck farms of the NSRA did not significantly affect low house mice densities, while mowing did have a significant negative effect on cotton rats. Given the multiple mechanisms that could have affected house mice and cotton rats during this study, additional experiments at greater population densities are needed to fully understand if mowing and barriers are useful in controlling these populations.

**CHAPTER 3: THE ECOLOGICAL AND ECONOMIC IMPACTS OF THE RED IMPORTED FIRE ANT, *SOLENOPSIS* INVICTA, IN THE SOUTHEASTERN UNITED STATES**

**Introduction**

In the United States, there are approximately 50,000 exotic species, comprised mostly of terrestrial plants, microbes, and arthropods (Pimental et al. 2005). While most of these species do not become established in native habitats, one in a thousand will create major ecological and economic damages (Williamson and Fitter 1996). These pest taxa exist in all major ecosystems, with a few altering natural processes and creating novel ecosystems dominated by nonindigenous species (Cox 1999). Among the most pervasive and damaging is the red imported fire ant, *Solenopsis invicta* (Buren), which affects native species and human society through additional costs associated with agricultural production, infrastructure, and healthcare (Pimental et al. 2005, Jetter et al. 2002, Lard et al. 2006, Gutrich et al. 2007).

Originally from South America, the red imported fire ant was accidentally introduced to Mobile, Alabama in the 1930's and due to its affinity for human disturbance, this scavenger and opportunistic predator has become common throughout the southeastern United States (Holway et al. 2002). The extensive ecological damages (Table 4) caused by this species are a result of direct interactions through predation and reduced survival from toxins, as well as indirect effects caused by the alteration of ecological processes and modified interspecific interactions (Holway et al. 2002, Allen et al. 2004, Tschinkel 2006). One possible reason for the severe ecological impact of red imported fire ant colonies is their great abundance and density. The introduced

*Solenopsis invicta* exhibits less intraspecific aggression in comparison to colonies in their native range, which is likely explained by the loss of genetic variation in the founding event(s) (Tsutsui et al. 2000). Thus, fire ant colonies can form dense congregations of up to 2000 mounds per hectare (Porter et al. 1991) with densities 4 to 7 times greater in North America than in their native range of Argentina and Brazil (Porter et al. 1997).

The economic impact from the invasion of *Solenopsis invicta* to the southeastern United States has been wide ranging, affecting agriculture, tourism, and human health and safety (Pimental et al. 2005). The cost of *S. invicta* was estimated at $1 billion per year for the United States (Pimental et al. 2005). In Hawaii, the potential economic damages from the introduction of red imported fire ants were estimated at $211 million per year, mostly from the foregone recreational and tourism activities (Gutrich et al. 2007). In California, projected costs were estimated to be $387 to $989 million each year (Jetter et al. 2002). Based on these estimates, the costs of red imported fire ants to the areas already invaded are nearly $5.6 billion annually (Jetter et al. 2002) with estimates from Texas in 2006 dollars estimated at $6.5 billion annually (Lard et al. 2006).

The purpose of this paper is to review some of the ecological impacts and examine the economic costs associated with the invasion of the red imported fire ant in the southeastern United States. In many habitats, ants form a significant portion of the biomass of the ecosystem (Ross and Keller 1995). The invasion by a non-native species of ant that exists in such high densities can result in the alteration of ecosystem processes as well as the biology and ecology of native species (Holway et al. 2002).

**Ecological Impacts**

*Arthropods*

Perhaps the most important impact of the red imported fire ant to arthropod communities has been the decline in species richness and abundance of native ant fauna (Porter and Savignano 1990). Once widespread over the entire southeastern United States the tropical fire ant, *Solenopsis geminata*, has declined in its distribution and density due to competition with the red imported fire ant. The red imported fire ant also dominates the larger *S. geminata* due to colony size and aggressiveness, replacing the latter in higher densities (Holway et al. 2002). In its native range of South America, *Solenopis invicta* occurs in low numbers and densities when compared with congenerics in their natural grassy habitat. However, where there is an anthropogenic disturbance, such as agricultural production, the population of *S. invicta* surges and becomes the most common ant species, likely due to a high degree of adaptation to disturbance. As with the Argentine ant, *Linepithema humile*, less genetic variation in the red imported fire ant has resulted in a loss of intraspecific conflict and the formation of super colonies (Tsutsui et al. 2000). These then aggressively displace native ant communities (Porter and Savignano 1990).

The distribution and abundance of other arthropod taxa are also influenced by the red imported fire ant. *Solenopsis invicta* reduced horn fly, *Haematobia irritans*, muscidoid and sarcophigid fly populations by 62.9 to 94.3%, plus populations of the predators of these flies, the staphylinid, hydrophilid, and carabid beetles in pastures (Hu and Frank 1996). In cotton fields, predatory lady beetle (50%), green lacewing (38%), spider, and big eyed bug (Heteroptera: Geocoridae) populations were reduced when aphids, their primary food source, were protected

by red imported fire ants. *S. invicta* excluded access by predatory arthropods in exchange for the carbohydrates secreted by the aphids (Eubanks et al. 2002, Kaplan & Eubanks 2002).

### *Reptiles and Amphibians*

The red imported fire ant is a voracious predator that affects many ground nesting vertebrate species (Holway et al. 2002). The entire ranges of the gopher tortoise, *Gopherus polyphemus*, and American alligator, *Alligator mississippiensii,* two species of critical importance to ecological processes of their respective habitats (Kushlan 1990, Myers 1990), are within the invaded range of the red imported fire ant. While mammalian predators are the leading cause of gopher tortoise nest predation, the eggs left undamaged by mammals are often then consumed by *Solenopsis invicta* (Landers et al. 1980). Gopher tortoise hatchlings are especially vulnerable; 27% of post hatching mortality is due to *S. invicta* (Epperson and Heise 2003). The red imported fire ant is also an important threat to the eggs and even the hatchlings of American alligators. The venomous sting of this invasive ant can cause decreased weight gain, thereby affecting the survival of individuals (Allen et al. 2001, Holway et al. 2002). Alligator nesting success also declines as a result of the presence of fire ants (Allen et al. 2004). Persistent alterations in the abundance or distribution of these two important ecosystem engineers could affect other species. For example, a decrease in the number of gopher tortoises would reduce the number of gopher tortoise burrows, thereby reducing habitat for over 300 species that also use the burrows (Myers 1990). Holes dug by the American alligator provide habitat for fish in the dry season and therefore a decline in the population of alligators by *S. invicta* could cause repercussions for aquatic environments (Kushlan 1990, Myers 1990).

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Endangered species such as the green and loggerhead sea turtles as well as fresh water turtles (red-eared sliders, red-bellied turtles, and box turtles) are also threatened by the red imported fire ant because the ants prey on eggs in the nest and emerging hatchlings (Allen et al. 2004, Wetterer & Moore 2005). In the presence of the red imported fire ant, red-eared slider, *Pseudomys nelsoni* hatchlings had a 70% decrease in survival (Allen et al. 2001). Sea turtle nesting success decreased 15% to 55% due to ants, primarily *Solenopsis invicta* (Allen et al. 2001, Moulis 1997, Wetterer et al. 2007). This does not include the potential morbidity of hatchlings stung by ants but that survive to enter the ocean. Declines of other herpetofauna may also be the result of an interaction with the *S. invicta*, including snakes (e.g. *Lampropletis getula spp.*) (Winnie et al. 2007, Wojcik et al. 2001) and salamanders (Todd et al. 2008).

### *Birds*

Ground nesting birds, in general, are considered more at risk of predation from red imported fire ants than aerial nesters, with one study showing population declines of up to 34% for swallows, *Hirindinidae* spp., (Kopachena et al. 2000). The presence of *Solenopsis invicta* has resulted in Northern bobwhite quail, *Colinus virinianus,* population declines of 28 to 50% (Allen et al. 2000, Allen et al. 2004). Stake and Cimprich (2003) documented the depredation of 31% of black-capped vireo, *Vireo atricapillus*, nests in Texas by red imported fire ants. This result is significant as the vireo nests in trees in wooded habitats showing that ground nesting species are not the only prey at risk. There is also anecdotal evidence that population declines of blue-gray gnatcatchers, eastern towhees, indigo buntings, loggerhead shrike, black rail, least tern, northern cardinals, and yellow-billed cuckoos are due to *S. invicta* (Allen et al. 2004).

*Mammals*

There are many aspects of behavior and health of mammals that are altered by the presence of red imported fire ants. Among small mammals, the old field mouse, *Peromyscus polionotus*, has been shown to reduce foraging in the presence of *Solenopsis invicta* even under optimal habitat conditions (Orrock and Danielson 2004). Likewise, the cotton rat, *Sigmodon hispidus*, may alter its habitat use during seasonally high numbers of the red imported fire ant (Pedersen et al. 2003). In a laboratory experiment, however, cotton rats where found to be immune to the venom of the *S. invicta*, even preying upon them (Ferris 1994). While Ferris et al. (1998) found no affect of the red imported fire ants on cotton rats. Northern pygymy mice, *Baiomys taylori*, increased in numbers with decreased fire ant density. This relationship was strongest during the summer, when fire ant densities were at their highest (Killion et al. 1995, Smith et al. 1990). In a laboratory experiment involving foraging behavior of deer mice, *Peromyscus maniculatus*, Holtcamp et al. (1997) showed that mice in the presence of *S. invicta* were more efficient than mice foraging in areas free of fire ants. Results of this study suggest little net effect of fire ants on foraging behavior of these small mammals, but many other behaviors are potential susceptible to the presence of fire ants. For example, the recruitment of young of white-tailed deer, *Odocoileus virginianus*, is reduced by half in the presence of *S. invicta*. It has been hypothesized that fawns are vulnerable to red imported fire ant stings and in turn are more susceptible to coyotes and other predators (Allen et al. 2004).

*Plants*

Plant-ant interactions are dependent on the attributes of the plants (i.e. seed characteristics and production of carbohydrates), ants (i.e. behavioral and colony characteristics),

and the relation of other organisms within the habitat (Holway et al. 2002, Lach 2003). The

substitution of *Solenopsis invicta* for some or a majority of a native ant community changes

plant-ant interactions that have evolved (Zetter et al. 2001). Alteration of reproduction,

predation, and pollination interactions may favor certain plant species that were disadvantaged

by native ant fauna, thereby altering plant communities over time (Zetter et al. 2001, Lach 2003).

Though there have been only a few attempts made at examining native plant interactions with *S.*

*invicta* in natural environments, there are a modest number of studies involving the response of

crops to *S. invicta* in agro-ecosystems.

Many plants have coevolved a mutualistic relationship with native ants, such as the native

red fire ant, *Solenopsis geminata*, by producing lipid-protein structures for seeds called eliasomes

to reward organisms for dispersing seeds (Holway et al. 2002). The native fire ant, *S. geminata,*

not only has a higher preference for seeds than *S. invicta*, but also is an intricate part of the

ability of native plants to tolerate fire. *S. geminata* places seeds within the nest allowing them to

be sheltered from seed predators and the frequent fires that many of North America's grassland

ecosystems require. *S. invicta*, however, after eating the eliasome also damages the seeds and

then expels the seeds into a pile outside of the nest, exposing the seeds to further predation and

abiotic forces (Tennant and Porter 1991, Zetter et al. 2001). As much as a third of the

herbaceous forest species within the southeastern U.S. bear seeds with eliasomes (Handel et al.

1981), thus the potential for alteration to the community by *S. invicta* is large. With the

displacement of the native ant fauna, the invasive *Solenopsis invicta* likely alters the composition

of the plant community once tended by native ants (Holway et al. 2002). The changes in

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behavior of the tending ant fauna likely result in changes to plant reproduction through differences in seed predation and dispersal (Zetter et al. 2001, Lach 2003).

A primary source of carbohydrates for *Solenopsis invicta* is directly obtained by feeding on plants (Shatters and Vander Meer 2000). Indeed, feeding on root systems has been shown to be important for *S. invicta*. The colonies damage roots both by feeding as well as extensive tunneling, reducing the biomass of root systems, and potentially increasing erosion of soils. It has been suggested that plants with deeper root systems may have an advantage over younger plants with shallow root systems (Shatters and Vander Meer 2000). Many of these factors also affect commercially important species such as vegetable and fruit crops exposed to *S. invicta*.

Pollinators and herbivores are potentially affected by the presence of the red imported fire ant (Lach 2003). Fire ants are more aggressive than most native ant fauna and recruit to food sources quicker and in larger numbers (Tschinkel 2006). This aggressiveness, along with a higher density within a landscape, may create difficulties for pollinators. Flowering plants, which normally attract pollinators, may be avoided if fire ants are defending the food source (Lach 2003). Furthermore, many homopteran species are protected from spiders and other predatory species by red imported fire ants (Kaplan and Eubanks 2002). As the homopterans feed on the plants, they excrete a carbohydrate rich liquid to the red imported fire ants. Thus both species benefit, with homopteran numbers increasing in the presence of fire ants (Kaplan and Eubanks 2002).

**Economic Impacts**

The costs considered were applied using 2007 as a baseline for dollar values to the ten southeastern states currently most affected (in which most counties are affected): Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, and Texas. An important feature of economic studies is to value all goods in the same time period (Boardman et al. 2001). To do this, commodity prices for the agricultural products (2007 Agricultural Census) and the consumer price index (CPI, Bureau of Labor Statistics) were used to align the value of impacts on different goods given the wide range of years in which the impact of *S. invicta* on various goods and services were conducted. Crop acreages were taken from 2007 agricultural census.

*Household*

Fire ants can cause a variety of problems for households ranging from reducing the aesthetics of a lawn to structural damage to buildings. Three different studies have estimated the annual expenditure of households on the control of red imported fire ants, based on surveys of residents in Georgia (1991), Arkansas (1995), and South Carolina (Miller et al. 2000). The expenditures in these studies were $35.26, $87.10, and $80.37 per year, per household respectively. After adjusting these values for the rise in prices, annual household expenditures on red imported fire ant reduction ranged from $53.67 to $118.51. Using Census data, over 29 million households in the southeastern United States were potentially affected by the infestation of *Solenopsis invicta* in the year 2000 (census.gov). Combining annual control costs per household and the Census data, the red imported fire ant costs households in the southeastern U.S. between $1.5 and $3.5 billion each year (Table 5).

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*Agriculture*

*Crop Production*

Millions of acres in the southeastern U.S. are used for agriculture (2007 U.S. Agricultural Census), therefore a minor alteration within the insect pest/predator communities can have extraordinary economic consequences. *Solenopsis invicta* has been found to harvest above-ground structures of plants and to damage root structures in the effort to obtain carbohydrates as food and in colony construction. These activities result in reductions in the yield of each plant, reduce the optimal density of the crops, and damage equipment related to harvesting and irrigation (Shatters and Vander Meer 2000, Knutson 2001, Jetter et al 2002).

Of the crops grown within the southeastern U.S., oranges and grapefruit are especially vulnerable to red imported fire ants that feed on the sap of these trees as well as the flowers and developing fruit (Jetter et al. 2002). Damages by red imported fire ants on the Texas grapefruit, orange, corn, and sorghum industries were estimated by Segarra et al. (1999). By extrapolating those damages to the number of harvested acres of each crop in 2007 within the range of red imported fire ants (Table 5), the citrus industry, lost almost $20 million in production yield. Likewise, the reduction in yield for corn and sorghum used for grain produced in the southeastern U.S. created an economic loss of $28 million and $120 million, respectively. The cost per acre for forage in Texas was calculated at $25.26 per acre (Knutson 2001). Using this cost per acre and applying it to the forage acreage over the states most affected by fire ants as well as the cost of this commodity, a cost of over $451 million is estimated. Jetter et al. (2002) estimated the damage to soybean and wheat crops at $8.95 per acre, which results in costs of $141 million and $238 million, respectively. A survey of pecan farmers in Texas showed that

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more than half would pay over $6 or more per acre to eliminate red imported fire ant (Lard et al. 2006). This would result in an approximate cost of $3 million. Most of the sunflower crop within the United States is harvested within North and South Dakota, far outside the potential range for red imported fire ant, however there is some production within Texas resulting in a cost of nearly $11 million. Vegetable crops such as sweet corn and cucumbers are also impacted by the presence of fire ants with costs totaling nearly $6 million. While eggplants are heavily impacted by fire ants, the costs of these damages have not been fully examined. Potato crops are also highly susceptible with fields at times being abandoned due to the density of *Solenopsis invicta* (Adams et al. 1988).

Other crops such as walnuts, figs, and prunes are highly susceptible to the presence of red imported fire ant (Jetter et al. 2002); however, relatively few acres are within the current introduced range of red imported fire ant. The main source of these commodities, however, is California which currently is trying to prevent the widespread introduction of *Solenopsis invicta* (Jetter et al. 2002).

Some crops may benefit from the presence of red imported fire ant. For example, peanut production does not significantly change in the presence of *Solenopsis invicta*, while some crops, such as cotton and sugarcane may benefit, due to the reduction of arthropod herbivores and parasites. Red imported fire ants feed on the sugarcane borer, *Diatraea saccharalis* (Adams et al. 1981), two pests of cotton, the beet armyworm, *Spodoptera exigua*,(Knutson 2001) and corn earworm, *Helicoverpa zea* (Nuessly and Sterling 1994). However, some beneficial predaceous arthropods are also removed as indicated by increases in the number of aphids with abundant red

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imported fire ant populations, which in turn increases damage to many crop species (Kaplan and Eubanks 2002). Counteracting effects of red imported fire ants on food webs in agro-ecosystems may lead to no change or increased yield of certain crops, however the interactions are not constant. Impacts from *S. invicta* directly as well as indirectly through the alteration of agro-ecosystem food webs could change, thus altering the economic losses that accrue.

*Livestock Production*

The presence of *Solenopsis invicta* has debilitating effects on many kinds of livestock, including cattle. In Texas, costs were estimated to be $5.77 per head (Barr and Drees 1996). Extrapolating to the total number of cattle within the adopted range of *S. invicta*, and adjusting for the rise in beef prices since the Barr and Drees study in 1996, damages to the cattle industry are nearly $200 million (Table 5). While red imported fire ants damage livestock, they also reduce populations of horn flies, *Haematobia irritans*, a major pest species (Hu and Frank 1996). In Florida alone, horn flies were estimated in 1986 to cost the Florida cattle industry $61 million each year (Hogsette and Koehler 1986). It is therefore possible that the cattle industry receives an economic benefit from *S. invicta* due to the reduction in horn flies. Costs associated with other commercial livestock such as chickens and turkeys have not been explicitly studied and therefore were left out of the estimated costs, but could be substantial given the high numbers of poultry raised in the southeastern U.S.

**Recreation**

The ecological consequences of red imported fire ants also result in large economic losses to wildlife associated stakeholders such as hunters and wildlife watchers. Lard et al.

(1999) found a 30% reduction in outdoors recreational activities by residents of Texas due to fire ants. In a survey conducted by the U.S. Fish and Wildlife Service, 86.5 million residents were estimated to spend $122.3 billion enjoying wildlife related activities in 2006. This includes nearly $11 billion in hunting and $7 billion in wildlife watching in the affected states. As the red imported fire ant significantly reduces the quantity and quality of a number of game and wildlife species within the southeastern U.S., this would suggest that a reduction of fire ants would increase the quantity of wildlife observed and therefore the quality of each trip. This factor alone could be worth billions of dollars each year from increased recreational expenditures. *Solenopsis invicta* populations are most significant in mesic and hydric soils (Holway et al. 2002), therefore outdoor recreational activities in these areas will suffer the greatest impact. The increased quality of wilderness habitat could yield a great deal of economic benefit. Due to the level of uncertainty involved, I did not include these costs in final economic costs calculated for this study, which makes my final estimate of the costs associated with this species conservative.

*Infrastructure*

The highest densities of *Solenopsis invicta* occur nearest to human disturbances, such as roadsides and utility easements (Tschinkel 2006). Utility companies paid $8.90 per capita in Texas to replace and repair equipment damaged by *S. invicta* activity (Segarra et al. 1999). Applied to the 10 states considered in this study and to the baseline 2007 dollar value, over $700 million per year must be paid by utility companies in the southeastern U.S. for the repairing and replacement of equipment (Table 5).

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### Human Health

The consequences for human heath from the red imported fire ant are quite substantial given the allergenic reactions of many people (Holway et al. 2002). Thirty to fifty percent of the residents in the areas infested with *Solenopsis invicta* are stung by the ants each year resulting in medical treatment for 660,000 people with 33,000 medical consultations each year (de Shazo et al. 1999). The annual estimated costs of these injuries by red imported fire ant in 1998 in South Carolina were $2.4 million each year (de Shazo et al. 1999). Extrapolation of these costs to the population in the area, suggests medical treatments and medical consultations reach nearly $60 million in 2007 dollars (Table 5). While deaths are rare from *S. invicta*, as of 1990, there had been 32 deaths confirmed related to reactions from fire ant stings (de Shazo et al. 2004). Most of these deaths were from individuals unable to move away from ants (i.e. infants and elderly). Litigation in two Florida cases in 2002 and 2005 resulted in over $3 million settlements. These types of events increase the perceived risks offered by fire ants, increasing the amount households and businesses are willing to pay to reduce *S. invicta* populations.

### Discussion

The red imported fire ant has become a major problem for ecological systems, agriculture, human health, and infrastructure. A number of ecosystems and species are heavily impacted and therefore a number of habitats could be less suitable due to the abundance of *Solenopsis invicta*. According to Gutrich et al. (2007), the greatest amount of economic damages in Hawaii from an invasion of this species would occur from the foregone outdoor activities by residents and tourists. Tourism and outdoor activities are important in much of the southeastern U.S., especially Florida, therefore the ecological and economic cost of red imported fire ants

could be enormous. Overall *S. invicta* contributed between \$3.5 and \$5.4 billion per year in damages to the southeastern U.S. in 2007 (Table 5). If red imported fire ants were to also invade California and Hawaii the number could increase by another \$1.2 billion annually. These costs exclude minor agricultural crops in the southeastern United States. In addition, variability in agricultural prices could make the annual cost per year of red imported fire ants dramatically change. This is important when calibrating economic losses. For example, from 2005 to 2007 corn prices doubled (bls.gov). As the U.S. and world population increases, food resources are likely to become more valuable and therefore costs from this invasive ant will increase.

In this study only the costs associated with the red imported fire ant, not benefits were examined. To be fair, the introduction of red imported fire ant to North America may result in some benefits to human society. Many agricultural pests are depredated by *Solenopsis invicta*, thereby benefiting several crops if the red imported fire ant does not harm the crop. One important benefit is the 90% reduction in the population of lone star ticks, *Amblyomma americanum*, reducing the potential spread of many diseases, such as lyme disease and Rocky Mountain spotted fever (Wojcik et al. 2001). However, many of these benefits are roles that native predators and parasites would undertake if not for the presence of red imported fire ants (Tschinkel 2006).

Many of the effects of red imported fire ant on ecological and economic systems are poorly understood (Tschinkel 2006, Holway et al. 2002). Most of the studies of the cost of the red imported fire ant only look at the response of wildlife in the absence or presence of *Solenopsis invicta*, when *S. geminata* and other native species of ant may fulfill similar

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interactions. The costs associated with *S. invicta* as compared to other native ant species are far from clear and thus highlights the need for additional research to insure confidence in making policy decisions. There is also a significant amount of variation in the impacts caused by the red imported fire ant between regions within a state, and even from county to county (Polk 1999). A county-by-county level analysis of the impacts of this invasive species over an extended time period would be required to attain the highest level of accuracy from the benefits and costs associated with *S. invicta*.

As one of the most intensely studied arthropods, the red imported fire ant, *Solenopsis invicta*, may serve as an exemplary organism for the study of the varying ecological and economic impacts of an invasive species. The diversity of impacts upon wildlife and human society makes this species an important example of the economic losses that can accrue to society from the introduction of nonindigenous species to areas outside their native range. The red imported fire ant is only one species of the tens of thousands that have been introduced and with many more being brought every year given current trends in commercial trade, movement of people, and the active and passive transportation of flora and fauna by humans.

**CHAPTER 4: THE EFFECTS OF LAND MANAGEMENT AND FIRE ANT
SUPPRESSION ON SMALL MAMMAL POPULATIONS**

**Introduction**

Nonnative species may be an important cause of the decline of many indigenous species (Vitousek et al. 1997). Insight into the interactions between invasive species and with native species is of crucial importance to the management of ecosystems and conservation of biodiversity. Two species that have become major pests around the world are the house mouse, *Mus musculus*, and red imported fire ant, *Solenopis invicta* (Elton 1942, Morrison et al. 2004). In Australia alone, house mice disrupt native rodent populations and cause tens of millions of dollars of damage each year (Caughley et al. 1994, Singleton et al. 2005). Fire ants in North America threaten many species, including many mammals (Holway et al. 2002) and generate billions of dollars of damages annually (Pimental et al. 2005, Lard et al. 2006).

The house mouse was introduced to North America from Europe and has adapted to living in man-made structures as well as human-altered and natural landscapes (Bronson 1979). The house mouse is an agricultural and residential pest, in part because of its wide distribution by human activity (Singleton et al. 2007). They are highly tolerant of disturbance, man-made and natural, and are often amongst the first colonizers into favorable habitats (Fox et al. 2003, Singleton et al. 2007). North American populations of house mice are widespread and often

relatively small though population outbreaks occur (Hall 1927, Bronson 1979, Pearson 1963, Rose and Kratimenos 2006).

Originally from South America, the red imported fire ant occurs in relatively low numbers in natural grassy habitats, but it becomes the most common ant with disturbances (e.g. agricultural production) and has become abundant in many parts of the United States (Wojcik 1983, Tschinkel 2006). The red imported fire ant is a voracious predator that has reduced populations of many species and affected ecosystems, particularly in the southeastern U. S. (Allen et al. 2001, Holway et al. 2002, Wetter and Moore 2005, Tschinkel 2006).

The responses of small mammals to the presence of the red imported fire ant are varied and depend on species, location, and season. Many researchers have noted the death of small mammals live-trapped within their studies due to *Solenopsis invicta* (Hill 1969, Killion 1992, Smith et al. 1990). Population density estimates of small mammals decreased when traps were near fire ant mounds compared to trap results of randomly-placed traps (Stoker 1992). Deer mice, *Peromyscus maniculatus*, and old field mice, *Peromyscus polionotus*, have been shown in field experiments to alter foraging behavior due to fire ant densities (Holtcamp et al. 1997, Orrock and Danielson 2004). The northern pygmy mouse, *Baiomys taylori*, avoids areas with high densities of fire ants, especially during the summer months when fire ants are more active and abundant (Smith et al. 1990 and Killion et al 1995). However, Pedersen et al. (2003) found no modification of habitat use by pygmy mice in the presence of fire ants. Numerous studies have found that cotton rat capture rates decline in the presence of fire ants (Killion and Grant 1993, Pedersen et al. 2003). However, Ferris et al. (1998) found no effect of fire ants on cotton

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rats. In addition, a laboratory study found that no effect of the fire ant toxin on adult cotton rats or their young with adult cotton rats even consuming fire ants (Ferris 1994).

In this study I examined the response of house mouse, *Mus musculus*, and cotton rat, *Sigmodon hispidus*, populations to the effects of mowing (altered habitat structure) and reduced abundance of red imported fire ants. The experiments were applicable to land management techniques used by the St. Johns River Water Management District (SJRWMD) regarding the house mouse, the cotton rat, and the red imported fire ant.

Habitat structure is important to small mammal abundance (Seitman et al. 1994) as variation in ground cover provides small mammals with different levels of resource availability, refugia, and risk of predation (Twigg and Kay 1994, Seitman et al. 1994, Fox et al. 2003, Jensen et al. 2003, Aurthur et al. 2004, Singleton et al. 2007). My first hypothesis was that mowing reduces small mammal abundance. Mowing may reduce house mouse and cotton rat abundances for three reasons. First, mowed areas provide little vegetative cover, potentially increasing aerial predation or the perception of the threat of predation, thereby decreasing habitat suitability (Stickel 1979, Jensen et al. 2003). Second, the reduction of the vegetation may reduce food resources of house mice and cotton rats (DeLong 1967, Cameron and Spencer 1981). Third, the mowing itself may directly cause mortality of small mammal or induce emigration.

Fire ants potentially affect the suitability of a habitat, decreasing capture rates of many small mammals (Killion and Grant 1993, Pedersen et al. 2003). My second hypothesis was that individuals of *Mus musculus* and *Sigmodon hispidus* occupying the same type of habitat (i.e. mowed or unmowed) should avoid areas where fire ant activity is highest, thus indicating a

reduction in the suitability of the habitat.  In addition to direct impacts, such as predation and competition, the red imported fire ant may affect small mammals in other ways.  For example, plant communities may be altered by *S. invicta's* effects on root systems, seed set and dispersal, as well as by changing patterns of herbivory (Shatters and Vander Meer 2000, Lach 2003). Invertebrate communities are also dramatically altered by the presence of *S. invicta* (Holway et al. 2002, Hu and Frank 1996, Eubanks et al. 2002, Kaplan and Eubanks 2002).  Changes to species composition or abundances of arthropods important in the diet of house mice should indirectly affect mice (Porter and Savignano 1990).  Food preferences of feral mice and cotton rats are not well known, though seeds, insects, and vegetation are all important.  Arthropods may be a higher percentage of the house mouse diet than plant seeds (Berry and Bronson 1992), though nutritional needs likely depend on reproduction and seasonal factors.

I predict the number of small mammals captured should increase where fire ant numbers are suppressed.  Alternatively, the number of small mammals could decrease where fire ants are suppressed for three reasons.  First, the house mouse diet primarily consists of arthropods (Berry and Bronson 1992), therefore fire ants could be a food resource.  In a laboratory experiment, adult cotton rats were observed consuming *S. invicta* (Ferris 1994), though the extent of their diet that consists of arthropods and the use of *S. invicta* as a potential food source are unknown. Second, the chemical treatment used to suppress ant populations might have a negative effect on the arthropods on which house mice and cotton rats rely (Berry and Bronson 1992, Cameron and Spencer 1981) and thereby decrease usage of ant-suppressed areas.  Third, the treatment could directly affect small mammals thereby reducing the number caught.

Fire ants favor disturbed, sunny areas (Tschinckel 2006). The mowing treatment should therefore have a positive effect on fire ant abundances. My third hypothesis was that the interaction of mowing and fire ant treatment should lead to an additional positive response by small mammals due to the greater difference in the abundance of fire ants compared to areas that are mowed and untreated for fire ants. However, a negative response was also possible if small mammals were more impacted (directly or indirectly) by application of pesticide in the mowed areas compared to unmowed areas.

## Methods

### *Study Area*

The North Shore Restoration Area (NSRA; Section 33, Township 20 South, Range 27) is almost 20,000 acres (8,000 hectares) of former agricultural land on the northern shore of Lake Apopka, in central Florida (Figure 1). The area was originally a shallow marsh habitat fringing the lake, but a system of levees was built in 1941 that drained the marshes for the production of corn and winter vegetables. This activity increased nutrient and pesticide influx into the lake, effectively eliminating recreational fishing and making Lake Apopka hypereutrophic. In 1996, the Lake Apopka Improvement and Management Act authorized the SJRWMD to acquire the farms located on the north shore of Lake Apopka for the purpose of restoring the hydrology and wetland marsh habitat, thus reducing nutrient flow into the lake. When a portion of the NSRA was flooded in the fall of 1998, heavy bird mortality resulted because of the release of high levels of residual pesticides from the soils within the area. To reduce usage by wetland birds, the SJRWMD has maintained the fields with no flooding by actively pumping rain water and

maintaining the levees around the lake.  This circumstance has resulted in the persistence of old field habitats suitable for many small mammals, including the house mouse (Hoge et al. 2003). A majority of the NSRA has been mowed in the expectation that mowed fields provide less suitable habitat for house mice (Stout et al. 2001).  For more details of the response of small mammals to the mowing treatments, see Chapter 2 of this document.

*Design and Sampling*

For this experiment, a split plot design (Figure 10) within the randomized block of the mowed and unmowed vegetation was used to examine the effects of the mowing treatment and fire ant suppression on house mouse and cotton rat abundance.  Blocks were oriented north to south separated by seasonally inundated ditches that approximately followed vegetation and soil boundaries.  Well drained sandy soils occurred on the eastern edge of the experiment (i.e. block 3), with a transition to more hydric soils moving west with parts of block 1 holding water just below the soil surface during July and August.   Mowed and unmowed areas were randomly placed in each of the treatments.  Mowing treatments were applied at 2 – 3 week intervals as determined by vegetation height.  Within each of these treatments a trapping grid was placed comprised of 20 trapping stations (each with 2 Sherman live-traps within one meter of the station) where each grid was arranged in a 5 X 4 rectangular configuration (Figure 10) with 10 meters between stations.  Half of each sampling grid was treated with pesticide (Spectracide®

Fire Ant Killer Mound Destroyer™ Granules) to reduce the density of fire ants in an area 60 meters by 25 meters (1500 $m^2$).  A single 3.5 lb bag was applied to each 1500 $m^2$ area by broadcast method, walking systematically over the area (June 12th, 2008).  Once each week,

Sherman traps were baited with sunflower seeds, set in the afternoon and checked the following morning. Individual house mice were ear tagged, weighed with a Pesola spring scale to the nearest 0.5 grams, sexed, and reproductive condition noted. The trapping period began on June 14th, 2008 and ended August 9th, 2008.

The abundance of fire ants was sampled by a fire ant mound survey and pitfall traps. A belt transect survey was conducted four weeks after fire ants were treated and only within the mowed areas due to the density of vegetation within the unmowed areas. Mounds were identified by walking 2 m wide transects inside the sampling grid and a 10 m buffer area around the grid to ensure the accuracy of the count (Forbes et al. 2000). Four pitfall traps were placed within each grid for a total of 24 traps. Two were located in the area where fire ants were suppressed and two were placed in the control. The pitfall traps were baited with ½ ounce (approximately 14 grams) of tuna fish for approximately 14 hours before being collected. The contents of each pitfall trap were put into an individually labeled container with non-acetone, ethyl acetate, and later placed in 70% isopropyl alcohol, to preserve specimens. Pitfall trapping occurred once prior to the reduction of fire ants (June 5th, 2008) and twice post treatment (June 28th, 2008 and August 2nd, 2008). *Solenopsis invicta* specimens counted for analysis and specimen identification was confirmed by a local expert.

### *Statistical Analysis*

*Fire Ants*

An ANOVA was used for the survey of fire ant mounds between the control and ant reduced areas within the mowed treated areas. Paired Wilcoxon signed-ranked tests were used to

examine the number of red imported fire ants from the baited pitfall traps in ant suppressed areas as well as the controls, before and after application of the pesticide (Spectracide™).

*Small mammals*

A runs test was first used to understand if the fluctuations of the house mice and cotton rats were random (Zar 1984). A zero-inflated negative binomial (ZINB) regression analysis was used to examine the effects of mowing on count data derived from trapping house mice and cotton rats, due to the high frequency of zeroes (no captures) and overdispersion (i.e., standard deviation ≥ mean). A zero-inflated negative binomial regression uses a negative binomial distribution, increasing the precision of the coefficients and calculating robust standard errors (Lambert 1992, Hall 2000, Ogutu et al. 2010).

**Results**

***Response of Fire ants to Mowing and Pesticide***

Significantly fewer fire ant mounds were observed in the treated sites than in the control areas where fire ants were not treated (ANOVA, $p < 0.05$, Table 6), while there was no pattern to the spatial distribution of fire ants (ANOVA, $p > 0.05$, Table 6). Fire ant abundance among pitfall traps was highly variable, but generally declined during the experiment (Figure 12). The pitfall trap data showed no significant difference in the number of fire ants caught in before and after comparisons of areas with and without pesticide treatments (Wilcoxon sign ranked test, $p > 0.05$, Figure 13).

*Overall response of small mammals to mowing and fire ants*

In general, house mice were rarely captured and so did not clearly respond to any

treatment combination (Figure 14). Cotton rats capture rate was ~ ten times greater than house

mice, but also highly variable (Figure 15). The mean capture rate of cotton rats was usually (8 of

9 weeks) greatest on unmowed grids where ants were treated, indicating that more cotton rats

existed in those areas than similar areas with active ant mounds. The mowed areas had much

lower rates of capture for cotton rats than unmowed areas. Cotton rats were not captured 3 out of

9 weeks in the combination of mowing and untreated ants. Captures of cotton rats lagged four –

five weeks after ant treatment in the girds treated for fire ants and mowed.

House mouse and cotton rat rates of capture were analyzed with a runs test to compare

temporal changes to a random pattern. For both species, average rate of capture between mowed

and unmowed did not differ from a random pattern ($p > 0.10$). House mice did not significantly

respond (ZINB, $p > 0.05$) to treatments (mowing or ant reduction) or spatial design of the

experimental (blocks) (Table 7). However, cotton rats were significantly affected by all factors;

block ($p < 0.01$) and ant reduction ($p < 0.01$) effects had a positive effect on capture rate and

mowing ($p < 0.01$) and the interaction of the mowing and ant reduction treatments ($p < 0.1$) had

negative effects on capture rates.

**Discussion**

The spatial distribution and abundance of small mammals can be affected by many

mechanisms. In this study, house mice and cotton rats were examined for their responses to

changes in habitat (mowed and unmowed) and the density of red imported fire ants. Results

from this study indicate that house mice and cotton rats respond differently to manipulation of habitat and fire ant densities.

Mowing, the density of fire ants, and the interaction between these two factors did not significantly affect the relative abundance of house mice ($p > 0.05$). This was unexpected as the mowing disturbance was repeated four times over the course of the experiment and in other studies house mice prefer habitats with structure (Twigg and Kay 1994, Seitman et al. 1994, Fox et al. 2003, Jensen et al. 2003, Aurthur et al. 2004, Singleton et al. 2007). While mowing reduced the height of the vegetation, it also created a mat of horizontal habitat (at times dense) structure that may provide suitable habitat for house mice. Rodents are prey for many species and the perception of the risk of predation in different habitats is an important factor in foraging behavior. Areas that provide shelter from predators are preferred by rodents (Orrock et al. 2002). However, in high densities and when food availability is low, house mice forage for short periods in habitats perceived as high risk to predator exposure (Ylonen et al. 2002). The extent of the horizontal structure of the vegetation after mowing events could have allowed mice enough cover to reduce the perception of predation risk and therefore access to food resources was unaltered between mowed and unmowed fields. The horizontal structure may be highly dependent on seasonal and climactic conditions and would suggest if less horizontal structure is present in winter months, the perception of predation risk in mowed areas would increase. In addition, these areas may have less food availability during different seasons then not considered in this study. For these reasons, similar studies should be conducted in the NSRA to include the winter months.

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Cotton rats were negatively influenced by mowing, consistent with known preferences by cotton rats for habitats with extensive ground cover (Browne et al. 1999), which may provide cover from aerial predators. In addition, cotton rats primarily feed on a mixture of dicots and monocots (Randolph et al. 1991, Cameron and Spenser 1985). Mowed fields were dominated by graminoid species, while unmowed fields were more diverse and dominated by elderberry, *Sambucus canadensis,* other dicots, and a mixture of monocots. Unmowed fields may have provided more suitable forage for cotton rats. Finally, cotton rats nest on the ground (Cameron and Spencer 1981) and therefore animals and nests are more exposed to the mowers than burrowing house mice, potentially leading to mortality.

Fire ant density did not affect house mouse capture rates. Perhaps because house mice and fire ants do not significantly interact or house mice may forage more efficiently, as reported for deer mice (Holtcamp et al. 1997), and avoid fire ants. Alternatively, experimental treatment of fire ants may have failed to cause an effect. Treatment of fire ants may have had little effect and thus no strong positive or negative response by house mice would be expected. Fire ant abundance was assessed by pitfall traps, which may be highly dependent on cloud cover, time of day, and the number of mounds within the area (Porter and Tschinkel 1987, Seymour and Hooper-Bui unpublished data). Also, the relatively small study (area, number of samples) and short time period of the study may have lacked the statistical power to detect subtle effects of fire ants on house mice. Finally, house mouse capture rates were low (~1%) at the time of the study compared to 30% in previous years within this same area (Stout et al. 2001, FFWCC 1999).

House mice are trap shy and can be difficult to capture (Krebs et al. 1994), but low densities during the study likely reduced the detectable variation due to treatment effects.

In contrast to house mice, cotton rats were negatively affected by higher densities of fire ants. Cotton rats were more frequently captured in areas where fire ants densities were suppressed. This study was conducted during the summer months, when fire ant activity is at its peak, and so inferred interspecific interactions may also be most intense. The interaction of the fire ant and mowing treatment (Figure 16) shows that cotton rat capture rates nearly doubled in the unmowed fields but had no difference in capture rates in the mowed fields. This indicates that the mowing effect overwhelmed the fire ant treatment.

Cotton rats were also affected by the experimental design (blocks) which differed in a east to west gradient from well-drained sandy soils more hydric soils. Cotton rats apparently preferred the drier habitat on the eastern edge of the NRSA property relative to areas that are occasionally inundated.

The response of mice to habitat management and the reduction of red imported fire ants might be very different when house mice are abundant. Few studies should focus on the behavioral responses of house mice and other small mammals to fire ants in laboratory and field conditions to better understand the effects of this nonnative arthropod. Also, the SJRWMD should conduct studies more consistently through time to collect results when mice are more numerous.

Management of nonnative species may negatively affect native species. The house mouse, *Mus musculus*, and red imported fire ant, *Solenopsis invicta*, are two nonnative species

that have become pests causing ecological and economic damage around the world (Holway et al. 2002, Pimental et al. 2005).  Understanding the complex interactions between nonnative species and native species is important to the management of species and ecosystems as well as conservation of biodiversity (Vitousek et al. 1997).

# CHAPTER 5:  GENERAL SUMMARY

Throughout recorded history, organisms have been introduced or accidentally transported outside their natural distributions by explorers and other human activities (Elton 1942, Elton 1958).  Two species accidentally brought to the United States are the house mouse, *Mus musculus*, and the red imported fire ant, *Solenopsis invicta*.  As early as the 1850's, the house mouse was established from New York to California to Indian River region of Florida (Baird 1857).  The red imported fire ant was brought in ship spoil piles in the 1930's to Mobile, Alabama and has expanded throughout the southeastern U.S. (Holway et al. 2002).  Though both species have been extensively studied, the ecological impacts from these species and factors contributing to their distribution and levels of abundance are still left to some interpretation and conjecture.

Two population outbreaks of house mice have occurred in the last decade on abandoned muck farms of the North Shore Restoration Area (NSRA) of Lake Apopka, Florida (Stout et al. 2007).  Two experiments were conducted to evaluate the efficacy of the land management protocols (i.e. mowing and plowing) of the St. Johns River Water Management District (SJRWMD).  Mowing, which occurred multiple times during the experimental period, showed no affect on the overall capture rates of house mice or any cyclic affect on the population.  The plowed soil barrier may have inhibited some movements of house mice, but a substantial percentage of individuals did cross the barrier, with a few individuals crossing multiple times.  The native cotton rat, *Sigmodon hispidus*, was negatively affected by the mowing treatments,

with large mortality and/or emigration occurring immediately after a mowing event. These populations recovered after some vertical habitat structure had been re-established.

The red imported fire ant is an important species due to its ecological and economic impacts within the southeastern United States. Often this species negatively impacts the native plants and animals within the region (Holway et al. 2002). There are also negative responses for human society in the reduction of quality of life and decline in commerce (Pimental et al. 2001).

There was a divergent response of house mice and cotton rats in response to suppression of fire ant densities. House mice were apparently unaffected by the presence of fire ants, while cotton rat capture rates were positively affected by the suppression of fire ants. This suggests that habitat suitability for cotton rats is greater in areas with fewer fire ants.

Resolution of the ecological mechanisms that affect house mouse reproduction, mortality and therefore the occurrence of house mouse outbreaks on the NSRA will require a sustained trapping effort over multiple years. Future research should expand trapping efforts to different habitat and soil types. Trapping within the uplands around the NSRA could make clearer the response of house mice to these various communities. In addition, the response of house mice to weather conditions, resource availability, and interspecific interactions could resolve some of the remaining questions as to the potential triggers to house mouse outbreaks.

If given the opportunity to do the study again, I would have increased the number of replicates and extended the experiment into the winter months potentially trapping more animals, thereby increasing the statistical power of the experiment. In this study, resources were not available to expand the sampling effort.

While house mice have at times become a pest species within the southeastern U.S., the red imported fire ant, *Solenopis invicta*, has expanded both its range and the resulting economic damages (Lard et al. 2006). Understanding the spatial and temporal distribution of an organism is central to ecology (Andrewartha and Birch 1954). In the case of invasive species, which may cause enormous ecological and economic damages, these answers can profoundly affect the management of ecosystems, conservation of species, and commerce (Elton 1942, Vitousek et al. 1997, Pimental et al. 2001).

# APPENDIX A:  FIGURES
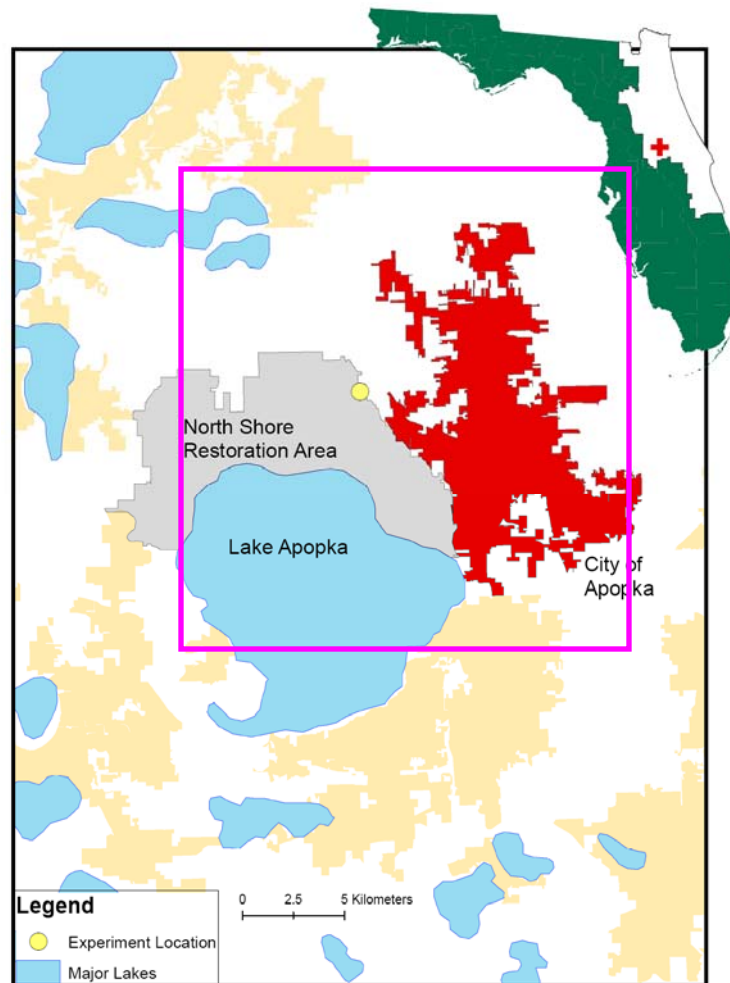
Figure 1 A graphical depiction of the Lake Apopka area including major lakes, the city of Apopka (with other cities shaded tan), and the North Shore Restoration Area (NRSA). In the upper right hand corner is the location of the St. Johns River Water Management District (SJRWMD) in white and the Lake Apopka area, represented by a plus-sign. The open box represents the approximate area house mouse outbreaks occurred in 1999 and 2006. The circle on the border of the NRSA is the site of my experimental study. Lake Apopka is denoted as darker than other cities as it has been the only city affected by house mouse outbreaks.
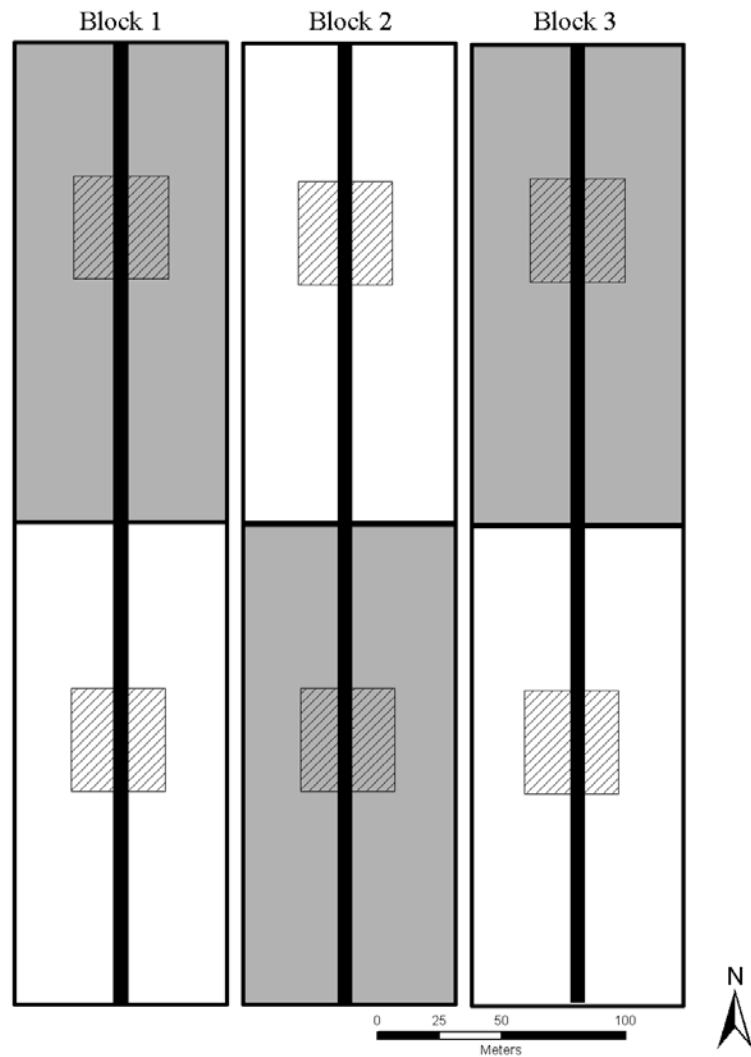
Figure 2  The block experimental design of area one examining the response of land management techniques (i.e. mowing and plowing) on small mammals.  Blocks are comprised of a mowed (unshaded) and unmowed (shaded) area.  The black lines are the plowed soil barriers placed in the middle of each block.  The 5 X 5 sampling grids made up of 25 stations with a total of 50 Sherman live-traps each are depicted by the hatched squares.  Blocks were separated by seasonally inundated ditches.
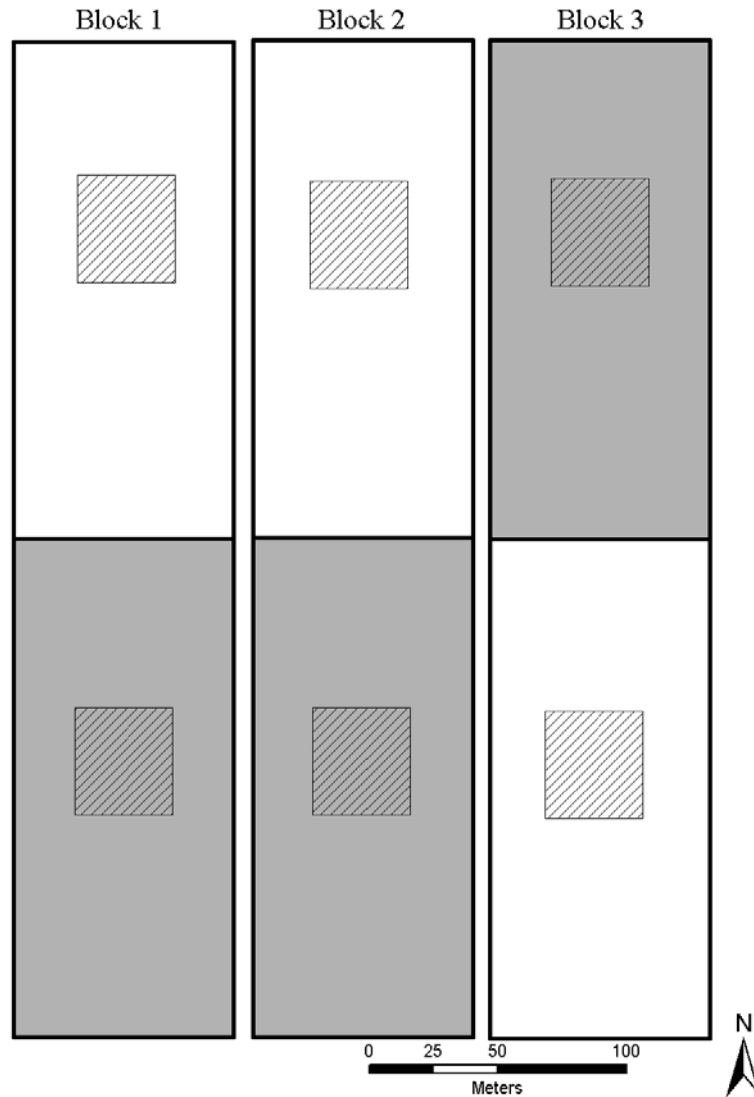
Figure 3  The block experimental design of area two, where the response of land management techniques (i.e. mowing) on small mammals was examined.  Blocks are comprised of a mowed (unshaded) and unmowed (shaded) area.  The 4 X 5 sampling grids mad up of 20 trap stations with a total of 40 Sherman live-traps each are depicted by the hatched squares.  Blocks were separated by seasonally inundated ditches.

a)



b)
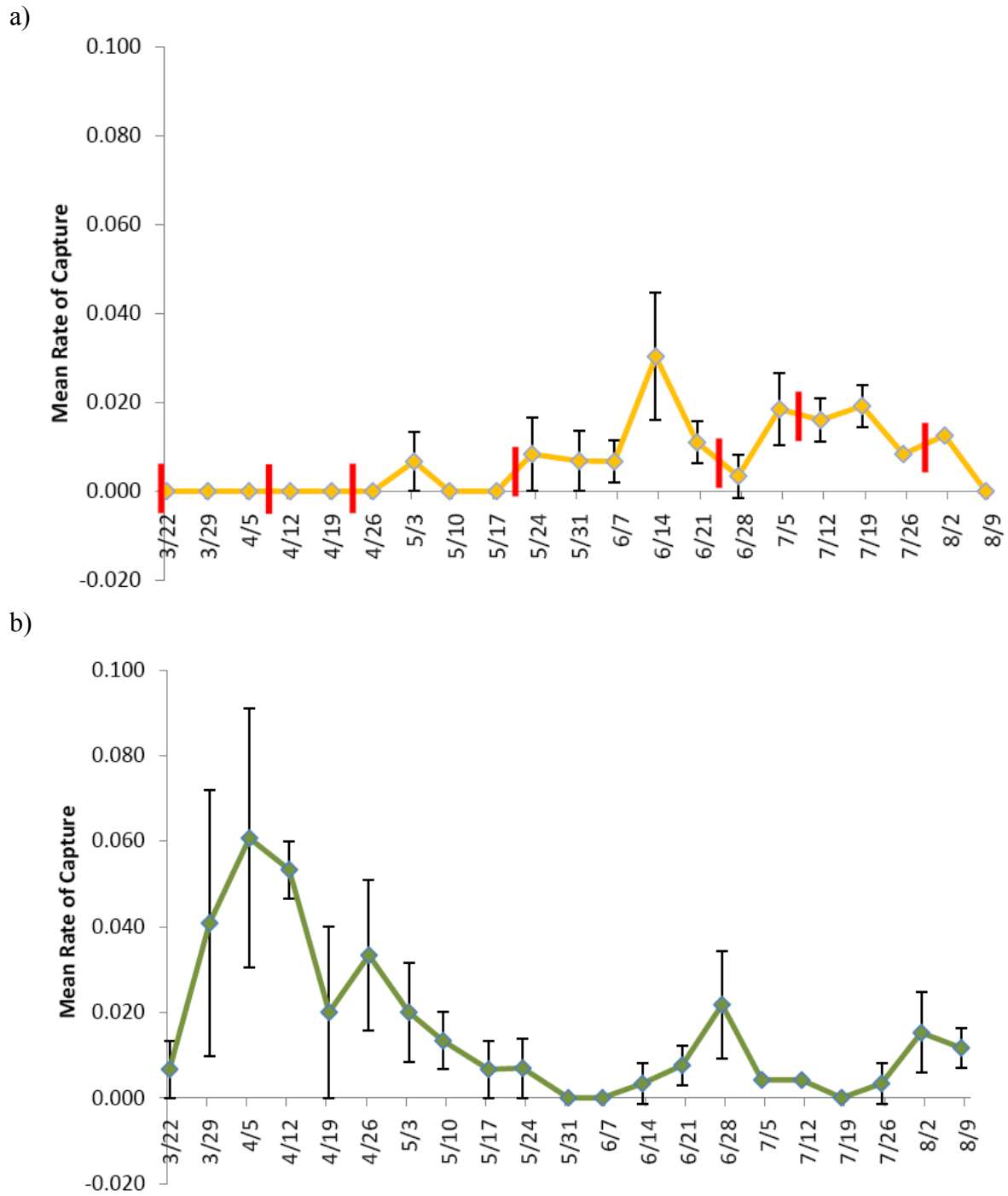


Figure 4  The mean (± SE) rate of capture of house mice for both experimental areas between mowed (a) and unmowed (b) fields over the 21 week trapping period.  The vertical lines on graph a) show the day mowing occurred (3/20, 4/9, 4/25, 5/21, 6/25, 7/9, and 7/28).

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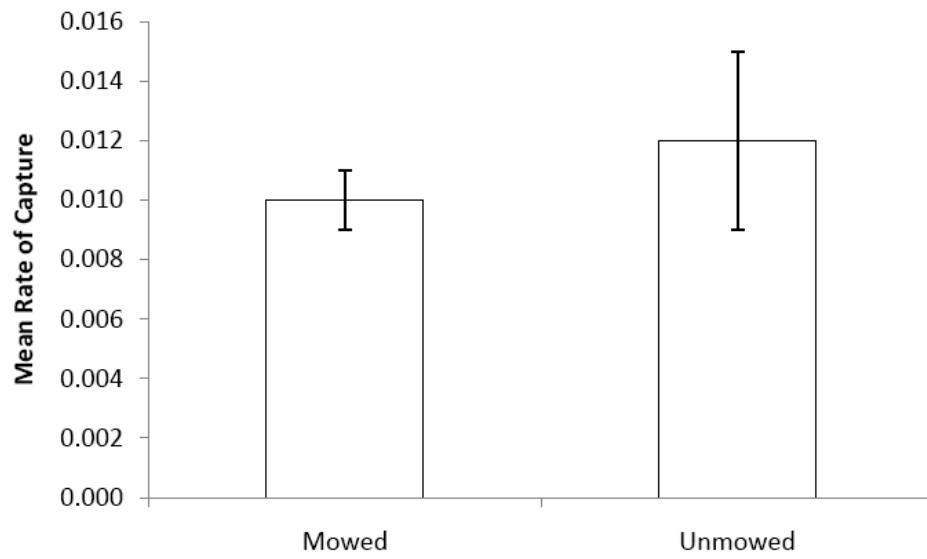
Figure 5  The mean (+ SE) rate of capture of house mice between mowed and unmowed fields over the 21 week study period.
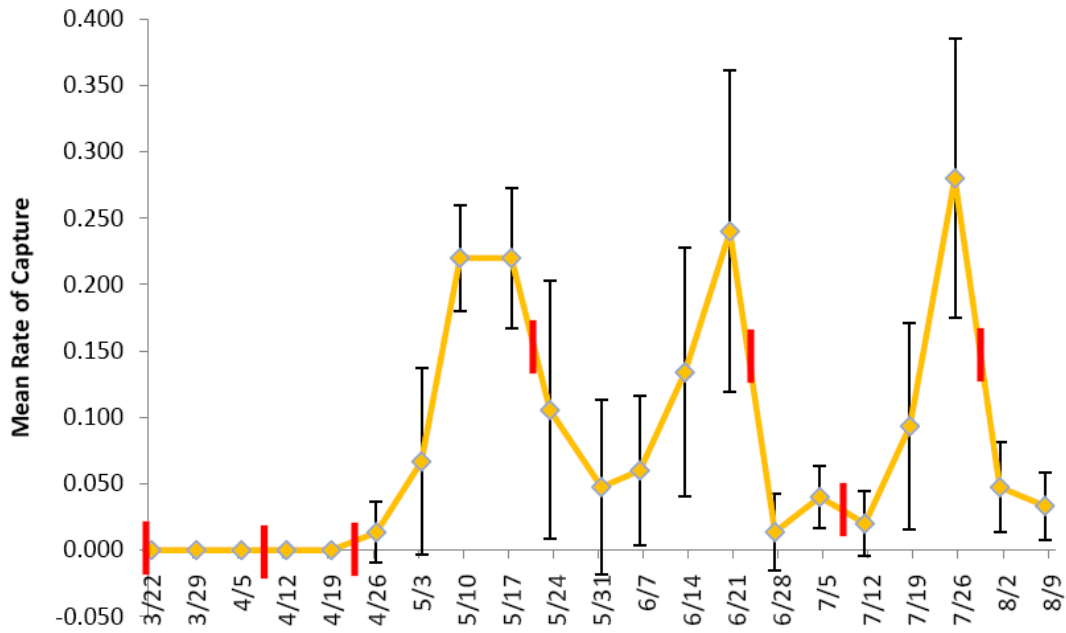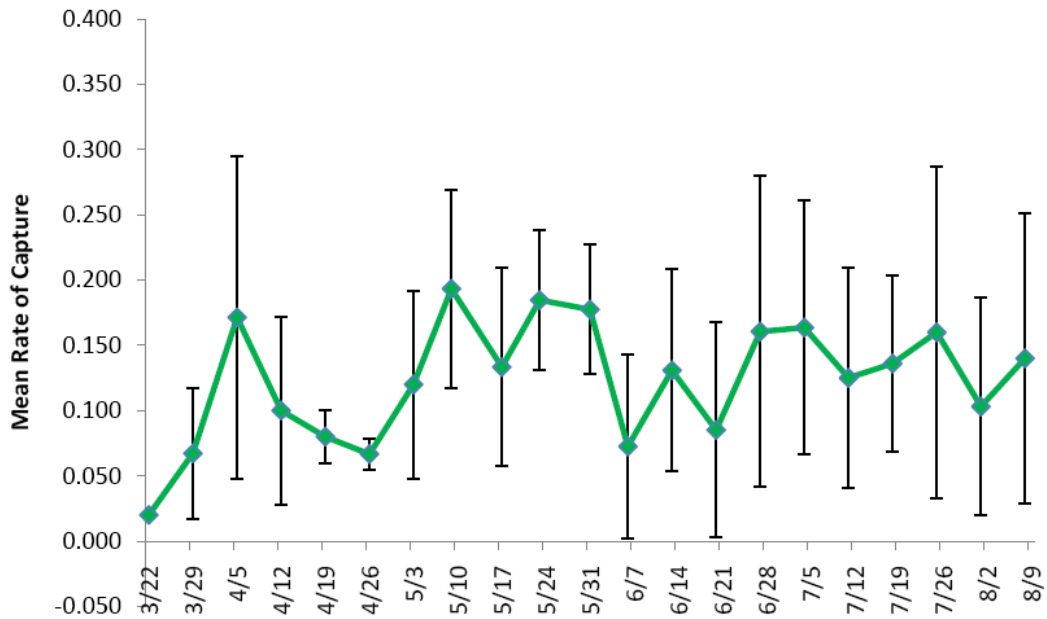
Figure 6 The mean (± SE) rate of capture of cotton rats between mowed (a) and unmowed (b) fields over the 21 week trapping period. The vertical lines on graph a) show the days mowing occurred (3/20, 4/9, 4/25, 5/21, 6/25, 7/9, and 7/28).
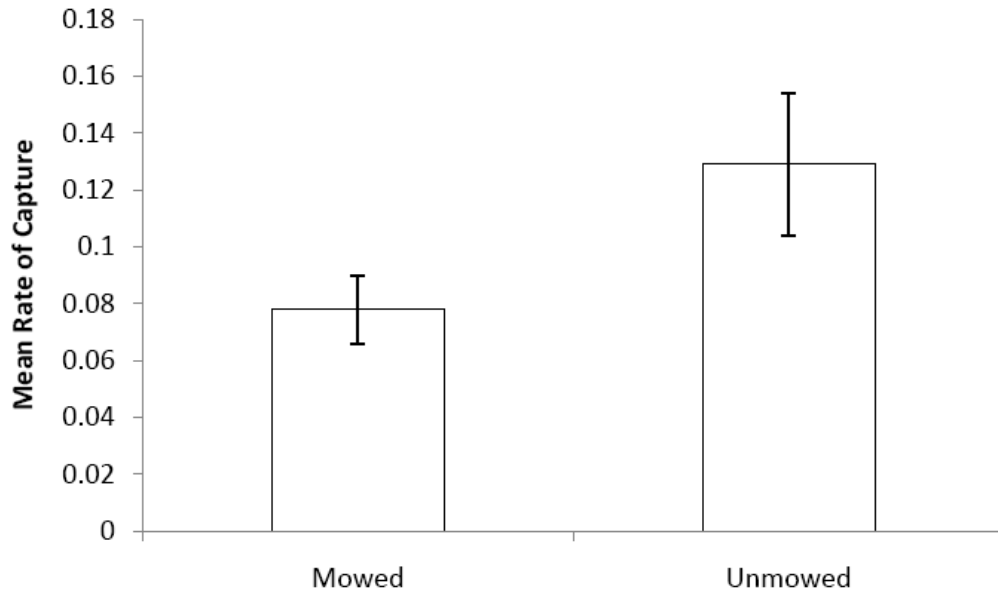
Figure 7  The mean ($\pm$ SE) rate of capture of cotton rats in mowed and unmowed fields over the 21 week study period.
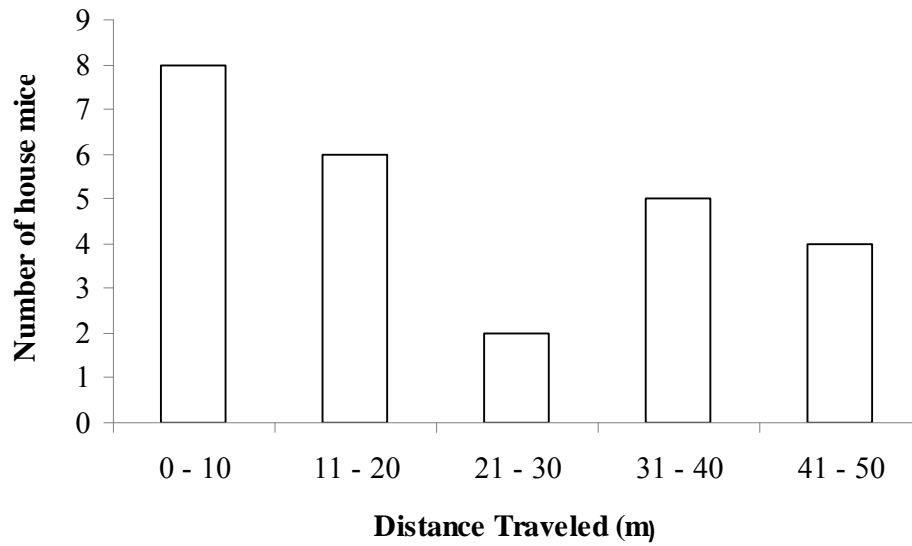
Figure 8  The number of house mice that traveled within the classified distances.
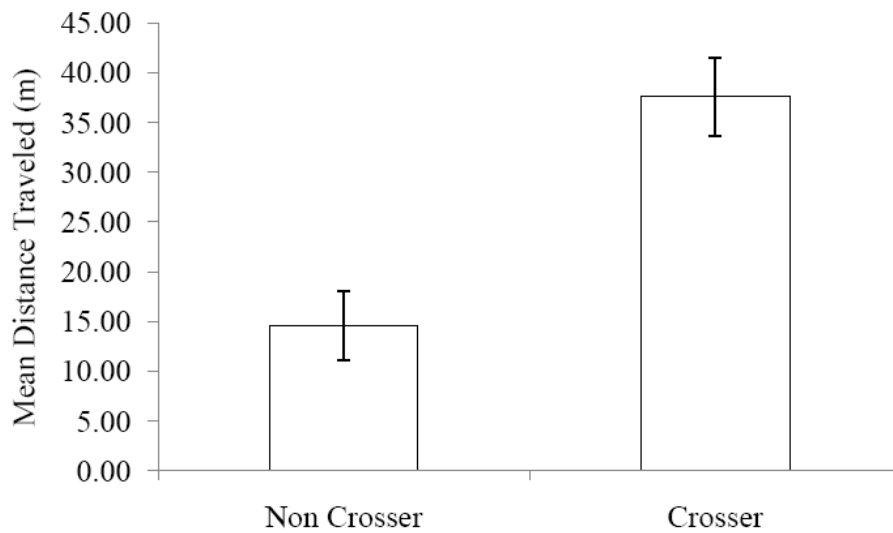


Figure 9  The mean ($\pm$ SE) distance traveled by house mice that did not and did cross the barrier (n = 10).
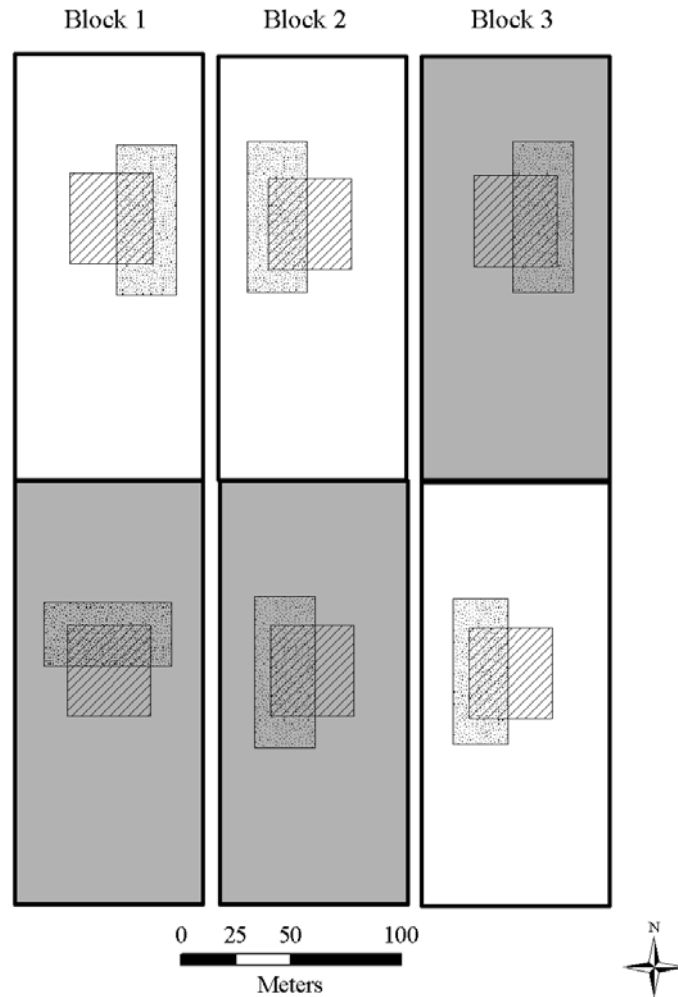
Figure 10  A split plot design used to compare the response of small mammals to the fire ant reduction and mowing treatments.  The three blocks each contained a mowed (unshaded) and unmowed (shaded) area, each with a 5 X 4 sampling grid (hatched square) and an area where fire ants were reduced (speckled rectangle) by the application of Spectracide$^{TM}$.  Blocks were separated by seasonally inundated ditches.
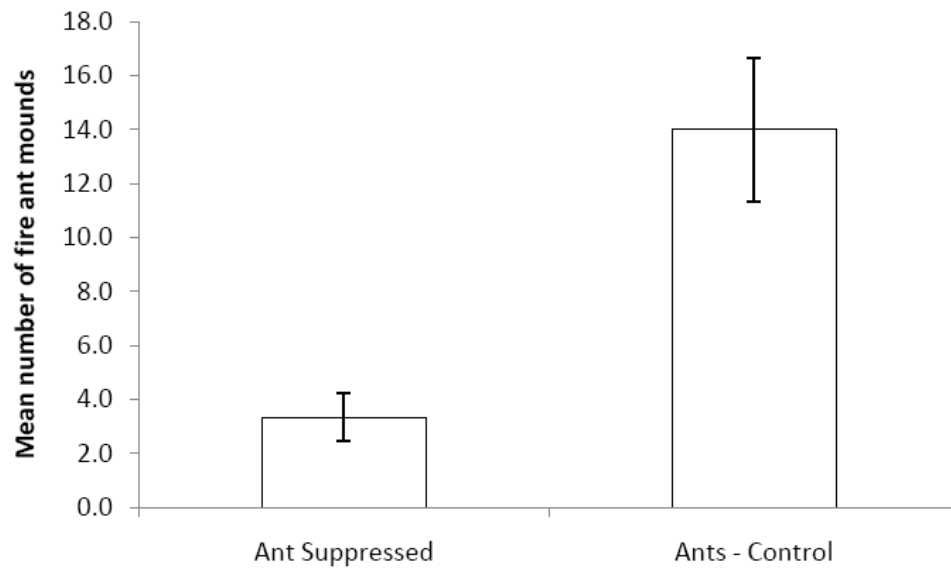
Figure 11  The mean (± SE) number of red imported fire ant mounds within the mowed fields where ant were reduced and the controls.
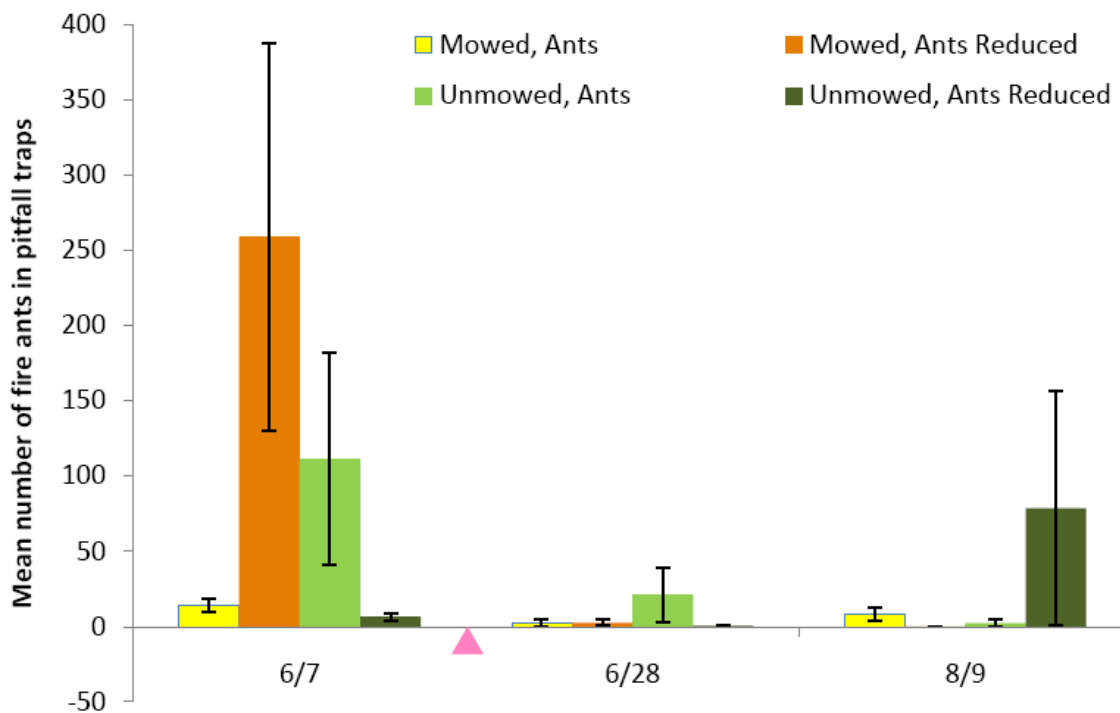
Figure 12  Mean (+ SE) number of red imported fire ant by mowing and bait (ant toxin) treatment over the three sampling periods.  The first pitfall sampling occurred on 6/7/2008 and then the pesticide (shown by the triangle along the x-axis) was applied.
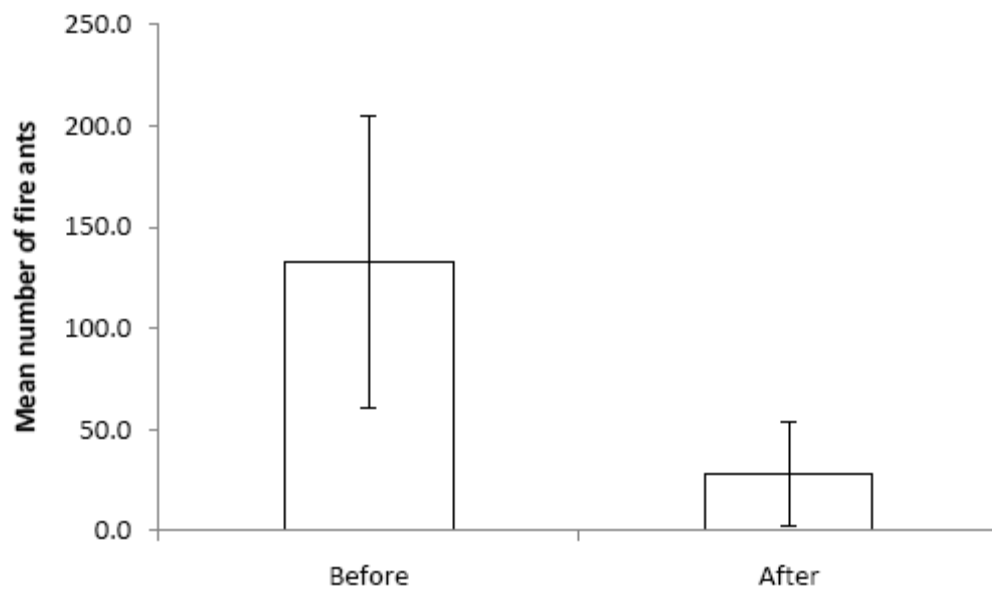
Figure 13  The mean (+ SE) number of red imported fire ants collected from the pitfall trapping in ant reduced areas before and after the application of the pesticide.
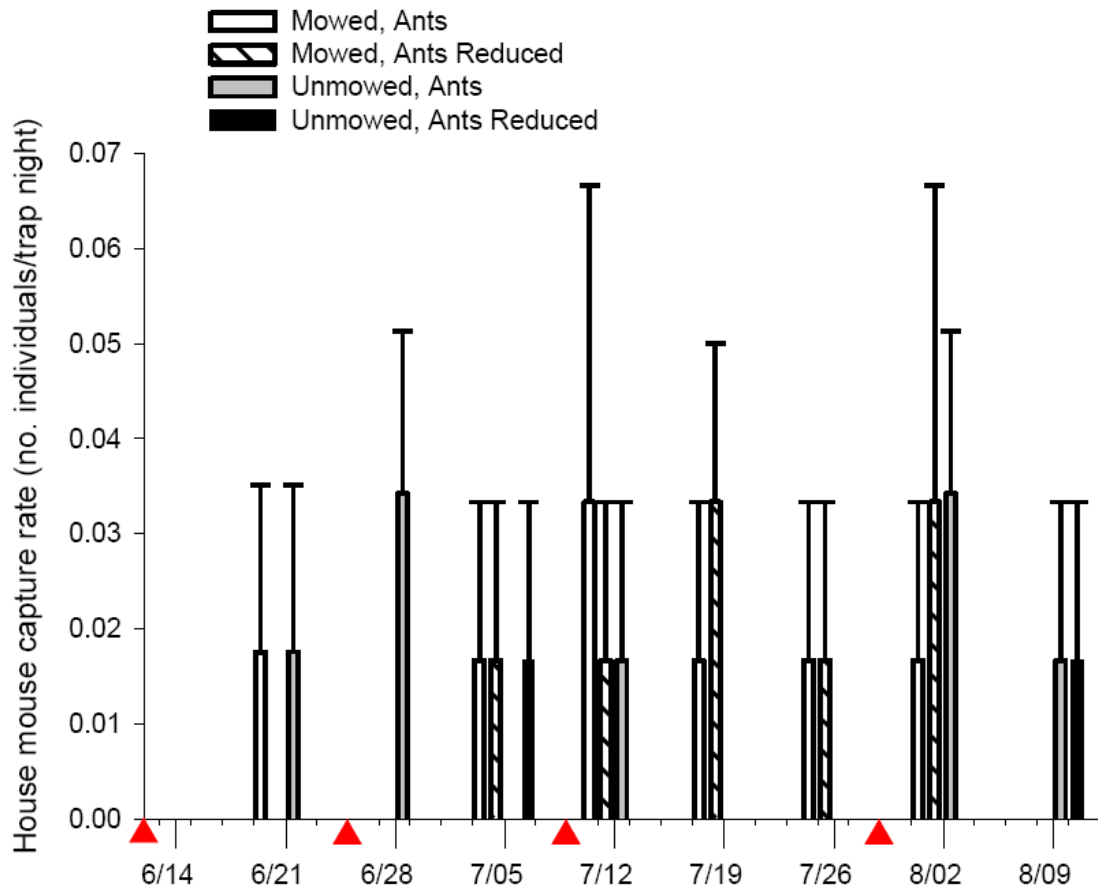
Figure 14  The mean (+ SE) rate of capture of house mice over the nine week sampling in response to the fire ant and mowing treatments.  The mowing events occurred on 5/21, 6/26, 7/9, and 7/29 denoted by the triangles along the x-axis.  The pesticide was applied on 6/12.
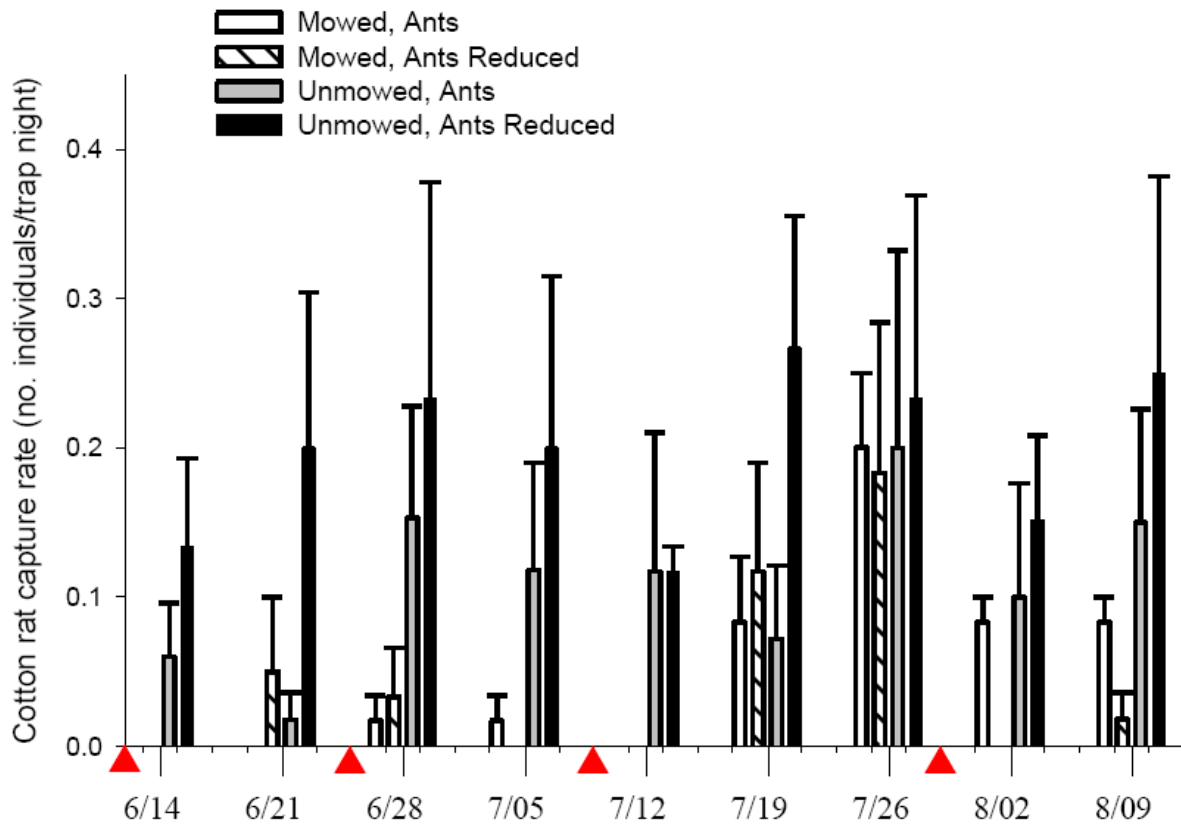
Figure 15 The mean (± SE) rate of capture of cotton rats over the nine week sampling in response to the fire ant and mowing treatments. Triangles along the x-axis denote the mowing events occurred on 5/21, 6/26, 7/9, and 7/29. The pesticide was applied on 6/12.

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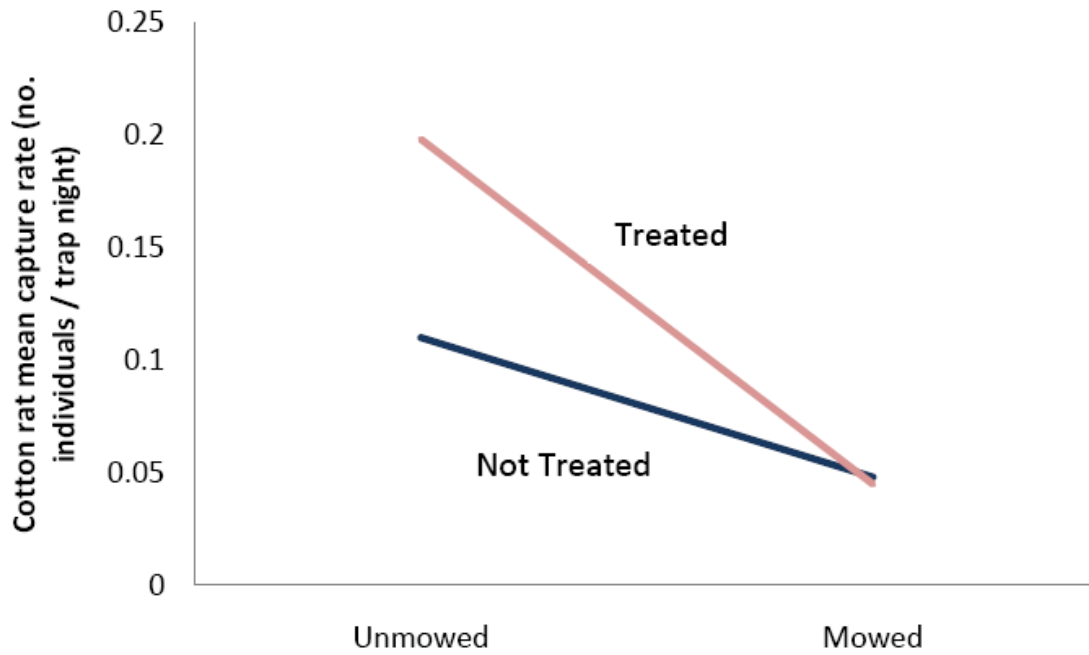
Figure 16  Represents the response of cotton rats to the interaction of the mowing treatment and the pesticide.

**APPENDIX B:  TABLES**

Table 1 The zero-inflated negative binomial using repeated measures examining the small mammal count data for experimental areas one and two.  This compares count data from house mice and cotton rats from mowed and unmowed areas.  Shown are the coefficients of the regressions along with standard errors in parentheses.

| | | Constant $\beta_0$ | Mowed $\beta_1$ | Block $\beta_2$ |
|---|---|---|---|---|
| House Mouse | | | | |
| | Area One | 0.673 (0.1429)*** | -0.3099 (0.2527) | - |
| | Area Two | -0.0647 (0.6363) | 0.2358 (0.4627) | - |
| Cotton Rat | | | | |
| | Area One | 1.77 (0.0835)*** | 0.1121 (0.1349) | - |
| | Area Two | -0.0913 (0.3791) | -1.2819 (.2375)*** | 0.2604 (0.1198)** |

*** significant at alpha of 1%
** significant at alpha of 5%

Table 2  The zero-inflated negative binomial using repeated measures examining the small mammal count data for experimental areas one and two.  This examines the response of count data from house mice and cotton rats to the cyclic occurrence of mowing.  Shown are the coefficients of the regressions along with standard errors in parentheses.

| | | Constant $\beta_0$ | Time Since Mowed $\beta_1$ | Block $\beta_2$ |
|---|---|---|---|---|
| House Mouse | | | | |
| | Area One | 0.0398 (0.3724) | 0.1755 (0.1543) | - |
| | Area Two | $-1.06 \times 10^{-12}$ (0.3946) | $-7.85 \times 10^{-3}$ (0.2716) | - |
| Cotton Rat | | | | |
| | Area One | 1.646 (0.1098)*** | 0.1028 (0.0377)* | - |
| | Area Two | -0.3828 (0.3946) | 0.1681 (0.0659)** | 0.4921 (0.1361)*** |

*** significant at alpha of 1%
** significant at alpha of 5%
* significant at alpha of 10%

Table 3 The Fisher's Exact Tests (2X2) comparing two nominal variables using recapture house mouse data.

| Nominal Variables | Fisher's Exact Test (Two Sided) | Fisher's Exact Test (One Sided) |
|---|---|---|
| Sex and Cross | 1.0 | ---- |
| Sex and Mowed | 0.278 | ---- |
| Sex and Distance | 1.0 | ---- |
| Cross and Mowed | --- | 0.274 |
| Cross and Distance | --- | 0.001*** |
| Mowed and Distance | --- | 0.363 |

*** significant at the 1% alpha

Table 4  Quantified ecological effects of *Solenopsis invicta*.

| Impacted Species | % Loss | Reference |
| --- | --- | --- |
| **ARTRHOPODS** | | |
| lone star tick | 90% decrease | Wojcik et al. (2001) |
| *Amblyomma americanum* | | |
| horn fly | | |
| *Haematobia irritans* | 63 - 94% decrease | Hu and Frank (1996) |
| green lace wing | | |
| *Chrysoperla cornea* | 38% decrease | Eubanks et al. (2002) |
| lady beetles | | |
| *Coccinella septempunctata* | 50% decrease | Eubanks et al. (2002) |
| | | |
| **REPTILES AND AMPHIBIANS** | | |
| gopher tortoise | | |
| *Gopherus polyphemus* | 27% decrease | Epperson and Heise (2003) |
| loggerhead sea turtle | | |
| *Caretta carretta* | 15 - 55% decrease | Allen et al. (2001), Moulis (1997) |
| green sea turtle | | |
| *Chelonia mydas* | 15 - 55% decrease | Allen et al. (2001) |
| Florida rRedbelly turtle | | |
| *Pseudemys nelsoni* | 70% decrease | Allen et al. (2001) |
| American alligator | | |
| *Alligator mississippiensis* | (NA) | Allen et al. (2004) |
| | | |
| **BIRDS** | | |
| Northern Bobwhite Quail | | |
| *Colinus virinianus* | 28 - 50 % decrease | Allen et al. (2004) |
| Swallow | | |
| Hirundinidae spp. | 34% decrease | Kopachena et al. (2000) |
| Black-capped Vireo | | |
| *Vireo atricapillus* | (NA) | Stake and Cimprich (2003) |
| | | |
| **MAMMALS** | | |
| Old Field Mouse | | |
| *Peromyscus polionotus* | (NA) | Orrock and Danielson (2004) |
| Cotton Rat | | |
| *Sigmodon hispidus* | (NA) | Pedersen et al. (2003) |
| White-tailed deer | | |
| *Odocoileus vriginianus* | (NA) | Allen et al. (2004) |

(NA) data not available

|  |  |  |  | Annual Cost($) | Reference |
|---|---|---|---|---|---|
| **Households Expenses** |  |  |  |  |  |
|  | Total Households' |  |  |  |  |
| Georgia Survey (Low Estimate) |  |  |  |  |  |
| $35.26/household | 29,094,889 |  |  | 1,561,523,000 | Diffie et al. (1991) |
|  |  |  |  |  |  |
| Arkansas Survey (High Estimate) |  |  |  |  |  |
| $87.10/household | 29,094,889 |  |  | 3,448,035,000 | Thompson et al. (1995) |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
| **Agricultural Products** |  |  |  |  |  |
| Crops |  |  |  |  |  |
|  | Total acerage | Change in Yield | Cost per acre($) |  |  |
| Orange | 570,604 | (NA) | 25.7 | 16.865,000 | Segarra et al. (1999) |
| Grapefruit | 91,271 | (NA) | 50.4 | 5,290,000 | Segarra et al. (1999) |
| Soybean | 10,032,000 | 20 - 30% decrease | 8.95 | 141,180,000 | Jetter et al. (2002) |
| Corn | 5,920,000 | 3% decrease | 2.589 | 27,733,000 | Segarra et al. (1999) |
| Wheat* | 15,175,000 | (NA) | 8.95 | 283,754,000 | Jetter et al. (2002) |
| Sorghum* | 4,230,000 | (NA) | 15.5 | 120,001,000 | Segarra et al. (1999) |
| Forage | 13,904,635 | (NA) | 25.26 | 451,556,000 | Knutson  (2001) |
| Sunflower | 101,000 | 40 - 50% decrease | (NA) | 11,092,000 | Miller et al. (2000) |
| Sweet Corn | 79,186 | 3% decrease | 2.589 | 217,000 | Drees et al. (1991) |
| Cucumber | 59,779 | 2.4 - 4% decrease | (NA) | 5,656,000 | Miller et al. (2000) |
| Pecans | 505,666 | (NA) | (NA) | 3,034,000 | Segarra et al. (1999) |
|  |  |  |  |  |  |
| Livestock |  |  |  |  |  |
|  |  |  | Cost per Animal |  |  |
|  | Total Quantity | Change in Yield | ($) |  |  |
| Cattle | 28,070,000 | (NA) | 5.77 | 198,649,000 | Barr and Drees (1996) |
| Quail | 1,779,235 | 28.4% decrease | (NA) | (NA) | Allen et al. (2000) |

Table 5 Annual costs of Solenopsis invicta in the southeastern United States[+](cont.)

| | Total Population | Cost per capita | Annual Cost($) | Reference |
|---|---|---|---|---|
| **Infrastructure Costs** | 83,372,378 | $8.90 | 742,014,000 | Segarra et al. (1999) |
| **Medical Costs** | | | 48,958,000 | de Shazo et al (1999) |
| | **Total Economic Costs (Low)** | | **3,600,657,000** | |
| | **Total Economic Costs (High)** | | **5,487,169,000** | |

(+) these states include Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, and Texas

(*) crops used for grain

(NA) data not available

Table 6  Analysis of variance (ANOVA) of the fire ant mounds surveyed by walking transects.

| Source | Partial SS | df | MS | F | p > F |
|---|---|---|---|---|---|
| block | 26.3 | 2 | 13.2 | 2.93 | 0.254 |
| ant treatment | 181.5 | 1 | 181.5 | 40.33 | 0.024** |
| residual | 9 | 2 | 4.5 | | |
| total | 216.8 | 5 | 43.4 | | |

** significant at alpha of 5%

Table 7  Zero-inflated negative binomial regression results examining the variables of mowing(mowed compared to unmowed), ant treatment, block, and the interaction of mowing and ants on the count data of house mice and cotton rats.  Shown are the coefficients of the regressions along with standard errors in parentheses.

| | Constant $\beta_0$ | Mowed $\beta_1$ | Ant $\beta_2$ | Block $\beta_3$ | Mowed*Ant $\beta_4$ |
|---|---|---|---|---|---|
| House Mouse | 16.6 (1447) | 0.062 (0.650) | -0.026 (0.805) | 0.011 (0.265) | -0.045 (1.1) |
| Cotton Rat | -0.272 (0.402) | -0.915 (0.355)*** | 0.712 (0.242)*** | 0.319 (0.121)*** | -0.824 (0.495)* |

*** significant at alpha of 1%
 ** significant at alpha of 5%
  * significant at alpha of 10%

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